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Original Research

Exploring Policy Interactions: A System Dynamics Study on Sustainable Household Waste Management in Rural Municipality

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ABSTRACT

This study explores household waste management challenges in Argao, a first-class rural municipality in Cebu, Philippines, through a System Dynamics (SD) modeling approach. The research evaluates four policy scenarios: banning household waste burning, implementing household recycling and composting, establishing a municipal recycling center, and a combined scenario integrating all three interventions. Results reveal that while banning waste burning significantly curbs carbon emissions, it redirects waste to landfills, stressing limited disposal capacity. Recycling and composting policies achieve a 20% improvement in waste recovery, reduce landfill dependency by nearly 9%, and cut carbon emissions by a similar margin, while generating household income that grows by more than 400% over a decade. The creation of a municipal recycling center offers the most transformative impact, increasing waste recovery by over 30%, lowering landfill reliance by nearly 14%, and creating close to 10,000 local jobs. When integrated, the combined scenario yields the highest overall benefit, delivering the largest net present value (₱15.9M) and providing a sustainable pathway for compliance with Republic Act 9003. These findings underscore that an integrated, phased approach starting with household-level interventions and

scaling up to infrastructure investment can significantly enhance Argao's waste diversion efforts, improve environmental outcomes, and generate meaningful economic opportunities for the community.

INTRODUCTION

Household waste management in the Philippines is characterized by significant challenges brought about by rapid urbanization, population growth, and poor infrastructure. The country generates approximately 41,000 tons of waste daily, with Metro Manila alone contributing over 9,670 tons (Agaton et al., 2020). This escalating waste generation is projected to increase by approximately 165% by 2025, leading to severe implications for waste management systems, including overcrowded landfills and environmental degradation (Coracero et al., 2021). The Philippine government has enacted the Ecological Solid Waste Management Act (Republic Act 9003) to address these issues, mandating local government units (LGUs) to implement effective waste management strategies (Atienza, 2020; Treyes et al., 2023). However, implementing these policies has faced numerous obstacles, including inadequate personnel training and limited resources at the local level (Camarillo and Bellotindos, 2021; Macusi et al., 2019). This situation is strengthened by rural municipalities, which usually generate a different composition of waste, with a substantial portion being organic, mainly due to agricultural activities and household consumption patterns, which present challenges and opportunities for composting and resource recovery initiatives (Baquero et al., 2022). The lack of public awareness and education regarding waste segregation and disposal practices further aggravates the issue, as households often lack the necessary knowledge to manage effectively (Handayani et al., 2018; Mihai, 2017; Treyes et al., 2023; Viljoen et al., 2021). This inadequacy leads to improper disposal practices, such as open dumping and burning, which pose serious environmental and public health risks. Burning household waste significantly harms the environment by releasing harmful pollutants and greenhouse gases. When waste is burned, it generates a variety of toxic emissions, including particulate matter, volatile organic compounds (VOCs), and heavy metals, which can severely degrade air quality and pose health risks to nearby populations (Florin-Constantin, 2019; Reyna-Bensusan et al., 2018; Waleed Makki et al., 2023). This highlights the potential for waste reduction through composting and recycling initiatives, which minimize landfill contributions and provide economic benefits by creating valuable compost and recycled products (Husna et al., 2023). Furthermore, the economic implications of waste management policies are significant; for instance, the costs associated with waste disposal can be mitigated through effective recycling and waste separation practices, which have been shown to reduce the overall volume of waste sent to landfills (Ogiri et al., 2019). Social factors also play a critical role in the effectiveness of waste management policies. Public awareness and education regarding the impacts of waste generation are essential for fostering responsible waste disposal behaviors among households (Institute of Environment and Development (LESTARI), National University of Malaysia (UKM), Bangi 43600, Selangor D.E, Malaysia et al., 2016). Programs aimed at increasing knowledge about the environmental consequences of food waste, for example, can lead to behavioral changes that significantly reduce waste generation (Chengqin et al., 2024). Studies have shown that education and awareness regarding waste management significantly influence community participation in waste reduction and recycling initiatives (Janmaimool and Denpaiboon, 2016). Research indicates that residents in Kinshasa are willing to pay for improved waste management services, suggesting that economic incentives could enhance participation in sustainable practices (Decka Kanyambu Makanga and Jacques Muhigwa Zahiga, 2023).

The environmental impacts of household waste policies cannot be overlooked. Poor waste management practices contribute to soil and water pollution and public health risks associated with waste mismanagement (Datta, 2022; Vongdala et al., 2018). Effective waste management strategies prioritizing environmental sustainability are crucial for mitigating these adverse effects. For instance, waste separation at the source has been shown to enhance the quality of recyclable materials and reduce the health risks associated with landfill odors and emissions (Al-Rumaihi et al., 2020). Similarly, the 3R principle (Reduce, Reuse, Recycle) has been proposed as a viable approach to mitigate waste generation at the household level, emphasizing the need for community education and engagement (Ridayati and Yunastiawan, 2021). The effectiveness of such initiatives is often contingent upon local government support and the establishment of efficient waste collection systems (Shelepina, 2023; Yukalang et al., 2018). Moreover, recycling is a collective effort, from the product designer to the trash thrower, the waste collector, and the recycling factory worker (Ibrahim Bilici, 2022). The urgency of addressing household waste management in Argao, Cebu, a 1st class municipality in the Philippines, stems from two interrelated concerns. First, the municipality faces the rapid depletion of landfill capacity vis-à-vis the continuous accumulation of household waste, a trend documented in Philippine studies showing that landfill reliance leads to long-term risks of groundwater contamination, methane emissions, and land scarcity (Coracero et al., 2021; Datta, 2022). Without effective diversion strategies, increasing landfill dependency threatens both environmental quality and public health. Second, strict compliance requirements under Republic Act 9003 (Ecological Solid Waste Management Act of 2000) place additional legal and financial pressure on local government units. RA 9003 mandates segregation, recycling, and waste diversion, and failure to comply may result in penalties, sanctions, or reduced funding allocations (Atienza, 2020; Treyes et al., 2023). These dual pressures namely environmental risk and legal obligation, make the development and implementation of sustainable waste management strategies not only necessary but urgent.

1.1 Locale of the Study

Argao, as the locale of the study, is a 1st class municipality in the province of Cebu, the Philippines, as shown in Fig. 1.

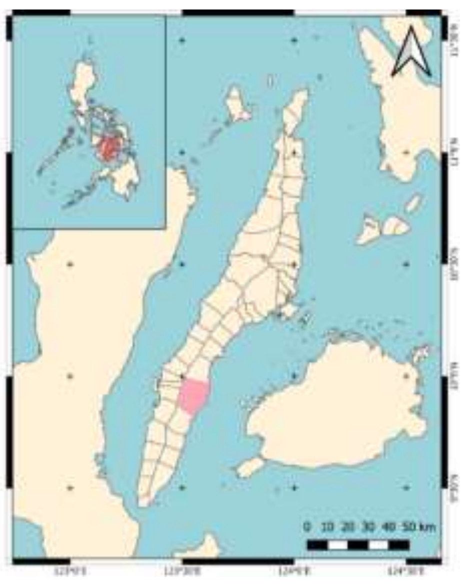

Fig. 1: Locale of the Study

Argao, according to the 2020 census, has a population of 78,187 and a household number of 16,574. It is located in the southeastern portion of Cebu province, approximately 68 kilometers from Cebu City. In 2015, the municipality was ordered to close its open dumpsite – the only disposal option currently adopted. Thus, the LGU planned to open a sanitary landfill in 2016. However, these projects remain unachieved since the existing disposal site is still not constructed as per sanitary landfill infrastructure standards. The municipality's solid waste management (SWM) ordinance requires each barangay to implement SWM programs strictly and educate its constituents on waste segregation to reduce garbage collected and brought to the landfill. Despite this, it has not produced a satisfactory result as expected. With plans to construct an additional landfill site, it is the primary concern for the local government to identify new approaches that can support their decision-making to start and adopt a sustainable way of managing the municipality's waste problems.

