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MODELING AN INTEGRATED SYSTEM DYNAMICS MODEL AND ANFIS FOR SEPARATION AND RECYCLING OF MUNICIPAL SOLID WASTE IN KHULNA CITY, BANGLADESH

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Abstract

The separation and recycling of municipal solid waste is an indispensable section for sustainable cities and communities, which is one of the sustainable development goals of the United Nations. Recycling techniques help with energy conservation and pollution abatement. The purpose of this research is to forecast waste generation, its transformation into other states, and the annual revenue from recycled MSW until the year 2040. An integrated model of System Dynamics Model and Adaptive Neuro fuzzy inference system (ANFIS) forms a support framework to predict the optimal decision. According to simulation findings, by 2040, the annual revenue from recycled waste grew from BDT 5304704 to BDT 6800922.79 per annum, and with the implementation of a developed policy that is to separate the recycled waste at the secondary disposal point, the revenue climbed from BDT 6365641.2 per year to BDT 8161103.748 per year. The amount of MSW rises from 169184972 kg/year to 199062135.2 kg/year. It is quite concerning that the amount of untreated MSW keeps growing exponentially over time. The model's result may be utilized as a functional testing subsystem for effective decision-making analysis and deliberate initiatives. In this research, the anticipated value was based on the population, educated vs. uneducated, MSW generation rate, and urban population effect on growth, as well as the production of garbage by the populace, the transformation of that waste, and the sorting of waste. At first, a casual loop diagram of the waste recycling model was developed. Secondly, a stock-flow diagram was developed, which is the fundamental physical structure of the system. The STELLA software then generated the required results for the parameters. Another model was made through ANFIS via MATLAB, and the results were compared. The study is validated by sensitivity analysis, which takes into account data and behavioral susceptibility. Both the local government and KCC will be tremendously benefited by these policies, as they are viable given the limitations and challenges neatly tackled by this model.

***Key words**: Recycling, Municipal solid waste, Khulna city, Sensitivity analysis, Uncertainty*

1. Introduction: Municipal solid waste (MSW) refers to the waste produced by families and businesses within a municipality. Typically, this consists of a variety of things, including paper, plastics, food waste, yard debris, and home objects. Community waste management is the process of collecting, transporting, and disposing of municipal solid waste. Common methods of MSW management include landfills, recycling, incineration, and composting. The improper disposal of municipal solid waste can negatively affect both human health and the environment. The management of municipal solid waste is frequently the duty of local governments, although it can also be managed by private organizations. Municipal solid waste (MSW) comprises the mass of discarded homogenous and heterogonous materials of an urban region. It is also highly heterogonous mixture of residential, commercial, industrial, institutional and other waste materials (Rafizul and Alamgir, 2012). To understand the continuously growing challenge of MSW management, it is evident that city authorities must quantify MSW in future to understand the limitations and opportunities of the era and provide objective based reliable prediction for the decision-makers (Rahayu et al., 2013).

Multiple factors can influence the development and management of municipal solid waste (MSW) in a community. The greater the population density of a community, the greater the amount of waste generated. Communities with greater economic activity generate more garbage as a result of increased consumption of products and services. Demographics suggest that communities with an elderly population are likely to produce more waste than those with a younger population. Due to the increasing usage of air conditioning and other cooling equipment, communities with warmer temperatures may produce more trash. Groups with a lower income may generate less garbage than those with a higher income because they consume less. The availability and accessibility of waste collection and disposal services can also influence the amount of waste created and its management. Communities with recycling and composting programs tend to generate less waste, as more items are repurposed and reused. Communities with a greater degree of waste management education and awareness tend to generate less garbage and recycle more. Government regulations and policies can also influence the amount and management of garbage produced. Presently, the generated amount of MSW around the world is 2.1 billion tons per year which is expected to rise about 3.4 billion tons by the year of 2050, showing a significant change of per capita generation of MSW in the upcoming year (Kaza et al., 2018).). In Khulna city, about 450–520 tons of MSW is generated daily and KCC authority is responsible for management of this huge quantity of MSW (Rafi et al., 2020). Because of consumers pattern and notable geo environmental difference, the amount of organic fractions of MSW of Bangladesh is almost double compared to Japan and India(Roy et al., 2019).

1.1 Applicability of SD model for waste recycling model:

A system dynamics model is a type of computer simulation that can be used to analyze and comprehend the complex interactions between the various system elements, such as those involved in waste recycling model. The model can be used to examine factors such as population growth, economic activity, waste generation and disposal, and the effects of various waste management policies and programs. The ability to simulate different scenarios and analyze the long-term effects of different policies and programs is one of the benefits of utilizing a system dynamics model in waste recycling model. The model can be used, for instance, to simulate the effects of a recycling program on the amount of waste generated and sent to landfills over time. In addition, System dynamics models can be used to comprehend the system's behavior and to identify the feedback loops that drive that behavior. These feedback loops are the relationships between various system elements that can either reinforce or oppose the system's overall behavior. In addition, they can be used to analyze the effects of various policies and programs on waste reduction and recycling and to identify the most effective strategies for enhancing solid waste management. Overall, the application of system dynamics models in solid waste management can assist decision-makers in gaining a deeper understanding of the complex interactions between the system's various components and in making more informed decisions regarding the sustainable management of solid waste.

1.2 Applicability of ANFIS model for waste recycling model:

The application of Adaptive Neuro-Fuzzy Inference System (ANFIS) in waste recycling model can be utilized to build and predict the system's behavior and to make decisions based on the predictions. ANFIS is comprised of a fuzzy logic system and an artificial neural network, enabling it to adapt to new information and improve its predictions over time. Predicting waste generation is one application of ANFIS in solid waste management. ANFIS can be used to model the relationship between factors like population density, economic activity, and waste generation, and to predict future waste generation based on these factors. This can help decision-makers plan for future waste management requirements and make more informed decisions regarding the sustainable management of solid waste. ANFIS is also utilized in solid waste management for predicting waste disposal methods. ANFIS can be used to model the relationship between various disposal techniques, such as landfilling, incineration, and recycling, and to predict which technique will be the most cost-effective and environmentally friendly. ANFIS can also be used to optimize solid waste management system parameters. This can be accomplished by modeling the relationship between various parameters such as collection frequency, recycling rate, and disposal costs using ANFIS, and then optimizing these parameters to minimize costs and maximize recycling rate using the model. All things considered, ANFIS's use in solid waste management can shed light on the system's behavior and help decision-makers make better, more well-informed choices for the long-term sustainability of waste management.

