BACHELOR OF TECHNOLOGY PROJECT (PART - II)

on

MODELLING INFORMAL WASTE MANAGEMENT PROCESSES USING SYSTEM DYNAMICS IN DELHI AND BALI

PROJECT CODE: PI-9

Submitted By

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Acknowledgement

This is to certify that the thesis entitled ‘’ submitted by TUSHAR BANSAL and TANMAY GOYAL to the Indian Institute of Technology, Delhi for the completion of Bachelor of Technology degree is a bonafide record of research work carried out by them under our supervision. This thesis has been prepared in conformity with the rules and regulations of the Indian Institute of Technology, Delhi. We further certify that the thesis has attained a standard required for a B.Tech degree. The research reported and the results presented in the thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Prof. Nomesh Bolia

Date: ____________

Abstract

Delhi is one of the most populous cities in the world and one of the fastest-growing economies in the world. This causes an increase in waste putting overwhelming pressure on the solid waste management system (SWMS) in Delhi. However, the informal sector helps in easing the pressure on municipal corporations. Not only that, the informal sector works in the recycling of waste which also helps the environment. The role of this informal sector is however not acknowledged at all evident from the absence of policies to improve their dwindling working and living conditions. The information documented on the informal sector is also very less and hence, to understand their importance, a system dynamics model has been developed incorporating the waste collection from households through formal and informal sectors. The model is then used to determine the environmental and social impact that is created due to the informal sector. The behaviour of waste flow under different scenarios is then studied in detail to understand their consequences on the informal sector. A case study of the waste management system in Bali, Indonesia using system dynamics is conducted to understand its municipal solid waste management system to further bring out the effect of tourists on waste flow in a city and its variation from the Delhi SWMS.

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Chapter 1: Introduction

Solid waste management system (SWM) is a very major problem in India. The process of waste management includes collection, transportation and treatment of waste (recycling, composting, incineration). Delhi comes as a prime example of major developments occurring in India: urbanization, industrialization, GDP growth. With this growth, it has been shown that the per capita waste generation also increases. However, the policies and the framework used to channel this waste flow is very out of date. Given the environmental and social impacts of an improper waste disposal system, it is important to highlight the work of the informal sector for SWM in Delhi and by extension, in India. The major portion of the waste recycled is due to the informal sector. It comprises rag pickers, kabadiwalas, thiawalas, pheriwalas, wholesalers and waste reprocessors. They collect recyclable items from households and ultimately take those to recycling mills. This not only helps in environmental well-being (by reducing greenhouse gases emission, saving land from landfills) but also helps in generating employment for thousands of people and also saving a lot of money for local municipal SWMS.

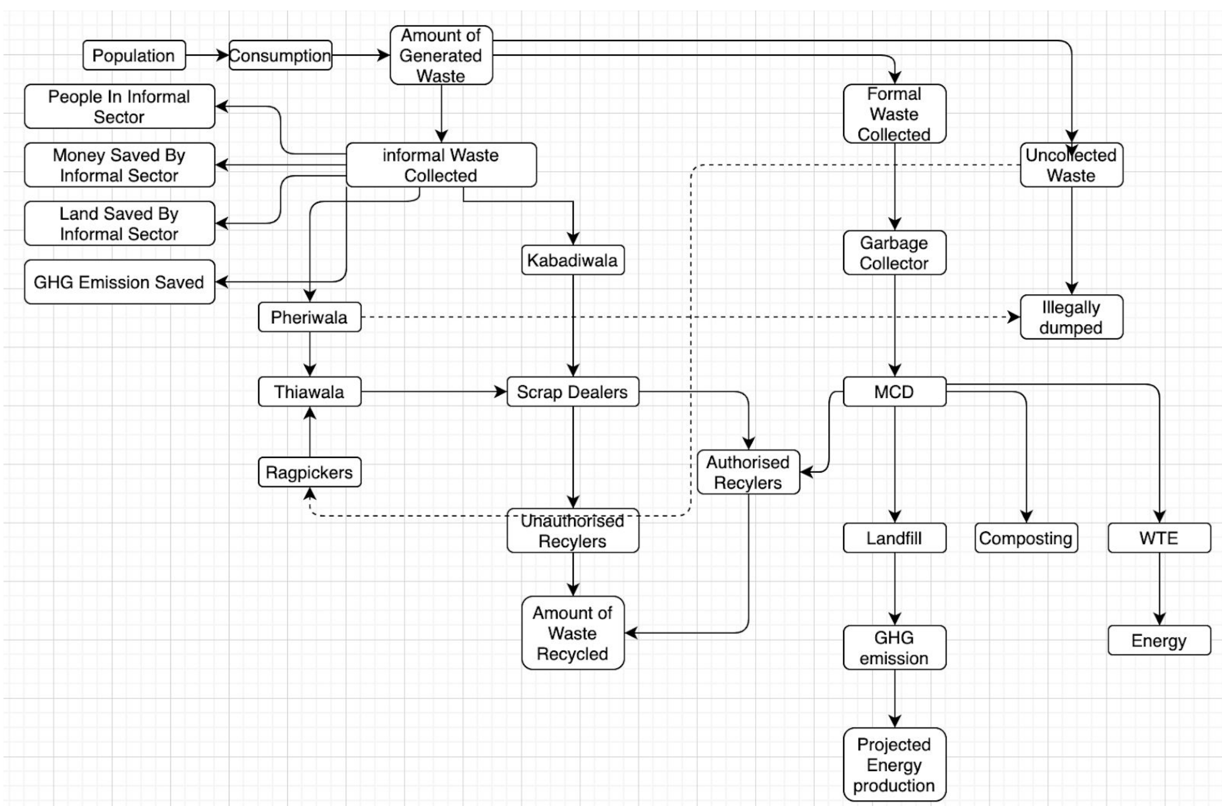

Fig 1.1 I/O diagram of the SWM system in Delhi

However, this sector is not well recognized when it comes to governmental recognition and possible incentives. Instead, recent policies like the introduction of GST have only made it worse for them to work. Also, the working conditions for them are hazardous. Most of the people in the informal sector are also socially marginalized. They have not been given the appreciation they deserve through carefully applied policies which can help them improve their working and living conditions.

This study recognizes the importance of the informal sector along with discussing various scenarios impacting them (removal of GST, elimination of privatisation, stricter of implementation of SWMR rules, adoption of formalization). The effect of the first three policies can be understood more practically as some form of these scenarios exists with either negative or positive implications. Formalization, however, is expected to bring about the change in the structure of waste flow throughout both the formal and the informal sector aiming to achieve maximum efficiency through their integration.

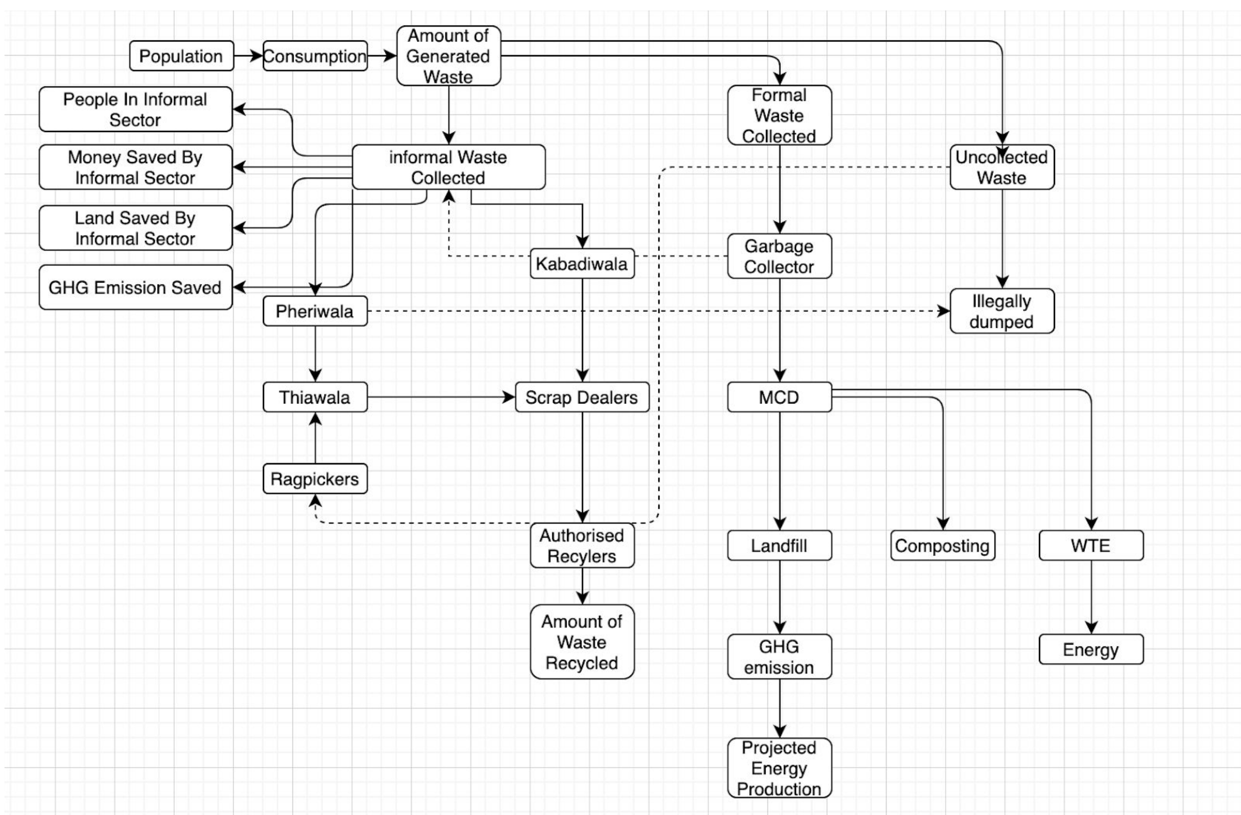

Fig 1.2 I/O diagram of Formalisation scenarios in Delhi

A case study on SWMS in Bali reveals the impact of tourists (Bali is a very popular tourist destination) in waste generation and the undermining of the informal sector despite plenty of opportunities. This has been brought out using a comparative study with the SWMS in Delhi.

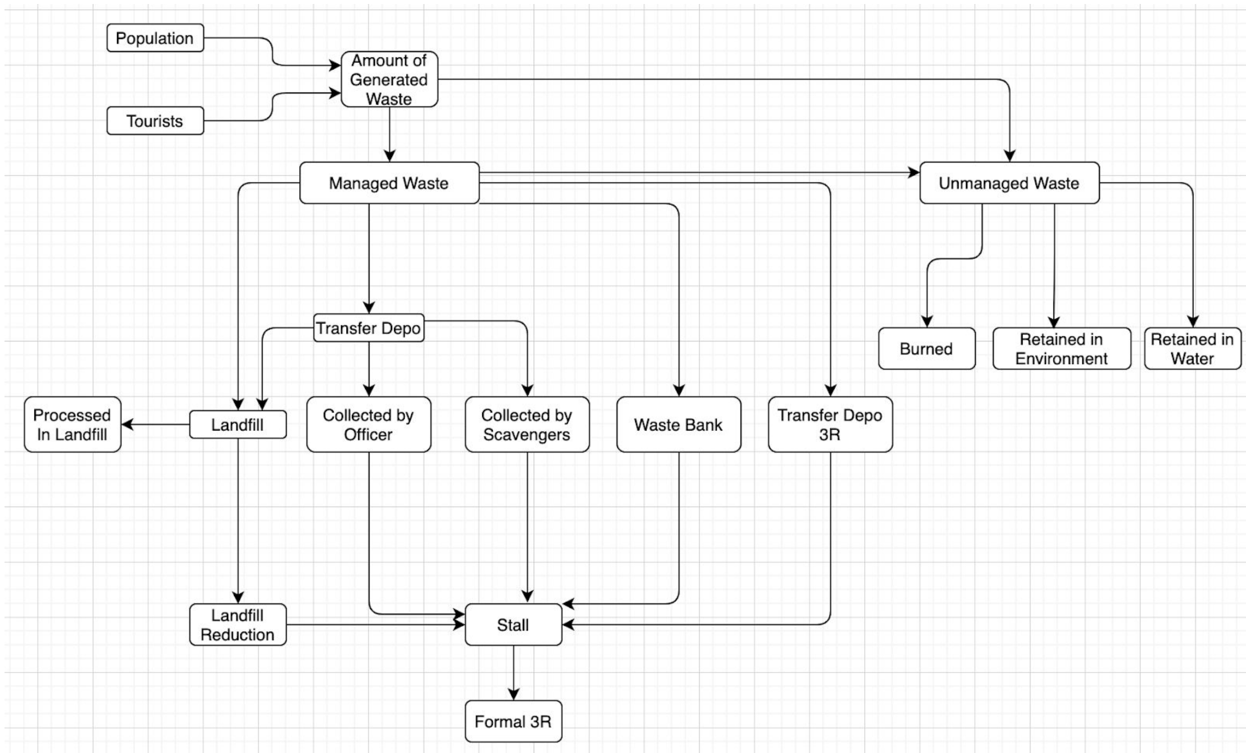

Fig 1.3 I/O diagram of the SWM system in Bali

System dynamics modeling has been used to model the SWMS in Delhi and Bali. The reasons for using system dynamics are plenty. It allows communication between different subsystems smoothly. It is easy to understand the impact of any single factor on various subsystems. It provides a good approximation for a system whose parameters are difficult to predict. It also allows the scope of creating and studying different scenarios to ultimately realize their impact.

As already mentioned, the study will include an understanding of the SWM model of Delhi, emphasizing the impact of the informal sector. Then, through different scenarios, it has been discussed on how to improve the conditions for the informal sector than with the help of the SWMS model of Bali an analysis is done to understand the relative work profiles of the informal sector in a metropolitan city (Delhi) and a tourist place (Bali).

Chapter 2: Literature survey

A review of solid waste management using system dynamics [32] established a review of solid waste management using system dynamics. It emphasizes the importance of SDM since it enables setting up relation and feedback formulation amongst different variables. It also helps in establishing the usefulness of SDM owing to the communication between different parameters to generate results for various scenarios which ultimately helps in decision making. As an example, it discusses how on increasing illegal disposal of materials, the recycling will decrease which was formulated using SDM and can be used for developing policies.

A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues [34] deals with the usage of subsystems to analyse Municipal solid waste management in Newark, New Jersey. It also showcases the forecasting of landfill usage and the impact of policy decisions on various parameters is discussed. It shows that landfill capacity will be used completely in 9 years but more attention directed at recycling by creating more recycling markets and decreasing its cost could not only help in decrease in landfills but an increase in recycled materials which will be better for the environment as well.

A system dynamics model for evaluating food waste management in Hong Kong, China [35] consists of food waste management in Hong Kong being modelled using system dynamics to understand its behaviour with the ongoing trends and with the help of different scenarios, it has been shown that the Hong Kong government can realize the objectives it has set if certain policies are implemented. It was seen that adapting Organic Waste Treatment Facility as well as waste charging, both in their own proportions, although a little costly was the most effective way to decrease waste sent to landfills.

System dynamics model for optimizing the recycling and collection of waste material in a closed-loop supply chain [37] : Simulation of a closed loop supply chain management using the case of an electrical manufacturing company has been discussed. It also reflects on scenario building to improve the model to understand the effect of customer patterns for recycling and collection office material in a closed supply chain. It was seen that by creating a collection center, the average customer satisfaction level increased by 21.6% due to decrease in backlogs. Also, this led to prompting companies to consume the used products again, hence increasing their Green Image Factor.

A system dynamics approach to product design and business model strategies for the circular economy [36] helps understand how an effective system can enforce feedback loops and time delays. It involves how product design, second-hand use, product use and replacement, collection and processing for product recycling and finally, product discard can affect the product's journey in a closed loop system. Considering the disassembly and recyclability indexes to model, it was observed that a median of two was preferable and along with a short life span, it helps in higher availability of used products which not only supports the inventory of recycled products but also the quicker replacement times for the used products.

A system dynamics model for recycling networks [16] aided in understanding how models for recycling networks can be created using system dynamics and how the parameters can be approached to consider policies and "what-if" scenarios. For example : Incorporating a capacity planning module can help in developing the policies for adjusting capacity at different collection centres efficiently.

System Dynamics Modelling of Remanufacturing and Recycling Mode Based on Closed-Loop Across-Chain Competition [31] : Considering two enterprises - Midea Corp. and Gree Corp., remanufacturing and recycling has been modelled for a competitive closed-loop supply chain. A low-carbon system can increase costs but increases general public awareness. The contract between retailers and manufacturers can also incorporate recycling to decrease payment lags and more market share of the supply chain.

Municipal Recycling: A System Dynamics Model [2] describes that when various social factors are considered to improve, they can dramatically impact the overall recycling activity in the US. Higher landfill cost, Easier recycling, Improved manufacturing to help recycling, Increasing in awareness amongst manufacturers and non-recyclers for recycled products, decrease in per capita waste generation decreased can help bring annual landfilled waste to 159 MT by the year 2050 as compared to 1174MT which is expected otherwise. Also, the percentage of recycled waste increases from expected 33% to over 70% for 2000.

Solid waste management in Delhi - A social vulnerability study [26] details socio-economic conditions, working conditions and health hazards that the waste pickers face in Delhi. Also, their importance has been highlighted and the policies introduced by the government have been discussed. The study also describes that policies like institutionalized waste picking, encouraging recycling, setting up of cooperatives will help in improving their conditions.

Recovery of consumer waste in India – A mass flow analysis for paper, plastic and glass and the contribution of households and the informal sector [27] discusses the chain of mass flow for different recyclables - glass, paper, plastic and indicates how an upper and lower estimate can be calculated for these to understand the quantities that are dealt with and the role of the informal sector in it. Calculating the parameters for Mohali, they have been estimated for India as well to reach the conclusions that at least 50–70% plastic waste, 30–65% paper related waste and about 100% of all glass bottles produced are recycled.

A System Dynamics Study of Solid Waste Recovery Policies in Phnom Penh City [18] uses system dynamics to model waste management in Phnom Penh City, Cambodia to put an emphasis on methodologies of waste recovery : informal recycling and small scale composting. It shows that without policy intervention like encouragement from municipalities by reducing compost sale price, providing subsidies on composting and supporting informal waste pickers, it is difficult to recover waste.

A system dynamics model to predict municipal waste generation and management costs in developing areas [20] deals with a system dynamics model of Nablus as a case study to predict MSW generation, recycling processes and the costs associated using only population as a factor. The waste was classified into 8 categories : glass, plastic, paper, cardboard, organic, inert, metal and others to understand the potential of recycling and disposal in accordance with the quantities of waste generated in these categories. It was found that if all recyclables are recycled by the Nablus municipality, it would save 17,513,410 NIS (New Israeli Shekel).

A system dynamics-based approach to help understand the role of food and biodegradable waste management in respect of municipal waste management systems [19] states the importance of separate treatment of food and biodegradable waste (FBW) with the help of a system dynamics model of Oita City, Japan. It showed that by strengthening the regulations, increase in sorted waste and reduced incineration of FBW waste will improve the MSW management system. Also, by introducing anaerobic digester plant for FBW treatment, the efficiency of incineration increases.

System dynamics modelling of waste management system [29] : In order to simulate the waste management system of a South Western State in Nigeria for 10 years, 13 parameters were considered which were determined using waste generation and collection activities. The performance of the model was identified in terms of waste collected and waste in stock. It was seen that when the waste collection factor is increased from 70% per year to 90% per year, the waste collected increases from 302,137 tons to 617, 794 tons.

An empirical study on greenhouse gas emission calculations under different municipal solid waste management strategies [28] : Directed by the guidelines in the Intergovernmental Panel on Climate Change, greenhouse gases (GHG) emission are calculated in Beijing. It is reflected that landfills produce more GHG than incineration and composting. It is also found that 70.82% of emission reduction benefit is attained if kitchen waste and other recyclables are first segregated and the remaining waste is incinerated, This also helps not only in recycling of the products but also electricity generation due to incineration.

Between hype and veracity; privatisation of municipal solid waste management and its impacts on the informal waste sector [33] : With the help of a case study for Amritsar city, the problems involved with privatisation of informal sector have been discussed with main emphasis on socio-economic conditions of people involved including the impact of privatisation on their access to waste, their income, the treatment they receive from local municipal corporations and private companies have been discussed. The study also throws light on the fact that the existence of privatisation cannot be ignored due to the attractive features of its efficiency and higher regard, but it should come with an understanding of integrating the informal sector within the bigger system.

Improving the informal recycling sector through segregation of waste in the household : The case of Dhaka Bangladesh [46] : With the city corporation of Dhaka collecting less than half of the waste generated, the remaining waste is being dumped indiscriminately which brings in an urgent need to improve the SWM system. The paper investigates the importance of segregation at source and how it will impact different sections involved in waste generation and management : households, stakeholders, local authorities and people from different parts of the informal sector. It is suggested that higher source segregation will only help in higher quality of recyclables and hence, an increase in their value.

Building recycling rates through the informal sector [47] discusses the importance of the informal sector in reaching high recycling rates of 20-50% which was achieved in North America and Europe at high costs. The examples of India and Pakistan highlight the general public notion of modernizing the informal sector hindering the recycling rates and the examples of itinerant waste buyers in the Philippines and China showcase their importance in recycling. These cases highlight the importance of official acknowledgement of the informal sector and segregation at source systems.

Role of informal sector recycling in waste management in developing countries [48] : The structure of the informal sector along with their tasks, the socio-economic conditions they suffer including the health hazards and economic pressure have been discussed. In order to improve their quality of life and increase recycling efficiency, some policies should be enacted. It has also been suggested that they should coalesce with the formal sector to help enhance their conditions.

Waste management and extended producer responsibility - Lessons from the past [49] critically analyzes the Solid Waste Management Rules, 2016, E-Waste (Management) Rules, 2016, and the Plastic Waste Management Rules, 2016 with respect to the role of Extended Product Responsibility (EPR) in the management of waste electronic and electrical equipments (WEEE) and recyclable waste esp. plastic waste. It has been concluded that these rules do not aptly cover the role of the informal sector and especially considering their role in managing WEEE, there should be some provisions to integrate it with the formal sector.

Chapter 3: Project Objectives and Workplan

3.1 Problem Definition and Motivation

The importance of the informal sector has already been established. It has also been observed that the community has been marginalized, underpaid and without any major acknowledgment. Due to this misrepresentation, the work carried out on this sector is also very limited. Especially in India, there is little information documented about this sector. Hence, it is important to understand the operations of this sector in order to address their issues. The main purpose of this study is to work on that by discussing the policies which they can benefit from.

This study deals with estimating an informal model of SWM for Delhi. Since there is a little data available for the model, an approach to system dynamics seems plausible. Essentially, a value chain consisting of Pheriwalas and Kabadiwalas through different dealers to recycle mills and ultimately back into the consumption chain will incorporate the operating pathways and thus, a sense of the underlying problems for the informal sector, ultimately aimed at improving the recycling rates. This project fundamentally deals with creating a model closely resembling the SWM system in Delhi and comparing it with the model of the Bali SWM system.

3.2 Objectives of the work

Following objectives have been considered to mark the progress along with the project :

- Understanding the value chain for an accurate depiction in the model
- With available research data (papers and primary research), a model designed closely resembling the value chain with optimal parameters and flow directions
- Selecting appropriate values of parameters using available data and possibly using regression among other tools to predict remaining parameters
- Validation of the model variables with results available from surveys and research
- Studying the impact of the informal sector on environment and costs incurred
- Analysing various scenarios and their effects on SWM in Delhi
- A Case study on Bali Solid Waste Management

3.3 Methodology

The goal of the project is to make a complete model including all the parameters for modelling informal Solid Waste Management (SWM) in Delhi. First, a study of the existing models on formal Solid Waste Management (SWM) was carried out. Numerous research papers were studied and along with an extensive discussion, it was concluded that System Dynamics can be used to model informal Solid Waste Management (SWM) because this approach doesn't need all the parameters, it mainly needs the supply chain and the flow. So, modelling using STELLA has been carried out with currently assuming all the unknown parameters.
After successfully creating the basic models in STELLA, the separate models were integrated to create a final model. After that, deductions of all the needed parameters by reading literature reviews and taking surveys were done. Once this was done, the model was validated using various validation techniques. Scenarios affecting the SWM system of Delhi were analysed and integrated. Once this was done, a model for simulating the SWM system of Bali - a tourist destination was modelled to conduct a comparative study discussing the SWM system of Delhi and Bali models.