1.2 Household Waste Management (HWM) Program and Policy Description.

Household waste management in the Philippines is guided by Republic Act 9003, yet implementation varies widely across municipalities. The policy scenarios analyzed in this study are grounded in programs already adopted elsewhere and tested for their applicability to Argao's local conditions. The ban on household waste burning reflects regulatory efforts in other towns to address air pollution and public health risks. Composting and recycling programs mirror practices in rural and agricultural municipalities where organic waste dominates, providing both environmental and economic benefits. The municipal recycling center scenario draws from examples where infrastructure investment has enabled large-scale diversion of recyclables and job creation. These approaches were narrowed down to four scenarios—burn ban, recycling and composting, recycling center, and a combined option because they represent a practical progression from regulation, to community-based participation, to infrastructure-driven solutions. Together, they provide a holistic set of alternatives aligned with environmental sustainability, economic opportunity, and compliance with RA 9003. The aims of each policy scenarios used in the study are the following.

Scenario 1: Ban on Household Waste Burning (Burned Waste Policy). This policy aims to protect public health, reduce pollution, and promote sustainable waste management by prohibiting the burning of household waste. This policy applies to all residents and covers all waste types. Open burning releases harmful pollutants that cause respiratory illnesses, environmental degradation, and climate change (Reyna-Bensusan et al., 2018). This policy aims to lessen undesirable carbon emissions.

Scenario 2: Recycling and composting policy. This policy promotes sustainable waste management by requiring households to segregate, collect, and dispose of recyclable and compostable materials. Recyclable scrap, including plastics, metals (tin cans), and paper, must be sorted, sold, or delivered to authorized recycling centers. In contrast, compostable waste, such as food scraps and yard debris, should be processed through home composting systems. Local authorities will provide designated bins, collection schedules, and educational programs to ensure compliance. This policy aims to reduce landfill waste, conserve resources, and promote environmental sustainability through responsible waste disposal practices. In this scenario, household waste burning is not restricted. Further, this policy seeks to provide information on household revenue from recycled and composted wastes.

Scenario 3: Municipal Recycling Policy (Creation of Recycling Center). LGU establishes a dedicated facility for processing recyclable waste to promote environmental sustainability and reduce landfill dependency. The center will collect, sort, and process all plastic waste materials and convert them into shredded recyclables as boiler fuel for factories utilizing fuels for burning and kiln drying. Local authorities will oversee operations, hire manpower, provide public education, and encourage community participation. Residents must properly segregate waste for collection or direct drop-off. In this policy, household waste burning is not restricted. This policy aims to enhance waste management efficiency, lower carbon emissions, and support a circular economy. Further, this policy aims to generate employment opportunities in the community.

Scenario 4: All scenarios combined. All three scenarios (burned waste policy, recycling and composting policy, and municipal recycling policy) are combined in this scenario. This policy aims to assess the effects on waste management efficiency when all policy switches are turned on.

1.3 System Dynamics Modeling

System dynamics is a modeling technique that aims to gain insight into complex systems and their development over time (Saysel et al., 2002). The use of the system dynamics approach requires systems thinking. It effectively evaluates solid waste management's sustainability (Giannis et al., 2017; Rahayu et al., 2013; Saysel et al., 2002). This method has been applied to different waste minimization management conditions. For instance, system dynamics were used to study Singapore's solid waste management system to explore whether the current waste disposal capacity can increase waste generation (Sloan School Of Management, 2024). The system dynamics model was used to evaluate various diverse policies and strategies the public and other stakeholders made.

Similarly, several studies used the systems dynamics approach to determine the impact of waste reduction on the amount of waste accumulated in landfills in Bandung City, Indonesia (Saysel et al., 2002). Thus, in many studies, the system dynamics approach is used to comprehensively understand the complexity of solid waste problems precisely by designing a model framework that can systematically craft the optimal recommendation that would be beneficial to the different stakeholders and government officials in their decision-making in establishing strategic plans towards a sustainable SWM. A comprehensive system dynamics model was used to evaluate the current and develop new policies. Therefore, it has been a powerful tool for addressing structural and dynamic complexity related to waste management since SD accounts for feedback, accumulations, delays, and non-linearity within a system (Escalante, 2013). Additionally, system dynamics represent decision-making in complex systems (Rahayu et al., 2013) and help policymakers see solid waste management's holistic views. The latter can recognize and understand the variables linked together in the model to achieve waste reduction (Zulkipli et al., 2018).

Sustainable MSWM is complex and challenging. Appreciating the various policies and their effects may provide a holistic picture of achieving efficient and effective SWM. Hence, this paper aims to evaluate the performance of the municipality's proposed SWM policies, particularly in reducing waste generation and waste disposed of in landfills using Systems Dynamics (SD). This study focuses on developing alternative scenarios that the municipality can adapt and integrate into attaining a sustainable SWM.

2. MATERIALS AND METHODS

To provide a clearer flow of analysis, this study adopts a research design framework anchored on the system dynamics (SD) approach. The framework was developed to ensure that the discussion proceeds in a logical sequence, moving from the identification of the local waste management challenges in Argao to the formulation and assessment of policy interventions. Each step of the framework reflects the methodological rigor needed to capture the complex interactions between waste generation, policy measures, and community participation.

Fig. 2: Research Design Framework

Fig. 2. illustrates the stepwise flow of the study, beginning with contextualization of Argao's waste management challenges and compliance requirements under RA 9003. Policy scenarios drawn from programs tested in other municipalities were formulated and simulated using a System Dynamics approach. The model results were validated through error analysis and assessed across environmental, economic, social, and legal indicators. This structured design guided the integration of findings into policy implications for sustainable household waste management.

2.1 Model Development

A system's dynamics (SD) model has been constructed in a system boundary by creating variables classified as stocks, flows and auxiliary variables. The causal loop signifies the cause-and-effect relationship of the variables. The descriptions in the loop denote parameters in the system, while arrows signify associations of parameters (Barton et al., 2008).

2.2 Model Formulation

This study utilizes Vensim and Stella to formulate and simulate household wastes (Forrester, 1997; Sterman, 2002). Vensim is used to develop the causal loop diagram (CLD) that identifies the specific variables and determines their effects on the other variable by specifying its polarity. It has either a positive or a negative polarity that shows the influence of one variable on another. After establishing CLD, it is transformed into a stock and flow diagram to simulate and project household waste in the next ten years. A positive loop or self-reinforcing loop (R) happens when an equal number of the same polarity arrow links exist. A negative loop or self-correcting loop (B) occurs when there is an unequal number of the same polarity arrows. Fig. 3 and 4 demonstrate this study's causal loop and stock and flow diagrams.