1.3 Practices in Bangladesh: In the past, trash was typically collected through a combination of household and municipal responsibility. The diagram below illustrates how waste was transported in the city of Khulna. In the interim, approximately 200 waste dustbins were in place to collect trash, but because fewer individuals were motivated to use them, they were demolished. In the current case scenario, approximately 700 tons of waste are produced, of which approximately 80% is collected by the current waste collection system. Initially, the waste is collected door-to-door with the aid of a three-wheeled van. The monthly cost per household for these vans is approximately Taka 100. The garbage is then transported to the Secondary Disposal Point via three-wheeled van. There are approximately seven major Secondary Disposal Point in Khulna, and many more are currently under construction. Trucks transport garbage from the Secondary Disposal Point to the landfill.

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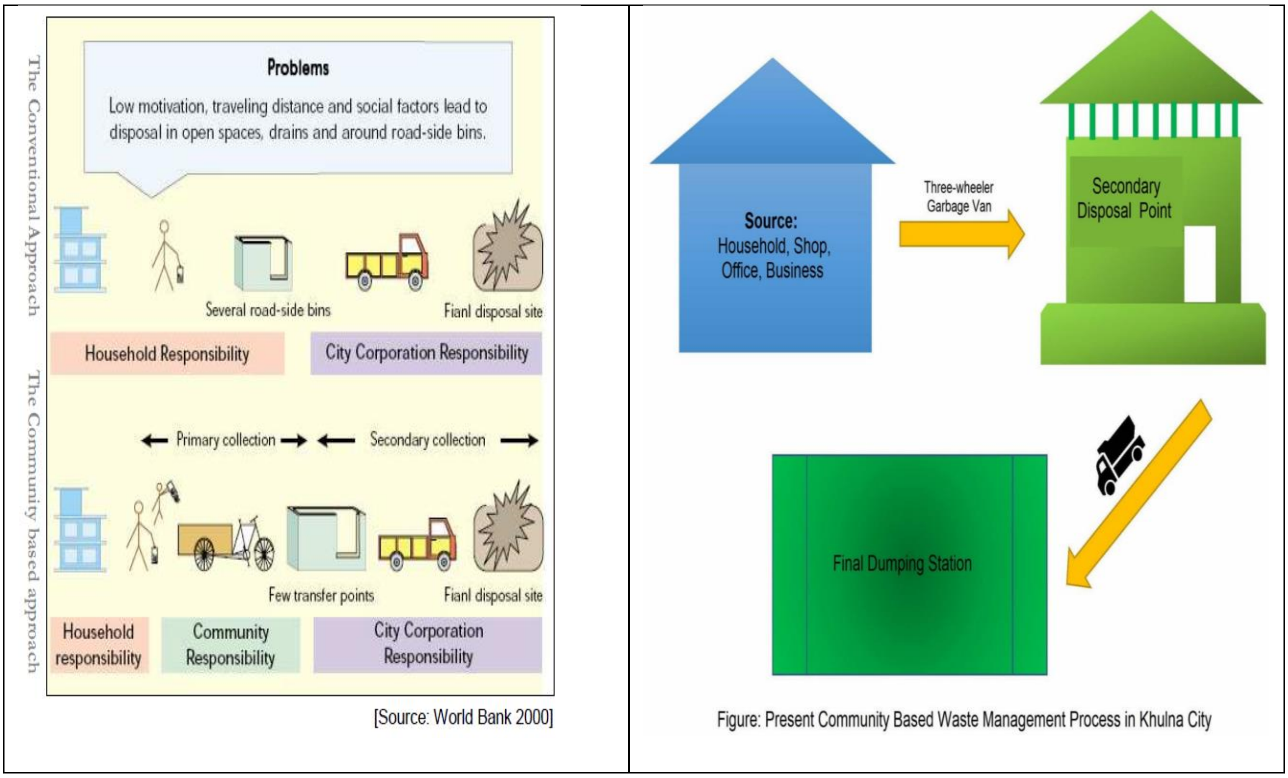

Figure 1: Present Community Based Waste Disposing System

2. Research Methodology:

2.1 Study Area: Khulna is located in the southwest of Bangladesh at a latitude of 22.49 degree North and a longitude of 89.34 degree East. According to the Population and Housing census 2022, the population of Khulna City is 17,416,645. The city has a rapidly expanding population having average annual growth rate 1.22. Numerous locations lack established garbage collection and disposal infrastructure, resulting in improper disposal of a major amount of the city's waste. Due to uncollected home garbage on the streets and other public spaces, the drainage system is clogged and water bodies are contaminated, posing a major threat to the city's health. This is very acute during the rainy season especially in the congested unplanned neighborhoods where roads are very narrow and municipal trucks cannot pass (World Bank 2000).

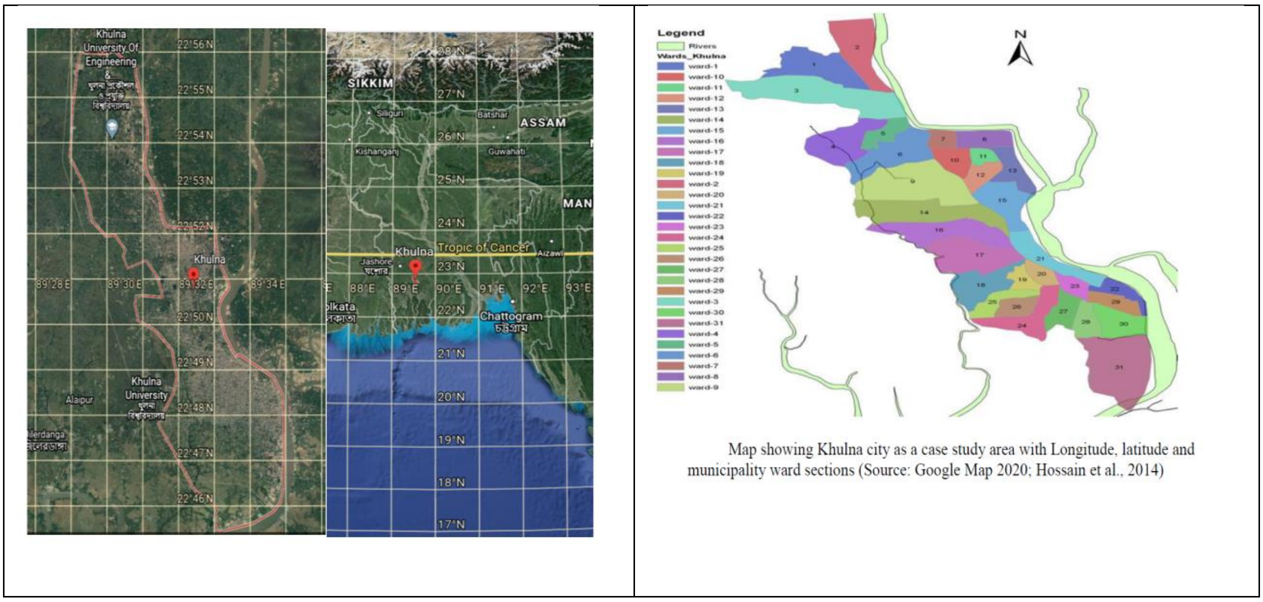

Figure 2: Map of Khulna City. Source: (S.M. Rafew and I.M. Rafizul,2020)