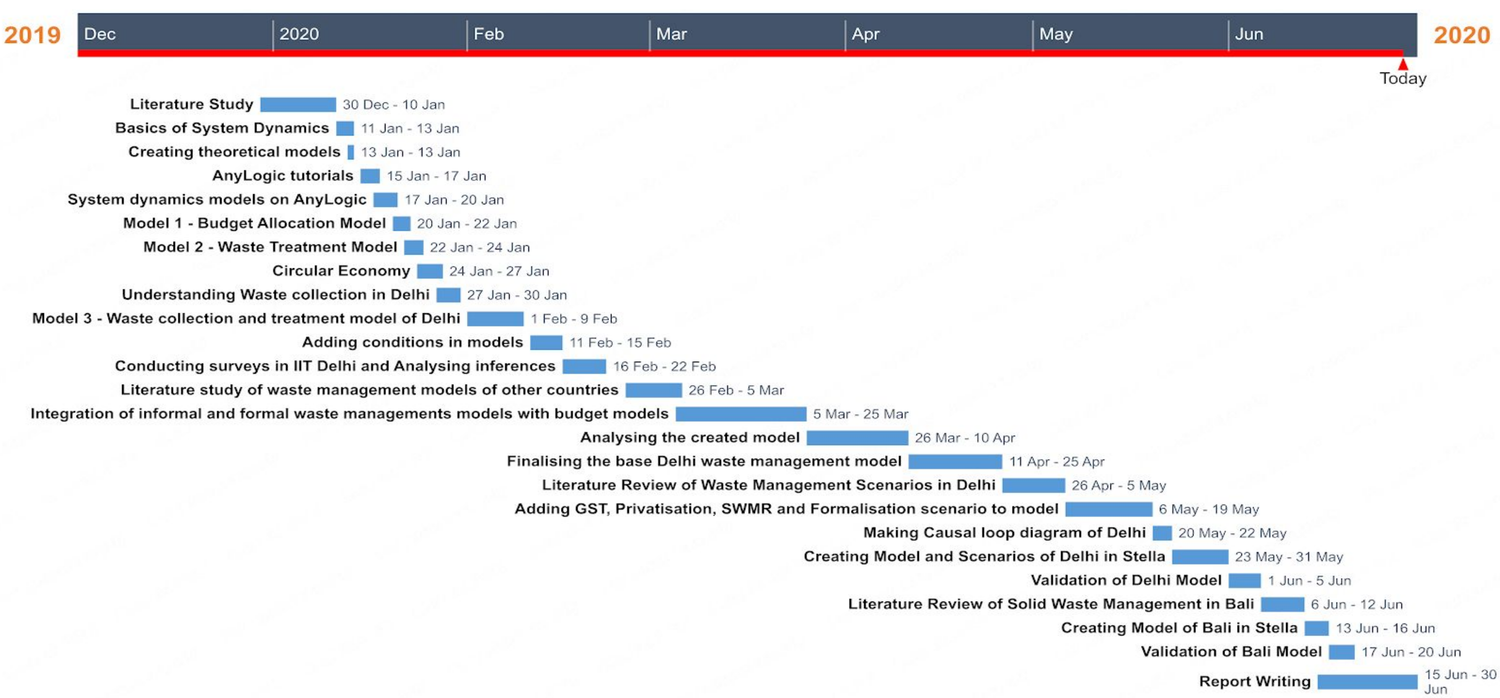

Fig 3.1 Gantt Chart

Chapter 4: System Dynamics Modelling in Delhi

4.1 Causal Loop Diagram

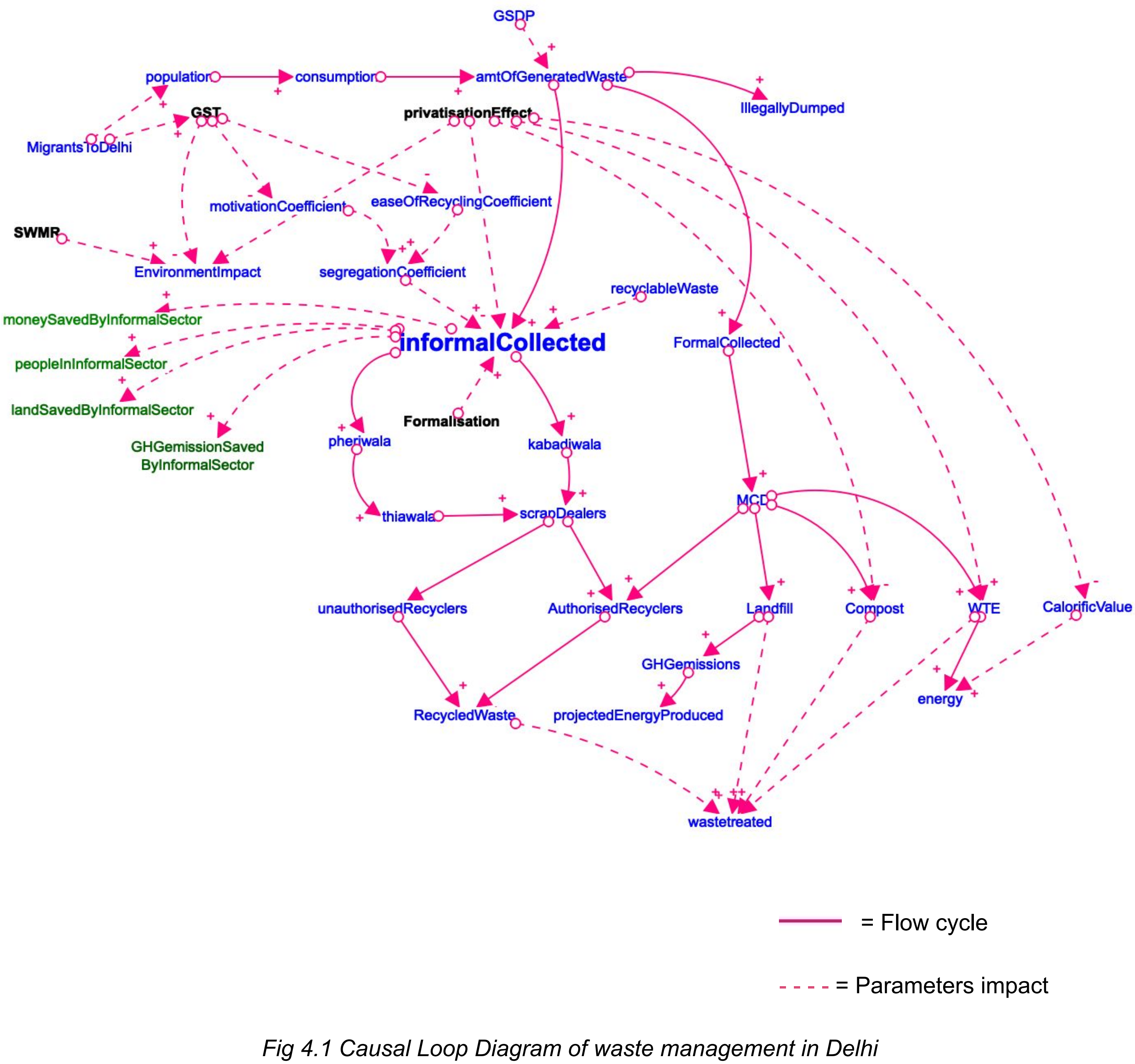

Fig 4.1 Causal Loop Diagram of waste management in Delhi

4.2 Stock and Flow Diagram

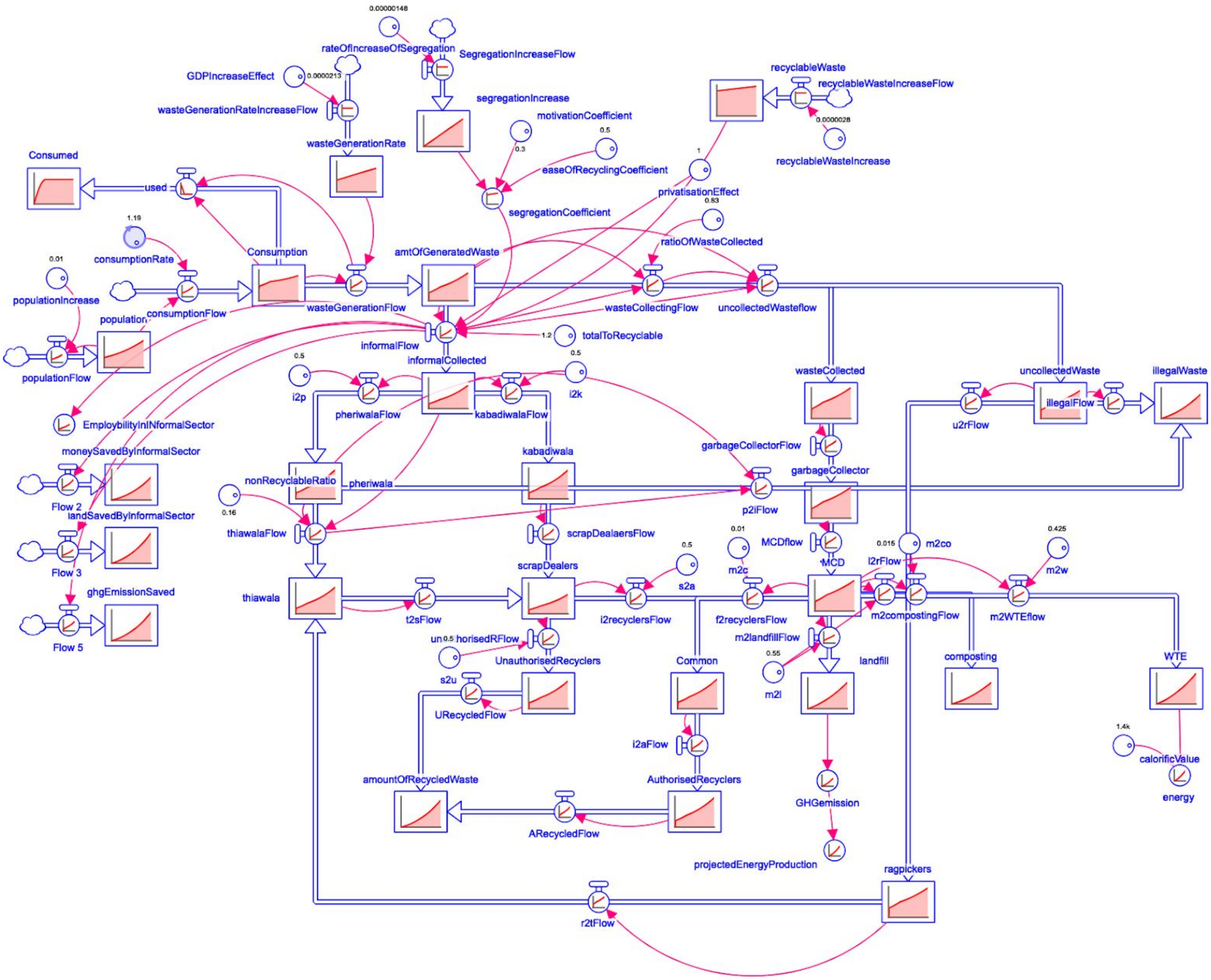

Fig 4.2 Waste Management model of Delhi in Stella

It is important to understand the terminology used for different sections of the informal sector.

a) *Pheriwalas* : They work in small capacities usually on a tricycle or a pheri. They collect waste from some smaller households, some local MCD bins and little shops. The waste they collect is usually not completely recyclable and has to be segregated afterwards before selling it further. The non-recyclable waste left is usually illegally dumped. They might pay a nominal amount of money for the collected waste.
b) *Kabadiwalas* : They work in larger capacities, usually with a motor cart or an electric vehicle. They collect waste from bigger households, mostly receiving segregated recyclable waste as they visit each of these houses after every one or two months, as per the household requirement. They collect the waste and pay a nominal amount of money for the collected waste.
c) *Ragpickers* : They usually collect recycling waste from illegally dumped waste (and landfills) to sell it further.
d) *Thiawalas* : These are small shop owners (usually they don't even have a shop and might only have a small stand or a set-up in a public space) to collect waste from pheriwalas and ragpickers.
e) *Scrap Dealers* : These have larger shops to collect waste from thiawalas as well as kabadiwalas. They only accept recyclable material and sell them later to both unauthorised recyclers as well as authorised recyclers.
f) *Unauthorised Recyclers* : They recycle the waste they receive and further sell to the manufacturing industries. They are not authorized by the government usually because they do not have permits, the work conditions they have are hazardous and they are not legally recognized.

1. The population of Delhi was taken, multiplied with the consumption rate which gave total consumption of the population. Multiplying it with the waste generation factor which is waste created per person per day (inclusive of both formal and informal data) on an average (0.77 kg/day/person) gives the total waste generated in Delhi per day. This was taken from total waste produced in Delhi in 1 day (collected by formal and informal sectors) divided by the population of Delhi. From this total waste generated per day in Delhi was deduced.

2. From the data of the population, it was deduced that the population increases by an annual factor of 1.01. It was also deduced from the data of waste generation per day to be increasing by an annual factor of 1.0077. This increase in waste generation can be attributed to the effect of GDP and it depends on the country's

GDP. Therefore the variable **GDPincreaedEffect** was used for evaluating this increase in waste generation.

3. From the generated waste, it was found that some waste goes to the informal sector while the remaining goes to the formal sector. The amount of waste going to the informal sector depends on the segregation coefficient, the amount of recyclable waste in the total waste, privatisation effect, and ***total2recycle.***

4. The segregation coefficient depends on the motivation coefficient and the ease of recycling. Also from the data, it was deduced that the segregation coefficient increases by an annual factor of 1.0005 which was shown in the model by the variable **increase**.

5. It was found that the amount of recyclable waste in the total waste was about 57% and from the data, it was deduced that the recyclable waste increases by an annual factor of 1.041.

6. It was found out from a study (Table 4.1) that the informal sector employs 1,50,000 people to cater to 2000 tonnes of waste. From this, the number of people employed in the informal sector per kg waste recycled by them to estimate employment in the informal sector. It was also deduced from the data from the study (Table 4.1) that the informal sector saves 1,00,00,000 rupees of the government per day and from this, the total money saved by the informal sector was estimated. It was also deduced from the data that 3,000,000 tonnes need 40 hectares of land for landfills. From this, the land saved from being used for landfills by the formal sector due to the work of the informal sector was calculated. GHG emission for every kg of the waste dumped in landfill was also studied. As without the informal sector, the waste going to recycling now would instead go to landfilling and result in GHG emission, the emissions prevented because of the work of the informal sector were predicted.

7. Now the waste collected by the informal sector was divided into 2 parts : depending on who collected it (based on the surveys taken and information available about the Delhi waste management system). The waste was divided uniformly between Kabadiwala **(i2k)** and Pheriwala **(i2p)** assuming both collected 50 percent waste.

8. It was seen that not all the waste collected by pheriwalas is recyclable and hence, the portion of waste which was non-recyclable actually is dumped illegally. This was estimated to be 16% of the informal waste. The remaining of the waste goes to Thiawala which then goes to scrap dealers. From kabadiwala waste goes directly to scrap dealers. Now from scrap dealers, the waste goes to authorised **(s2a)** and unauthorised **(s2u)** recyclers. It was assumed to be 50% waste going to each of them.

9. Now to see the formal sector, Formal waste flow was deduced by multiplying total municipal waste (which is given by total waste generated - informal flow) by waste collection factor (83%) based on data from a study (Table 4.1). This gave the total waste collected by the formal sector in Delhi per day.

10. This waste collection is done by garbage collectors and reaches the MCD. From MCD it goes into different types of treatment -
    a. **Authorised recycling (m2c)** - 1% of MCD waste goes to authorised recyclers for recycling. This is very less as this waste is not segregated properly.
    b. **Landfill (m2l)** - It was deduced from the data of total waste going to landfills in Delhi that 55 percent of waste from MCD is going to landfills.
    c. **Composting (m2co)** - It was deduced from the data of total waste going to composting in Delhi that 1.5 percent of waste is going to compost.
    d. **WTE (m2w)** - It was deduced from the data of total waste going to WTE in Delhi that 42.5% of waste is going to WTE for producing energy. It was also deduced from the data that the calorific value of waste was 1400 kcal/kg (less than national standards of 1500 kcal/kg because of the lack of segregation of waste) and multiplying waste going in WTE by 1400 kcal/kg gives energy produced in the process.

11. From this, the total waste recycled, landfilled, composted, and used in WTE plants per day i.e total waste treated per day was deduced.

12. The waste which was not collected by both formal and informal sectors goes as uncollected waste. From the uncollected waste, some waste is collected by rag pickers **(u2r)** which is roughly 0.1% of the total waste uncollected. This waste then goes to thiawala **(r2tFlow)** which in turn is recycled. All the remaining uncollected waste is illegally dumped.

4.3 Model Formulation

Table 4.1 Parameters in Delhi model

Name	Values	Formula / Derivation	Source	Type
population	19500000	Section 5.1.2	[1]	Static
populationIncrease	0.01	Deduced by taking population data over several years	Deduced	Static
populationFlow		populationIncrease*population/365	Deduced	Dynamic
consumptionFlow		population*consumptionRate	Deduced	Static
used		Consumption-wasteGenerationFlow	Deduced	Dynamic
wasteGenerationRate	0.77 per day	Section 5.1.2	[44], [7]	Static
wasteGenerationRateIncreaseFlow		GDPIncreaseEffect	Deduced	Dynamic
GDPIncreaseEffect	0.0000213 per day	Deduced by taking increase in waste generation over several years	Deduced	Static
wasteGenerationFlow		consumption*wasteGenerationRate	Deduced	Static
rateOfIncreaseOfSegregation	0.00000148 per day	Deduced by taking increase in segregation over several years	Deduced	Static
SegregationIncreaseFlow		rateOfIncreaseOfSegregation	Deduced	Dynamic
motivationCoefficient	0.3	Section 5.1.2	[3], [4]	Dynamic
easeOfRecyclingCoefficient	0.4	Section 5.1.2	[2]	Dynamic
segregationCoefficient		(segregationIncrease+motivationCoefficient)*easeOfRecyclingCoefficient*1.67	Deduced	Static
recyclableWaste	0.57	Section 5.1.2	[7], [6]	Static
recyclableWasteIncrease	0.0000028 per day	Deduced by seeing increase in waste recyclable over several years	Deduced	Static
recyclableWasteIncreaseFlow		recyclableWasteIncrease	Deduced	Dynamic
privatisationEffect	1	Section 5.1.2	Deduced	Static
totalToRecyclable	1.2	Section 5.1.2	[3]	Static
informalFlow		segregationCoefficient*amtOfGeneratedWaste*recyclableWaste*privatisationEffect*totalToRecyclable	Deduced	Static
EmployabilityInINformalSector		informalFlow*0.075	[7]	Dynamic
moneySavedByInformalSector		informalFlow*5	[7]	Dynamic
landSavedByInformalSector (sq m)		informalFlow*0.000133	[9]	Dynamic
ghgEmissionSaved (TPD)		informalFlow*0.28	[10]	Dynamic
pheriwalaFlow		informalCollected*i2p	Deduced	Static
i2p	0.5	Justified using sensitivity analysis	Assumed	Static
kabadiwalaFlow		informalCollected*i2k	Deduced	Static

i2k	0.5	Justified using sensitivity analysis	Assumed	Static
nonRecyclableRatio	0.16	Section 5.1.2	[3]	Static
thiawalaFlow		pheriwala-nonRecyclableRatio*informalCollected	Deduced	Static
scrapDealaersFlow		kabadiwala	Deduced	Static
t2sflow		thiawala	Deduced	Static
unauthorisedRFlow		scrapDealers*s2u	Deduced	Static
s2u	0.5	Justified using sensitivity analysis	Assumed	Static
i2recyclersFlow		scrapDealers*s2a	Deduced	Static
s2a	0.5	Justified using sensitivity analysis	Assumed	Static
URecycledFlow		UnauthorisedRecyclers	Deduced	Static
i2aFlow		Common	Deduced	Static
ARecycledFlow		AuthorisedRecyclers	Deduced	Dynamic
wasteCollectingFlow		ratioOfWasteCollected*(amtOfGeneratedWaste - informalFlow)	Deduced	Dynamic
ratioOfWasteCollected	0.83	Section 5.1.2	[6]	Static
garbageCollectorFlow		wasteCollected	Deduced	Dynamic
MCDflow		garbageCollector	Deduced	Dynamic
f2recyclersFlow		MCD*m2c	Deduced	Dynamic
m2c	0.01	Section 5.1.2	[8]	Dynamic
m2landfillFlow		MCD*m2l	Deduced	Dynamic
m2l	0.55	Section 5.1.2	[8]	Dynamic
m2compostingFlow		MCD*m2co	Deduced	Dynamic
m2co	0.015	Section 5.1.2	[8]	Dynamic
m2WTEflow		MCD*m2w	Deduced	Dynamic
m2w	0.425	Section 5.1.2	[8]	Dynamic
l2rFlow		MCD*m2l*0.0018	Deduced	Dynamic
r2tFlow		ragpickers	Deduced	Dynamic
energy (kcal)		WTE*calorificValue	Deduced	Dynamic
calorificValue	1400	Section 5.1.2	[8]	Static
GHGemission (TPD)		landfill*0.26	[10]	Dynamic
Projected Energy produced (MJ)		GHGemission*0.045	[11]	Dynamic
uncollectedWasteflow		amtOfGeneratedWaste-wasteCollectingFlow-informal Flow	Deduced	Dynamic
u2rFlow		uncollectedWaste*0.00103	Deduced	Dynamic
illegalFlow		uncollectedWaste*0.99897	Deduced	Dynamic

Chapter 5: Models Tests and Validation

5.1 Tests of Model Structure

5.1.1 Structure Verification Test

The structure verification test is an empirical way of comparing the relations and equations in the model and in the real world. The developed model should be in keeping with the system's descriptive information. For the structural verification of the model on Informal Waste Management in Delhi, 5 models and literature data from various research papers were used. During the model development, the following were utilized -

1) Causal loop diagram structure of waste management
2) The specific case - Delhi's data of Solid Waste Management
3) Recycling and movement of waste through the various people involved in the waste trade
4) the sub-models/structures of the existing models of the domain
5) Scenarios by understanding implications and details

The causal relationships developed in the model, which were based on the available knowledge about the real system and parameters affecting the model, provided a sort of 'empirical' structural validation. The adopted sub-models of the existing models of the domain served as a 'theoretical' structural validation.