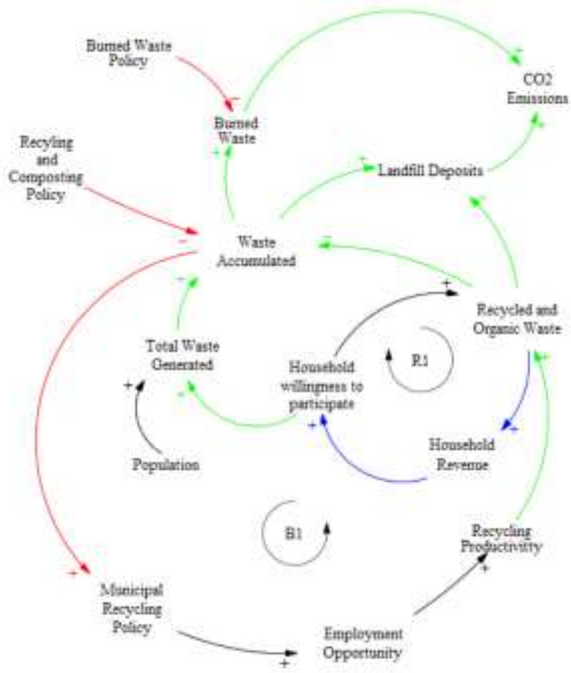

Fig. 3: Causal Loop Diagram

The feedback loops in black represent the system's social aspect, which comprises the population, the employment opportunity, and the recycling productivity. The green color represents the environmental aspect of the system, which represents the effect of the composting and recycling policy and the burned waste policy on landfill deposits and CO2 emissions. The red color represents the political aspect in which policies are introduced in the system. The blue color represents the economic aspect that drives motivations and incentives.

The Causal Loop Diagram (CLD) illustrates the interactions between household waste generation, waste management policies, and economic incentives. It highlights the impact of recycling and composting policies, burned waste policies, and municipal recycling efforts on waste accumulation and disposal. The diagram contains a balancing loop (B1) and a reinforcing loop (R1), which regulate the system's behavior. The balancing loop (B1) operates through municipal policies that encourage waste diversion into recycling and composting, reducing waste accumulation over time. As household willingness to participate increases, more waste is processed into recycled and organic waste, minimizing landfill deposits and emissions. Meanwhile, the reinforcing loop (R1) focuses on the economic benefits of recycling, where households generate revenue from composting and recycling. This financial incentive further increases participation, increasing recycling productivity and employment opportunities and reinforcing the system's growth. Additionally, the burned waste policy is critical in limiting CO_2 emissions but may result in higher waste accumulation if recycling policies are not effectively implemented. This CLD highlights how policy interventions, economic incentives, and public participation shape an efficient waste management system. A well-implemented recycling and composting policy can significantly reduce waste accumulation, lower environmental impact, and enhance economic opportunities. However, without strong enforcement and household engagement, the system risks continued landfill dependency and environmental degradation.

The Stock and Flow Diagram (SFD) comprehensively presents the Causal Loop Diagram (CLD). It outlines the variables and their relationships with one another and explores the system's behavior to test policy scenarios' effect on the system's structure. Thus, in SFD, variables are identified and considered stocks, flows, or converters. Stocks represent accumulations of data whose value at any given time depends on the system's past behavior. These are affected by whatever flows enter in and out of them. Flows illustrate how the stock changes at a given time as they fill in or sewer the buildups. Converters are system parts whose values can be derived from other parts at any given time. It can hold coefficient values, calculate numerous mathematical equations, and collect graphical functions. Broadly, converters alter inputs into outputs.

The Stock and Flow Diagram (SFD) presented in Fig. 4 was developed once the elements, their interrelationships, and mathematical equations were established.

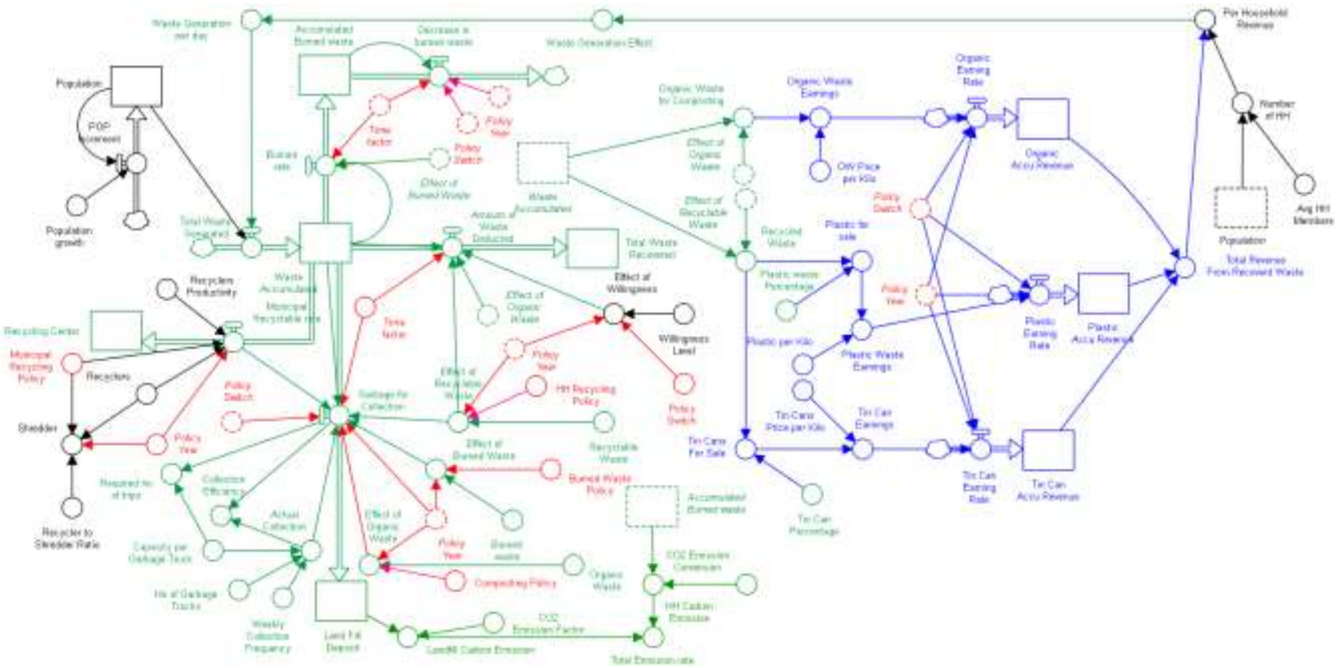

Fig. 4: Stock and Flow Diagram

The model illustrates the intricate relationships between population growth, waste generation, environmental impact, and the effects of various waste management policies. The economic, ecological, and social aspects and waste policies were incorporated into the model. Table 1 presents all the model elements in the SD model, such as element type, element name, mathematical equations and the corresponding units.