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2.2 Collecting Input Data: The MSW management budget of KCC, the salary of the conservancy garbage section, the KCC budget for the base year, the cost of fuel and maintenance, etc. are extracted from the KCC budget book (KCC, 2019). Secondary data sources are mined for the base year's values of things like GDP, population, population growth, mortality rate, income multiplier, incineration capacity, composting potency, recyclable MSW inventory, landfill development, number of trucks, collection capacity of trucks, etc.

Table 1: Wet mass, Dry mass and moisture content data of MSW of Khulna city (Source Ahsan et al., 2015;Alamgir et al., 2007; Mondol et al., 2016)

MSW Component	Percentage of MSW	Moisture Content %	Wet Weight (Ton/Year)	Dry Weight(Ton/Year)
Food and Vegetable	78.9	64	418.17	150.5412
Paper and Paper Products	9.5	7	50.35	46.8255
Polythene and Plastic	3.1	4	16.43	15.7728
Textile and Woods	1.3	14	6.89	5.9254
Rubber and Leather	0.5	7	2.65	2.4645
Metal and Tins	1.1	2	5.83	5.7134
Glass and Ceramics	0.5	1	2.65	2.6235
Dust, ash, mud Product	3.7	8	19.61	18.0412
Brick, Concrete and Stone	0.1	12	0.53	0.4664
Others (e.g.: bone and rope)	1.2	35	6.36	4.134
Total	99.9	154	529.47	252.508

Table 2: Historical MSW generation Data of Khulna City from 2013 to 2020 (After: S.M. Rafew and I.M. Rafizul, 2020)

Year	2013	2014	2015	2016	2017	2018	2019	2020
Population (Nos.)	673093	773094	911094	1083094	1201094	1351094	1415094	1500689
Per Capita Waste Generation(Kg/day)	0.27	0.277	0.284	0.291	0.298	0.305	0.311	0.318
Population Growth Factor	0.14856937	0.1785035	0.188784033	0.108947146	0.124886145	0.047369021	0.060487148	0.0137
Waste Generation Capacity(Kg/year)	66333315.2	78163669	94444004.04	115040829.2	130642994.4	150410539.6	160634395.4	169184972.2
GDP Per Capita (BDT)	67529	676940.718	68000.44298	69080.73181	74612.33409	83069.17804	94359.92584	1032900.6399

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Table 3: Population and Housing Census 2022

POPULATION & HOUSING CENSUS 2022		
Population	718,735	Khulna City
Floating Population	1,328	
Population Growth Rate	1.22	Bangladesh
Population Density	1,119	

2.3 Modelling of SD for MSW management:

2.3.1 Development of Casual Loop Diagram:

To construct a casual flow diagram in Stella, the program is launched and the "Casual Loop" template is chosen. The "Add Variable" and "Add Stock" buttons are clicked to add variables and stocks to the diagram. Causal loops between the variables and stocks are connected by dragging and dropping the arrow tool between them. The desired variables and configurations are adjusted to complete the diagram.

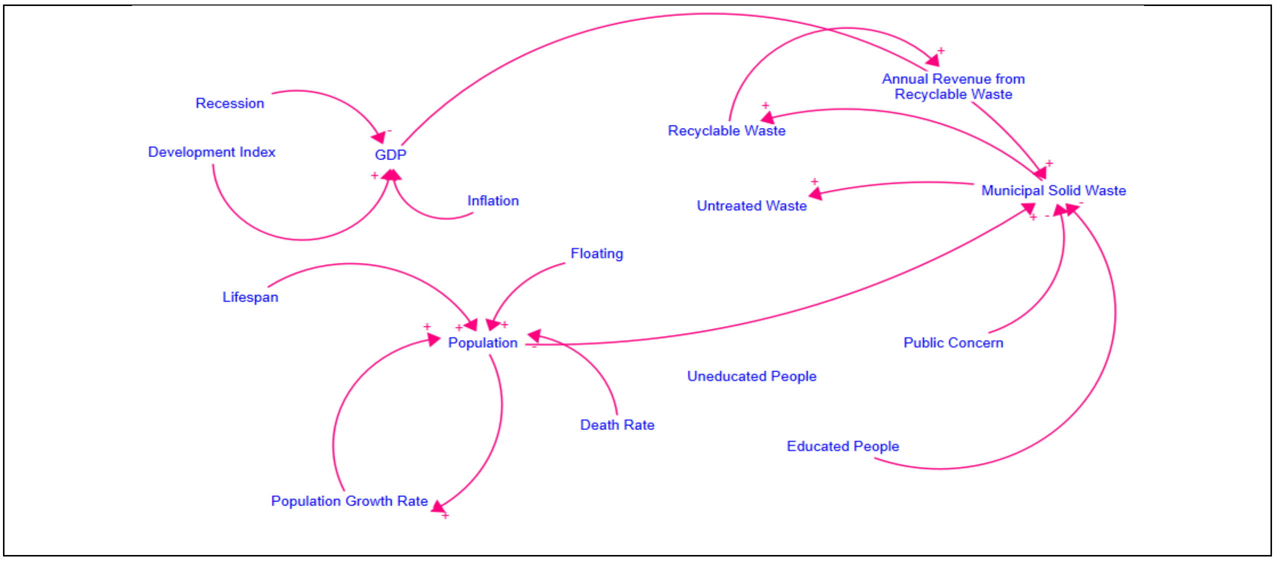

Figure 3: Casual Loop Diagram for Annual Revenue generation from Recyclable MSW

2.3.2 Construction of Stock-Flow Diagram:

In Stella, a stock flow diagram is created by selecting a waste recycling-appropriate template, adding stocks and flows with the appropriate buttons, connecting them with causal loops, adjusting values and settings, and running a simulation. By adding variables, modifying their properties, and adding additional flows between variables, the diagram can be further customized. The simulation can be run to see the results after manipulating the stocks and flows to reflect the real-world scenario.