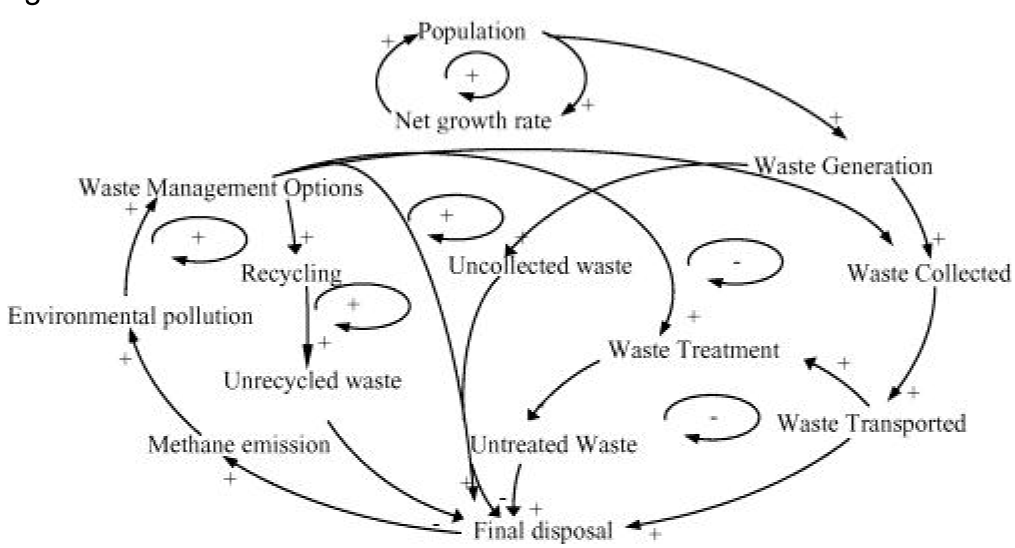

Fig 5.1 Causal Loop Diagram of waste treatment [43]

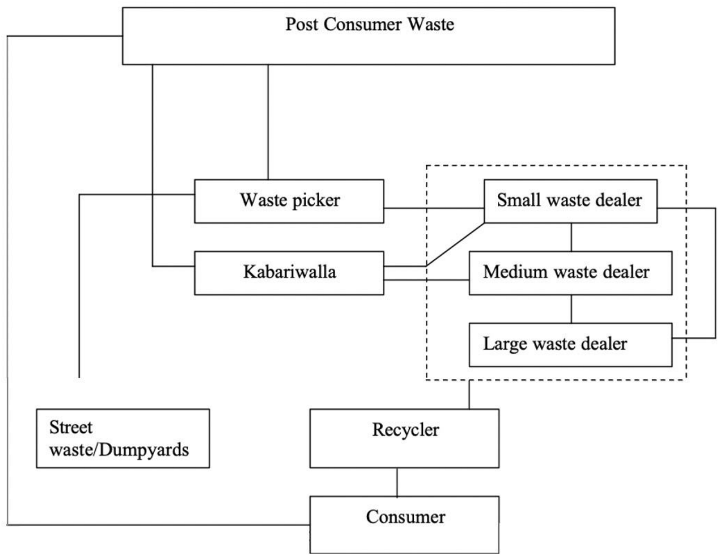

Fig 5.2 Movement of waste through various subsections of the informal sector [26]

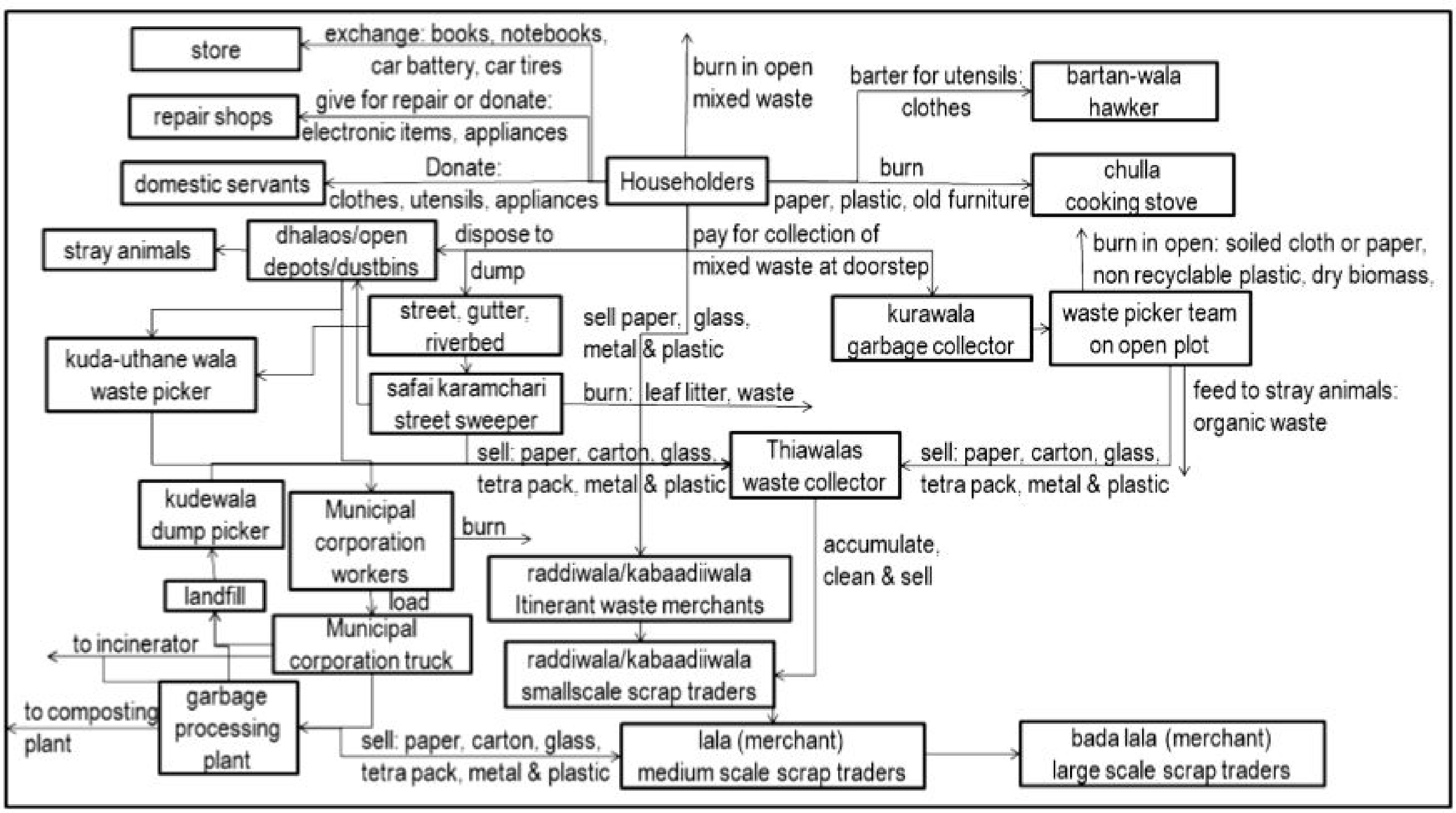

Fig 5.3 A Typical Solid Waste Management Model in India [27]

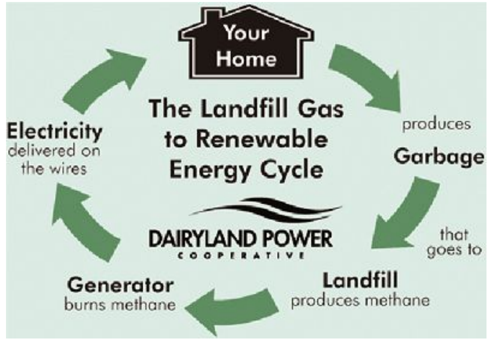

Fig 5.4 Waste to Energy cycle [11]

Table 5.1 Adopted Structures in the Delhi model

Structure/Concepts	Remarks
Causal Loop Diagram of waste Management (Fig 5.1)	The causal structure was adopted
Movement of waste through the various various subsections of informal sector (Fig 5.2)	Informal sector structural formulation was adopted.
Solid Waste Management in Delhi (Fig 5.3)	Formal sector structural formulation was adopted.
Waste to Energy cycle (Fig 5.4)	WTE cycle sub-model adopted

5.1.2 Parameter Verification Test

It means evaluating all the constant parameters and comparing it with the existing knowledge of the real system numerically and conceptually.

1. **Population of Delhi**: [1] (Page 1)

2. **Waste Generation rate**: It was estimated by summing the formal and informal waste collected & taking into account the ratio of waste collection
   a. Formal sector = 1,30,00,000 kg/day/1,95,00,000 = 0.67 kg/day/person [44] (Page 1)
   b. Informal sector = 20,00,000 kg/day/1,95,00,000 = 0.10 kg/day/person [7] (Page 15)

3. **Motivation Constant**: Motivation was estimated by the quantity of waste collected in a day by the informal sector.
   The following values were found for Hyderabad [3] (Page 17)
   a. More than 75kg/day waste is collected by only 3% of the workers

b. 50-75 kg waste is collected by 5% of the workers
c. 25-50 kg waste is collected by 20% of the workers
d. Less than 25kg/day is collected by 72% of the people

Using these values, it is safe to say that around 30.875 kgs of average waste is collected by a worker in the informal sector in a day.
Assuming that the maximum waste collected by a worker is 75kg/day, this translates to a motivation coefficient of 0.35. Since the costs & conditions of the informal sector are similar in Hyderabad and Delhi, a similar value can be considered for the informal sector in Delhi.

Since this study was conducted before the implementation of GST, hence, motivation constant if GST is removed = 0.35
Considering this, the motivation coefficient was assumed to be 0.3 for the current scenario when GST is applicable.
This is due to increase in taxes causing a decrease in income [4] (Page1)

4. **Ease of Recycling:** It was about 0.5 in the United States in the 1990s. [2] (Page 7). Since the technology used by India currently is similar to that in the US in the 90s, hence, current ease of recycling can be taken to be 0.4. This would have increased without GST since the cost of recycling has increased under the recycling tax imposed which makes it difficult to recycle waste. Hence, ease of recycling if GST is removed is assumed to be about 0.45.

5. **Segregation Coefficient:** 1.67 was an adjustment value for coherence

6. **Recyclable Waste:** 1. Informal sector collects about 20% of the recyclable waste [7] (Page 72)
   2. 80% of the waste collected by formal is either recyclable or Compostable. Assuming 50% of this waste is recyclable, it was deduced that 0.5*waste collected by formal/total waste = 0.375. [6] (Page 1)
   Hence, total recyclable waste = 0.2+0.375 is approximately 0.57

7. **TotaltoRecyclable:** Correction term of 1.2 is assumed to consider non-recyclable waste collected by the informal sector which is later

assumed to be dumped illegally. It was found that at least 85% of the people in informal sector collect unsegregated waste [3] (Page 17)

8. **nonRecyclableRatio:** It has been assumed that about 16% of the waste in the informal sector is non-recyclable (owing to 85% of the people collecting unsegregated waste). [3] (Page 17)

9. **ratioOfWasteCollected:** [6] (Page 1)

10. **calorificValue:** [8] (Page 21)

11. **peopleInInformalSector:** [7] (Page 15)

12. **moneySavedByInformalSector:** [7] (Page 7)

13. **landSavedByInformalSector (sq m):** [9] (Page 1)

14. **GHG emission saved (TPD):** We subtracted the waste going to landfill in presence of informal sector from the waste going to landfill in absence of informal sector & multiplied that with GHG emitted/kg waste in landfill [10] (Page 15)

15. **GHG emission (TPD):** [10] (Page 15)

16. **Projected energy:** [11] (Page 1)

17. **m2l, m2co, m2w, m2c:** [8] (Page 22)

18. **Recyclable waste increase rate:** It was assumed that the recyclable waste increases by at least 0.1% annually. This translates to 0.001 of the total waste. Considering everyday change it can be taken approximately to be 0.001/365 = 0.0000028

5.1.3 Dimensional Consistency Test

It involves checking the LHS and RHS of all the equations in the model for dimensional consistency using Dimensional equations.

Table 5.2 Dimensional Consistency in Delhi model

Equations	Dimensional Equations
populationFlow = populationIncrease*population/365	no. of people/day = constant*no. of people/day
consumptionFlow = population*consumptionRate	kg/day = no.of people*kg/(day*person)
used = Consumption-wasteGenerationFlow	kg/day = kg/day - kg/day
wasteGenerationRateIncreaseFlow = GDPIncreaseEffect	kg/day = kg/day
wasteGenerationFlow = consumption*wasteGenerationRate	kg/day = kg/day*kg/day
SegregationIncreaseFlow = rateOfIncreaseOfSegregation	constant = constant
segregationCoefficient = (segregationIncrease+motivationCoefficient)*easeOfRecyclingCoefficient*1.67	constant = (constant + constant)*constant
recyclableWasteIncreaseFlow = recyclableWasteIncrease	kg/day = kg/day
informalFlow = segregationCoefficient*amtOfGeneratedWaste*recyclableWaste*privatisationEffect*totalToRecyclable	kg/day = constant*kg/day*constant*constant*constant
EmploybilityInINformalSector = informalFlow*0.075	no. of people = kg/day * (no. of people/(kg/day))
moneySavedByInformalSector = informalFlow*5	rupees = kg/day * (rupees/(kg/day))
landSavedByInformalSector (sq m) = informalFlow*0.000133	sq m = kg/day * (sq m/(kg/day))
ghgEmissionSaved = informalFlow*0.28	TPD = kg/day * (TPD/(kg/day))
pheriwalaFlow = informalCollected*i2p	kg/day = kg/day * constant
kabadiwalaFlow = informalCollected*i2k	kg/day = kg/day * constant
thiawalaFlow = pheriwala-nonRecyclableRatio*informalCollected	kg/day = kg/day - (kg/day * constant)
scrapDealaersFlow = kabadiwala	kg/day = kg/day
t2sflow = thiawala	kg/day = kg/day
unauthorisedRFlow = scrapDealers*s2u	kg/day = kg/day * constant
i2recyclersFlow = scrapDealers*s2a	kg/day = kg/day * constant
URecycledFlow = UnauthorisedRecyclers	kg/day = kg/day
i2aFlow = Common	kg/day = kg/day
ARecycledFlow = AuthorisedRecyclers	kg/day = kg/day
wasteCollectingFlow = ratioOfWasteCollected*(amtOfGeneratedWaste-informalFlow)	kg/day = constant * (kg/day - kg/day)
garbageCollectorFlow = wasteCollected	kg/day = kg/day
MCDflow = garbageCollector	kg/day = kg/day

f2recyclersFlow = MCD*m2c	kg/day = kg/day * constant
m2landfillFlow = MCD*m2l	kg/day = kg/day * constant
m2compostingFlow = MCD*m2co	kg/day = kg/day * constant
m2WTEflow = MCD*m2w	kg/day = kg/day * constant
l2rFlow = MCD*m2l*0.0018	kg/day = kg/day * constant * constant
r2tFlow = ragpickers	kg/day = kg/day
energy (kcal) = WTE*calorificValue	kcal = kg/day * (kcal/(kg/day))
GHGemission = landfill*0.26	TPD = kg/day * (TPD/(kg/day))
Projected energy (MJ) = GHGemission*0.045	MJ = TPD * (MJ/TPD)
uncollectedWasteflow = amtOfGeneratedWaste-wasteCollectingFlow-informalFlow	kg/day = kg/day - kg/day - kg/day
u2rFlow = uncollectedWaste*0.00103	kg/day = kg/day * constant
illegalFlow = uncollectedWaste*0.99897	kg/day = kg/day * constant

TPD = Tonne/day MJ = MegaJoule kcal = Kilocalorie

5.1.4 Boundary Adequacy Test

It involves checking all the parameters and feedback loops in the model and analysing their impact. The impact can be external and internal. If the impact is external, then only those parameters with significant impacts should be accounted for in the model. By analysing the model, it was found out that **population, populationIncrease, and GDPIncreaseEffect** are exogenous variables that have a significant impact on the model. All the remaining variables in the model are endogenous variables.

5.2 Tests of Model Behaviour

5.2.1 Behaviour Sensitivity Test

Method of writing: “Parameter - The rage in which it has been varied”
After that, the graphs have been noted to see the variation in results by changing the parameters in the range of -15% to +15%. Few parameters that were estimated to produce significant variation in results were chosen for the analysis and results were analysed.

1. s2u - 0 to 1 (scrap dealers to unauthorised recyclers)
   s2a - 1 to 0 (scrap dealers to authorised recyclers)

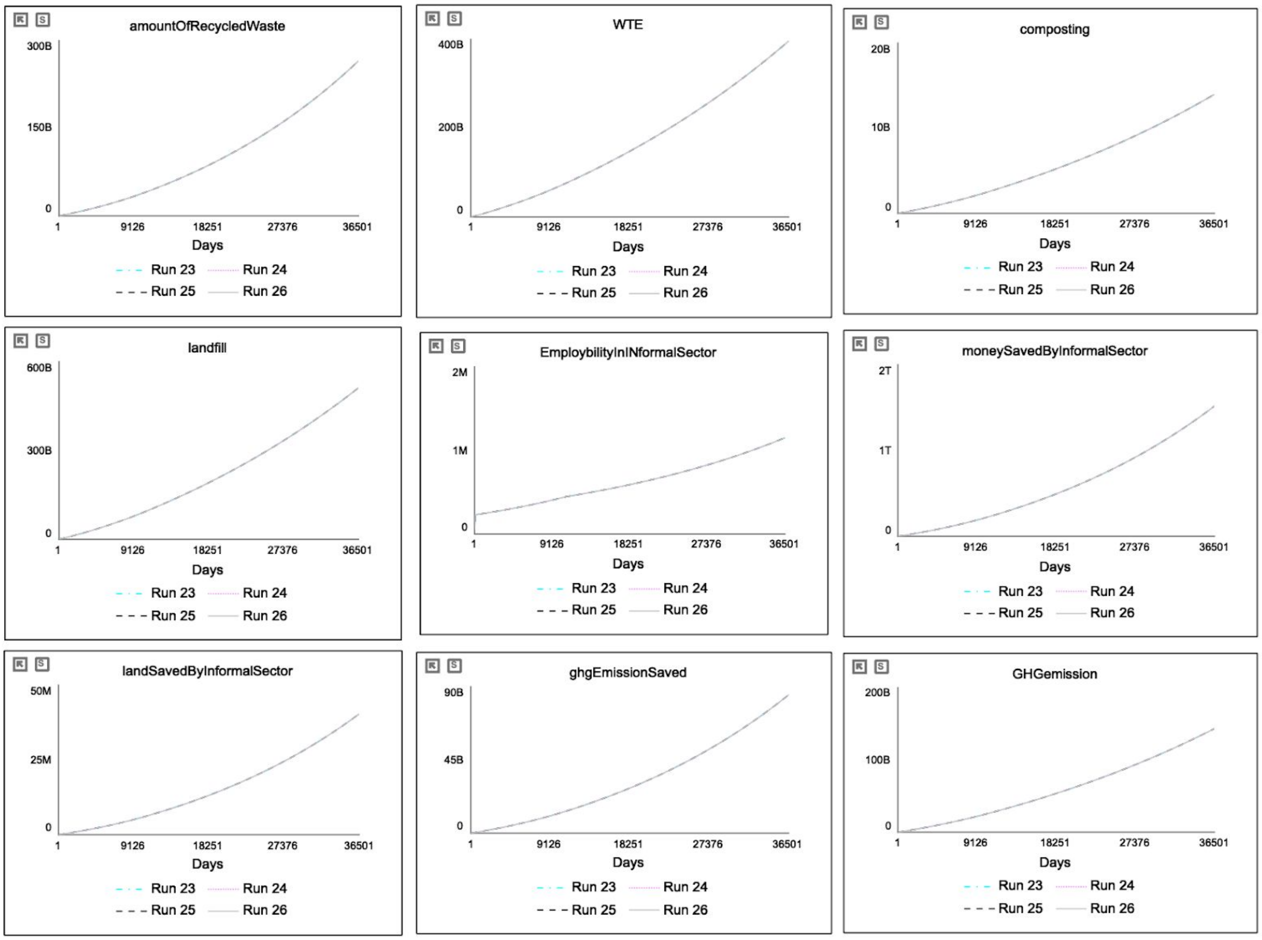

Fig 5.5 Sensitivity analysis of s2u and s2a

By seeing the analysis results, it was concluded that varying s2u and s2a do not have any impact on the results of the model if the total sum of ratios is 1. This justifies the assumption of 50 percent waste going to both authorised and unauthorised recyclers, which was assumed because of the lack of data.

2. i2p - 0-1 (ratio of informal waste collected by pheriwalas)
   i2k - 1-0 (ratio of informal waste collected by kabadiwalas)

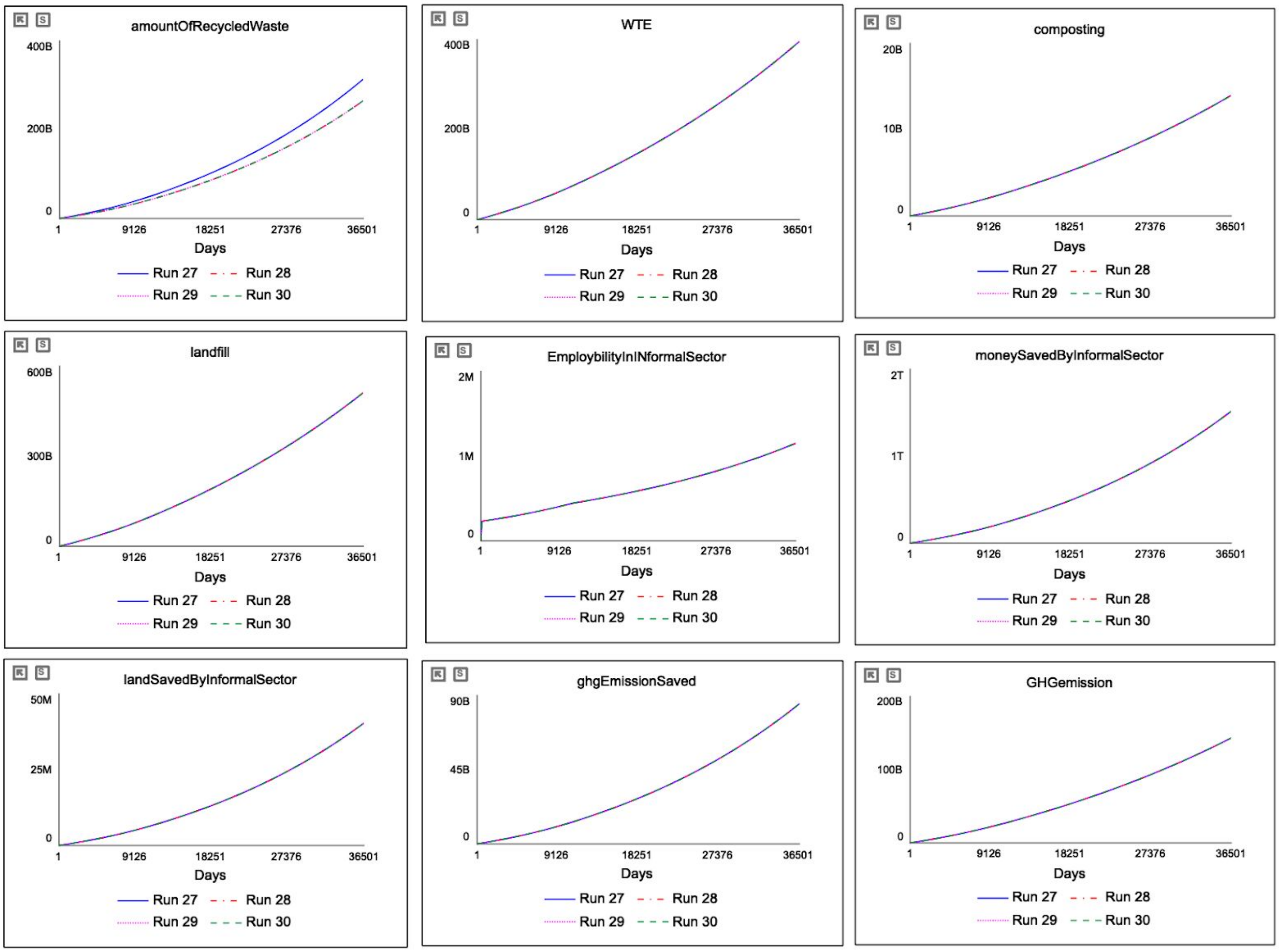

Fig 5.6 Sensitivity analysis of i2p and i2k

By seeing the analysis results, it was concluded that varying i2a and i2k do not have a significant impact on the results of the model if the total sum of ratios is 1. There were small variations in the amount of waste recycled which was of concern but it can be accepted given the percentage error to be very small. Variations in the amount of illegal waste were of no significance from the model analysis point of view. This justifies the assumption of 50 percent waste going to both pheriwalas and kabadiwalas, which was assumed because of the lack of data.