Table 1: Elements in the SD Model of the household waste management system in a rural Philippine setting

Element Type	Element Name	Equations Generated from Stella v.10.0.6	Unit
Stock	Accumulated Burned Waste (ABW)	ABW(t - dt) + (Burned__rate - Decrease_in__burned_waste) * dt	kg per month, million
Flow	Burned Rate	Waste Accumulated*Effect of Burned Waste/Time factor	-
Flow	Decrease in burned waste	(IF(Policy Switch=1)OR(TIME=Policy Year)THEN(ABW/Time factor)ELSE(0))	kg per month, million
Stock	Volume of Landfill Deposit	Land Fill Deposit(t - dt) + (Garbage for Collection) * dt	kg per month, million
Flow	Volume of Garbage for Collection	if(Policy Switch=1)and (Time factor>Policy Year)then(Actual Collection-Municipal Recyclable rate)ELSE ((1-(Effect of Recyclable Waste+Effect of Burned Waste+Effect of Organic Waste))*Waste Accumulated/Time factor))	kg per month, million
Stock	Organic Waste Accumulated Revenue	Organic Accumulated Revenue(t - dt) + (Organic Earning Rate) * dt	PHP per month, in million
Flow	Organic Waste Earning Rate	if(Policy Switch=1)and(TIME>Policy Year)then(Organic Waste Earnings)ELSE(0)	-
Stock	Plastic Waste Accumulated Revenue	Plastic Accumulated Revenue(t - dt) + (Plastic Earning Rate) * dt	PHP per month, hundreds
Flow	Plastic Waste Earning Rate	if(Policy Switch=1)and(TIME>Policy Year)then(Plastic Waste Earnings)ELSE(0)	-
Stock	Population	Population(t - dt) + (Population Increment) * dt	Persons per year, thousands
Flow	Population Increment	Population*Population growth	Persons per year, thousands
Auxiliary	Population Growth rate	Population growth = 0.0164	Percentage, per year
Stock	Number of Recycling Center	Recycling Center(t - dt) + (Municipal Recyclable rate) * dt	unit
Flow	Municipal Recyclable Rate	If (Municipal Recycling Policy=1)AND(TIME>Policy Year)THEN (Recyclers*Recyclers Productivity)ELSE(0)	-
Stock	Tin Can Accumulated Revenue	Tin Can Accumulated Revenue(t - dt) + (Tin Can Earning Rate) * dt	PHP per month, million
Flow	Tin Can Earning Rate	if(Policy Switch=1)and(time>Policy Year)then(Tin Can Earnings)else(0)	PHP per month, thousands
Stock	Total Waste Recovered	Total Waste Recovered(t - dt) + (Amount of Waste Deducted) * dt	kg per month, million
Flow	Amount of Waste Recovered	Waste Accumulated*(Effect of Recyclable Waste+Effect of Organic Waste)*(1+Effect of Willingness)/Time factor	kg per month, million
Stock	Waste Accumulated	Waste Accumulated(t - dt) + (Total Waste Generated - Amount of Waste Deducted - Garbage for Collection - Burned rate - Municipal Recyclable rate) * dt	kg per month, million
Auxiliary	Total Waste Generated	Waste Generation per day*Population	kg per month, thousands
Auxiliary	Actual Garbage Collection	Capacity per Garbage Truck*No. of Garbage Trucks*Weekly Collection Frequency	kg per day, thousands
Auxiliary	Collection Efficiency	Actual Collection/Garbage for Collection	Percentage, per month
Auxiliary	Effect of Burned Waste Policy	if(Burned Waste Policy=1)and (time >Policy Year)then(Burned waste/100)else(.428)	Percentage, per month
Auxiliary	Effect of Recycling Policy	IF(HH Recycling Policy=1)and(time>Policy Year)THEN(Recyclable Waste/100)ELSE(.0616)	Percentage, per month
Auxiliary	Effect of Composting Policy	IF(Composting Policy=1)and (time >Policy Year)THEN(Organic Waste/100)ELSE(.117)	Percentage, per month
Auxiliary	Effect of Willingness	IF(Policy Switch=1)AND(TIME>Policy Year)THEN(Willingness Level)ELSE(.40)	Percentage, per month
Auxiliary	Volume of Household Carbon Emission	ABW*CO2 Emission Conversion	kg CO2/kg waste
Auxiliary	Volume of Landfill Carbon Emission	LandFill Deposit*CO2 Emission_Factor	kg CO2/kg waste
Auxiliary	Number of Households	Number__of_HH = Population/Avg_HH_Members	
Auxiliary	Organic Waste Earning	Organic Waste for Composting*Organic Waste Price per_Kilo	PHP per month, thousands
Auxiliary	Organic Waste for Composting	Effect of Organic Waste*Waste Accumulated	Percentage per month
Auxiliary	Household Revenue	Total Revenue From Recoverd Waste/Number of HH	PHP per month, thousands
Auxiliary	Volume of Plastic For Sale	Recycled Waste*Plastic waste Percentage	kg per month, thousands
Auxiliary	Revenue of Plastic Waste	Plastic for sale*Plastic per Kilo	PHP per month, thousands
Auxiliary	Recycled Waste	Waste Accumulated*Effect of Recyclable Waste	Percentage, per month
Auxiliary	Required Number of Trips	Garbage for Collection/Capacity per Garbage Truck	frequency (times), per week
Auxiliary	Number of Shredder	if(Municipal Recycling Policy=1)and(time>Policy Year)then (round(Recyclers/Recycler to Shredder Ratio))else(0)	units
Auxiliary	Volume of Tin Cans for Sale	Recycled Waste*Tin Can Percentage	kg, in thousands
Auxiliary	Revenue of Tin Can	Tin Cans For Sale*Tin Cans Price per Kilo	PHP per month, thousands
Auxiliary	Total CO2 Emission	Landfill Carbon Emission+HH Carbon Emission	kg CO2/kg waste
Auxiliary	Total Revenue from Recovered Waste	Tin Can Accumulated Revenue+Organic Accumulated Revenue+Plastic Accumulated Revenue	PHP per month, millions
Auxiliary	Policy effect on waste	IF(Per Household Revenue=0)THEN(1)ELSE(ABS(0.5-(1/(1-Per Household Revenue))))	-
Auxiliary	Generated Waste Per Day	{IF(Waste Generation Effect=0)THEN(1)ELSE(ABS(0.218*Waste Generation Effect))}	kg, per day

Given the equation in the model, the total waste generated is multiplied by the population. As the population increases, daily waste generation rises, leading to higher waste accumulation. Without proper intervention, waste is either burned, increasing the burning rate, or dumped into landfills, contributing to increased CO2 emissions and environmental degradation.

By integrating sustainable waste management policies with economic incentives, the model presents a sustainable approach to addressing waste generation while fostering environmental sustainability and economic growth.

2.3. Model Validation

This section discusses the structural and behavioral validation of the proposed SD model. An extreme condition test was conducted on the population to test the validity by setting it to extremely low and extremely high values. Fig. 5 shows the simulated result of structural validity on the status quo, extremely low, and extremely high population tests. Population growth is a primary driver for municipal solid waste (MSW) generation. Household waste likewise increased due to an extremely high population in the pink line. The household increase generally results in higher waste output, as each residential unit contributes to overall waste production (Manea et al., 2024). Subjected similarly to a very low population in the red line, the waste generation also decreases. Given the model's behavior when subjected to an extreme-value test, the robustness of the model is validated.