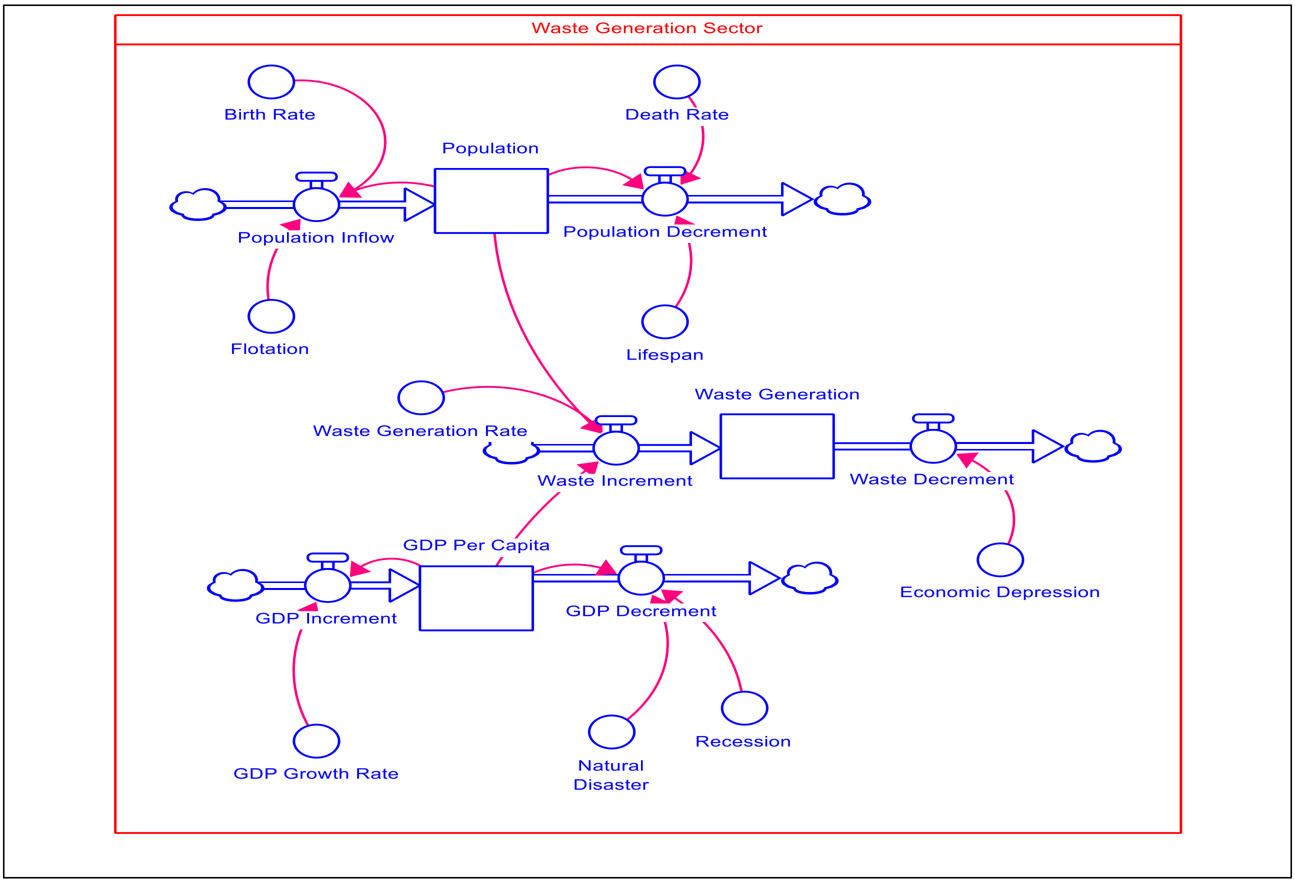

Figure 4: Stock- Flow diagram of Population, GDP and Waste Generation

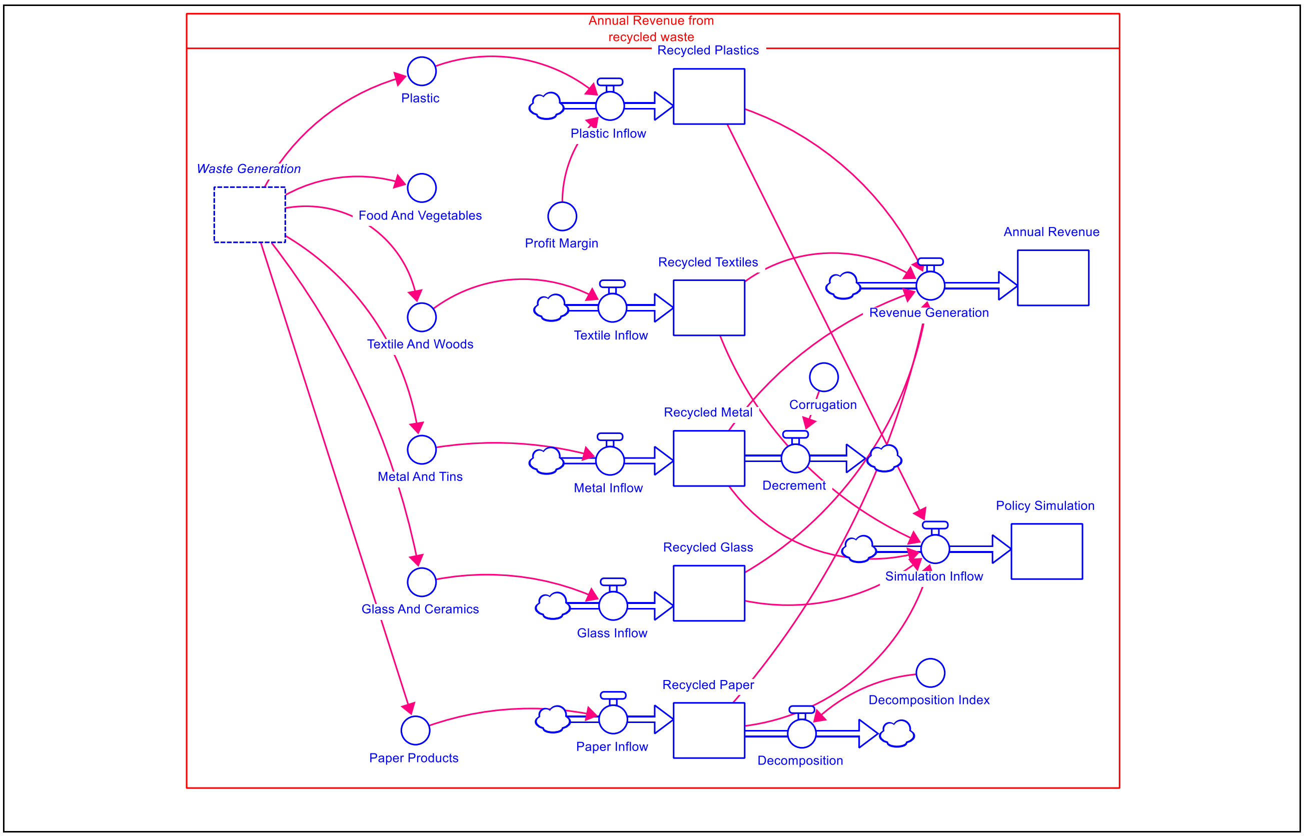

Figure 5: Stock –Flow diagram of Annual Revenue and Policy Simulation

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2.3.3 Execution of the SD Model:

Initially, a schematic diagram of the entire process is drawn. Having followed subsequent inputs are made for the stocks. Secondly, flow and converter values are respectively assigned to each stock. Then, the entire system is modeled using equations. Finally, the model is executed, and the necessary graphs and tables are generated.

2.4 Modelling of ANFIS for MSW management:

ANFIS model is then used to analyze the simulated data from the system dynamics. Adaptive Neuro-Fuzzy Inference System (ANFIS) is a model that combines fuzzy logic and artificial neural networks. It can be used to analyze and forecast the behavior of the system in municipal solid waste management. This section provides an overview of the ANFIS model's operation. The first step in utilizing an ANFIS model for solid waste management is collecting data on the pertinent variables. This can include information regarding population density, economic activity, waste production, disposal methods, and the effects of various policies and programs. Next step is Fuzzification which involves converting the collected data into fuzzy sets, which are used to represent the uncertainty and vagueness of the data. This allows the model to account for imprecise or inadequate data. Next, a rule base defining the relationships between fuzzy sets and the output variable is developed. The rule base consists of if-then statements that describe the influence of input variables on output variables. It is the responsibility of the inference engine to generate predictions based on the rule base and the input data. It uses fuzzy sets and rules to determine the output variable. Through adaptive learning, ANFIS models can adapt to new data and improve their predictions over time. This is achieved by adjusting the parameters of the model based on the deviation between the predicted and actual output. The