Exploratory Dynamic Analysis of the Adoption of Biowaste Separation Behavior in Households

Nicolas Escalante M.
Chair of Waste Management and Emissions
Institute for Sanitary Engineering, Water Quality, and Solid Waste Management
University of Stuttgart
Bandtäle 2, 70569 Stuttgart, Germany
Phone +49-711-68565456
nicolas.escalante@iswa.uni-stuttgart.de

Abstract

Biodegradable waste (biowaste) corresponds to the largest fraction of household waste in low and middle-income countries. However, very low recovery rates for this material stream are obtained. In part, this is due to the fact that the adoption of source separation at household level is not given sufficient attention. In cases where source separation has been ineffectively introduced, the lack of awareness is named as culprit for the failure. Unfortunately, managers of such initiatives are not cognizant of the need of moving households from a stage of non-compliance to compliance. Furthermore, the feedback effects of social interaction, awareness raising campaigns, financial incentives, and punitive actions have never been studied in this socioeconomic context. Thus, the model presented explores the possible behaviors resulting from these interventions in the setting of urban centers in developing and emerging economies.

1. Problem Description

Organic waste or biowaste corresponds to 50% to 70% of the waste generated by households in urban centers in low and middle-income countries (Hoornweg and Bhada-Tata, 2012). In most cases, biowaste is not recovered, and therefore is sent together with other household waste for disposal. Without treatment, biowaste becomes then at the final disposal site the main potential source of gas emissions and soil and groundwater pollution. Furthermore, when collection of household waste is not adequate, the organic fraction can cause public health problems as it serves as food for vermin, thus stimulating their proliferation, which increases the risk of transmission of infectious diseases. Additionally, by burying the material, valuable organic matter and nutrients are lost, since they are not returned to the natural geochemical cycles as would occur under natural conditions.

Because of this, it is reasonable that local administrations strive to reduce the amount of biowaste that is disposed, and to separately collect the material for posterior treatment and valorization. For example, the Cleansing Management Agency of the city of Addis Ababa, Ethiopia plans, according to the draft of the Integrated Waste Management Plan, to collect by 2020 "70 percent of the residential organic waste…in a way that will meet the production of quality compost" (CMA, 2011). However, there is no certainty that the objective established would be attained within the given time frame, since there are several factors that make the introduction of separate collection of biowaste and the adoption of separation at source a dynamically complex problem. As a result, the model presented in this document will address the dynamic puzzle that is represented in Figure 1, which describes the time paths of the desired behavior of the variable *source separated fraction* (i.e. the fraction of the total organic waste generated that is separated by households) in contrast to the undesired outcome. The desired outcome is the result of the successful diffusion and adoption of source separation by households. In the case of Addis Ababa, the indicator separated fraction starts at zero in 2012 and grows until it reaches 70% in 2020. On the other hand, the behavior that is undesirable evolves when the measures to stimulate biowaste separation at household level are insufficient. As a result, the source separated fraction reaches a 10% at the most at the end of the simulation period.

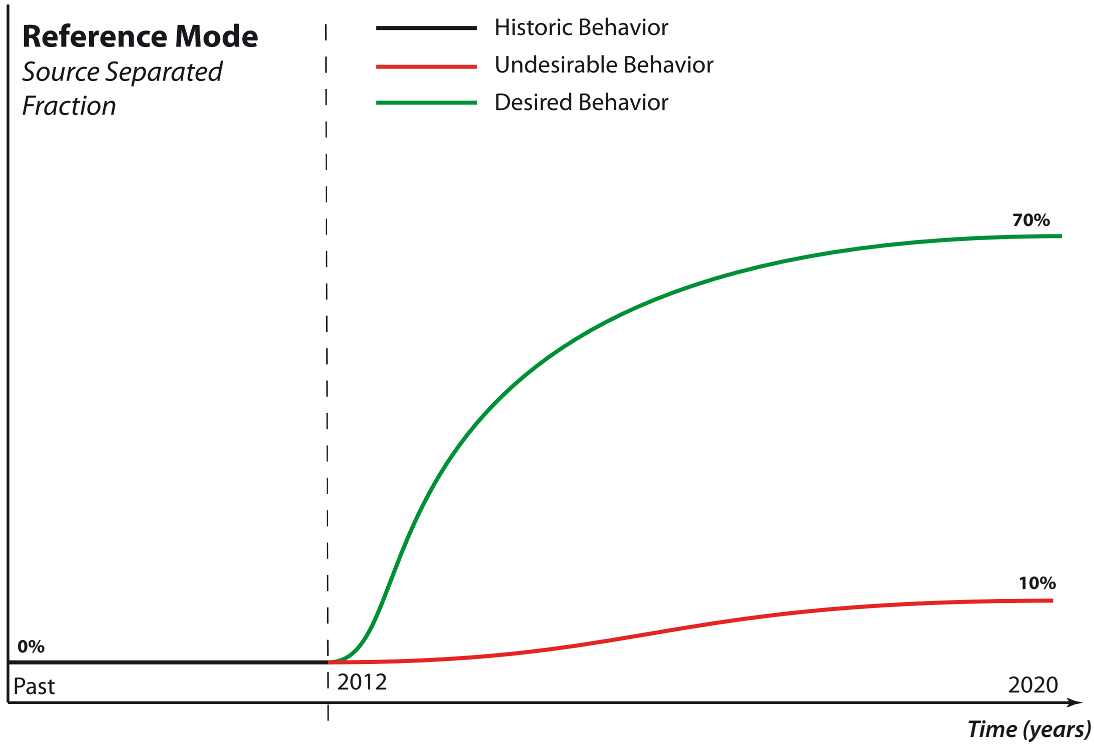

Figure 1 - Dynamical Problem Description

2. Model Description

The purpose of the model is to test how different factors influence the viability of a source separation strategy for biowaste management for the case of Addis Ababa. At the core of the model is the assumption that none of the households in the city sort organic waste and that the strategy of separate biowaste collection will be introduced over a period of time of 2 years. Therefore, not all households will be connected to the system immediately, and therefore will not be required to sort until they are served by the separate collection system. The model assumes also that when households start to be served by the separate collection system, they initially do not comply with the requirement to sort. Only until the households have adopted the routine of source separation will they comply with the requirement. The model also recognizes that personal and social factors may lead to households giving up the behavior, and going back to being noncompliant. Figure 2 illustrates how household can flow from not being served by separate collection to not being compliant at first. It also depicts how through behavior adoption, non-compliant households can fulfill the requirement to sort biowaste, and through abandonment of the routine, compliant households dropout from the pool of complaints.