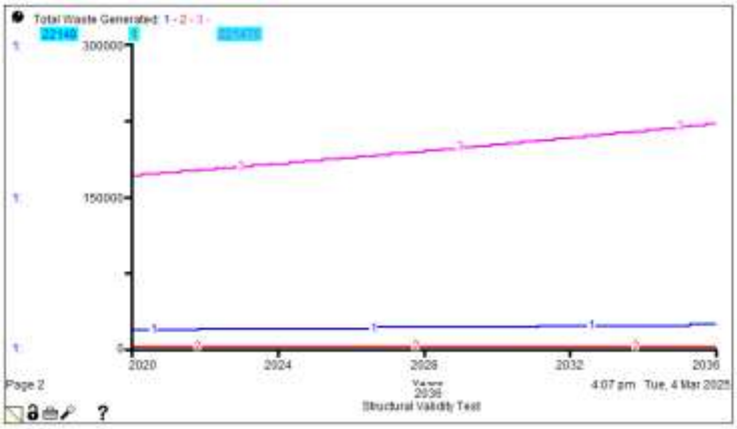

Fig. 5: Structural Validity Test Result

The simulated behavior of the model is compared to the behavior observed in the historical data. To make this comparison, statistical methods are employed, specifically error analysis. In this case, the Mean Absolute Percentage Error (MAPE), as shown in equation (1), is utilized to evaluate the model's performance.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Actual_i - Model_i}{Actual_i}\right| x\,100 \quad (1)$$

Historical data on household waste generated from 2020 to 2024 were statistically compared with the model forecast, and the mean absolute percentage error was calculated, as shown in Table 2.

Table 2: Mean Absolute Percentage Error (MAPE)

Year	Historical Waste Data	Forecasted Waste Data	Average Percentage Error
2020	17,044.00	17,045.00	0.01
2021	17,368.00	17,335.49	0.19
2022	17,698.00	17,622.13	0.43
2023	19,027.67	17,913.52	5.86
2024	19,389.23	18,209.72	6.08
MAPE			**2.51**

The MAPE of 2.51 forecasted household waste generation values is, on average, only 2.51% different from the actual recorded values. It connotes that the model is highly accurate in predicting future household waste values.

The five-year historical dataset (2020–2024) was sufficient to generate highly accurate forecasts of household waste, as reflected in a MAPE of 2.51 %, which falls well below the 10 % threshold for strong forecasting performance (Montaño Moreno et al., 2013). Household waste trends are primarily shaped by recent demographic, behavioral, and policy changes, making long-term historical data less relevant for predictive modeling (Fan et al., 2021; Solano Meza et al., 2019). Since the five-year horizon captures both gradual growth and short-term fluctuations, it provides a balanced foundation for reliable projections and actionable waste management planning. This insight suggests that five years of appropriately segmented data should yield sufficient information for reliable predictions of waste generation dynamics (Ahmed et al., 2022).

3. RESULTS AND DISCUSSION

3.1 Status Quo

This section discusses the present state, simulating the household waste management system without policy intervention. Fig. 6 illustrates the trends in municipal household waste management under the status quo scenario from 2020 to 2036. The four key variables shown are total waste generated, accumulated burned waste, landfill deposits, and total emissions rate. The current per capita amount of household waste is 0.218 kg, which is attributed to the population's annual growth rate of 1.65%. Of the total waste generated, only 6.16% are recycled or sold, and 11.7% are composted at the household level. Most of the waste is burned at 42.8%.

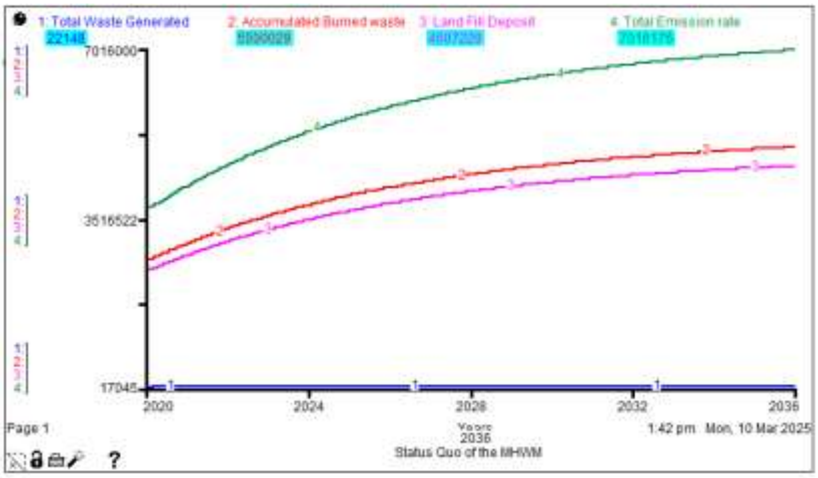

Fig. 6: Status Quo of the Municipal Household Waste Management

As shown, the total waste generated represented in the blue line remains nearly constant at a very low level, from 17,045 kg in 2020 to 22,148 kg in 2036, an increase of 29.94% in a span of 10 years, indicating that waste production is not increasing significantly over time. However, accumulated burned waste in the red line increased by 87.65% by 2036, and landfill deposits in the pink line steadily increased by 88.12% by 2036, suggesting that a substantial portion of household waste is either burned or sent to landfills. The continued rise in burned waste contributes to an increase in total emissions, which reflects the environmental impact of waste combustion, particularly in terms of air pollution and carbon emissions.

Further, landfill deposits exhibit a consistent upward trend, from 2,449,151 kg in 2020 to 4,607,229 kg in 2036, an increase of 88.11%, indicating that waste disposal relies heavily on landfills. This trend suggests potential long-term challenges, such as land depletion, groundwater contamination, and increased methane emissions from landfill decomposition. The growing landfill deposits also highlight the lack of efficient recycling, composting, or waste reduction policies.

The total emission rate follows a similar course with the accumulated burned waste and landfill deposits, signifying that waste management practices under the current system contribute to environmental degradation. The increasing emissions of 88% from 3,731,927 kg CO_2/kg waste in 2020 to 7,016,176 kg CO_2 in 2036 indicate the urgent need for policy interventions, such as stricter waste segregation, enhanced recycling and composting programs, and stricter burning regulations.

Municipal household waste management will continue to have a significant environmental impact without intervention, leading to rising emissions, excessive landfill use, and sustained waste burning. Sustainable waste management policies would mitigate these long-term ecological consequences, such as composting, recycling, and limiting landfill reliance.

3.2 Ban on Household Waste Burning (Burned Waste Policy)

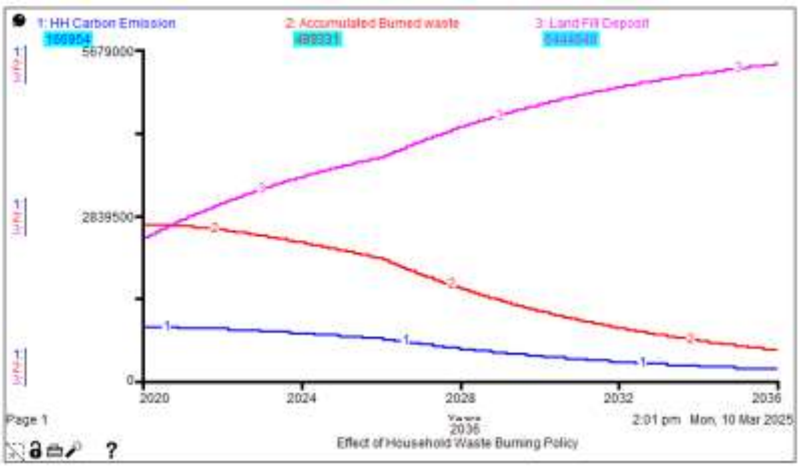

Fig. 7: Effect of Ban on Household Waste Burning

Fig. 7 illustrates the impact of banning household waste burning on three key variables: landfill deposits, accumulated burned waste, and household carbon emissions from 2020 to 2036.