final step is to evaluate the model's performance and make any necessary modifications. This involves comparing the model's predictions with actual data and adjusting the model's rule base or other parameters to improve its accuracy. The MATLAB software's fuzzy logic designer toolbox is used and the SUGENO analysis procedure is selected. The input variables are then associated. . The data are being loaded and trained with 100 epochs respectively. Adjusting the training error, rule viewer is generated. Lastly, using evalfis command the output data are generated.

3. Result and Discussion:

3.1 Verification of the Model:

In order to validate the model, the waste's dynamic behavior is considered. The plausible factors contribute to the predicted result. Then, sensitivity analysis is used to validate the result with the necessary boundary constraints.

3.2 GDP, Population and Municipal Solid Waste Generation:

In Fig. 6, the simulated outcomes of GDP, population, and municipal solid waste generation are projected, which are obtained from the System Dynamics Model Software Stella. This figure shows simulated data from 2023 to 2053. In 2023, the GDP is BDT 103290, which rose to BDT 451812.8 in 2053. The population is 718735 in 2023, which increased to 1367405 within 2053. There’s been a significant increase in waste generation from 169184972 kg/year to 235596163 kg/year.

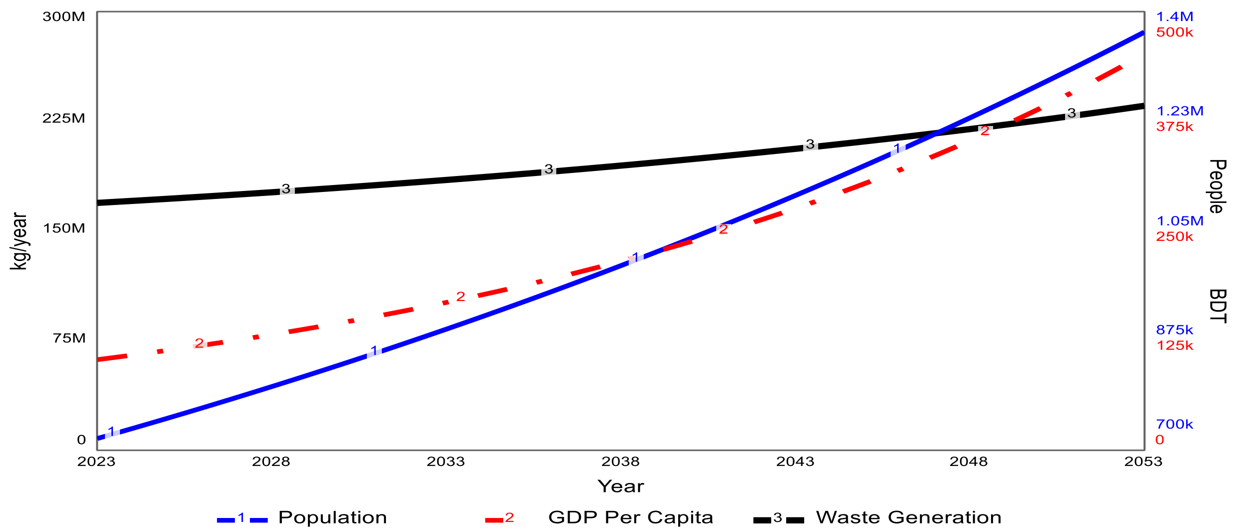

Figure 6: Simulated Population, GDP and Waste Generation in SD

3.3 Simulated Data of Recycled Components:

The System Dynamics Model Software Stella is used to project the recycled components generation scenarios depicted in Figure 7. This graph displays simulated data for the years 2023 through 2053. In 2053, the Recycled Glass

will have increased to 6096 kg/year from 3666 kg/year in 2023. In 2023, the Recycled Metal is 15792 kg/year; by 2053, it has climbed to 48000.88 kg/year. The rise Recycled Textiles creation from 7050 kg/year to 18745.37 kg/year is considerable. In 2023, the Recycled Paper is 3948 kg/year; by 2053, it has climbed to 5414.7 kg/year. In 2023, the Recycled Plastics is 33840 kg/year; by 2053, it has climbed to 70995 kg/year.