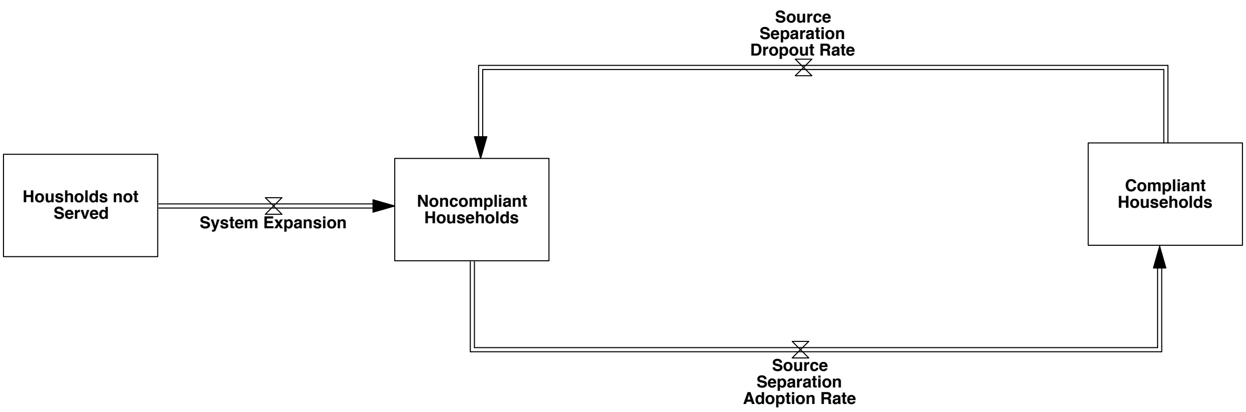

Figure 2 – Main Stock and Flow Structure

The model also assumes that the adoption of source separation behavior occurs as the result of normal social diffusion processes, and of measures taken by the city administration to stimulate compliance. This include awareness raising campaigns, financial incentives through the reduction of the waste collection fee, and financial disincentives through the introduction of fines in case of not complying with the requirement to separate.

The fundamental premise of the model is that source separation is a behavior that is adopted and abandoned through a social process. Based on the model of Ulli-Beer, et al. (2010) for acceptance dynamics, the model represents the adoption process as the result obeying to a social norm, which is established through time as it becomes more and more common. In a similar form, biowaste sorting is dropped as a household routine if it is not perceived as a common social behavior. The feedback structure in Figure 3 illustrates the interplay between the compliant and non-compliant households to generate the behavior that can be displayed by households. The reinforcing feedback loop R1 is the growth engine responsible for the diffusion of the routine of organic waste separation. As more households adopt the behavior, the perceived social norm to separate rises, and as a result the social pressure to adopt the behavior grows. This leads to a higher adoption rate and to an even larger pool of compliant households. In a similar fashion feedback loop R2 is responsible for the growth of not separating biowaste at household level as the dominant behavior, since as more households reject the routine, it becomes the social norm, and therefore the drop out rate rises, leading to more and more noncompliant households.