With the prohibition of household waste burning, the accumulated burned waste shows a sharp and continuous decline of around 81.26% over time, from 2,664,557 kg in 2020 to 499,331 kg in 2036. This indicates the efficacy of the policy at the household level, significantly reducing the total amount of waste burned. Consequently, household carbon emissions, which are directly linked to waste burning, decreased steadily by 81.26% throughout the period from 890,911 kg CO_2/ kg waste in 2020 to 166,954 kg CO_2/ kg waste by 2036. Proportionally translates that whatever decrease in the volume of accumulated burned waste, the same decrease in household carbon emission. This reduction in emissions highlights the environmental benefit of the policy, as it helps mitigate air pollution and greenhouse gas emissions associated with waste combustion.

The pink line represents landfill deposits, which show a continuous upward trend. This increase indicates that with the ban on waste burning, more waste is being redirected to landfills instead of being burned in backyards or homes. The rise in landfill deposits suggests an added burden on landfill sites, highlighting the need for alternative waste management strategies such as recycling or composting.

3.3 Recycling and composting policy

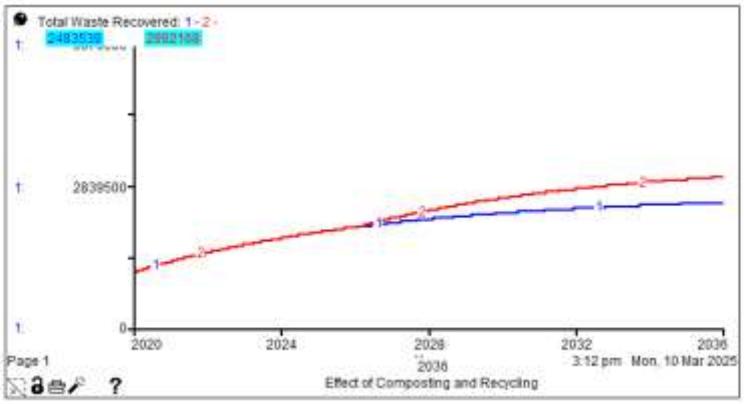

Fig. 8a: Effect on Total Waste Recovered

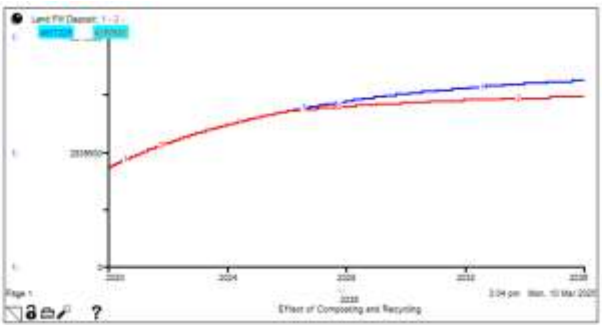

Fig. 8b: Effect in Landfill Deposit

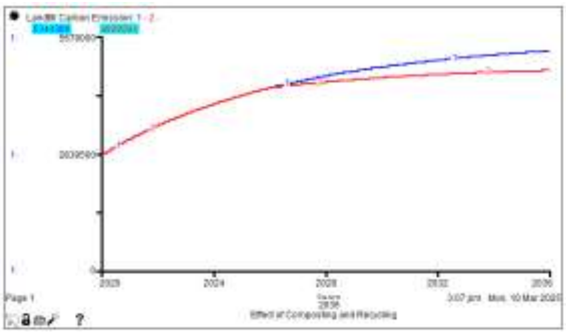

Fig. 8c: Effect on Landfill Carbon Emissions

Fig. 8: Effect of Recycling and Composting Policy

Fig. 8 illustrates the impact of a composting and recycling policy on household waste management, focusing on total waste recovered, landfill deposits, and landfill carbon emissions from 2020 to 2036.

Fig. 8a shows the total waste recovered, where two scenarios are compared: the status quo (blue line) and the effect of the policy implementation (red line). Implementing composting and recycling policies leads to a higher waste recovery over time than the status quo at 20.48%. This indicates that waste diversion efforts are improving, reducing waste disposed of through traditional landfill methods.

Fig. 8b shows the landfill deposit trends. Without intervention, landfill deposits increase at a higher rate (blue line) at 4,607,229 kg by 2036. In contrast, with composting and recycling policies in place (red line), the accumulation of landfill waste grows slower at 4,197,641 kg, a slight decrease of 8.89% in the span of 10 years. This suggests that a portion of the waste that would have gone to landfills is now being diverted through recycling and composting, thereby reducing the strain on landfill capacity as evidenced in the other studies (Farhat et al., 2023).

Fig. 8c presents landfill carbon emissions, which are directly linked to the volume of waste dumped in the landfill. The scenario with the composting and recycling policy (red line) results in lower emissions at 4,869,264 kg CO_2/kg waste compared to the status quo (blue line) at 5,344,386 kg CO_2/kg waste, a decrease of 8.89% as well. This is because when composted instead of landfilled, organic waste produces significantly less methane, a potent greenhouse gas(Pansuk et al., 2018). The decline in emissions highlights the environmental benefits of composting and recycling in reducing the carbon footprint of household waste management.

Simulation results demonstrate that implementing composting and recycling policies leads to higher waste recovery, slower landfill growth, and reduced carbon emissions. These outcomes suggest that waste diversion strategies effectively mitigate environmental impacts and improve waste management sustainability.

Moreover, Fig. 9 illustrates the total revenue generated by households from recycling and composting organic waste, plastic, and tin cans over time.

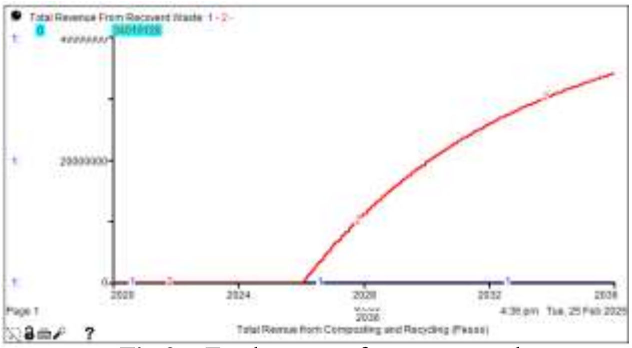

Fig.9a: Total revenue from recovered waste

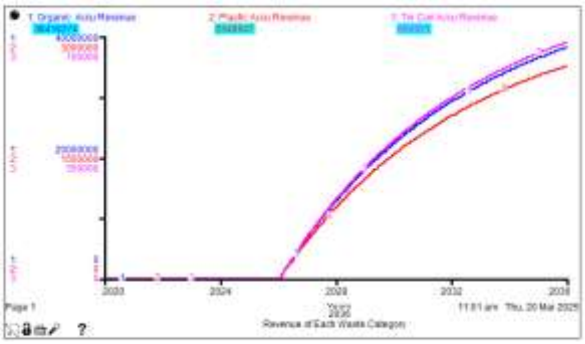

Fig.9b: Revenue from each waste

Fig. 9: Total Revenue of Composting and Recycling Policy

Fig. 9a presents the total revenue of recovered wastes, showing a huge increase of 91.97% from 2,731,356 pesos in the implementation year 2026 to 34,019,128 pesos in the year 2036. Fig. 9b shows the individual revenue households can get from each waste. From 2020 to 2025, no revenue was generated, suggesting the phase before households fully adopt recycling and composting practices. However, after this period, in 2026, revenue from all three waste categories begins to rise steadily, indicating increased participation and efficiency in waste recovery. A steeper growth revenue increase of 496.26% among the three waste categories is shown. Composting (organic waste) in the blue line generates the highest income at 31,511,034 pesos every month by 2036, from 5,284,764.14 in the year 2026 compared to plastic waste and tin cans revenue. Plastic waste revenue, represented by the red line, also increases from 334,019.11 pesos in the year 2026 to 1,991,629 pesos in the year 2036 but remains lower than organic waste, implying that recycling is beneficial and not as financially rewarding as composting. Recycling tin cans, depicted by the pink line, shows the lowest revenue accumulation, although it follows a similar upward trend of earning 86,617.28 pesos in 2026 to 516,466 pesos in 2036. This highlights that implementing recycling and composting policies produces tangible economic benefits for households. The delayed revenue increase suggests that time is required for awareness, infrastructure, and participation to develop. Therefore, adopting sustainable waste management practices, such as composting and recycling, is environmentally beneficial and a viable financial opportunity for households, with composting emerging as the most profitable approach.