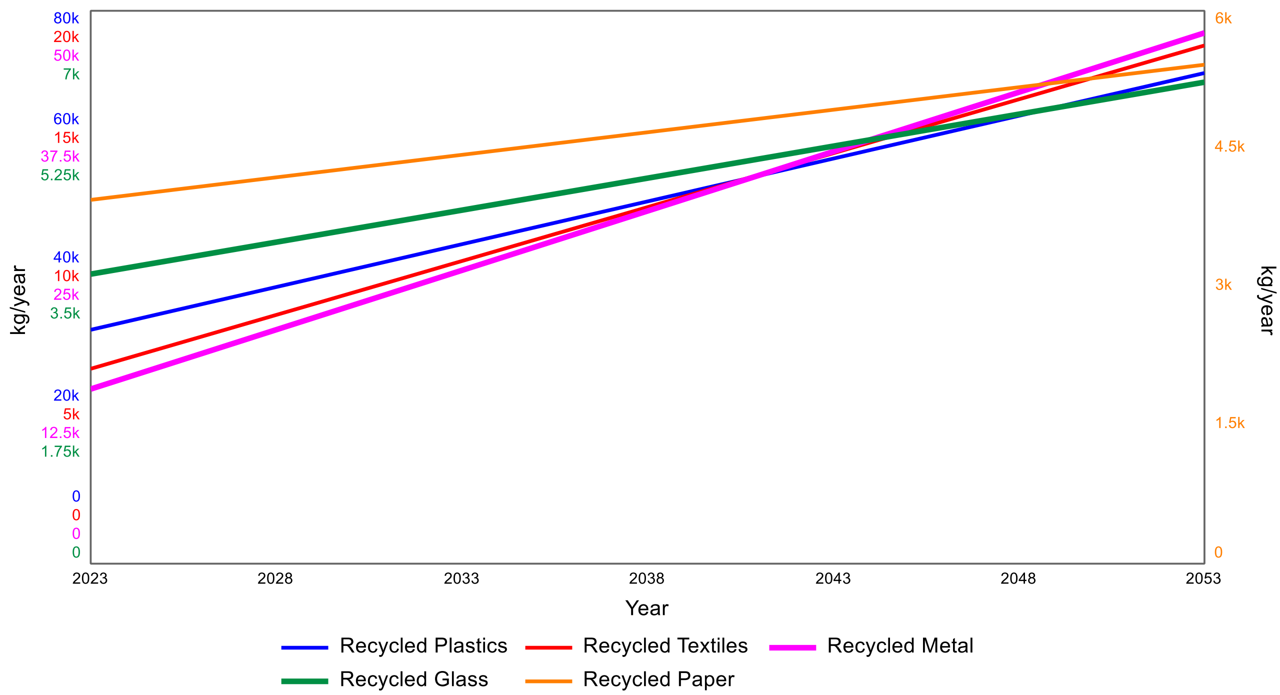

Figure 7: Simulated Data of Recycled Components from SD

3.4 Comparison of Annual Revenue and Policy Simulation:

Policy: Implementation of workers and scavengers on a wide scale at the secondary disposal point. It is done at the secondary disposal point to separate the recycled waste so that it does not end up in a landfill.More than 30% more recycled waste would be generated in this manner. According to Figure 8, implementing this policy generates more BDT 1060937.2 revenue in comparison to the original simulation in Stella software in

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2023. According to Figure 9, incorporating this policy in 2023 generates additional revenue of BDT 1061187.668 compared to the original ANFIS simulation.