3. easeOfRecyclingCoefficient - 0.34-0.46

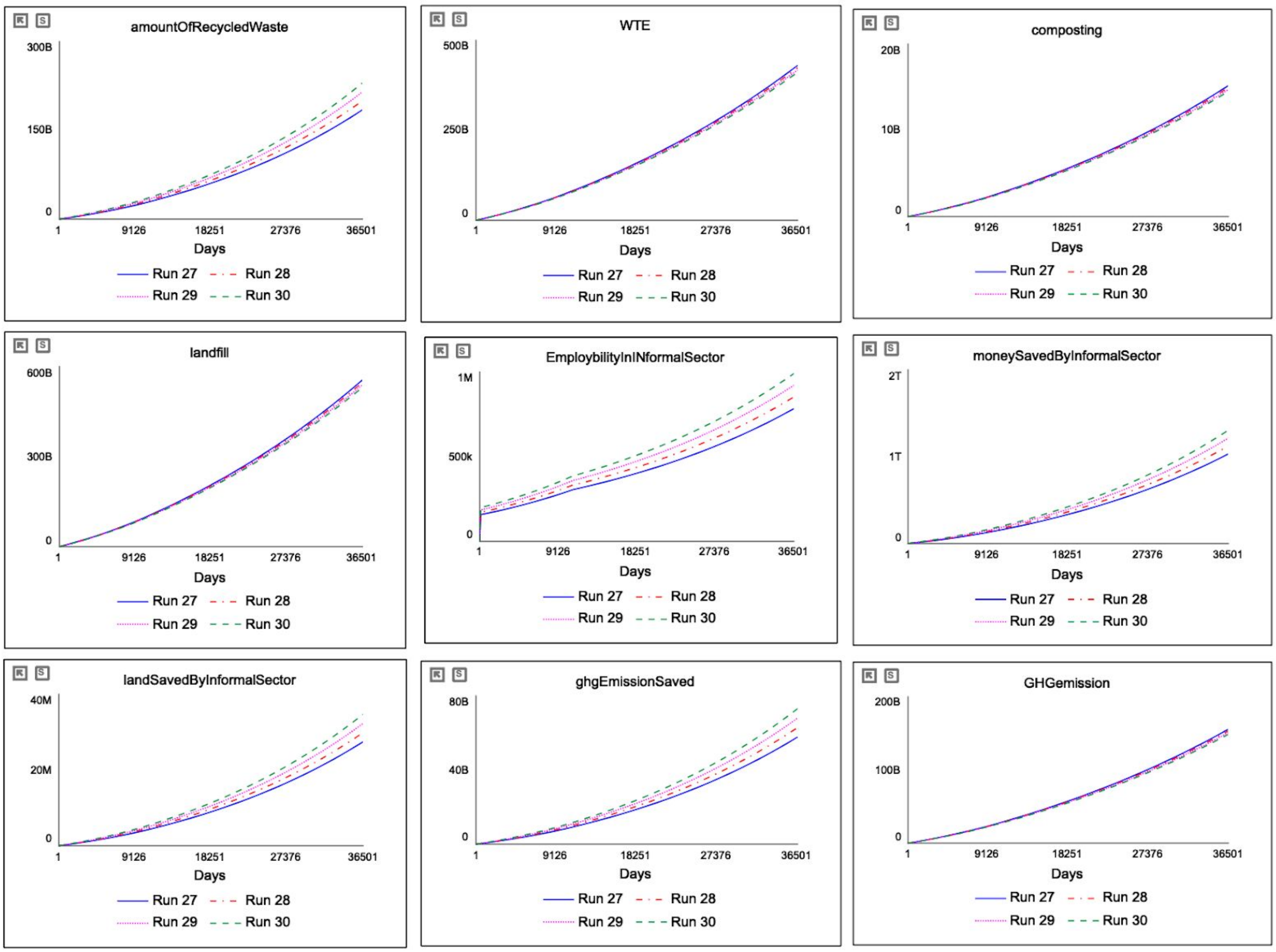

Fig 5.7 Sensitivity analysis of easeOfRecyclingCoefficient

By seeing the analysis results, it was concluded that varying easeOfRecyclingCoefficient had a significant impact on the results. Its increase led to an increase in the informal flow and recycling and reduced formal flow. The effect was more significant in the study of how waste is treated in the informal sector and impact on the benefits of informal sector forecasted. Therefore, it was carefully deduced from the literature review and data analysis and results of its variations in different scenarios were analysed to justify the model.

4. motivationCoefficient - 0.255-0.345

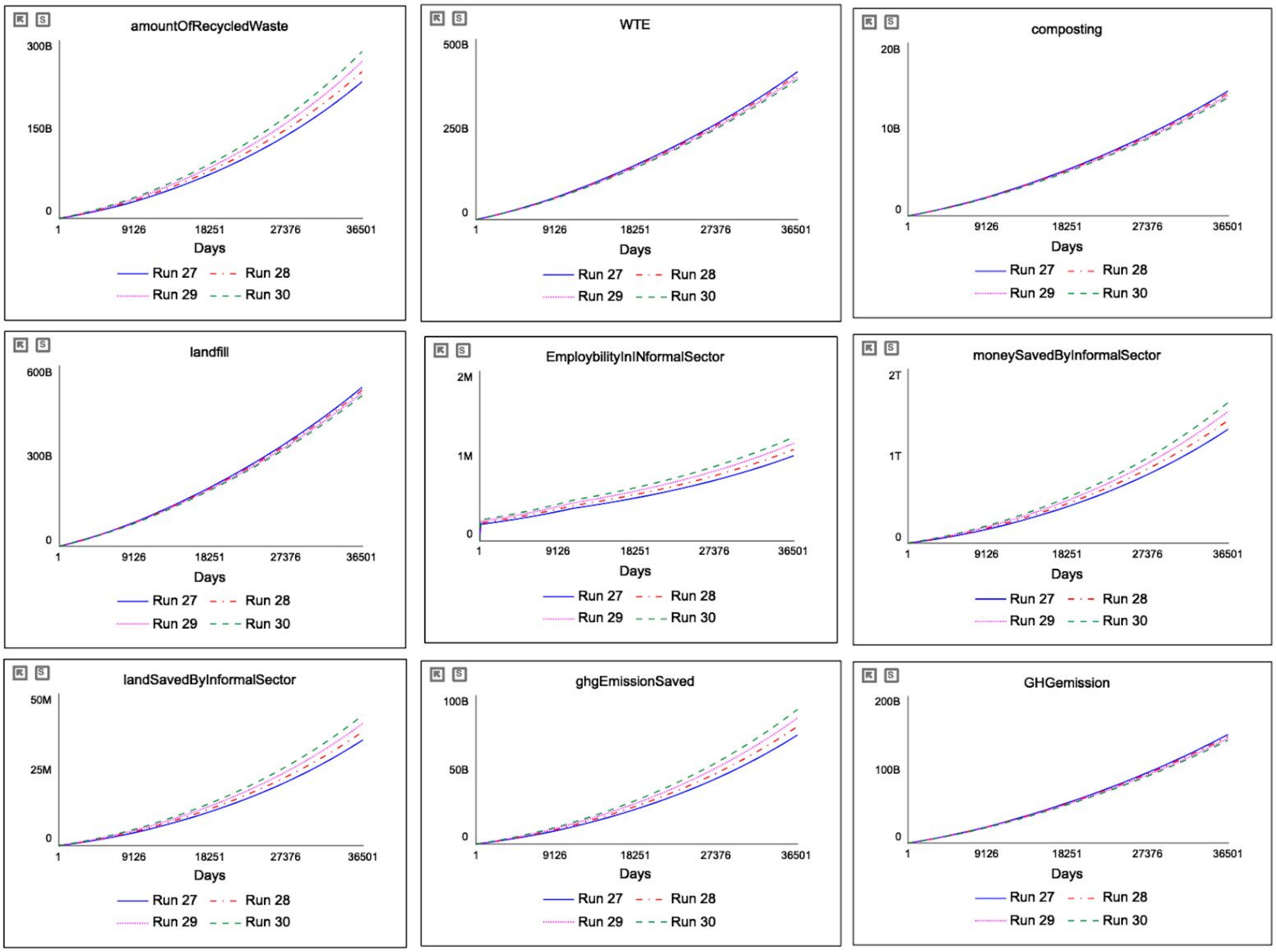

Fig 5.8 Sensitivity analysis of motivationCoefficient

By seeing the analysis results, it was concluded that varying motivationCoefficient had a significant impact on the results. Its increase led to an increase in the informal flow and recycling and reduced formal flow. The effect was more significant in the study of how waste is treated in the informal sector. Therefore, it was carefully deduced from the literature review and data analysis and results of its variations in different scenarios were analysed to justify the model.

5. motivationCoefficient - 0.255 - 0.345
   easeOfRecyclingCoefficient - 0.34-0.46

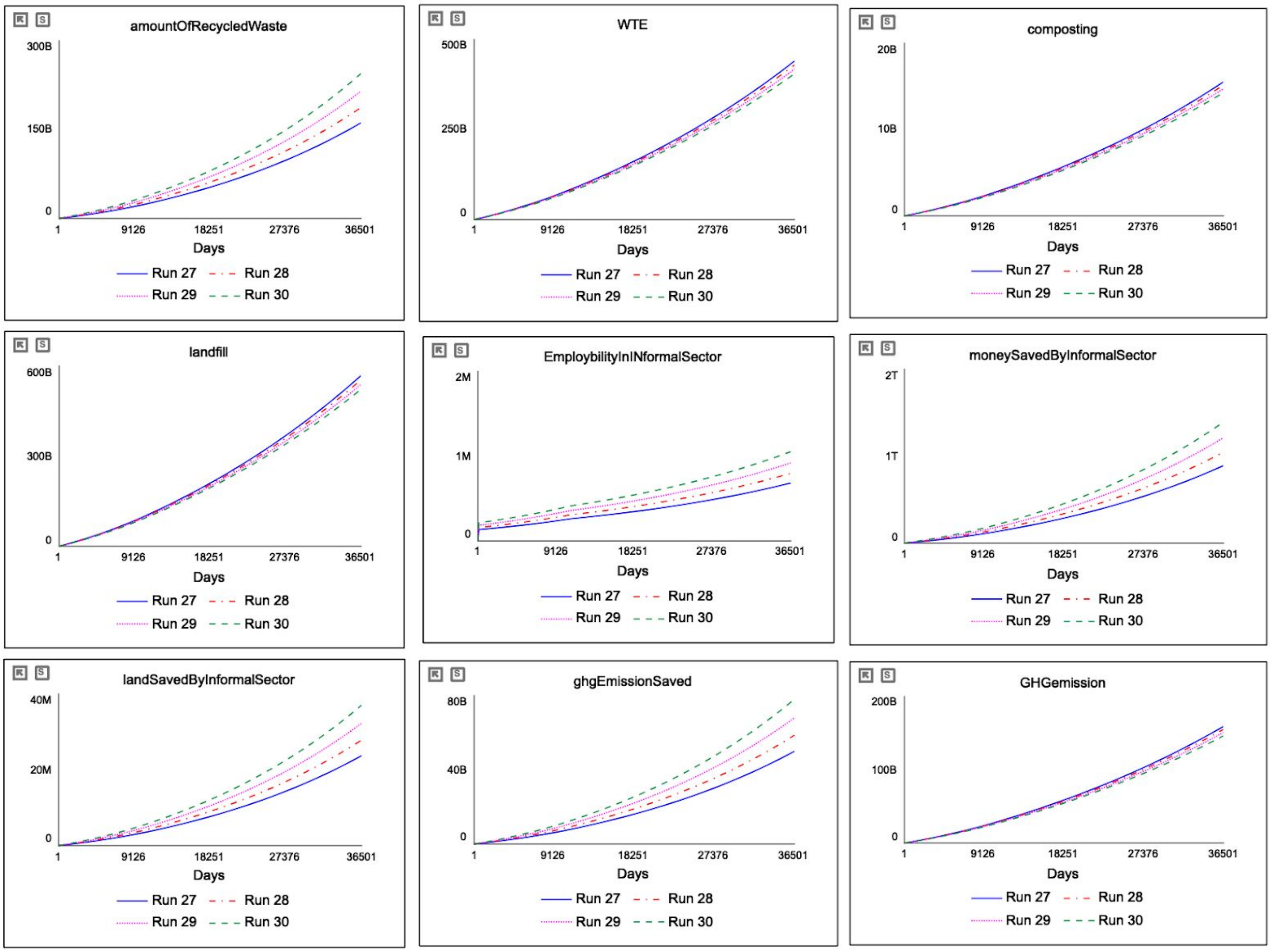

Fig 5.9 Sensitivity analysis of motivationCoefficient and easeOfRecyclingCoefficient

By seeing the analysis results of the combination of 2 variables, it was concluded that varying motivationCoefficient and easeOfRecyclingCoefficient, together, had a significant impact on the results. Their increase led to an increase in the informal flow and recycling and reduced formal flow. The effect was more significant in the study of how waste is treated in the informal sector.

6. privatisation effect - 1.105-1.495

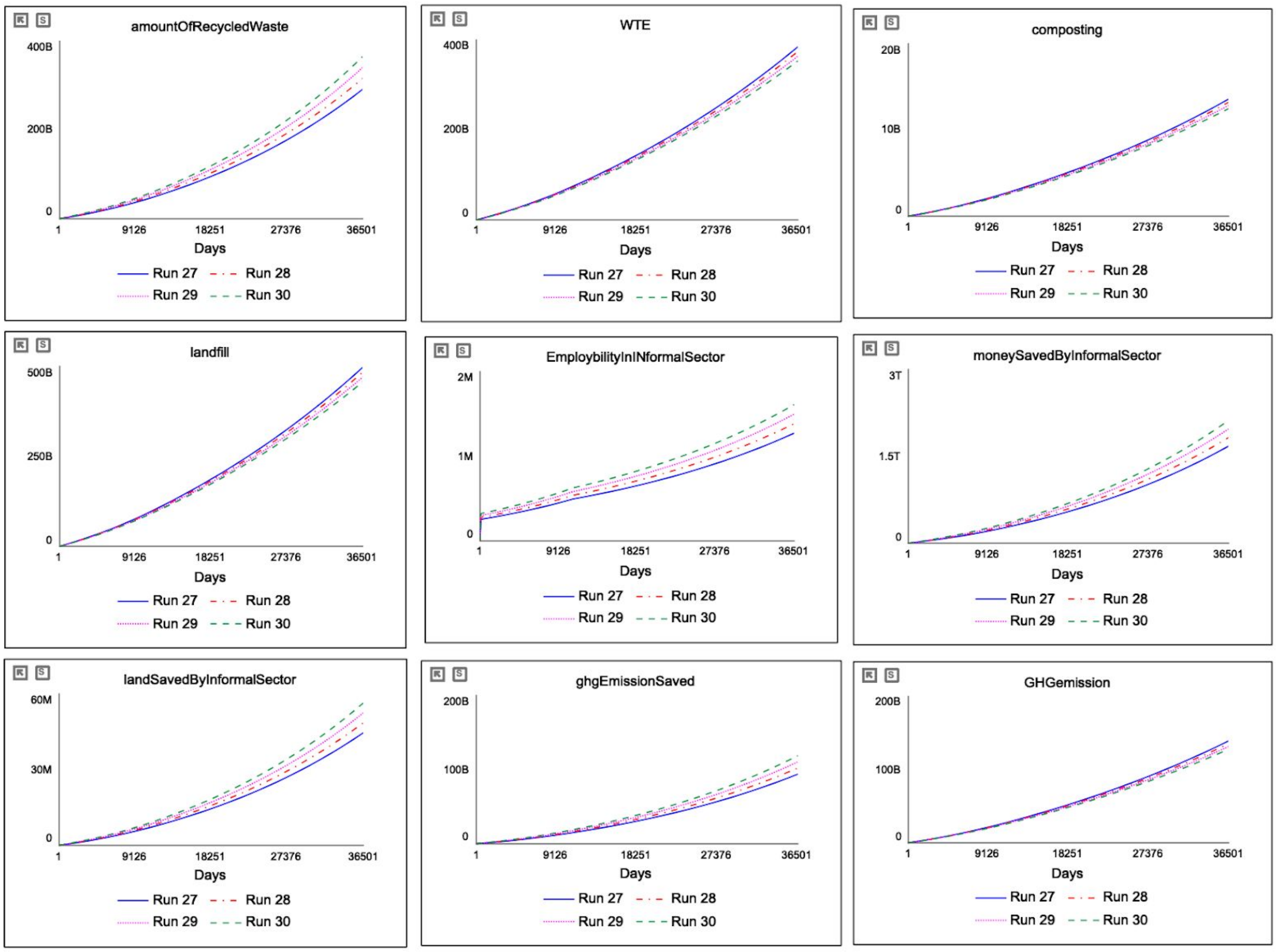

Fig 5.10 Sensitivity analysis of privatisation effect

By seeing the analysis results, it was concluded that varying privatisationEffect had a significant impact on the results. Its increase led to an increase in the informal flow and recycling and reduced formal flow. The effect was more significant in the study of how waste is treated in the informal sector. Therefore, it was carefully deduced from the literature review and data analysis and results of its variations in different scenarios were analysed to justify the model.

7. privatisation effect - 1.105-1.495
   motivationCoefficient - 0.255 - 0.345
   easeOfRecyclingCoefficient - 0.34-0.46

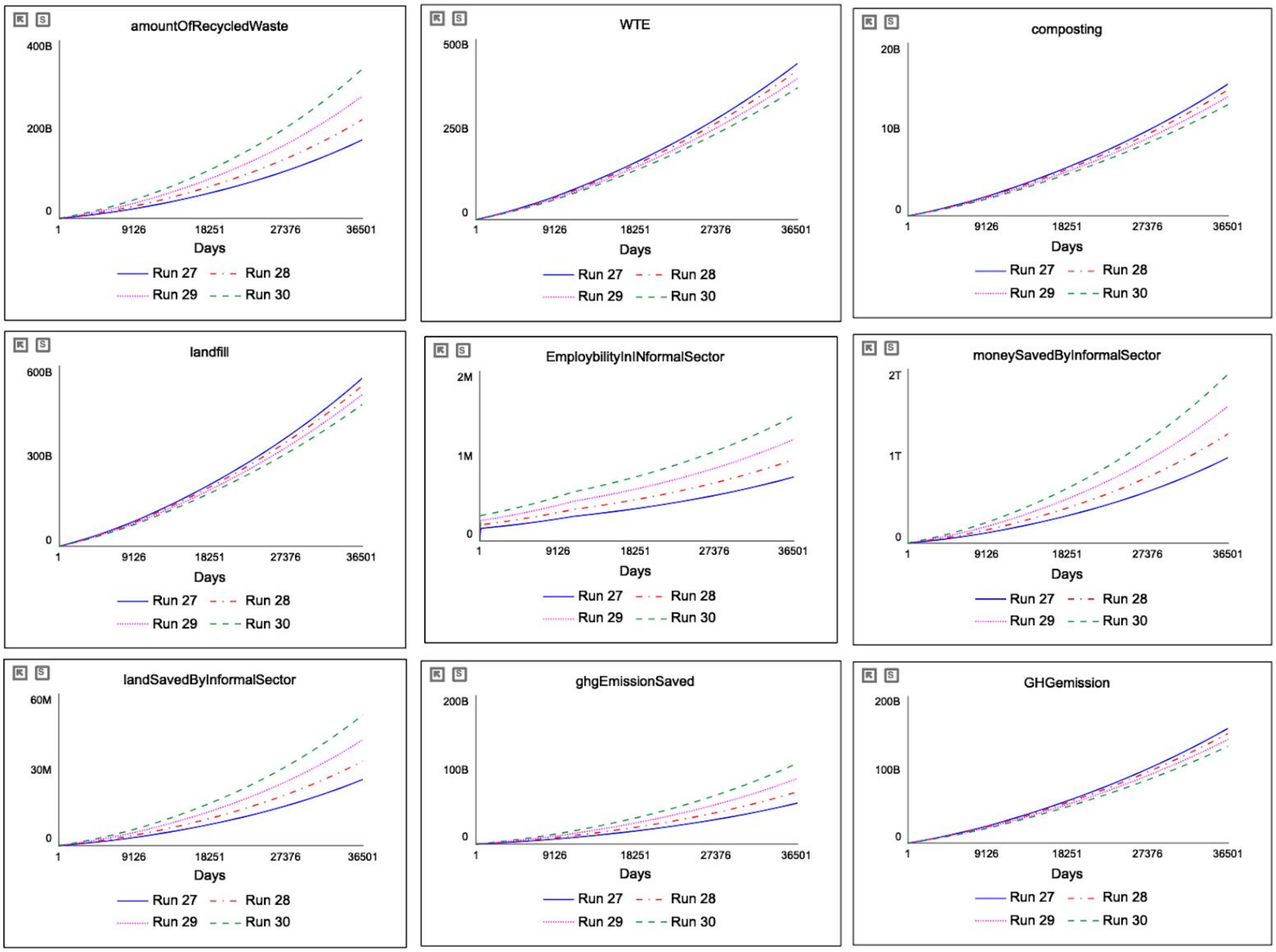

Fig 5.11 Sensitivity analysis of privatisation effect, motivationCoefficient and easeOfRecyclingCoefficient

By seeing the analysis results of the combination of 3 variables, it was concluded that varying privatisationEffect, motivationCoefficient, and easeOfRecyclingCoefficient, together, had a significant impact on the results. Their increase led to an increase in the informal flow and recycling and reduced formal flow. The effect was more significant in the study of how waste is treated in the informal sector. We can see that the rate of increase of waste recycled increases as the value of these parameters increase.

8. wasteGenerationRate - 0.6545-0.8855

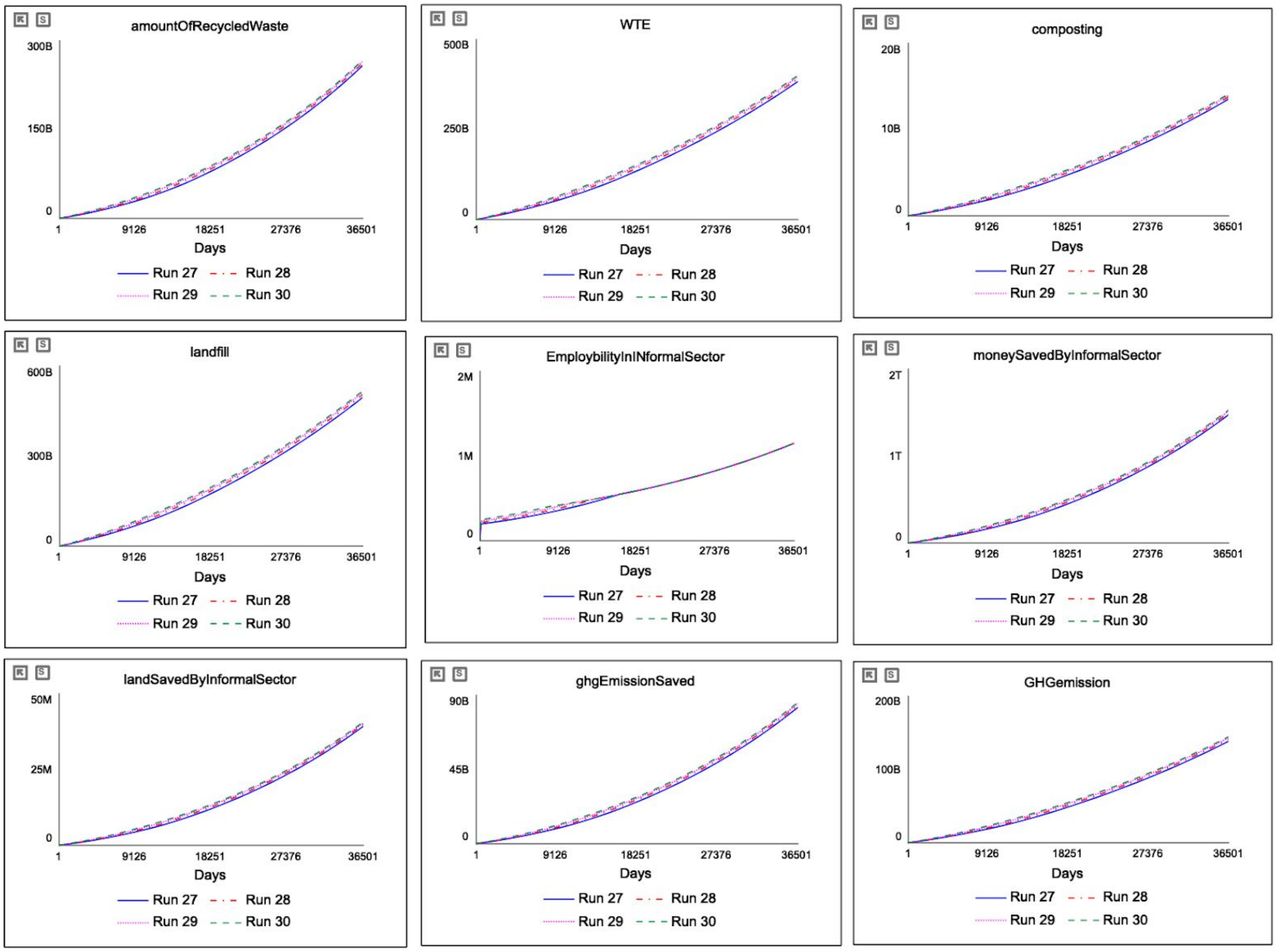

Fig 5.12 Sensitivity analysis of wasteGenerationRate

By seeing the analysis results, it was concluded that varying wasteGenerationRate had a little impact on the results. Its increase led to an increase in the amount of waste generated which led to an increase in the formal and informal flow. But this increase was not very significant because of which all the results were increased but not by a large value. Thus the model is less sensitive to the variation in wasteGenerationRate.