Additionally, Fig. 10 shows each household's income from implementing the composting and recycling policy.

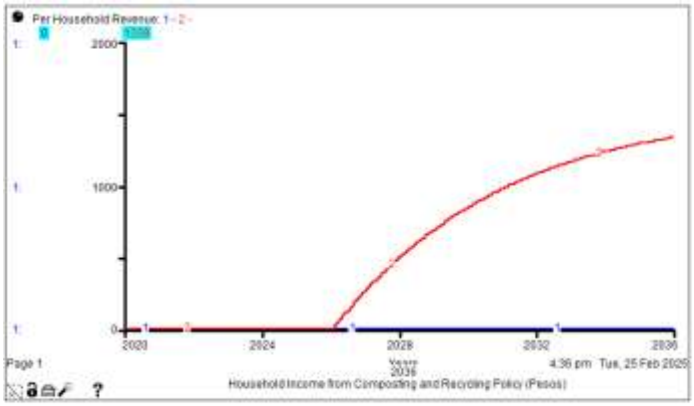

Fig. 10: Household Income

In the beginning year of 2026, households can earn 260.50 pesos in almost a month, increasing to 1,339 pesos per month by 2036, an increase of 414%. Effective management of household waste presents multiple avenues for augmenting household income, primarily through recycling and composting initiatives that generate marketable products(Handayani et al., 2018; Jalalipour et al., 2025; Yukalang et al., 2018).

3.4 Municipal Recycling Policy (Creation of Recycling Center)

Fig. 11 presents the system's behavior when establishing the municipal recycling center.

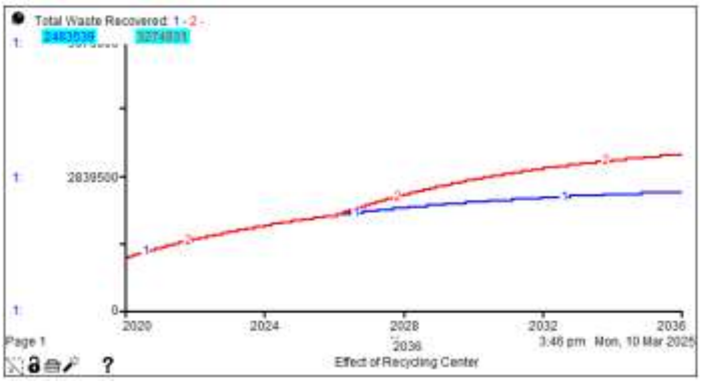

Fig.11a: Effect on Total Waste Recovered

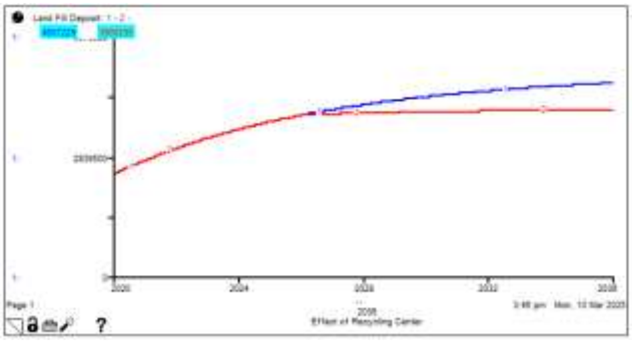

Fig. 11b: Effect on Landfill Deposit

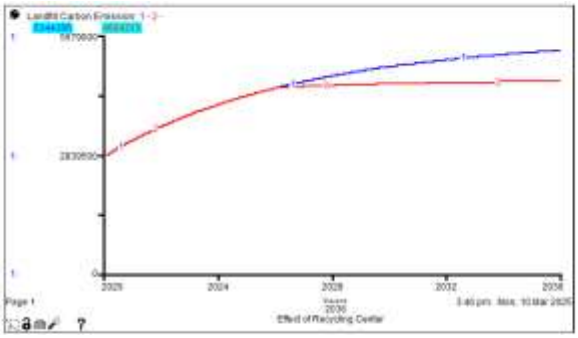

Fig. 11c: Effect on Landfill Carbon Emission

Fig.11: Effects of Municipal Recycling Policy

Results showed a similar trend to the composting and recycling policy alone. A slightly more significant volume of waste was recovered compared to the composting and recycling policy alone. With the policy implemented, waste recovered increases to 31.86% by 2036 compared to 20.48% for household recycling and composting alone. The same is true of landfill deposits and their carbon emissions, which decrease by 13.85% by 2036 compared to the 8.89% decrease solely by household recycling and composting. The main difference between the composting and recycling policy and the creation of a recycling center is the social impact on employment opportunities when this policy is implemented.

Fig. 12shows the employment opportunities that can be provided to the community by establishing a recycling facility.

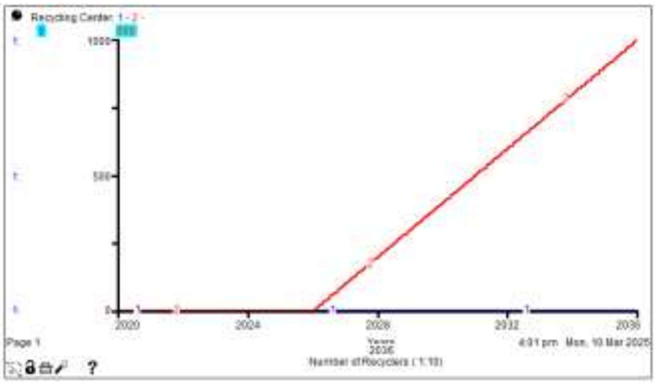

Fig. 12: Number of Recyclers in the Recycling Center

The volume of waste recovered for recycling and composting is at 3,274,931 kg. as reflected in Fig. 11a. Based on the simulated result as shown in Fig. 12, creating a recycling center with a ratio of one shredder to ten recyclers or laborers (1:10), can create employment of as many as 9,999 employees in the next ten years. The ability of recycling centers to stimulate local economies through job creation is also emphasized by the recommendation to expand recycling infrastructure, which enhances waste management practices and creates employment (Hall et al., 2024). This aligns with findings from Thailand, where community-led recycling initiatives have effectively created job opportunities, especially in economically disadvantaged areas, by establishing buy-back centers(Yukalang et al., 2018).