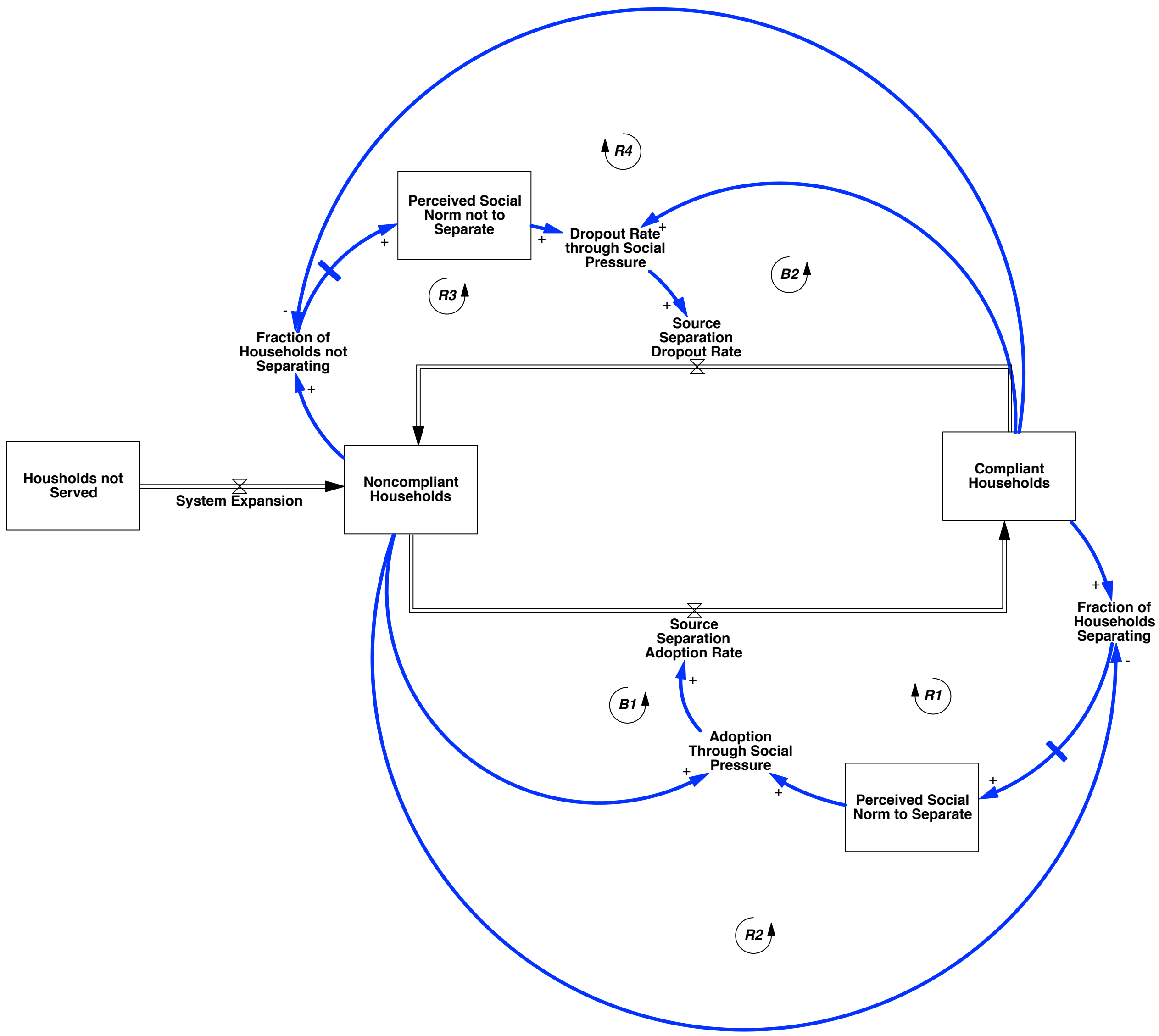

Figure 3 – Feedback Structure for the Source Separation Dynamics as Result of Social Processes

The balancing feedback loop B1 slows down the growth of adoption, as result of the draining of the stock of non-compliant households that could potentially adopt the behavior. This means that as the adoption of source separation increases, the number of remaining households that could adopt the behavior diminishes and as a result the adoption through the social process goes down. At the extreme, when all households have adopted the environmental desirable behavior, the adoption rate is zero, as there are no more households that could change their routine and comply with the environmental regulation. The loop B2 slows down the disadoption process, and operates in the same way: as the dropout rate rises, the number of compliers decreases, and therefore the dropout rate decreases. Additionally, feedback loops R3 and R4 speed up the adoption or the elimination of the separation behavior. For example, in the case of compliers, as their number grows, the social norm of non-separation drops, and as a result, the disadoption rate goes down, which leads to the pool of compliers to grow beyond it would otherwise have done.

The model also considers that capability of households to sort appropriately varies with time depending on different factors. Specifically, it posits that when households actively separate their biowaste, they will take part in a learning cycle where their capability improves with time. However, there is a saturation effect, since as the fraction of organic waste appropriately separated rises, it becomes harder and harder to make improve the effectiveness. This is captured by the balancing feedback loop B3 (Figure 4). Additionally, the model assumes that both compliers and non-compliers have the capability to separate biowaste, independently of whether they are applying it or not. This is of importance because in the model the capability of households to separate rises, then they are less likely to quit separating when the social norm of source separation begins to erode. This is because once active households have achieved high separation rates they are better equipped to understand why separation is a desirable social behavior. This is represented by the positive feedback loop R5 in Figure 4. In the case of inactive households, the model assumes that a certain degree of separation is achievable by households, even if they had no previous experience. Additionally, if households had experience sorting and dropped the behavior, they will continue to have for some time the ability to sort. However, this ability will erode as it is considered that practice is necessary to maintain a high level of sorting capability. Nonetheless, feedback loop R6 illustrates that when noncompliant households have a high capability to separate they will be more easily drawn again to adopt the environmental desirable behavior.

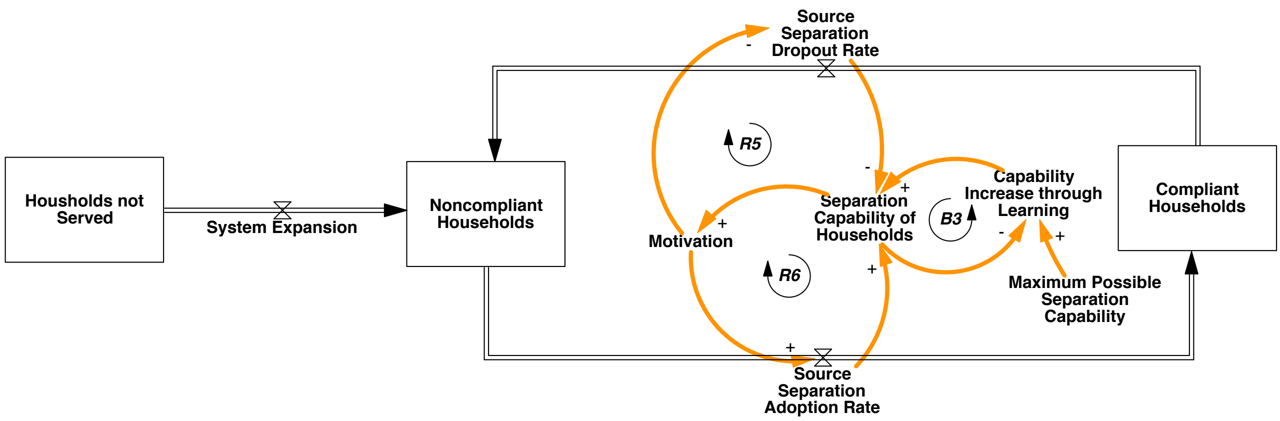

Figure 4 – Feedback Structure for the Source Separation Dynamics including Effect of Motivation

Finally, in order to make it possible to test the effectiveness of different policy levers, the model includes the impact of awareness raising efforts, the reduction of the waste collection fee, and the introduction of fines to non-compliers. Figure 5 illustrates that adoption through awareness raising depends on how many noncompliant households are exposed to information about source separation, and the effectiveness of the measure (feedback loop B4). Additionally, the feedback structure shows that the adoption rate increases as the collection fee is reduced relative to the current one (feedback loop B5), and that when fines are introduced people will adopt the behavior more swiftly in order to avoid the financial punishment (feedback loop B6). Finally, the model assumes that if collection fees are reduced, current compliers will be deterred from disadopting the behavior, since they will lose the financial benefits of a reduced waste collection fee. Similarly, if fines are charged, complying households will be less likely to give up the separation behavior.