9. GDPIncreaseEffect - 0.0000181-0.0000245 (increase in waste generation rate due to GDP increase)

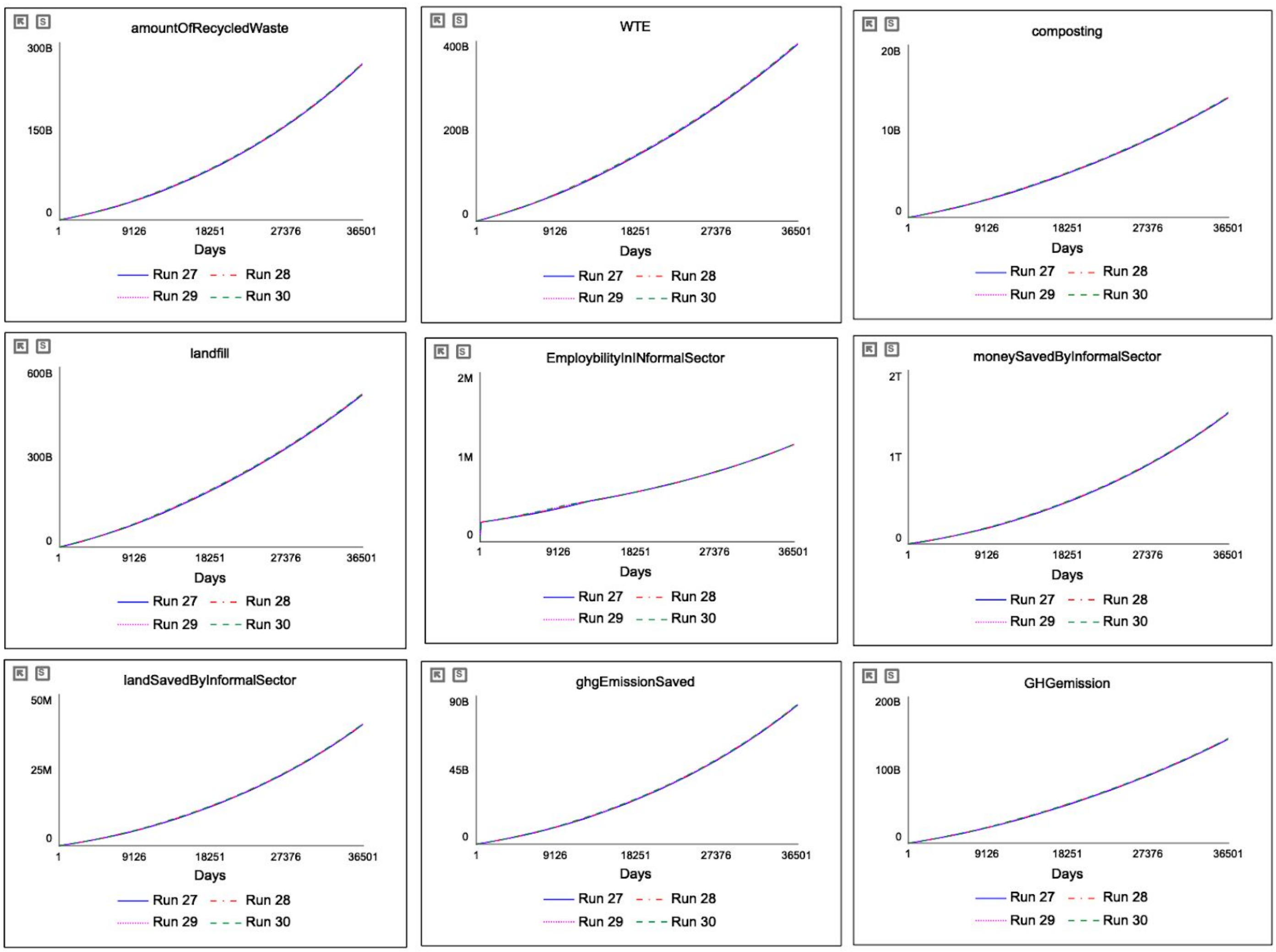

Fig 5.13 Sensitivity analysis of GDPIncreaseEffect

By seeing the analysis results, it was concluded that varying GDPIncreaseEffect had almost no impact on the results. Its increase led to an increase in the amount of waste generated which led to an increase in the formal and informal flow. But this increase was negligible because of the very low values. Thus the model is almost insensitive to the variation in GDPIncreaseEffect.

10. recyclableWasteIncrease - 0.000001 - 0.000005

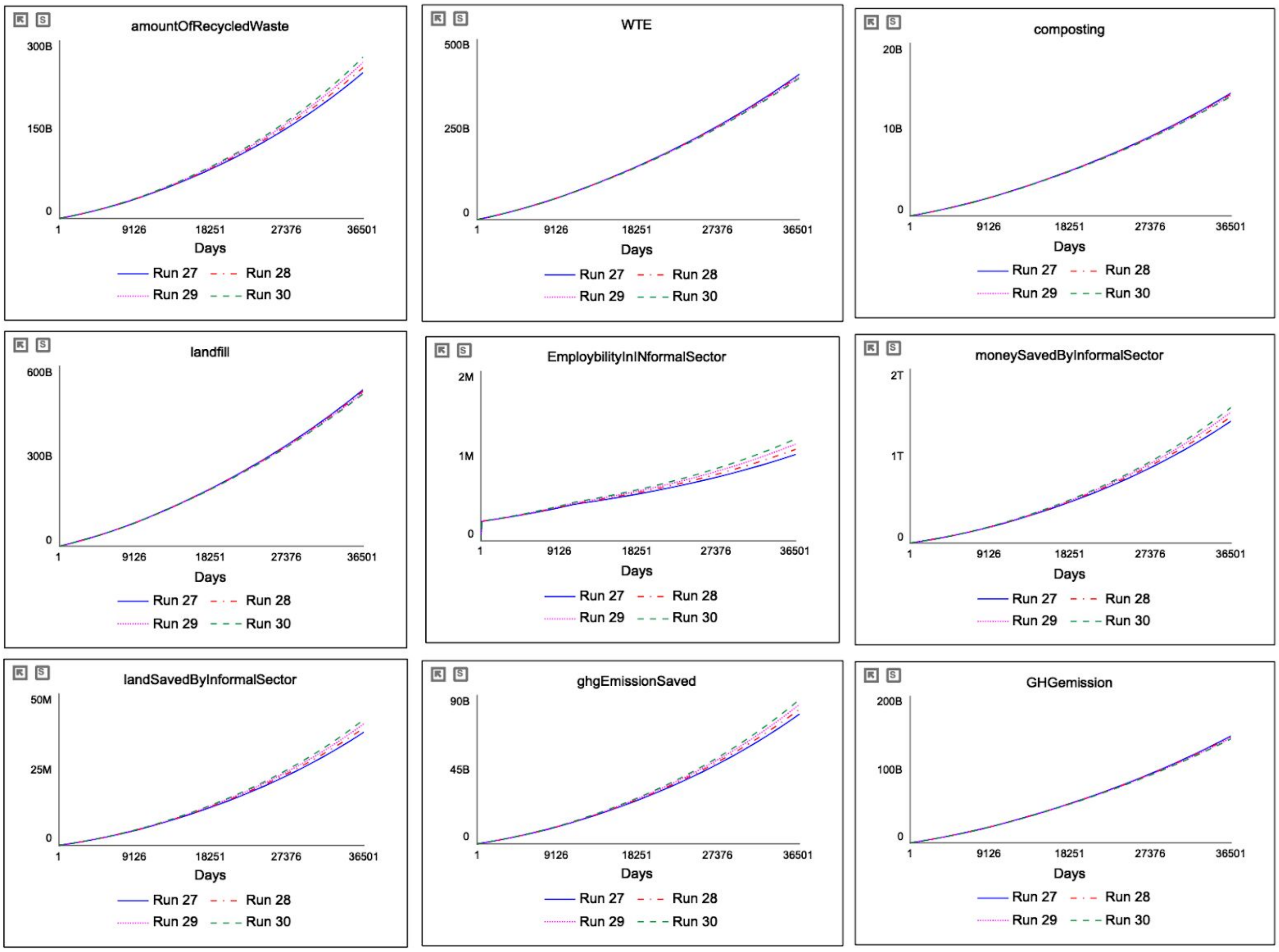

Fig 5.14 Sensitivity analysis of RecyclableWasteIncreasingRate

By seeing the analysis results, it was concluded that varying RecyclableWasteIncreasingRate had almost very little impact on the results. Its increase led to an increase in the amount of recyclable waste generated which led to an increase in the informal flow. But this increase was very little because of the very low values of rate of increase. It impacts the flow in the formal sector but it is not the focus of the study and hence, not considered. Also, the percentage change is considerably small. Thus, the model is very less sensitive to the variation in RecyclableWasteIncreasingRate.

By analysing the changes in the behavior of graphs of the results because of the variations in the parameters, following conclusions were drawn that were consistent with the results of Sensitivity analysis -

1. Most of the results were robust and did not vary highly by variations in most of the parameters. By this the robustness of the model was justified.
2. Some parameters that were assumed due to lack of data were proven to have no effect on the results, thus justifying the assumption.
3. The parameters that were seen to produce maximum effect on the result when varied were justified by carefully deducing the values of the parameters by studying the literature review and analysing available data.
4. Variation of combination of parameters indicated the difference in the rate of increase of the results as the values of the parameters increase.

5.2.2 Extreme Behaviour Test

This was done to realize if the model works in an extreme condition. In this case, some of the inflow parameters were taken to be zero to realize the behaviour of the model and see if it is in accordance with what should be the outcome.
Here,
Motivation coefficient = 0
Ease of recycling coefficient = 0
rateOfIncreaseOfSegregation = 0

This shows that with no motivation and with a very very difficult recycling process, there will be no collection of the recyclable waste by the informal sector. The flow in the informal sector will become zero and all the waste will either go to the formal sector or will be illegally dumped.

This makes sense since the graph now obtained only shows the amount of waste recycled due to the formal sector. This will also not be less in amount because the formal sector will have to collect more waste and recycle it as well, although obviously the efficiency and the amount of waste recycled will decrease dramatically when compared with when the informal sector is working.

Also, the illegally dumped waste will increase since the formal sector will be overloaded with the waste collection and might not be able to reach all the areas to collect waste.

Also, with no waste going to the informal sector, it can be seen that the economic and social incentives because of the informal sector become zero : Government money saved, Employability, Land saved from landfills, ghg emissions reduced.

The entire recycling will take place through authorized recyclers. And, hence this highlights the dependency of unauthorized recyclers on the informal sector.

The waste being landfilled and going in WTE will increase dramatically and ghg emissions because of that will increase along with probable further decrease in calorific value for WTE since waste will be more heterogeneous with respect to the waste suitable for WTE.

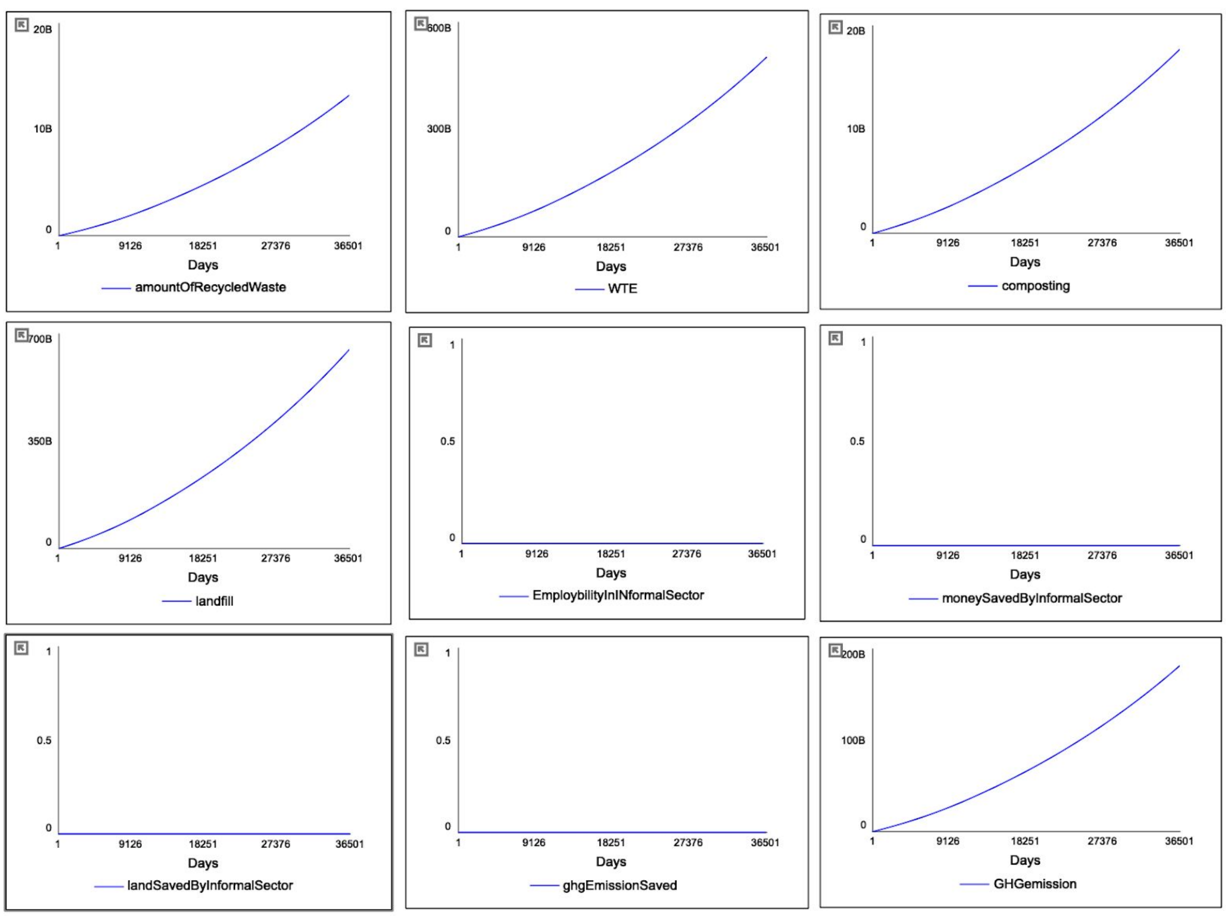

Fig 5.15 Extreme Behavior test graphs

Chapter 6: Scenario Analysis

6.1 Goods and Services Tax (GST)

It was found out from the data when GST was implemented, workers' motivation to recycle and ease of recycling was reduced because of the increased taxes on recycled products. Because of heavy taxes on recycling, the cost of recycled plastic became more than the cost of virgin plastic leading to the closure of recycling shops. As a result, ease of recycling was reduced in the GST case. Hence, waste recycled was reduced and less waste was collected by the informal sector. Thus, a scenario is assumed when GST is removed and for that, the motivationCoefficient was increased to 0.35 from 0.3 and easeOfRecyclingCoefficient was increased to 0.45 from 0.4, producing a combined effect of 22% increase in waste collected by the informal sector.

Table 6.1 GST scenario variables

Variables	GST scenario	NO GST scenario
motivationCoefficient	0.3	0.35
easeOfRecyclingCoefficient	0.4	0.45

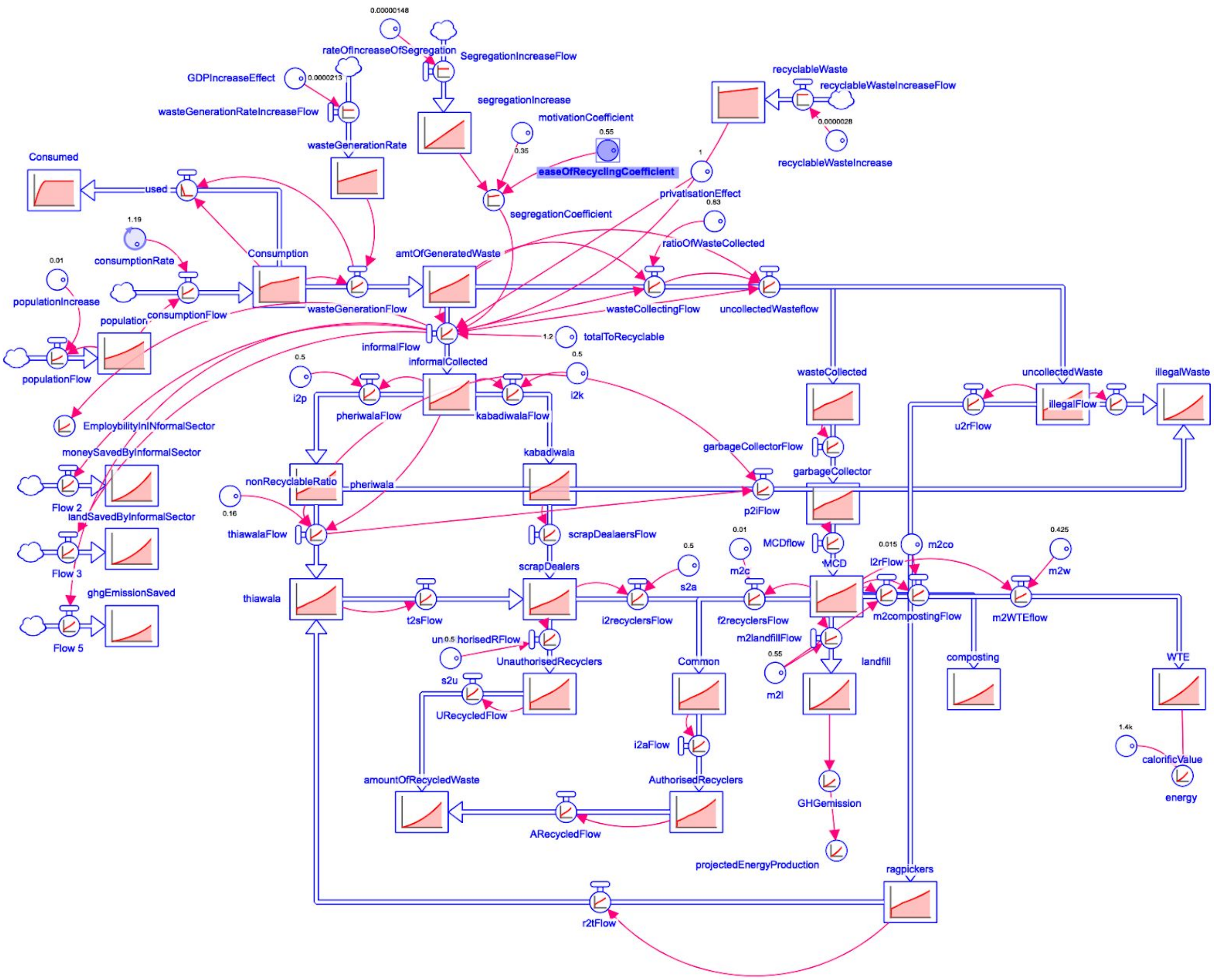

Fig 6.1 GST scenario

6.2 Privatisation

Privatisation of waste can be a misleading term as the informal sector is also private. However, the privatisation considered here is in fact, the wholesale outsourcing of government work to privately owned, for-profit companies through contracts, concessions, public memberships or franchises. This obviously does not cover the informal sector. Here, the private firms are involved in collection, transportation and treatment of waste that is otherwise collected by the formal sector. The informal sector works in a different channel altogether whose working doesn't alter the working of the formal sector. However, in recent times, with the privatisation, the companies have actually been competing with the waste collected by the informal sector.

In this case, when there is privatisation, the companies collect waste themselves and send most of the waste to WTE plants for high returns. Thus, they send all kinds of waste including those which have low calorific values. Hence, they produce low energy as average value reduces from 1600 kcal/kg to 1400 kcal/kg. This also reduces the amount of waste going to the informal sector as companies try to collect all types of waste (including recyclable). If no privatisation is there, then more waste goes to the informal sector, assumed by a factor of 1.3, the ratio of waste going to WTE plants is assumed to reduce to 0.255 from 0.425 and ratio of waste going for composting is assumed to increase to 0.033 from 0.015. Also, waste going to the WTE plant is well segregated with only high calorific value waste. Thus the average calorific value is 1600 kcal/kg.