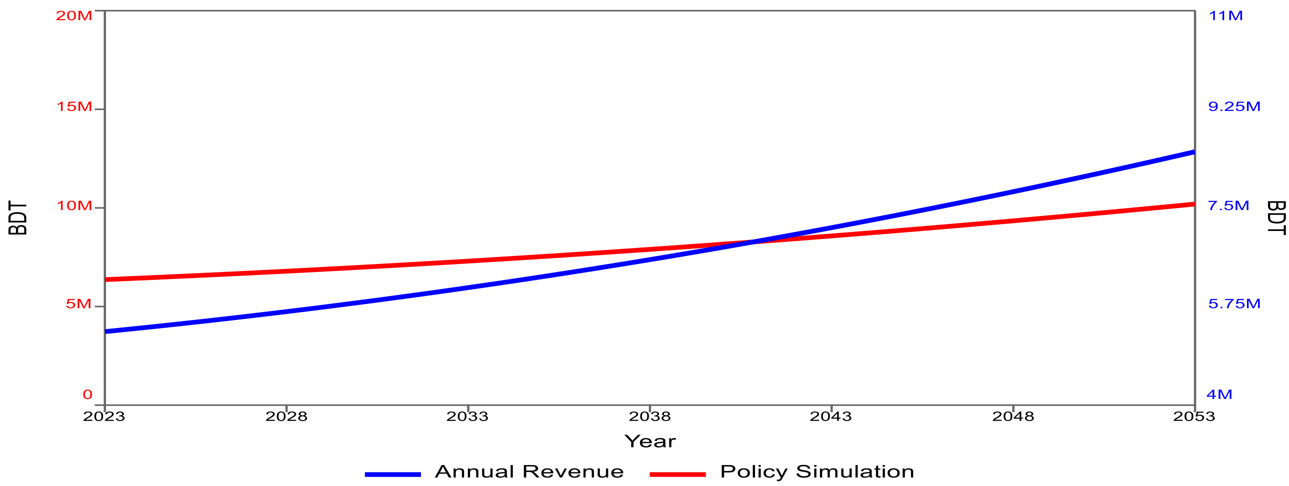

Figure 8: Comparison of Annual Revenue and Policy Simulation in SD

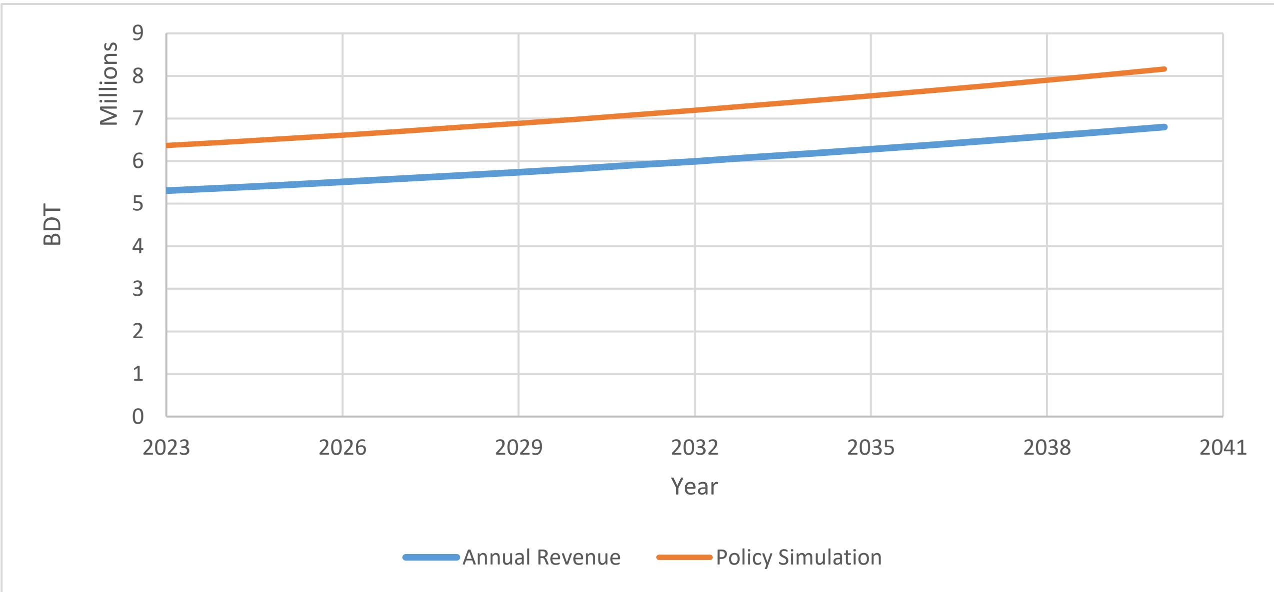

Figure 9: Comparison of Annual Revenue and Policy Simulation in ANFIS

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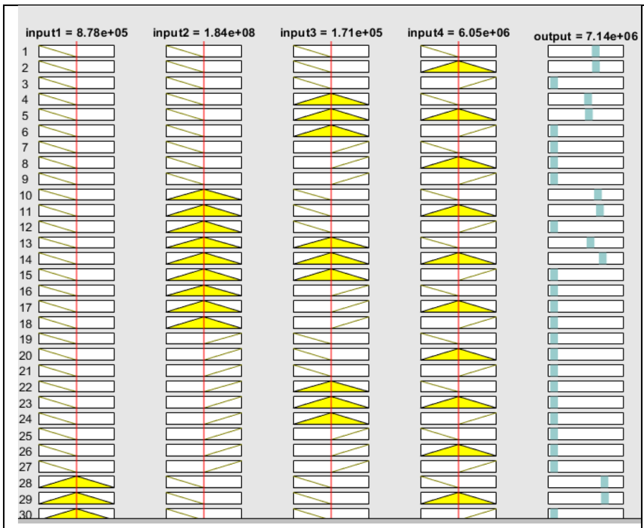

Figure: Rule Viewer of Membership Functions

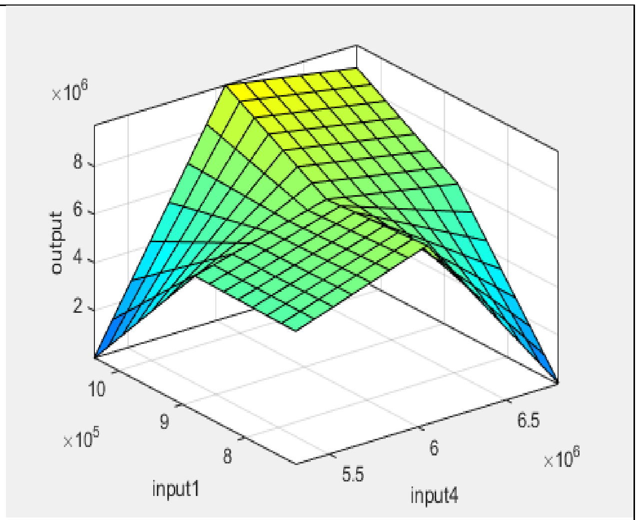

Figure: Response Surface for input variables

Figure 10: Rule viewer and response surface generated in ANFIS

3.5 Comparative Analysis between SD and ANFIS:

Both of the system yields generation data which have minor differences. This scenario validates the simulation outcome positively.