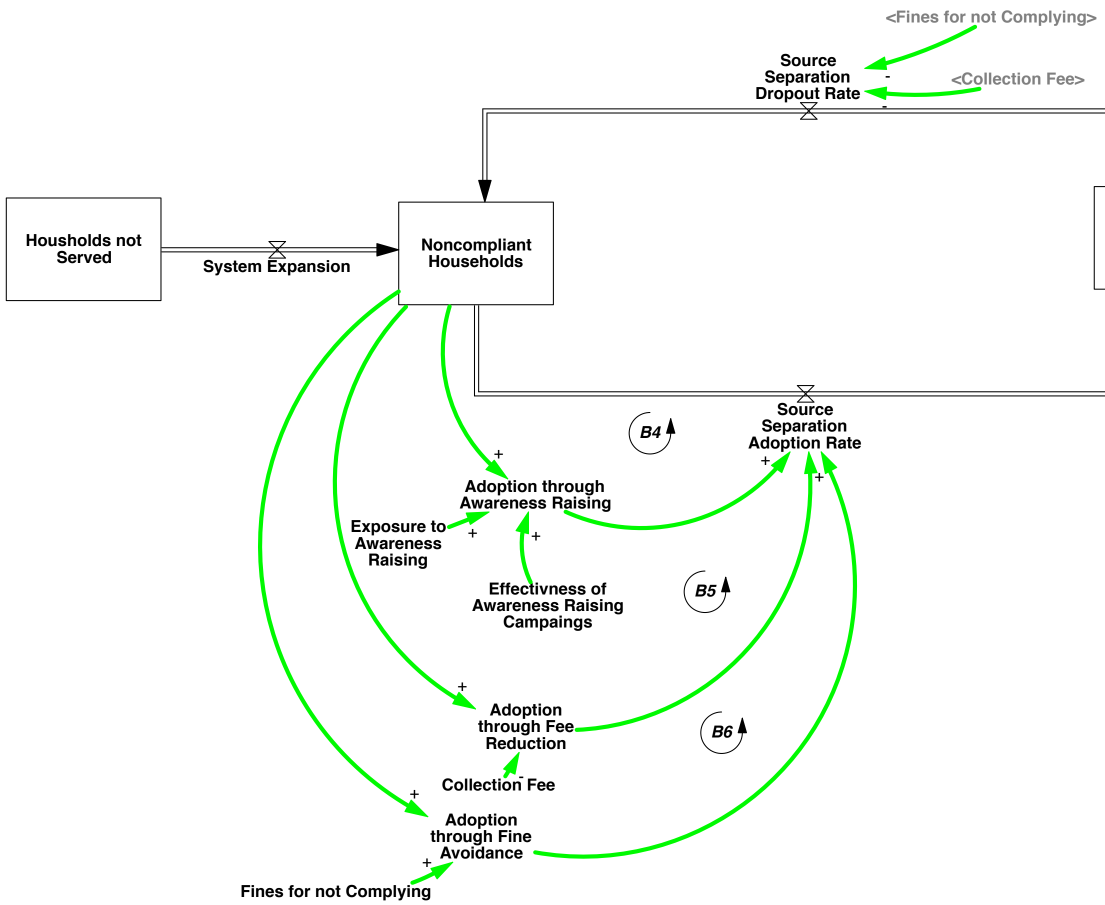

Figure 5 – Feedback Structure for the Source Separation Dynamics including Potential Policy Levers

3. Simulations

Base Run

The base run in Figure 6 shows the behavior that can be expected in Addis Ababa, when the separate collection system is introduced, but no other measure is put in place. As the system is expanded, more households are connected to the separate collection system, until 2020, when only, 9600 are left unserved, which is equal to a coverage of 98 percent. However, since there are no compliant households to initiate the social process that would lead to adoption, then all 600,000 households become noncompliant households. The result is that the source separation fraction is zero and no biowaste is available for collection and recovery.

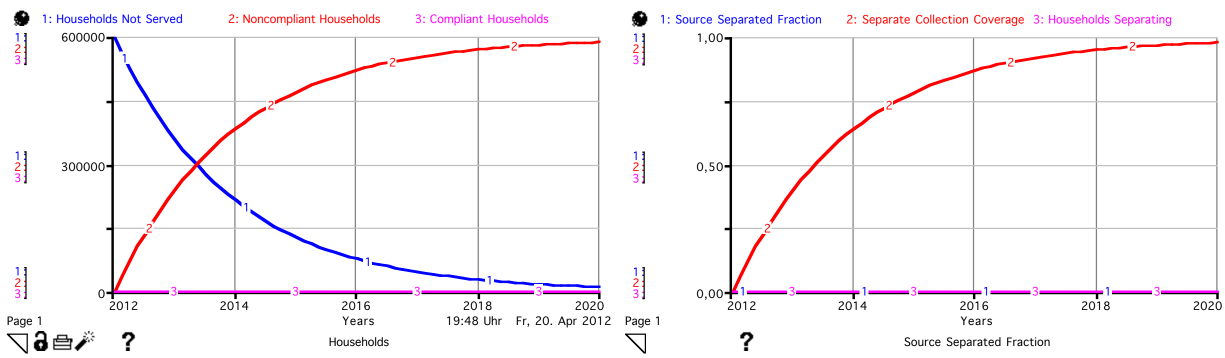

Figure 6 – Simulation Results for the Base Run Simulation

Awareness Raising

The first measure that is tested is informing 20% of the non-compliant households per year of the reasons for biowaste separation in order to try to make them aware of the need of the adoption of the source separation. The simulation results show that given the expansion process, and that the effectiveness of awareness raising is 50% (i.e. only 50% of the exposed households adopt separation), by 2020 425,000 households do not separate, while 165,000 do so. This results in a source separated fraction equal to 16%, and a participation level of 28%. The trajectories of the adoption rate component show that the adoption rate is mainly driven by the external effort to make citizens aware, which is twice as large as the adoption resulting from social pressure. Finally, the model illustrates that the sorting effectiveness of participating households rises from the initially assumed 50% to 59%.