Table 6.2 Privatisation scenario variables

Variables	Privatisation scenario	NO Privatisation scenario
privatisationEffectCoefficient	1	1.3
m2co	0.015	0.033
m2w	0.425	0.255
Energy	WTE*1400	WTE*1600

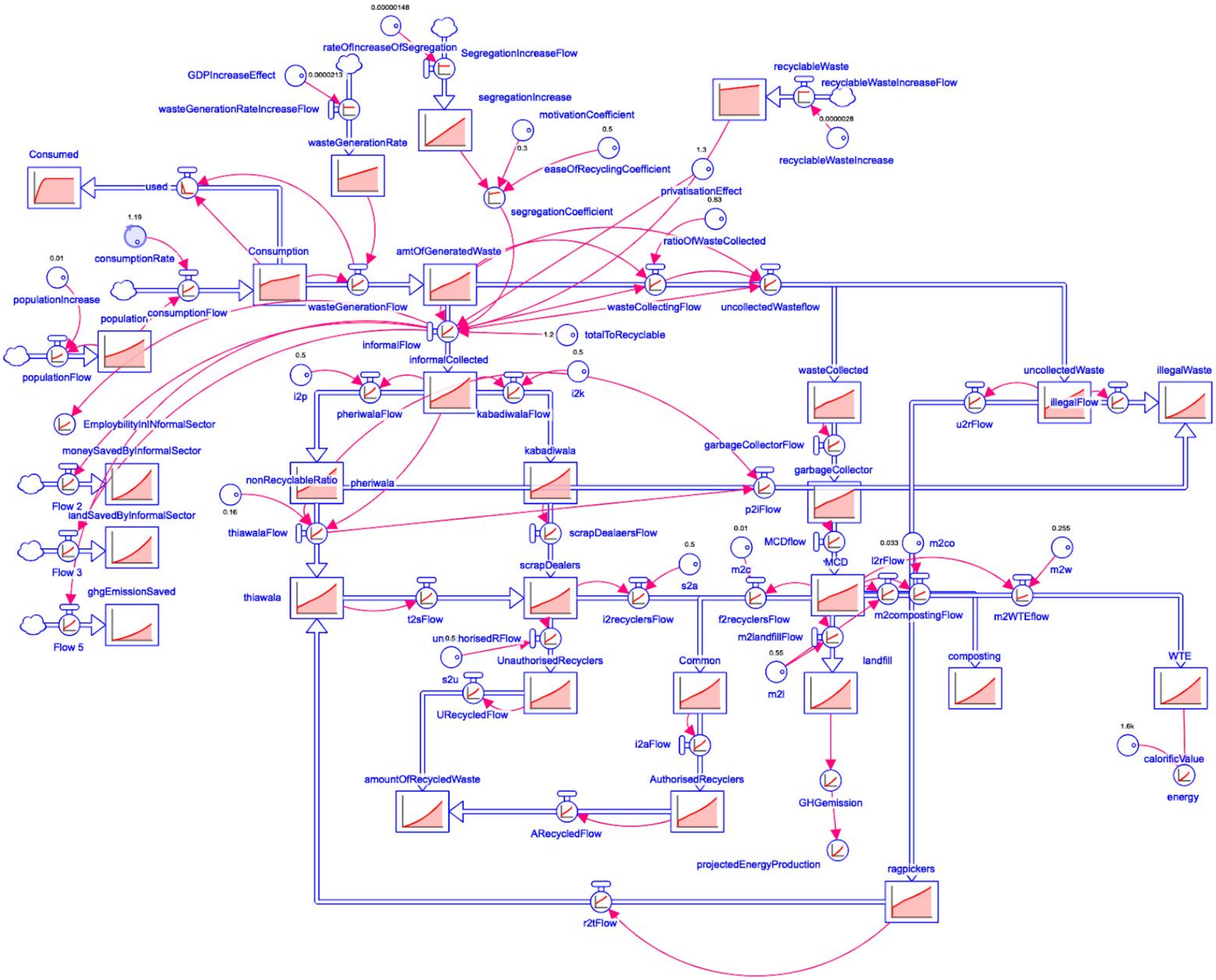

Fig 6.2 Privatisation scenario

6.3 Solid Waste Management Rules (SWMR)

In this scenario, the effect of SWM rules on the segregation of waste was studied. It was realised that if SWM rules are properly implemented and checked, the rate of the increase of segregation increases annually from a factor of 1.00054 to 1.0018. This implies that there the waste segregation is accelerated and more waste goes to the informal sector.

Table 6.3 SWMR scenario variables

Variables	SWMR scenario	NO SWMR scenario
rateOfIncreaseOfSegregation (per day)	0.000005	0.00000148

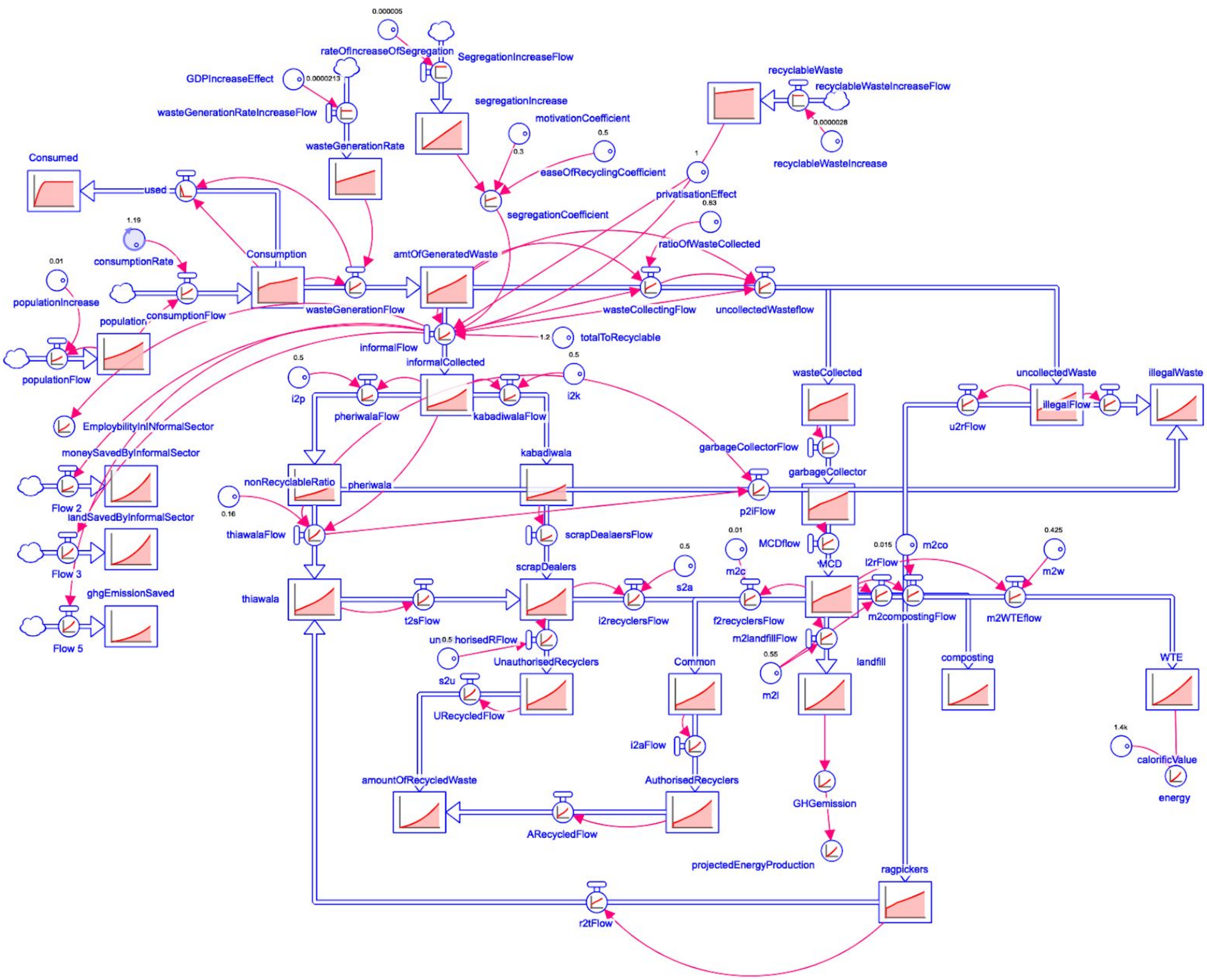

Fig 6.3 SWMR scenario

6.4 Formalization

Despite what the name suggests, formalisation doesn’t necessarily mean converting the informal sector into the existing formal sector or a differently defined but formal sector. It also includes integration of the informal as well as formal sector so that they work together while also maintaining their autonomy in the way of work.

The need for formalisation is because of the following reasons :

1. To decrease illegal dumping in the city.
2. To also decrease the amount of waste landfilled in the city by better segregation such that all recyclable material is taken out of the waste before it is landfilled.
3. The unauthorised recyclers work in hazardous conditions. Hence, to improve their conditions it is necessary for them to be following governmental norms and be designated as authorised recyclers.
4. To use the well-built network of the informal sector across the city in the best possible way to not only collect more waste but work in integration with the formal sector to ensure better segregation and waste treatment.

Different ways of Formalisation -

1. Formulating an entirely new branch for waste collection from the households which will collect recyclable waste just like the informal sector

However, this approach has the following disadvantages :

a. The involvement of the informal sector will decrease which can lead to unemployment.
b. Also, this will compete with an already competitive informal sector network.
c. This can also lead to other conflicts over prices paid for recycling materials to the households, areas divided for both the informal sector and the new branch.
d. This can also have a toll on the collection efficiency of the informal sector as the new branch might not be as systematic and efficient leading to increased illegal dumping.

2. Collection and Segregation of the entire waste (including non-recyclables) is done by the informal sector such that the non-recyclable part is picked by garbage collectors, MCD trucks and recyclable part is sent over to the recyclers by the informal sector

The problems with this approach are :

a. Many people living in posh areas like Greater Kailash in gated societies actually do not let people from the informal sector enter their areas as they don't really care about selling their recyclable waste for the little amount of money that is usually earned by selling these. Also, a few of them have prejudice against the people in the informal sector and view them as poor people who might steal things from their house.
b. There is not good enough infrastructure (including vehicles to collect waste and store them at a place where they can segregate it) available for people in the informal sector to actually collect such a large amount of waste and segregate it as well.
c. Also, this will lead to greater nuisance as right now, most households segregate bulk recyclable materials on their own. This helps in ease of segregation after collection. If all the waste will have to be segregated after collection, it will lead to more time spent when the current system works more efficiently.
d. This will also lead to the mixing of recyclable materials with unrecyclable ones which might alter them such that they might not be recyclable anymore.
e. There is a small amount of budget right now going into the collection of waste by the formal sector, which even when distributed to the people from the informal sector will not be an incentive enough for them to actually do the entire collection on their own.
f. Also, this will lead to an increase in the role of government in the informal sector. But, the informal sector likes to work independently without government interference as then they will have to pay taxes and be answerable to someone which they might not like.

3. Entire waste collection is done by formal sector and then transferred to different government waste collection locations like MCD bins where it is segregated by the informal sector such that the non-recyclable part is picked by garbage collectors, MCD trucks and recyclable part is sent over to the recyclers by the informal sector

This approach is not really promoted because :

a. As mentioned above, this will lead to the deterioration of recyclable waste as it is mixed with non-recyclable waste.
b. This again, as mentioned above, will lead to government interference with the workings of the informal sector.

c. There will be a lack of infrastructure for the formal sector as now they will have to collect more waste than they normally collect which might get difficult for them.
d. The informal sector has a well-built network all over the city which would still be used as some people from the informal sector might still want to collect the recyclable waste directly from houses if they receive better incentives that way or find it easier to do so as they will then not have to segregate the waste themselves.

4. To continue the collection by formal and informal sector separately as it has been happening currently. But instead allow the informal sector to segregate the recyclable waste from the waste collected by the formal sector. And then, the non-recyclable part is picked by garbage collectors, MCD trucks and recyclable part is sent over to the recyclers by the informal sector

This approach can work because :

a. This will reduce the stress of the informal sector to segregate the entire waste as in the above approaches and also give them an incentive to segregate from the waste collected by the formal sector as it will be easier.
b. The informal sector can then be pressurised to only sell the recyclable materials to the authorised recyclers in return for giving them an opportunity to take recyclable material from the waste collected by the formal sector free of cost or for minimal cost. This in turn will pressurise the unauthorised recyclers to better the working conditions at their plants to get a government permit and become authorised.
c. Since the informal sector is more efficient, they will be able to segregate better (their population is also growing a lot so some members of the sector can only be attributed to segregation) which will eventually lead to lesser waste in landfills.
d. This will also not take away the independence of the informal sector and they can work without interference (except for having to give their materials to authorised recyclers which will not be much problem as they will take more waste from informal sector as more unauthorised recyclers become authorised)
e. This will use the network built by informal as well as formal sectors efficiently which work towards better segregation.

SCENARIO: EPR (EXTENDED PRODUCER RESPONSIBILITY)

It can be seen that EPR actually conflicts with the already efficient informal sector as it competes for waste usually collected by the informal sector (mainly WEEE - waste from electronic and electrical equipment). This will lead to lesser opportunities for people in the informal sector, lower employment, and possibly, indirectly also affect the other recyclable waste picked by this sector.

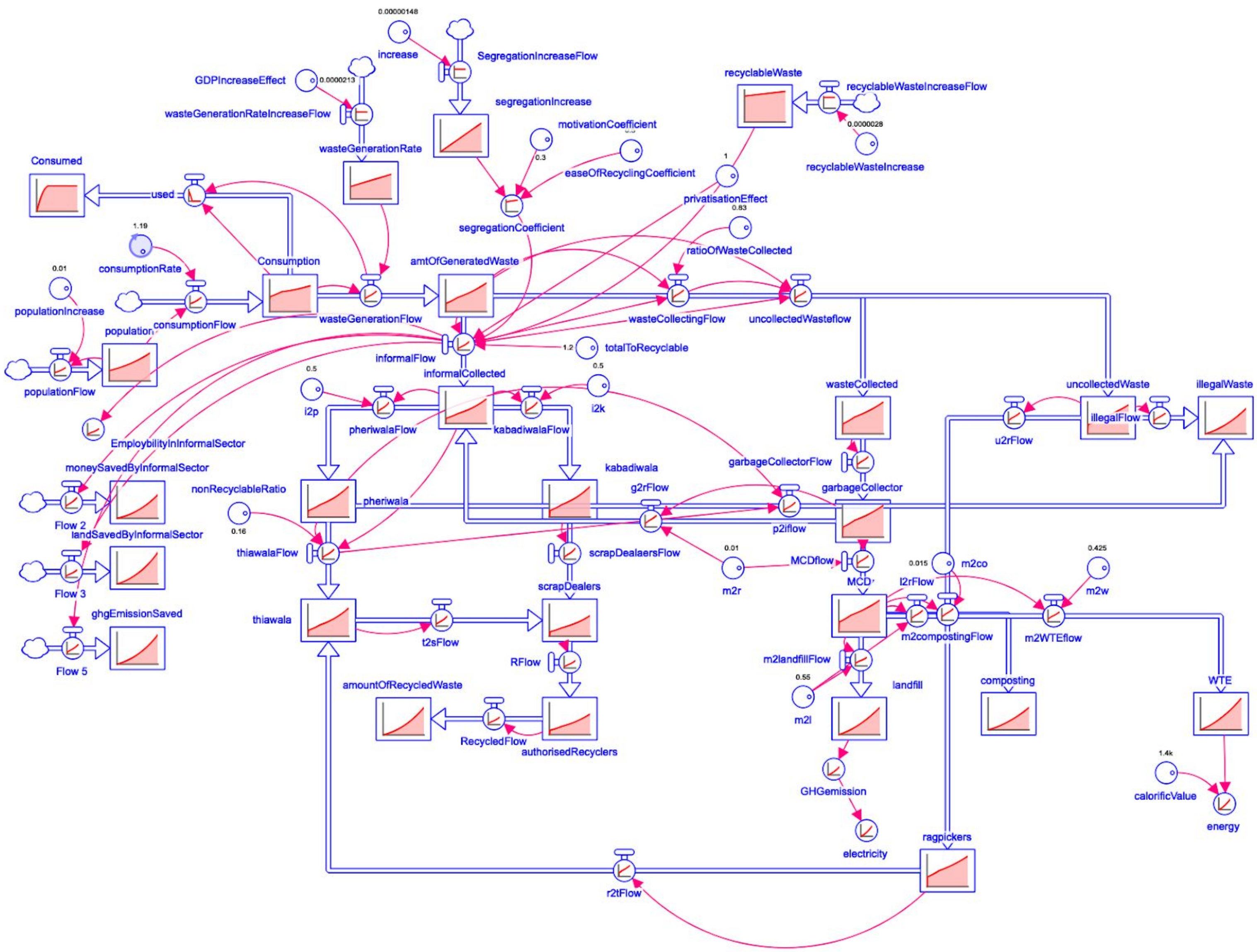

Fig 6.4 Formalisation scenario

Chapter 7: Bali - A case Study

7.1 Causal Loop Diagram

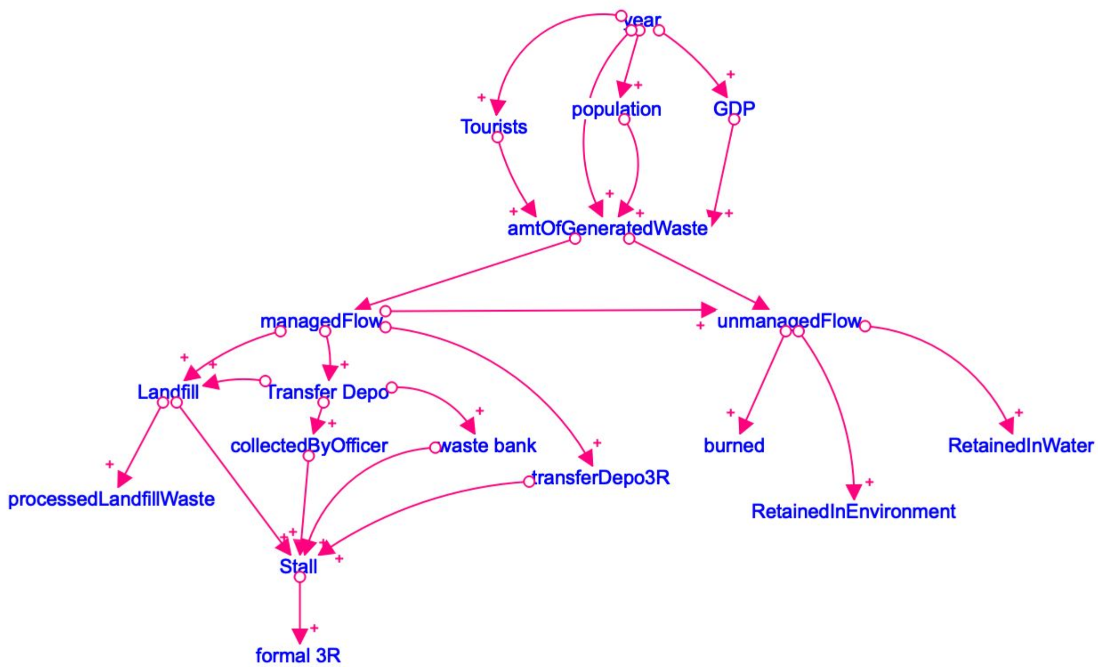

Fig 7.1 Causal Loop Diagram of waste management in Bali

7.2 Stock and Flow Diagram

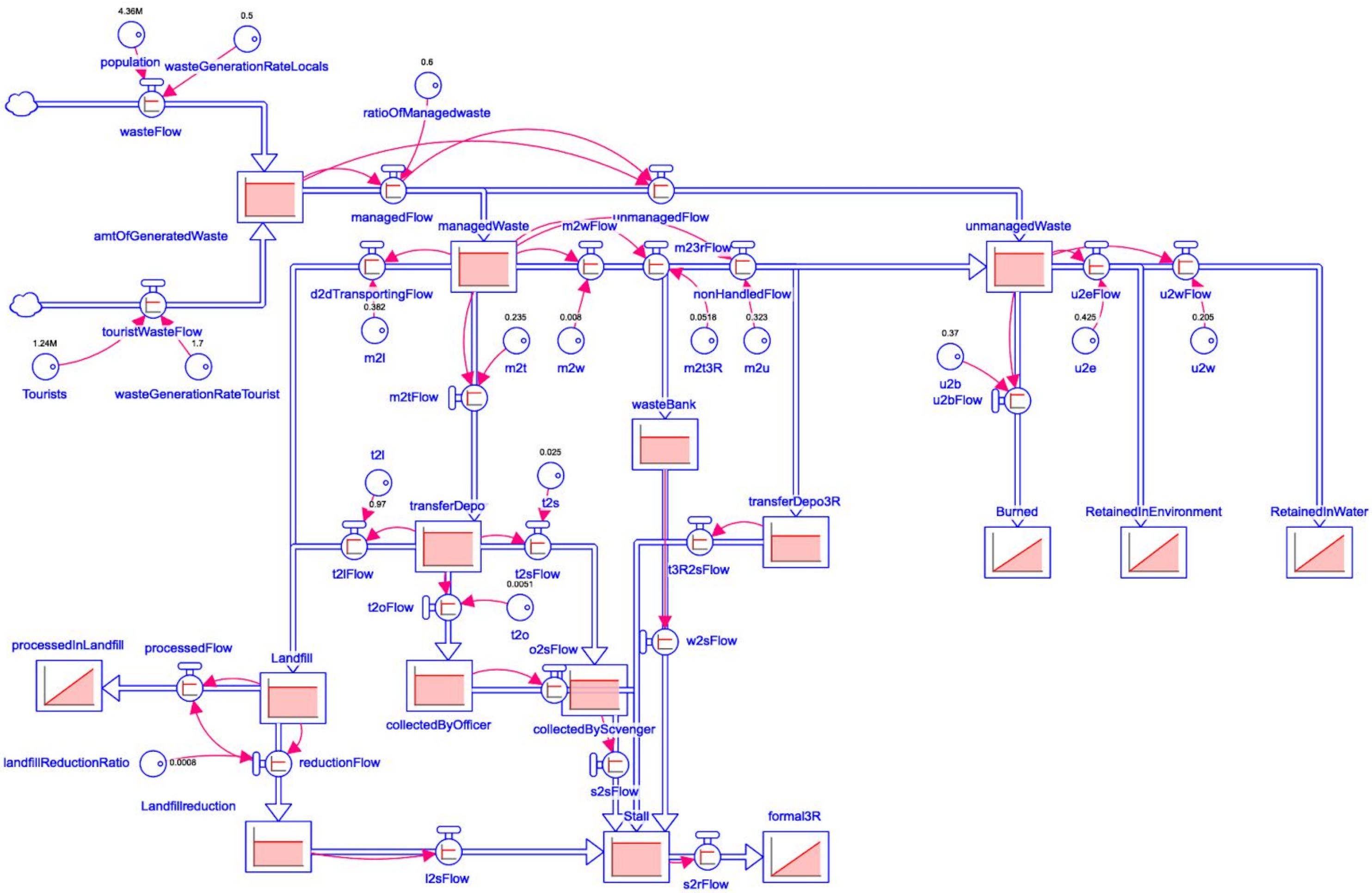

Fig 7.2 System Dynamics Model simulation results of 365 days of waste management in Bali

1. The local population of Bali was taken, multiplied with the waste generation rate by locals which is waste generated by locals per person per day which is on an average 0.5 kg/day/person. This gives the total waste generated in Bali per day by locals.

2. The tourist population of Bali multiplied with the waste generation rate by tourists which is waste generated by tourists per person per day which is on an average 1.7 kg/day/person. This gives the total waste generated in Bali per day by tourists. The sum of the above 2 gives the total waste generated in Bali per day.

3. From the generated waste, it was found out that some waste is managed by waste-collecting authorities in Bali (60% of generated waste) and is collected as managed waste. The remaining 40% of the generated waste is not managed by the authorities.

4. From the managed waste -
    a. **Landfills** - 38.2% of the managed waste goes for processing in landfills directly via door-to-door transportation, found by multiplying managedWaste with **m2l**.
    b. **Transfer Depo (A)** - 23.5% of the managed waste is collected at a transfer depo (A) before going for landfilling, found by multiplying managedWaste with **m2t**.
    c. **Waste Bank** - 0.8% of the managed waste goes to waste bank, found by multiplying managedWaste with **m2w**
    d. **Transfer Depo (B)** - 5.18% of the managed waste is collected at a transfer depo (B) before going for recycling, found by multiplying managedWaste with **m2t3R**.
    e. **Unmanaged waste** - 32.3% of the managed waste is again left at various levels and is treated as waste which is again not managed. Therefore this waste becomes unmanaged waste. This was found by multiplying managedWaste by **m2u**.

5. From transfer depo (A) -
    a. 0.51% of the waste is collected by officers **(t2o)**
    b. 2.5% of the waste is collected by scavengers **(t2s)**
    c. 97% of the waste is transported to landfills for processing **(t2l)**

6. From the waste that is processed in landfills, some recyclable waste is collected by waste pickers and is sent for recycling. This is around 0.08% of the waste landfilled, found by multiplying landfill waste with landfillReductionRatio.

7. Similarly, the waste collected by officers at transfer depo (A), the waste collected by scavengers at transfer depo (A), waste collected at the waste bank, and waste collected at transfer depo (B) is together collected at stalls from where it goes for recycling.