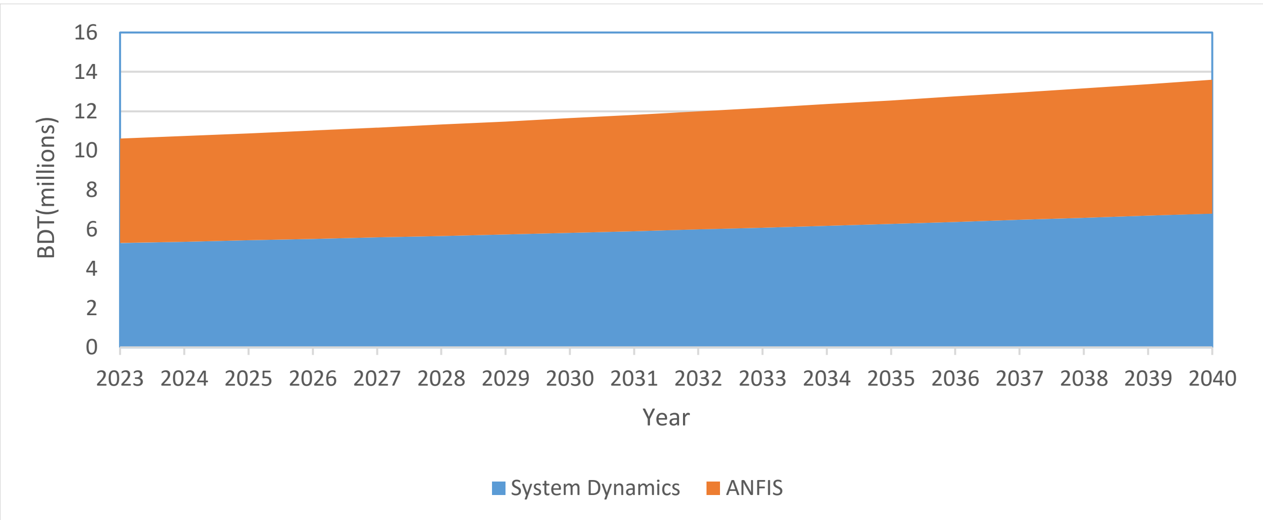

Figure 11: Comparative Analysis between SD and ANFIS

3.6 Sensitivity Analysis:

Sensitivity analysis using system dynamics is a technique that can be used to evaluate the potential impact of different factors on Municipal Solid Waste (MSW) management. This technique can be used to identify key drivers of the waste management system, and to evaluate the potential impact of changes in these drivers on the overall performance of the system. The system dynamics approach necessitates the construction of a mathematical model of the MSW management system, which can incorporate variables such as population growth, waste generation, collection and disposal infrastructure, and recycling and recovery practices. The model can then be used to simulate the system over time and assess the impact of potential changes in key drivers on the system's performance. One of the primary benefits of employing system dynamics for sensitivity analysis is that it enables a comprehensive examination of the waste management system and can help to identify potential improvement areas. In addition, this method can be used to investigate the potential effects of various policy options and to assess the trade-offs between various alternatives. However, one of the limitations of sensitivity analysis using system dynamics is that it can be time-consuming and complex to develop the model and perform the analysis. In addition, the model may be unable to capture all the complexities of the real-world system and may not accurately represent the system's actual behavior.

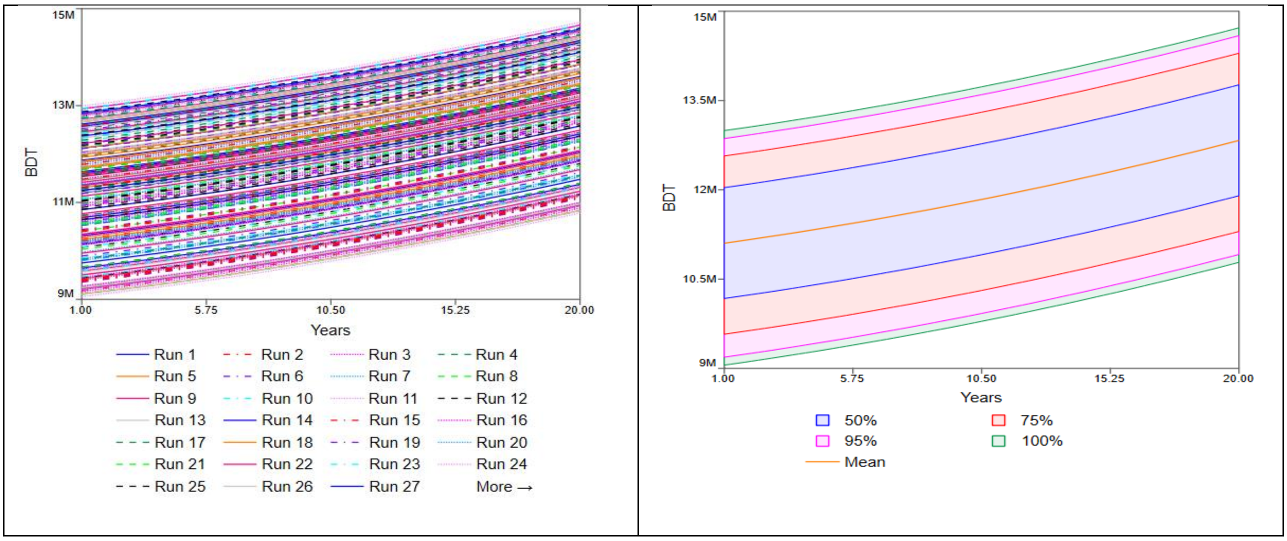

Figure 12: Sensitivity Analysis run of 250 nos. to produce confidence interval for waste recyclable model for the next 20 years

From figure 12, the sensitivity analysis after alteration of five parameters Birth Rate, Flotation, Natural Disaster, Decomposition Index and Annual Revenue is simulated through 250 runs. Due to high volume of data it is difficult to distinguish data so, from confidence interval graph, it is clearly seen that 50% of the data is within the range of 10M-12M. Furthermore, from histogram analysis the standard deviation is 1.14M which is less than the interquartile range 1.86M, which validated the analysis.

3.7 Limitation and challenges and viability of the policies:

In many regions of the country, there are insufficient waste collection and disposal facilities, resulting in inadequate management of municipal solid waste. The government and municipalities frequently lack the funds necessary to properly manage and dispose of municipal solid waste, resulting in insufficient services. Many people in Bangladesh are unaware of the significance of proper waste management and disposal and do not participate in efforts to properly manage municipal solid waste (MSW). In Bangladesh, there are few regulations governing the management and disposal of municipal solid waste, making it difficult to enforce proper waste management practices. Rapid urbanization in Bangladesh has resulted in unplanned and uncoordinated growth, which has contributed to an increase in the amount of waste produced. Inadequate waste management is the result of a lack of appropriate technology for the collection, transportation, and disposal of municipal solid waste. The recycling process is hazardous to health due to the presence of numerous biohazard situation that are harmful to health and consequently cause significant health issues. Therefore, the majority of individuals are not keen to participate actively in this endeavor.

4. Conclusions:

This research has demonstrated the utility of incorporating sensitivity analysis using system dynamics into Separation and Recycling of Municipal Solid Waste (MSW) management. The findings of this study indicate that this methodology can be a useful tool for identifying key waste management system drivers and assessing the potential impact of changes in these drivers on the system's overall performance. The study depicts that population growth, waste generation, and infrastructure for waste collection and disposal are key drivers of the waste management system. It also indicates that recycling and recovery practices can play a substantial role in reducing the amount of waste sent to landfills and enhancing the overall performance of the waste recycling model. The study also illuminated the trade-offs between various policy options and demonstrated that there is no one-size-fits-all approach to MSW management. System Dynamics Model (SDM) and Adaptive Neuro-Fuzzy Inference System (ANFIS) possess distinct advantages and are utilized differently. The SDM is a computer simulation tool that permits the analysis of complex interactions between various system components over time. It can also help identify the feedback loops that drive the system's behavior. ANFIS, on the other hand, is a combination of a fuzzy logic system and an artificial neural network, allowing it to adapt to new data and improve its predictions over time. However, SDM is more useful for understanding the long-term effects of different policies and programs and identifying the system's feedback loops, whereas ANFIS is more useful for predicting future behavior and optimizing the system's parameters.

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