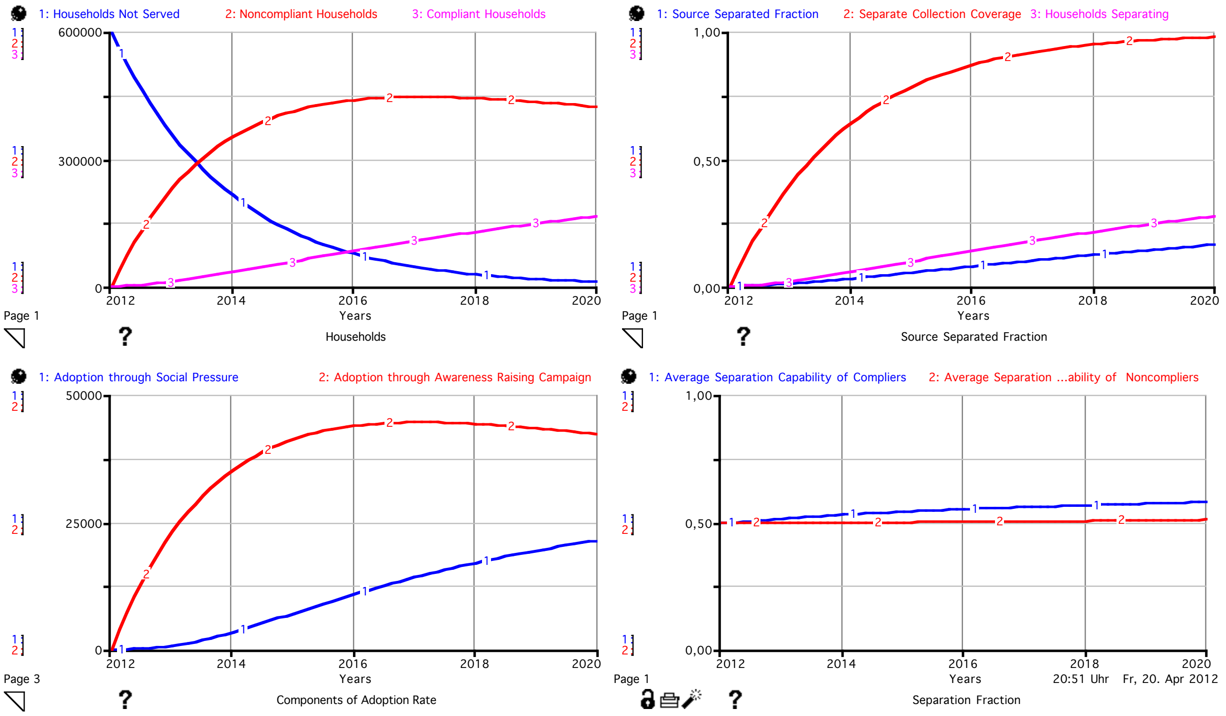

Figure 7 – Simulation Results for Awareness Raising Efforts Addressing 20% of Households not Separating

Even if it would be possible to address all households and convince half of them of the benefits of source separation, the objective of reaching a 70% source separation target is not possible. Figure 8 illustrates that 99,000 still do not exhibit the desired behavior, while 491,000 households do so. This results in a source separation fraction equal to 52% and a participation level of 82%. Furthermore, this illustrates that the desired objective will not be reached if only awareness raising campaigns are carried out to stimulate the source separation. In terms of the components of the adoption rate, the externally driven adoption through awareness raising grows fast until 2014, following the profile of noncompliant households. In terms of the quality of source separation, compliant households achieve a separation effectiveness of 57%.