8. From the 40% unmanaged waste and the waste left at various levels while treating waste becomes the total unmanaged waste resulting in -

a. **Burned** - 37% of the total unmanaged waste is burned out, found by multiplying unmanagedWaste with **u2b**.
b. **Retained in the environment** - 42.5% of the total unmanaged waste gets retained in the environment, found by multiplying unmanagedWaste & **u2e**.
c. **Retained in water** - 20.5% of the total unmanaged waste gets retained in the water, found by multiplying unmanagedWaste with **u2w**.

7.3 Model Formulation

Table 7.1 Parameters in Bali model

Name	Values	Formula / Derivation	Source	Type
population	4362000	Section 7.4.2	[41]	Static
wasteGenerationRateLocals	0.5	Section 7.4.2	[41]	Static
wasteFlow		wasteGenerationRateLocals*population	Deduced	Dynamic
Tourists	1235300	Section 7.4.2	[42]	Static
wasteGenerationRateTourist	1.7	Section 7.4.2	[42]	Static
touristWasteFlow		Tourists*wasteGenerationRateTourist	Deduced	Dynamic
ratioOfManagedwaste	0.6	Section 7.4.2	[41]	Static
managedFlow		amtOfGeneratedWaste*ratioOfManagedwaste	Deduced	Dynamic
m2l	0.382	Section 7.4.2	[41]	Static
d2dTransportingFlow		m2l*managedWaste	Deduced	Dynamic
m2t	0.235	Section 7.4.2	[41]	Static
m2tFlow		managedWaste*m2t	Deduced	Dynamic
m2w	0.008	Section 7.4.2	[41]	Static
m2wFlow		managedWaste*m2w	Deduced	Dynamic
m2t3R	0.0518	Section 7.4.2	[41]	Static
m23rFlow		m2t3R*managedWaste	Deduced	Dynamic
m2u	0.323	Section 7.4.2	[41]	Static
nonHandledFlow		m2u*managedWaste	Deduced	Dynamic
landfillReductionRatio	0.0008	Section 7.4.2	[41]	Static
reductionFlow		Landfill*landfillReductionRatio	Deduced	Dynamic
processedFlow		Landfill-reductionFlow	Deduced	Dynamic
i2sFlow		Landfillreduction	Deduced	Dynamic

t2l	0.97	Section 7.4.2	[41]	Static
t2lFlow		transferDepo*t2l	Deduced	Dynamic
t2o	0.0051	Section 7.4.2	[41]	Static
t2oFlow		transferDepo*t2o	Deduced	Dynamic
o2sFlow		collectedByOfficer	Deduced	Dynamic
t2s	0.025	Section 7.4.2	[41]	Static
t2sFlow		transferDepo*t2s	Deduced	Dynamic
s2sFlow		collectedByScvenger	Deduced	Dynamic
w2sFlow		wasteBank	Deduced	Dynamic
t3R2sFlow		transferDepo3R	Deduced	Dynamic
s2rFlow		Stall	Deduced	Dynamic
u2b	0.37	Section 7.4.2	[42]	Static
u2bFlow		unmanagedWaste*u2b	Deduced	Dynamic
u2e	0.425	Section 7.4.2	[42]	Static
u2eFlow		unmanagedWaste*u2e	Deduced	Dynamic
u2w	0.205	Section 7.4.2	[42]	Static
u2wFlow		unmanagedWaste*u2w	Deduced	Dynamic

7.4 Model Tests and Validation

7.4.1 Structure Verification Test

The structure verification test is an empirical way of comparing the relations and equations in the model and in the real world. The developed model should be in keeping with the system's descriptive information. For the structural verification of the model on Waste Management in Bali, 3 models & literature data from various research papers were used. For model development, the following were utilized -

1) Causal loop diagram structure of waste management
2) The specific case - Bali's data of Solid Waste Management
3) Mis-managed flow in Bali

The causal relationships developed in the model, which were based on the available knowledge about the real system and parameters affecting the model, provided a sort of 'empirical' structural validation. The adopted sub-models of the existing models of the domain served as a 'theoretical' structural validation.

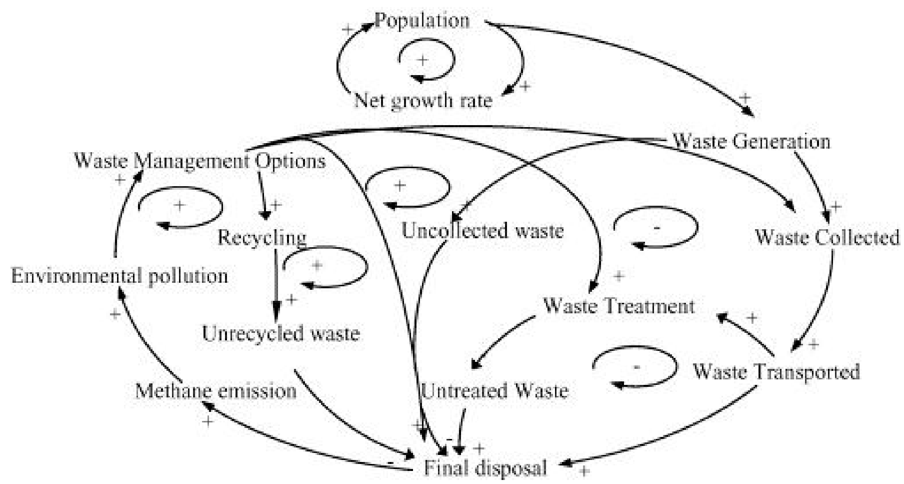

Fig 7.3 Causal Loop Diagram of waste treatment [43]

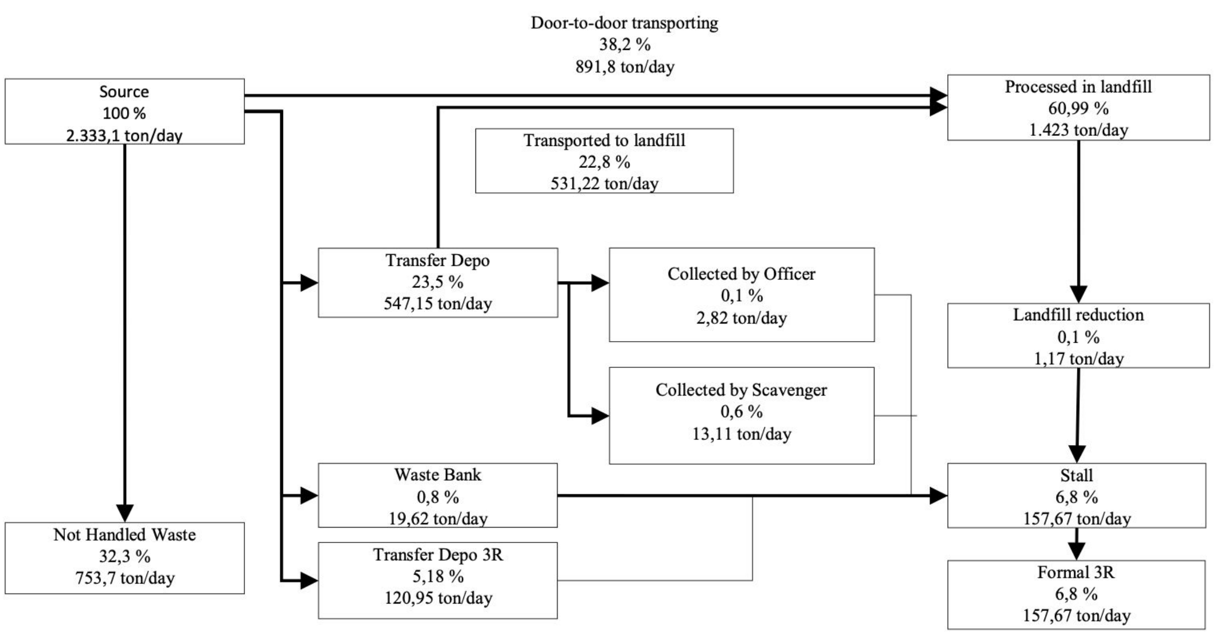

Fig 7.4 Waste material flow in Bali province [41]

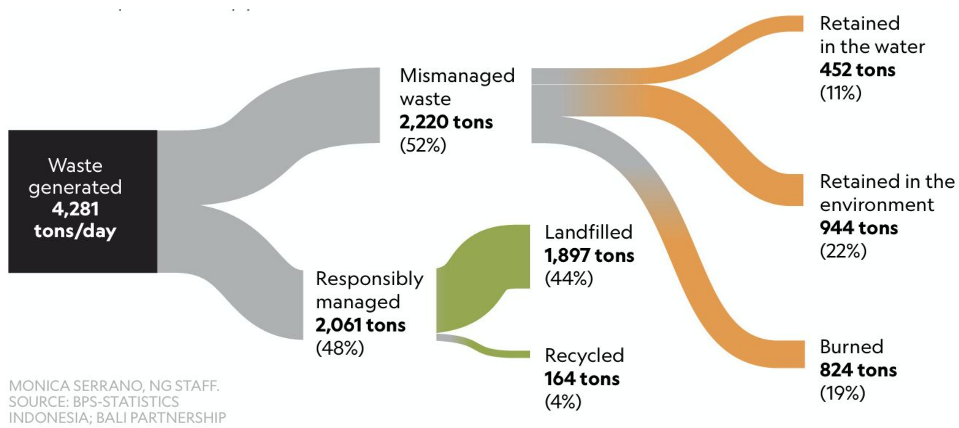

Fig 7.5 Mismanaged waste flow in Bali province [42]

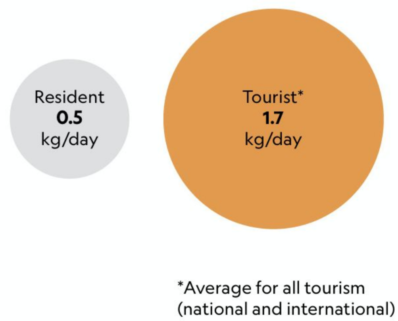

Fig 7.6 Waste generation by tourists and residents [42]

Table 7.2 Adopted Structures in the Bali model

Structure/Concepts	Remarks
Causal Loop Diagram of waste Management (Fig 7.3)	Causal structure was adopted
Waste material flow in Bali province (Fig 7.4)	Managed waste structural formulation and data was adopted
Mis-managed waste flow in Bali province (Fig 7.5)	Mis-managed waste structural formulation and data was adopted
Waste generation by tourists and residents (Fig 7.6)	Tourism explosion and its effect on waste generation structure and data adopted

7.4.2 Parameter Verification Test

It means evaluating all the constant parameters and comparing it with the existing knowledge of the real system numerically and conceptually.

Table 7.3 Parameters in Bali model, their Assigned Values and sources

Parameters	Assigned Value	Sources
population	4362000	[41] (Page 3)
wasteGenerationRateLocals	0.5	
ratioOfManagedwaste	0.6	
m2l	0.382	
m2t	0.235	
m2w	0.008	
m2t3R	0.0518	
m2u	0.323	
landfillReductionRatio	0.0008	
t2l	0.97	
t2o	0.0051	
t2s	0.025	
Tourists	1235300	[42] (Page 1)
wasteGenerationRateTourist	1.7	
u2b	0.37	
u2e	0.425	
u2w	0.205	

7.4.3 Dimensional Consistency Test

It involves checking the LHS and RHS of all the equations in the model for dimensional consistency using Dimensional equations.

Table 7.4 Dimensional Consistency in Bali model

Equations	Dimensional Equations
wasteFlow = wasteGenerationRateLocals*population	kg/day = no. of people*kg/(day*person)
touristWasteFlow = Tourists*wasteGenerationRateTourist	kg/day = no. of people*kg/(day*person)
managedFlow = amtOfGeneratedWaste*ratioOfManagedwaste	kg/day = constant*kg/day
d2dTransportingFlow = m2l*managedWaste	kg/day = constant*kg/day
m2tFlow = managedWaste*m2t	kg/day = constant*kg/day
m2wFlow = managedWaste*m2w	kg/day = constant*kg/day
m23rFlow = m2t3R*managedWaste	kg/day = constant*kg/day
nonHandledFlow = m2u*managedWaste	kg/day = constant*kg/day
reductionFlow = Landfill*landfillReductionRatio	kg/day = constant*kg/day
processedFlow = Landfill-reductionFlow	kg/day = kg/day - kg/day
i2sFlow = Landfillreduction	kg/day = kg/day
t2lFlow = transferDepo*t2l	kg/day = constant*kg/day
t2oFlow = transferDepo*t2o	kg/day = constant*kg/day
o2sFlow = collectedByOfficer	kg/day = kg/day
t2sFlow = transferDepo*t2s	kg/day = constant*kg/day
s2sFlow = collectedByScavenger	kg/day = kg/day
w2sFlow = wasteBank	kg/day = kg/day
t3R2sFlow = transferDepo3R	kg/day = kg/day
s2rFlow = Stall	kg/day = kg/day
u2bFlow = unmanagedWaste*u2b	kg/day = constant*kg/day
u2eFlow = unmanagedWaste*u2e	kg/day = constant*kg/day
u2wFlow = unmanagedWaste*u2w	kg/day = constant*kg/day

7.4.4 Boundary Adequacy Test

It involves checking all the parameters and feedback loops in the model and analysing its impact. The impact can be external and internal. If the impact is external, then only those parameters with significant impacts should be accounted for in the model. By analysing the model, it was found out that **population and Tourists** are exogenous variables that have a significant impact on the model. All the remaining variables in the model are endogenous variables.

7.4.5 Behaviour Sensitivity Test

Method of writing: “Parameter - The rage in which it has been varied”
After that, the graphs have been noted to see the variation in results by changing the parameters in the range of -15% to +15%. Few parameters that were estimated to produce significant variation in results were chosen for the analysis and results were analysed.

1. ratioOfManagedwaste - 0.51 - 0.69

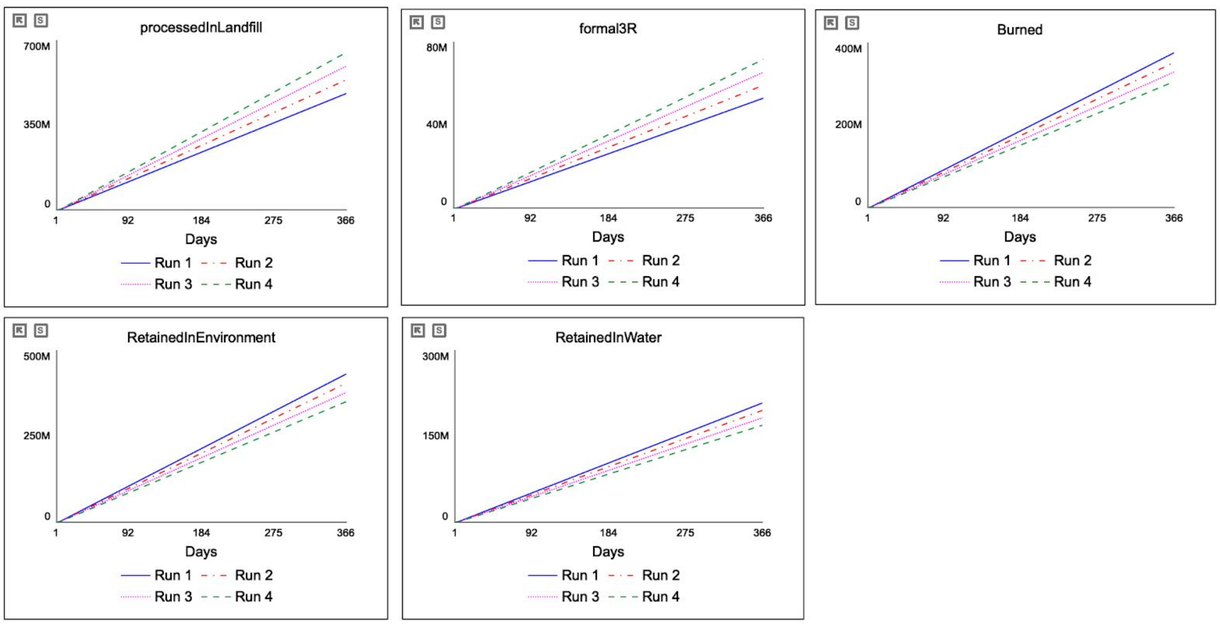

Fig 7.7 Sensitivity analysis of ratioOfManagedwaste

By seeing the analysis results, it was concluded that varying ratioOfManagedwaste had a significant impact on the results. Its increase led to an increase in the managed waste flow. The effect was thus more significant in the waste processed in landfills and recycled waste. Therefore, it was carefully deduced from the literature review and data analysis to justify the model.

2. m2l - 0.3247 - 0.4393 (managed waste going to landfill)
   m2t - 0.19975 - 0.27025 (managed waste going to transfer depo)
   m2t3R - 0.04403 - 0.05957 (managed waste going to recycling)
   m2u - 0.27455 - 0.37145 (managed waste that is not treated)
   m2w - 0.0068 - 0.0092 (managed waste going to waste bank)

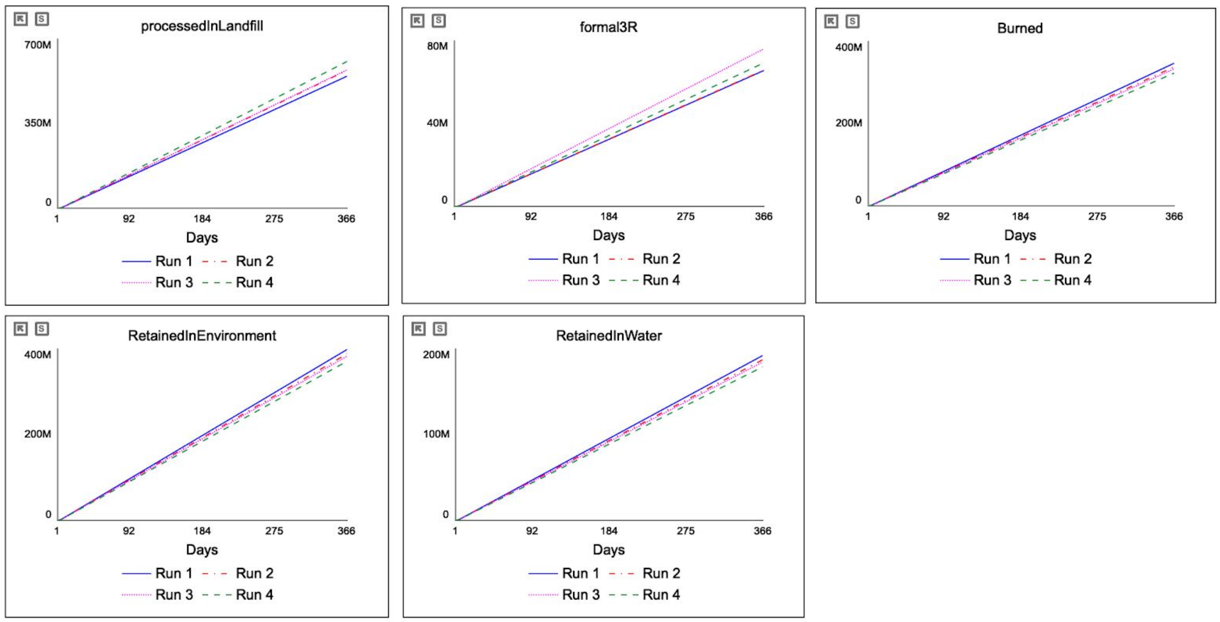

Fig 7.8 Sensitivity analysis of m2l, m2t, m2t3R, m2u, and m2w

By seeing the analysis results of the combination of 5 variables, it was concluded that varying m2l, m2t, m2t3R, m2u, and m2w had a little impact on the results. The effect was more significant in the waste processed in landfills and recycled waste as these parameters are associated with the managed waste. The effect on the results associated with the mismanaged flow was negligible. The model is thus robust to these variations in the parameters, as all the managed waste eventually flows to the same destination through different ways that were varied by these parameters.

3. t2l - 0.8245 - 1.1155 (transfer depo to landfill)
   t2o - 0.004335 - 0.005865 (transfer depo to officers)
   t2s - 0.02125 - 0.02875 (transfer depo to scavengers)

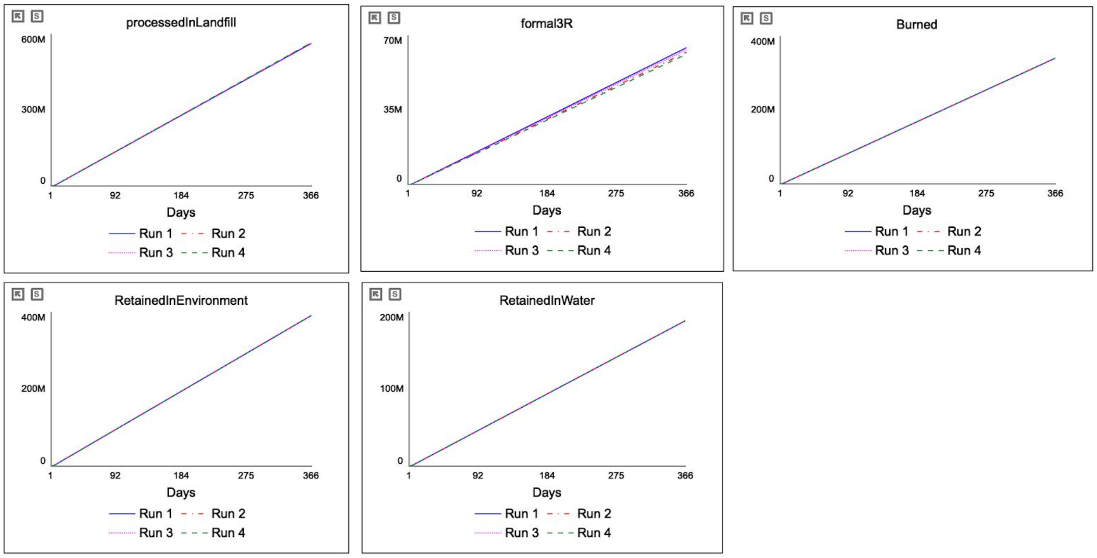

Fig 7.9 Sensitivity analysis of t2l, t2o, and t2s

By seeing the analysis results of the combination of 3 variables, it was concluded that varying t2l, t2o, and t2s had a negligible impact on the results. It is because it only varies the path through which the same results are achieved. Thus the model is almost insensitive to the variations in t2l, t2o, and t2s.

4. u2b - 0.3145 - 0.4255 (unmanaged waste that is burned)
   u2e - 0.36125 - 0.48875 (unmanaged waste that goes in environment)
   u2w - 0.17425 - 0.23575 (unmanaged waste that goes in water)

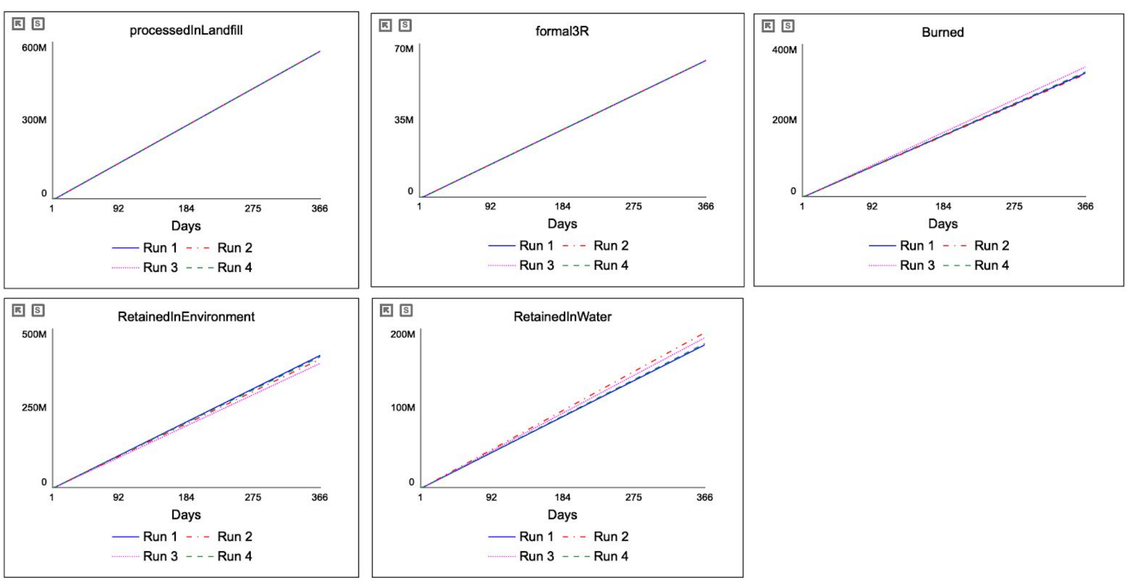

Fig 7.10 Sensitivity analysis of u2b, u2e, and u2w

By seeing the analysis results of the combination of 5 variables, it was concluded that varying u2b, u2e, and u2w had a little impact on the results. The effect was more significant in the waste burned, retained in the environment, and retained in the water as these parameters are associated with the mismanaged waste. There were no effects on the results associated with the managed flow. The model is thus robust to these variations in the parameters.

By analysing the changes in the behavior of graphs of the results because of the variations in the parameters, the following conclusions were drawn that were consistent with the results of Sensitivity analysis -

1. Most of the results were robust and did not vary highly by variations in most of the parameters. By this, the robustness of the model was justified.
2. The parameters that were seen to produce the maximum effect on the result when varied were justified by carefully deducing the values of the parameters by studying the literature review and analysing available data.
3. The parameters that were associated with the managed flow produced variation in the managed flow results only and were robust to mismanaged waste results.
4. The parameters that were associated with the mismanaged flow produced variation in the mismanaged flow results only and were robust to managed waste results.

Chapter 8: Results and Discussion

8.1 Delhi Model

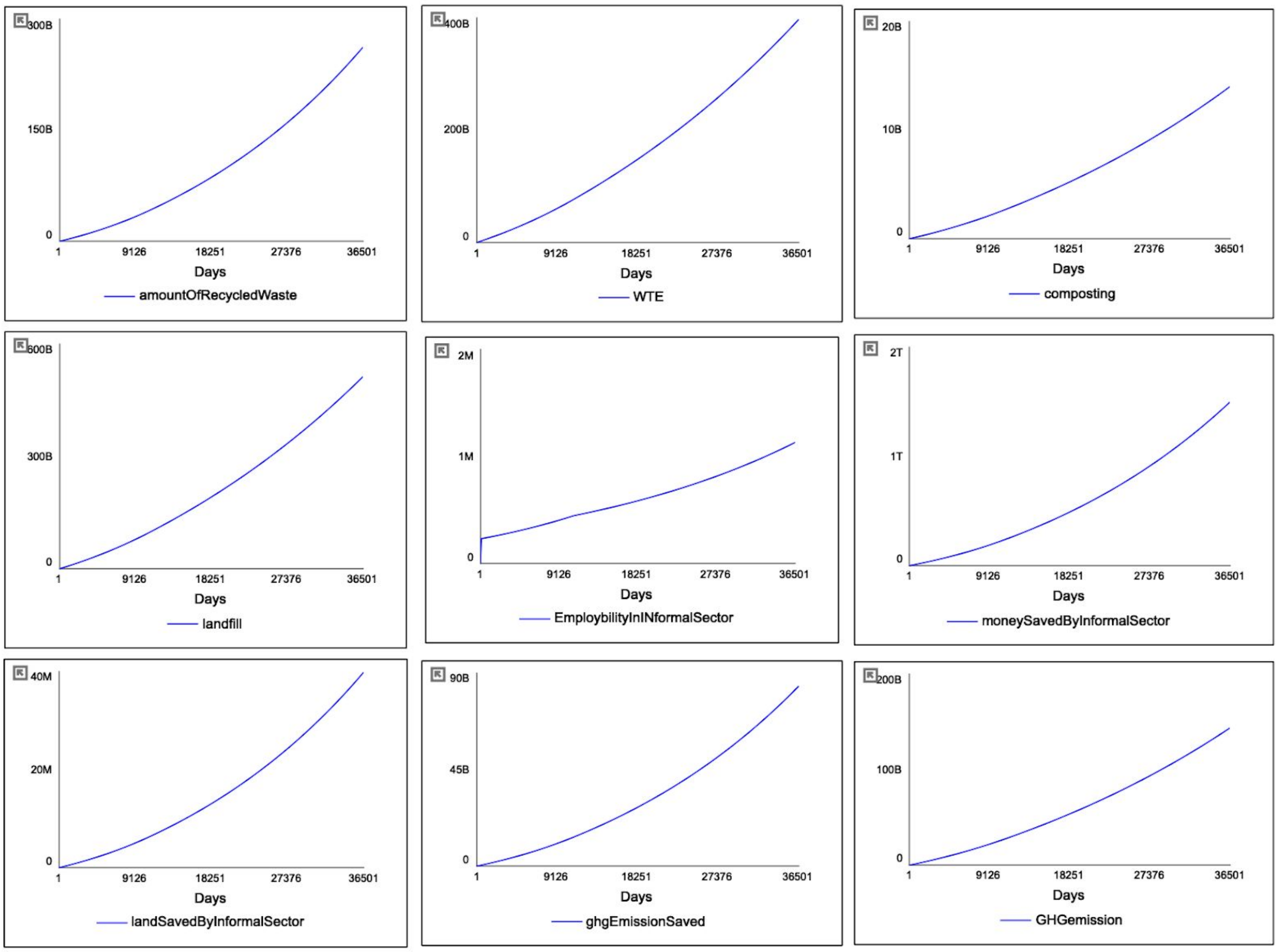

Fig 8.1 Delhi Model simulation results

By simulating the Delhi model for 100 years, the graphs as shown in Fig 8.1 were made. As in the current scenario, waste collected by informal flow is increasing as the recycling practices are increasing (owing to increase in awareness, more recycled products entering markets). As a result in the coming years, it can be seen that the amount of waste recycling would keep on increasing and all the results based on this also keep on increasing. On the other hand, results like waste processed in Landfill, composting, and WTE and the results based on these also increase but the rate of increase of them is less than the rate of increase of the waste going in informal flow.

Table 8.1 Forecasts based on Informal Flow in Delhi model

Forecasts	Value
People employed in the informal sector at after 100 years	10.2 Million
Government budget saved by informal sector in 100 years	₹ 6.16 Trillion
Land saved by informal sector in 100 years	164 Million sq km
GHG emissions saved by informal sector in 100 years	345 Billion Tonnes

As illustrated in Table 8.1, the informal sector is so much beneficial in waste management currently and as projected in the future as well. It is necessary to improve it as well and fulfill the needs of people involved. The conditions of most of them are currently very bad. There are no laws for protection of workers in this sector and also, they are often marginalized and poorly treated. Therefore, as projected by the model, with 10.2 million people being employed in the informal sector, it is necessary for the government to protect them as well and implement and enforce labour laws in these areas as well.

It can also be seen that the informal sector will save ₹ 6.16 Trillion of the government budget, 164 Million sq km land and 345 Billion Tonnes of GHG emissions in next 100 years as projected by the model. This would reduce the pollution significantly because of reduced GHG emissions by WTE cycles and landfills. It will also save the land which can be used for other more important needs and would not cause infrastructural overload for the government. Hence, this data only increases the emphasis on the point that the government should support the informal sector and encourage people to rely on and encourage the informal sector for waste segregation and recycling. This would increase the rate of segregation of waste significantly as well.

To achieve maximum benefits of the informal sector, the informal sector should be integrated by the government with the formal sector for better functioning which is known as formalisation. (Section 6.4)

8.2 Analysis of Scenarios of Delhi Model

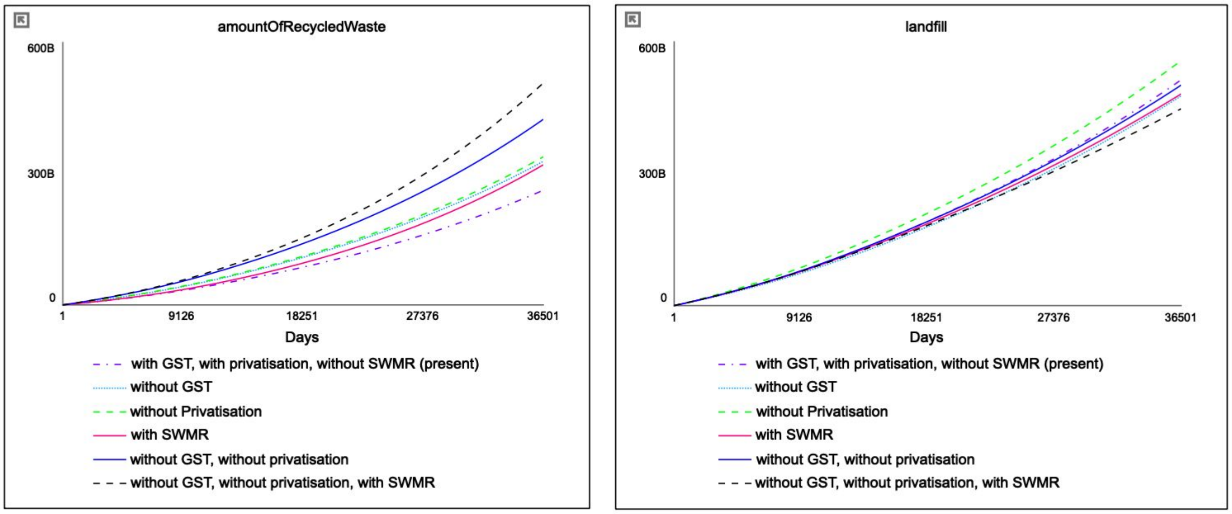

Fig 8.2 Scenario effects on amountOfRecycledwaste & landfill

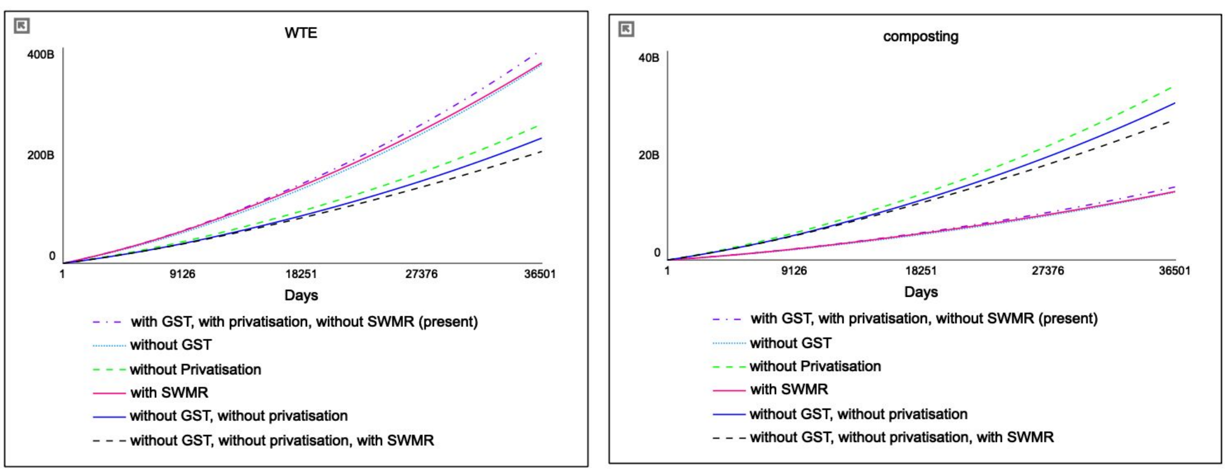

Fig 8.3 Scenario effects on WTE & composting

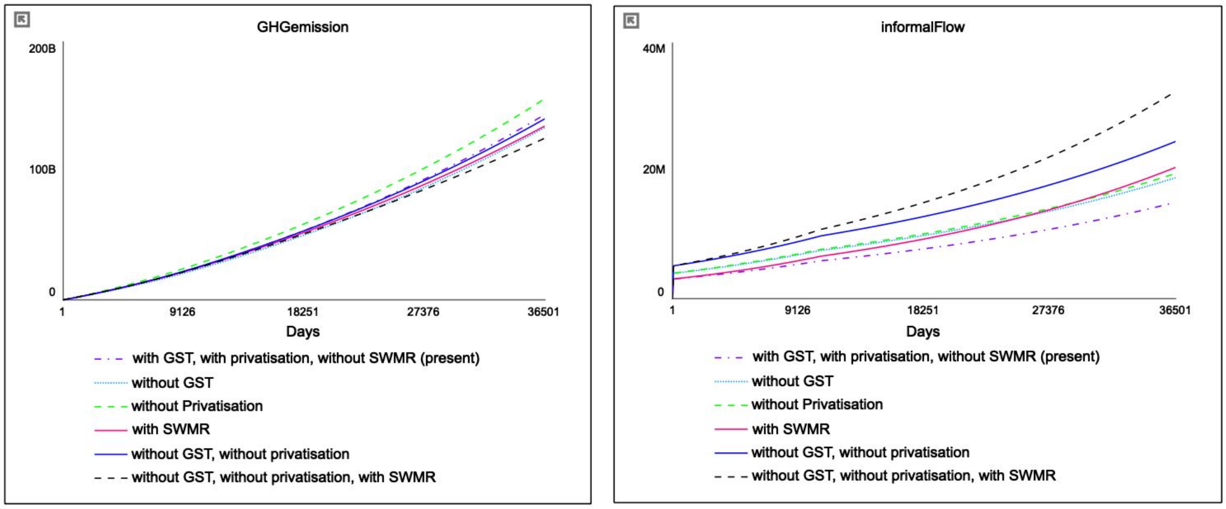

Fig 8.4 Scenario effects on GHGemission & informalFlow

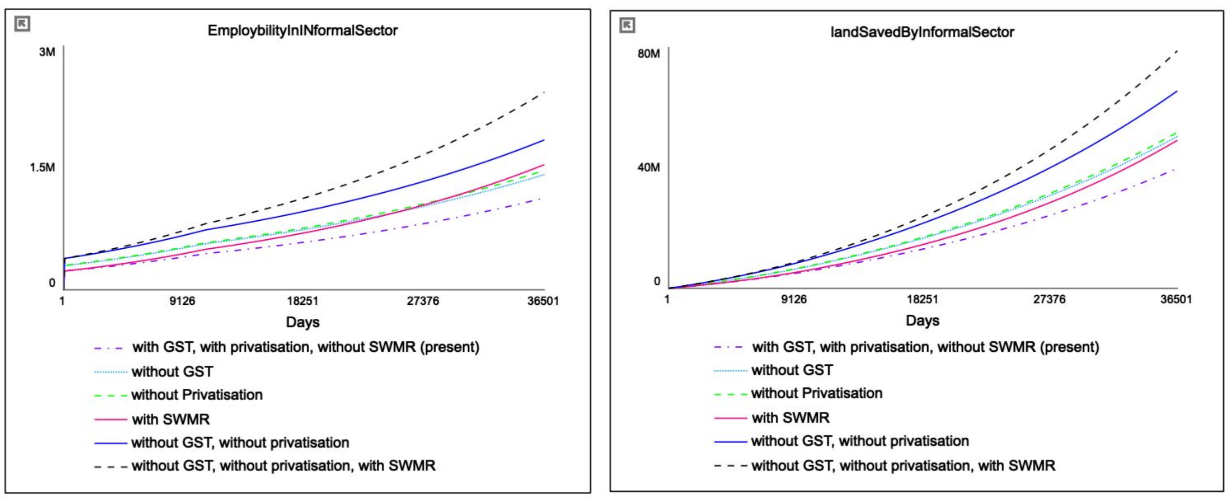

Fig 8.5 Scenario effects on EmploybilityInInformalSector & landSavedByInformalSector

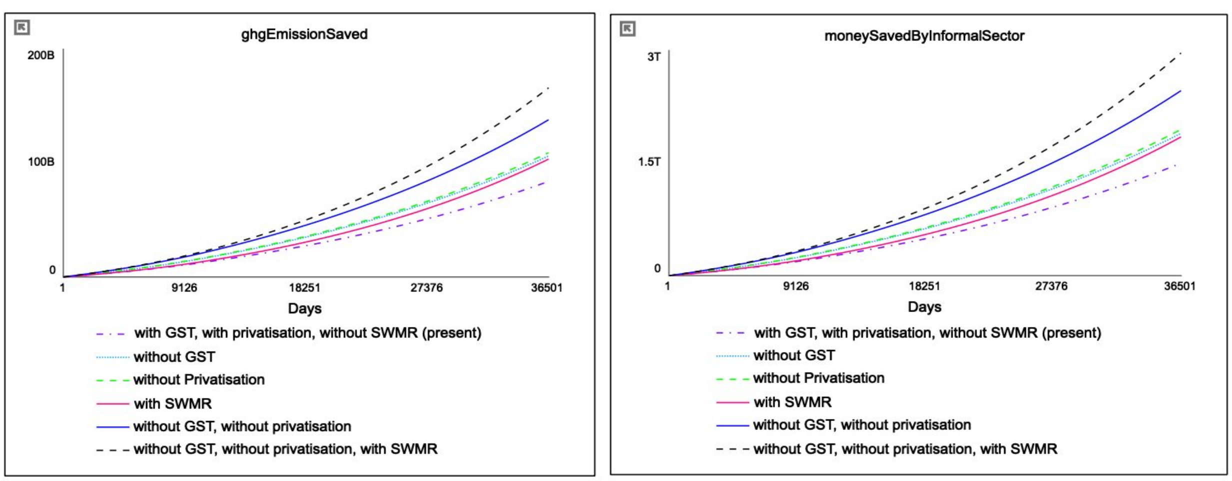

Fig 8.6 Scenario effects on ghgEmissionSaved & moneySavedByInformalSector

Table 8.2 Scenario results on different parameters*

Results	with GST, with privatisation, without SWMR	without GST	without privatisation	with SWMR	without GST, without privatisation	without GST, without privatisation, with SWMR
WTE	1	3	4	2	5	6
Composting	4	6	1	5	2	3
GHG emission, Landfill	2	5	1	4	3	6
Amount Of Recycled waste, Informal Flow, Employability In Informal Sector, Land Saved By Informal Sector, ghg Emission Saved, Money Saved By Informal Sector	6	4	3	5	2	1

*1 refers to maximum amount and 6 refers to the minimum amount

From the point of view of the informal sector, it can be seen that the effect of applying all the three policies together appears to be the best case scenario.This is closely followed by devising a policy to reduce privatisation. It is also visible that the current scenario : with GST, with privatisation and without SWMR is least desirable. This calls for reform in any of these scenarios to even a small extent as it will clearly help the informal sector.

Privatisation, if not removed, could at least be limited with the scope of WTE and door-to-door collection actually utilized systematically by the informal and formal sector. This will be difficult to do especially considering the above case when WTE is most efficient in the existing case. The companies might pressurize the government to not make any changes in this regard.

Formalisation can also help in improving the amount of waste recycled and in general, improve the socio-economic lifestyle and safety of the workers.
These results provide an inspiring analysis that there is a huge amount of scope in working for the welfare of the people who are a part of this sector. This is not only required because they deserve it but also because helping them will eventually help all the sections of society.

8.3 Policy Implications

1. **Need a comprehensive policy that takes into account the informal sector and other policies related to it.**

   In developing countries like India, waste management has not been an environmental priority while the informal sector has managed to reduce the problem through their systems. Many existing environmental policies and laws acknowledge waste management directly or indirectly. However, these policies are not comprehensive enough to properly take into account the informal waste management system. If some policies actually exist for the welfare of the informal sector, they are poorly implemented such that they often weaken the informal sector instead of strengthening it. Existing policy instruments do not give recommendations on what needs to be done, such as source segregation of waste and integration of the informal sector. These policy instruments predominantly fall short in terms of defining mandatory rules or precise descriptions of how measures should be implemented, by what means, in what allocated space, and which target figures should be reached. Another shortcoming of these policy incentives is that they only mostly reach the formal recycling sector and not the larger informal one.

   The current scenario clearly points out that India needs a policy initiative that is entirely focussed on the legitimization of the informal waste management sector. This formalisation, however, should be done by carefully analysing the present situation. A comprehensive policy that guides formalisation of the informal sector by defining all the provisions in detail is the need of the hour.

2. **Since SWM rules, if implemented effectively, show some promising results w.r.t informal waste sector, therefore steps should be taken to make strict bye-laws for their implementation.**

   The formal sector is not able to implement SWM rules effectively. Stakeholders outside the municipal government system such as rag pickers contribute considerably to waste management and resource efficiency by collecting, sorting, trading, and processing waste materials. They can be significantly benefited by this. The rules are notable for their acknowledgment of the role of the informal sector in waste management practices, but they provide little guidance on the process or framework for including waste pickers in practice. There are no bye-laws that state what sort of integration would be beneficial for India.

With the door-to-door collection (mostly by the private sector), the informal sector loses access to waste material. The municipal corporations should work with waste pickers' collectives and NGOs for arranging door to door collection of segregated waste and providing material recovery facilities (MRFs) and personal protective equipment (PPE) for secondary segregation.

Also, none of the WTE plants comply with the SWMR, 2016 that states only segregated non-recyclable high-calorific fractions be sent to these plants. The Solid Waste (Management and Handling) Rules 2016 call for recycling, which is not possible to do especially if recyclable waste is used for such technologies.

8.4 A Comparative Study for Delhi and Bali Models

The first major difference that can be observed is the consideration of waste from tourists in the Bali model. This follows from the very high tourist waste generation rate in Bali (1.7 kg/day) in comparison to waste generated by a resident in Bali (0.5 kg/day). This is however not evidently true for Delhi which can be seen from the overall tourist behaviour in Delhi.

Table 8.3 Tourist Analysis in Delhi

Type of Tourist	Percentage tourists visiting for leisure in Delhi
Domestic (Single Day)	81%
Domestic (Overnight)	37%
Foreign	60%

As can be clearly seen from Table 8.3, the tourists visiting for leisure are mainly for a single day in Delhi. And, although 60% of the foreign tourists visit for leisure, foreign tourists make up only about 7% of the total tourists. [45]

Since, clearly the waste due to leisure-based tourists should be much higher than non-leisure/ business based (owing to more spending and usage of resources, as in the example for Bali), this sets an idea of why waste generation due to tourists is not important for the model of Delhi.

Another important factor to be considered is the role of the informal sector. Clearly, the contribution of the informal sector in Bali is somewhat less than that in Delhi. This is not due to better management of waste in Bali as clearly 57% of the waste in Bali is mismanaged. This can be thought to come from a lack of infrastructure and a lack of realization of employment in this sector. Still, there is a small section of waste (about 0.8% of the waste landfilled), which is sent to recycling by the informal sector. There is another factor that can be understood for this behaviour. Majority of people in the informal sector in Delhi collect waste from households and the complete informal waste economy works around that waste (majorly). Only a small insignificant amount is collected in landfills. This however is not the case for the informal sector in Bali and it’s not productive as well because, as discussed above, a major part of waste in Bali is produced by tourists, and mapping a waste flow incorporating tourist waste is difficult in Bali.

8.5 Further Work

The primary aim of the project is to create a Solid Waste Management model of Delhi and analyse both informal and formal sectors. Several scenarios were then tested on the model to see the results. After that, the model was compared to the waste management model of Bali - A tourist destination. The future works that can be done -

1. Detailed analysis of the SWM budget and how it is divided for different waste treatment methods. This should be a transparency driven analysis where what is actually spent for the SWM is determined.
2. Finding through surveys, the waste treatment cost per kg for different methods to integrate budget models in the system.
3. Through surveys, the model can be further verified by real-time data and also, assumed parameters can be derived.
4. Integrating factors in the Bali SWM model that affects the flow of the waste.
5. Analysing various scenarios on the Bali SWM model.
6. Developing the SWM model of European countries to compare the Delhi SWM model with the best SWM models for understanding the scope of improvement.

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