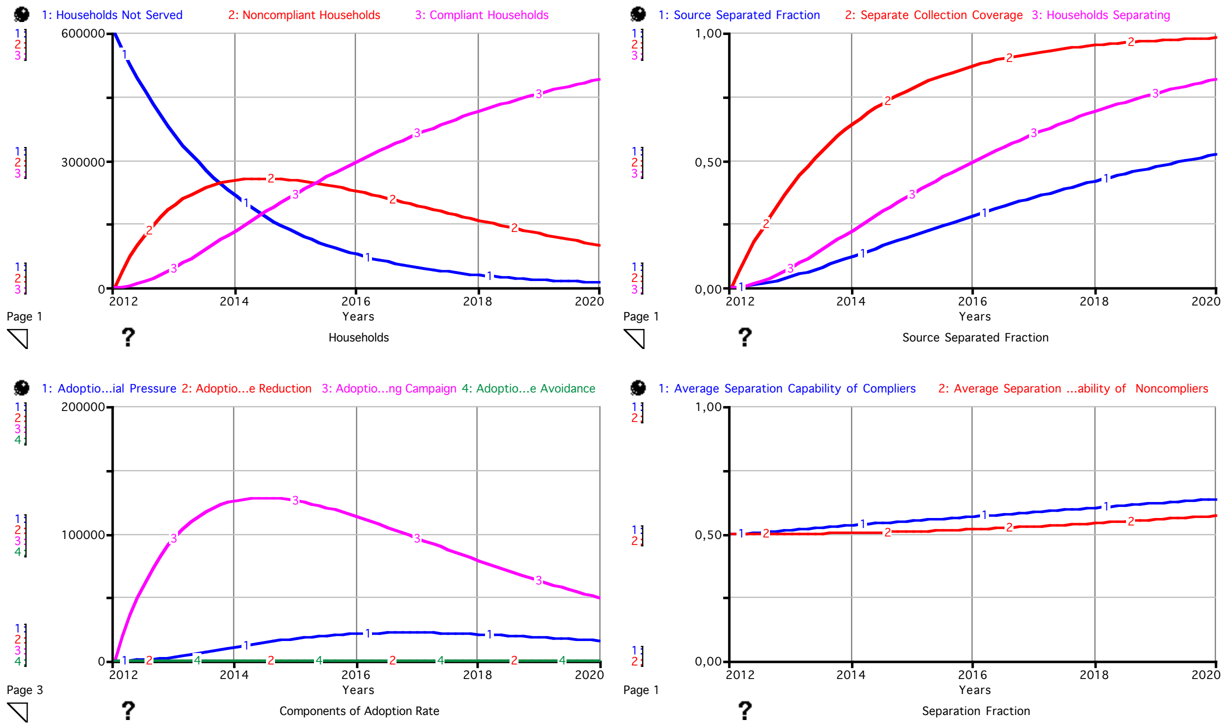

Figure 8 – Simulation Results for Awareness Raising Efforts Addressing 100% of Households not Separating

Fee Reduction

Although fee reduction is demanded by households in Addis Ababa in compensation for participating in source separation of biowaste, the effectiveness of the measure is not promising. The results in Figure 9 show that by 2020 564,000 households will keep on not separating their biowaste, while only 27,000 will be complying with the new requirements (4%). This results in a source separated fraction that is only 3% of the total generated biowaste, while the separation effectiveness is 57%. In terms of the components of the adoption rate, social pressure accounts to one third of the households converting to compliers per year, while fee reduction is responsible for the remaining two thirds.

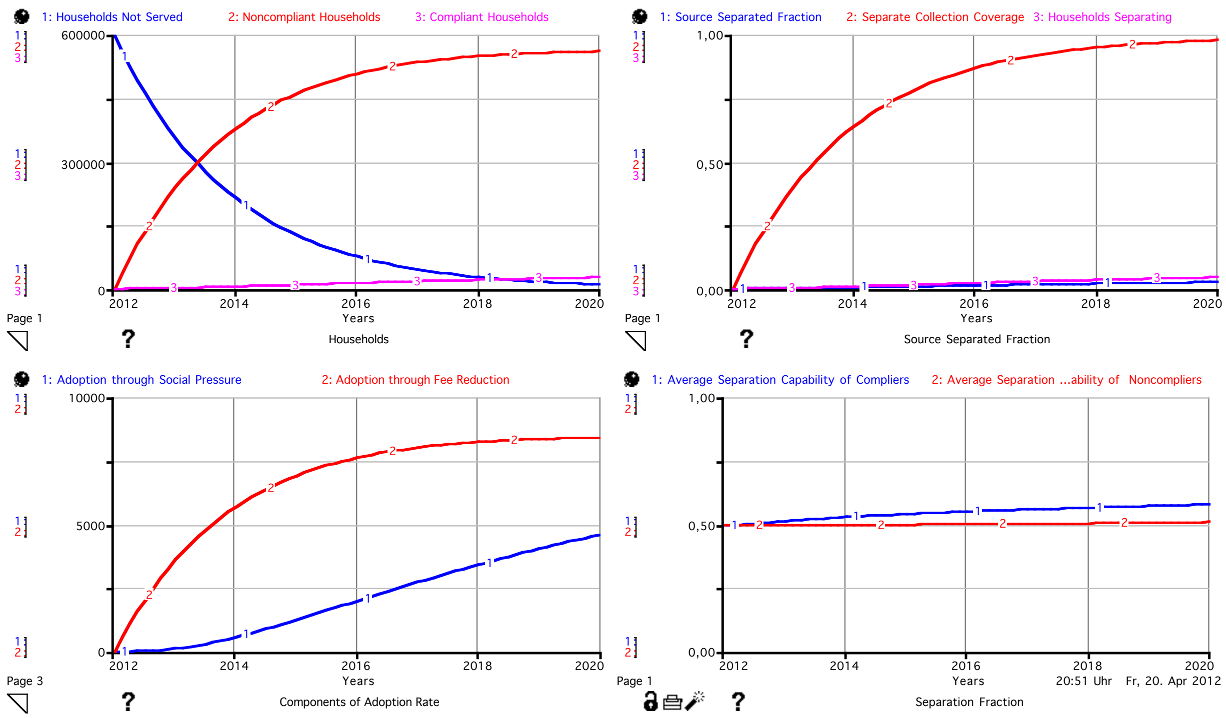

Figure 9 – Simulation Results for 20% Reduction in Waste Collection Fee

Although in reality not implementable, testing a full reduction of the waste collection fee reveals the lack of effectiveness of the policy. Although by 2020 490,000 would have adopted organic waste sorting, only 52% of the organic waste would be recovered, instead of the intended 70%. Furthermore, 82% of the households would participate in separation. The adoption through fee reduction peaks in 2015 at 187,000, while the social process drives conversion at a maximum rate of 21,500 around 2017. In terms of separation capability of the complying households, a sorting effectiveness of 64% would be reached.

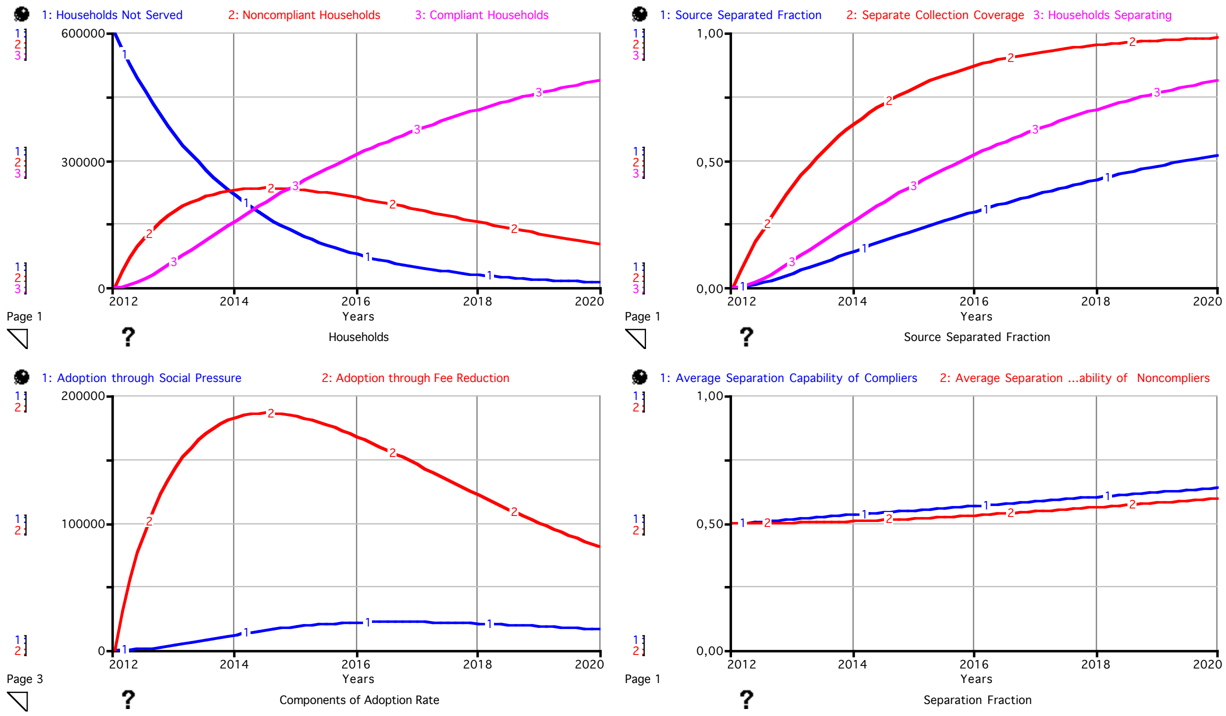

Figure 10 – Simulation Results for Elimination of the Waste Collection Fee

Fine Charging

The next test is on the strategy of charging the equivalent to the monthly minimum wage to households that do not cooperate with biowaste separation. This implies that the system is mandatory, while in the previous two simulations the measures could be applied to voluntary or mandatory systems. The results in Figure 11 show that a low fine, as the one suggested, is not very effective, since compliants are a minority (139,000 or 23%) compared to the 452,000 that are not abiding the law. The resulting source separated fraction is 14%, which is still low. Relative to the adoption through social interaction, adoption resulting from the motivation to avoid fines grows quickly and peaks around 2017, while the adoption through social interaction grows almost linearly through out the simulation run. The performance of households in terms of their separation effectiveness is not extremely good, since only 60% of the biowaste is correctly sorted.

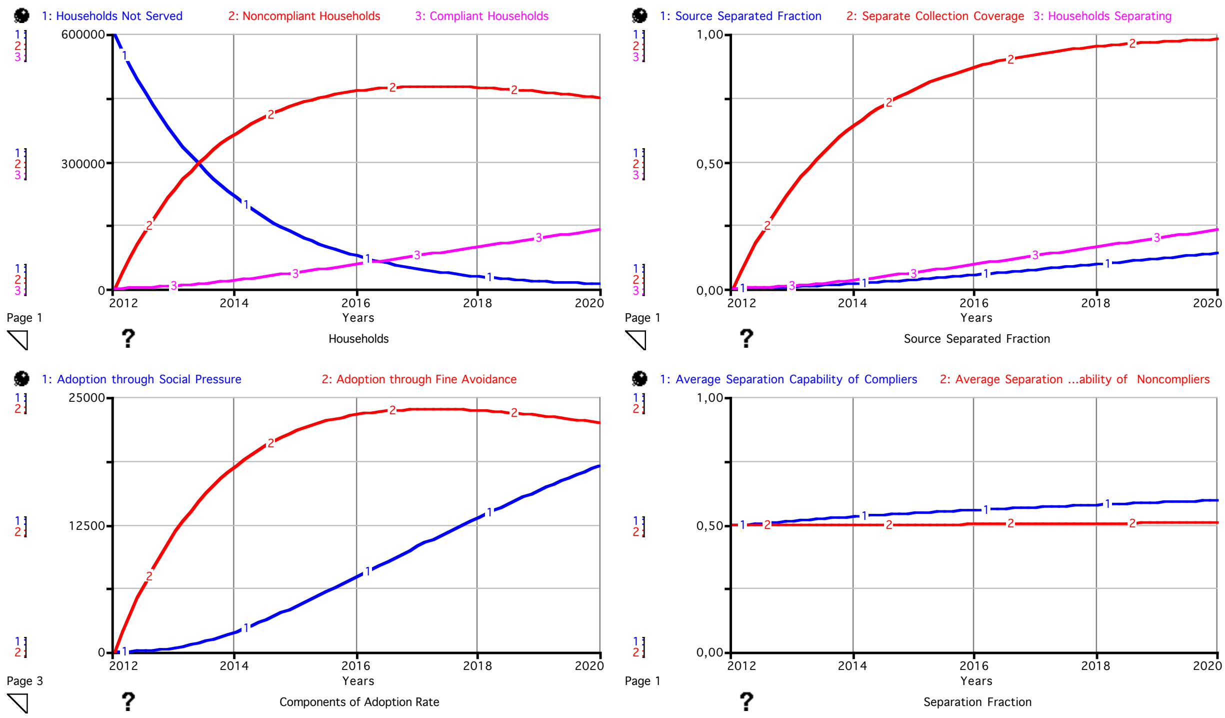

Figure 11 – Simulation Results for Charging a Fine Equal to 1 Minimum Wage

When setting the fine for households not complying with the obligation to separate biowaste to five times the minimum wage, the results are substantially different as the ones observed until now. To begin with, non-compliance peaks in 2012 and drops quickly down to 10,000 households by 2020. Meanwhile, compliant households have grown with an S-shaped pattern to reach 580,000 or 97% of all households. Furthermore, the separation rate is the highest that has been observed until now, with a value of 64% by the end of the simulation. The adoption process has peaked in 2013, when fine avoidance is highest (139,000). Additionally, those households complying with source separation achieve by 2020 a sorting capability of 66%.

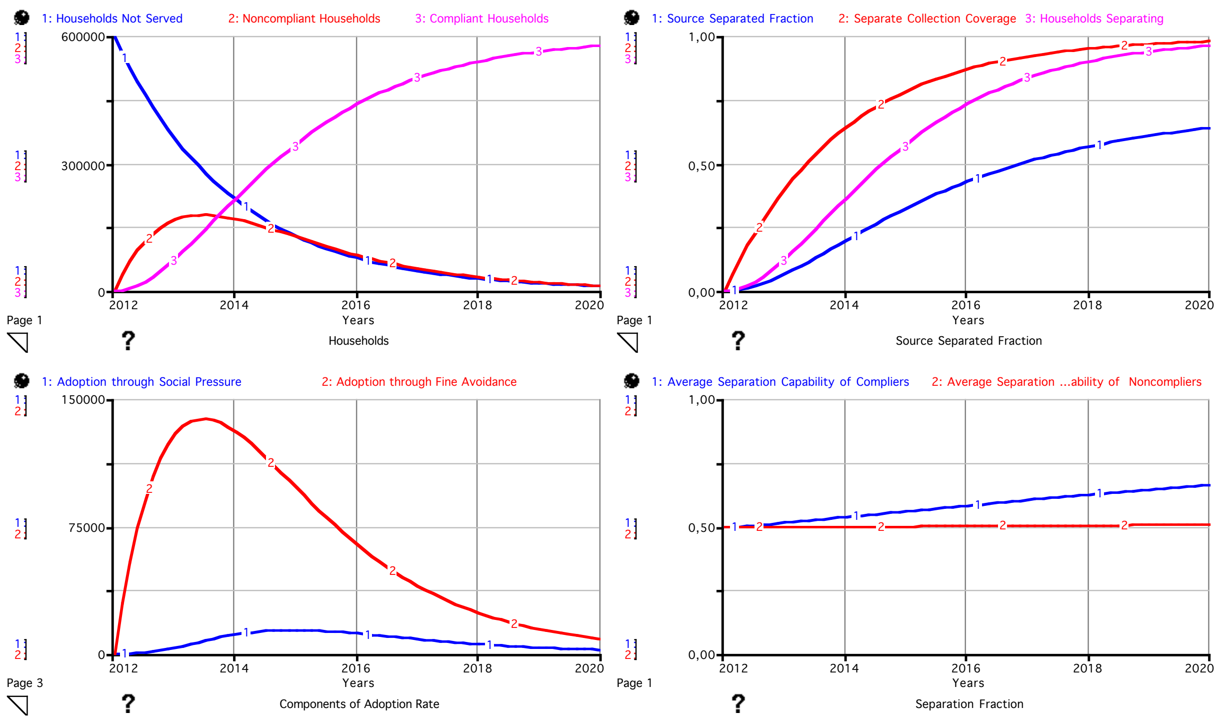

Figure 12 – Simulation Results for Charging a Fine Equal to 5 Minimum Wage

4. Conclusions

From the simulation experiments carried out, it can be concluded that the strategy that has most effectiveness is making source separation mandatory and charging fines that are not very low. However, there is an even more effective strategy, and it is having patience. Unfortunately the inherent delays in social systems and adoption processes make it impossible for the system to achieve the 70% separate collected fraction within a period of 8 years. Extending the simulation horizon to 2030 shows (Figure 13) that around 2023 the 70% mark is achieved if the fine is 5 times higher than the minimum wage.

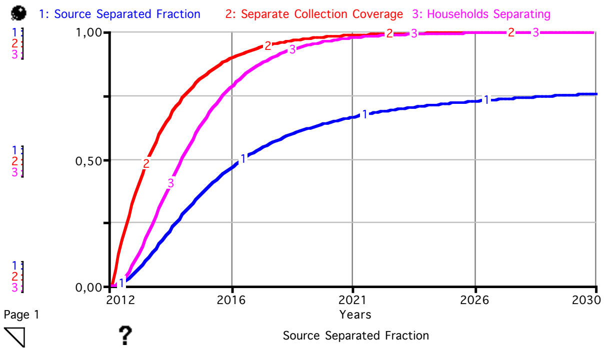

Figure 13 – Simulation Results for Charging a Fine Equal to 5 Minimum Wage until year 2030

Additionally, there are several insights that were gained through the simulation, which would certainly help waste managers in Addis Ababa, and other cities in developing countries. First, adoption of biowaste separation needs to be mandatory for all households in the city. Only this will guarantee a high recovery rate. Second, the adoption process through social pressure does not run on its own and needs to be supported by other measures including incentives, awareness raising campaigns, and most importantly, negative consequences for non-compliers. Furthermore, the intervention measures will have an effect on the determination of the collection capacity, and therefore the adjustment of the collection capacity should be done based on the information of the system in operation and not the expectations of managers before the separate collection system has been implemented. In turn, the capacity of the collection system and its effectiveness to collect all separated biowaste will have an effect on the adoption and disadoption process, since underinvestment in capacity will lead to biowaste that has been source separated to be left uncollected. This can lead to citizens deciding to give up separation as they see that the system does not work well and become disappointed. Moreover, the policies chosen will have costs and will take time to organize and implement, therefore the policies chosen and tested will not necessarily unfold when implemented in the way shown by the simulations.

Regarding the limitations of the model, as every model it is imperfect and formulations, parameters, and non-linear functions can have fundamental impacts on the behavior that emerges from the model. These need to be validated with the knowledge of local experts and through other model tests. Especially, behavior modes that lead to the collapse of the system need to be considered when thinking of improving and extending the model, since this is a potential behavior that can occur if coordination between biowaste separation, collection, processing, and the market is not appropriate.

5. References

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