Fig. 13a and 13b further show the revenue households can get from each waste type. It can be seen that households can get as much as Php 1,643 pesos per month from recycling and composting with the recycling center in the community. It can serve as significant sources of revenue for households, particularly through strategies such as participation in local recycling programs, composting initiatives, and direct sales of collected recyclables. These avenues not only encourage sustainable practices but also provide tangible economic benefits to families. This highlights the financial gains from optimized waste practices that benefits the household (Practice and Attitude on Household Waste Management in Tumpat and Kuala Krai, Kelantan, 2018) (Iqbal et al., 2022).

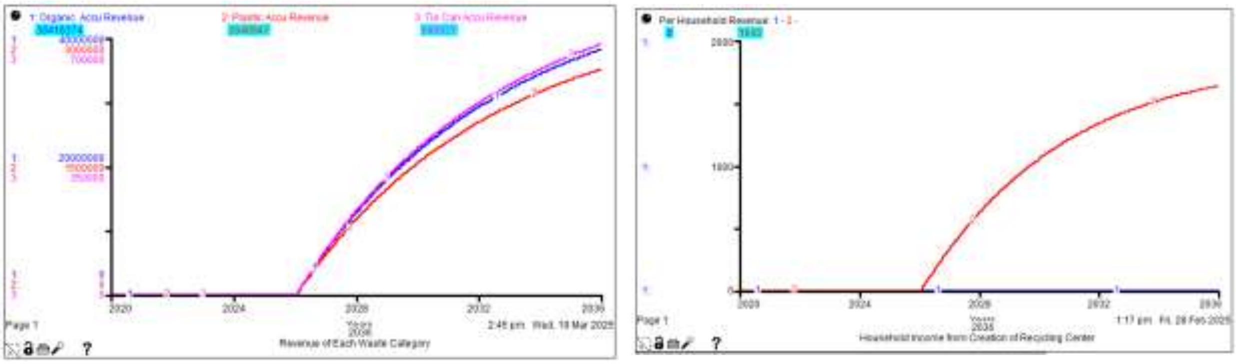

Fig.13a: Revenue of Waste per Type

Fig. 13b: Household Income

Fig. 13: Economic Incentive

3.5 All Scenarios

This scenario shows the combination of all policies' social, economic, and environmental implications. Fig. 14a shows its effect on the volume of waste deposited in the landfill, the volume of accumulated burned waste, and the total carbon emission rate. Compared with other policy combinations, this scenario emits more carbon than recycling and composting and the creation of recycling centers. This could be attributed to the fact that as more waste is being collected with the ban on burning waste being in force, more waste is dumped in landfills, contributing to an increased emission rate, as shown in Fig. 14b and 14c. Research indicates that high rates of organic material disposal in landfills lead to substantial GHG emissions, which threaten environmental quality and food security (Hall et al., 2024). Estimates suggest that landfills are among the largest sources of methane in many regions, underscoring the critical need for effective waste management practices (Reyna-Bensusan et al., 2018). Moreover, vast amounts of organic matter dumped in landfills contribute to greenhouse gas emissions, exacerbating global warming (Dalmora et al., 2023).

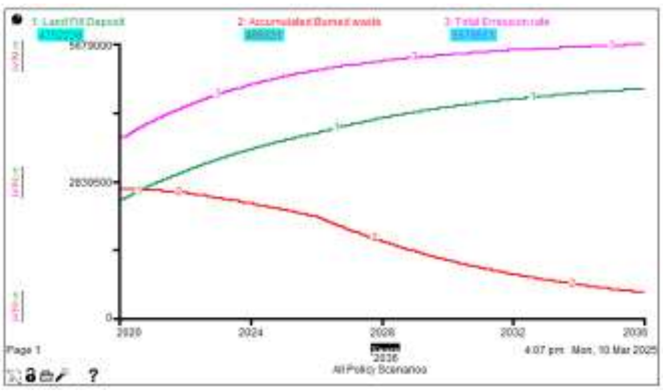

Fig.14a: Effect on Landfill Deposit, Accumulated Burned Waste and Total Emission rate

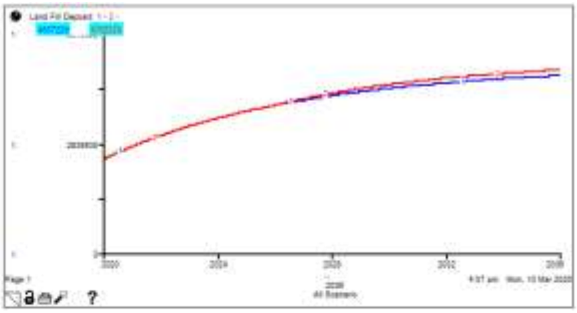

Fig. 14b: Effect on Landfill Deposit

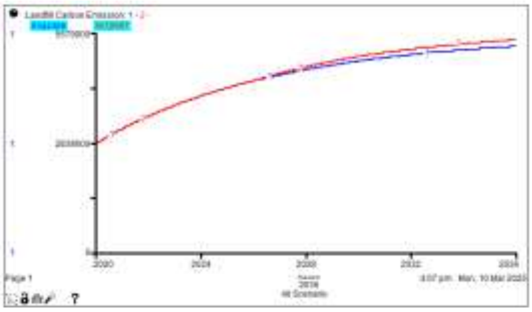

Fig.14c: Effect on Landfill Carbon Emission

Fig. 14: Effect of All Policy Scenarios on Waste

3.6 Scenario Analysis

This section summarizes the financial and policy implications of four household waste management scenarios modeled for the Municipality of Argao. The analysis integrates capital and operating requirements, revenues, and savings from landfill diversion over a 10-year horizon. Net Present Value (NPV) and Internal Rate of Return (IRR) were estimated at a social discount rate of 8%, a real discount rate appraisal for public investment in the Philippines (NEDA ICC Philippines, 2021). Using a social discount rate is appropriate for waste management projects because their benefits go beyond direct revenues. They also include reduced environmental impact, better public health, and compliance with Republic Act 9003. Choosing 8% helps give proper value to these long-term benefits and avoids undervaluing projects that have strong social and environmental impacts. The costing estimates are likewise anchored on recent studies and reports on solid waste management infrastructure and program expenditures in the Philippines and Asia (*Asian Development Bank Annual Report 2021*, 2022); (Department of Environment and Natural Resources, 2022); (Iqbal et al., 2022); (Hall et al., 2024). As shown in Table 3a is the 10-year projected values of each policy scenarios. Table 3b presents the ranking of the policy scenarios.

Table 3a. 10-year Projected Values

Scenario	By Year 2036 Projected Values						
	Waste Accumulated (kg)	Total Emission (kg CO2/kg waste)	Total Revenue (Php)	Employment (people)	NPV (PhP, 10 yrs @8%)	IRR (%)	Annual Net Benefit (PhP)
Status Quo	5,000,028.86	7,016,176.28	0	0	n/a	n/a	n/a
Scenario 1: Ban on Waste Burning	499,330.90	6,482,737.20	24,769,002.05	0	-1,168,549.25	0.00	-150,000.00
Scenari0 2: Recycling and Composting	858,421.10	5,133,705.04	35,914,079.32	0	3,771,131.05	69.60	700,000.00
Scenario 3: Creation of Recycling Center	858,303.72	5,133,572.70	35,905,618.55	9,990	13,185,799.75	38.50	3,000,000.00
Scenario 4: All Scenarios	499,330.90	5,942,627.64	35,905,618.55	9,990	15,903,545.99	35.70	3,750,000.00

Table 3b. Ranking of Policy Scenario

Scenario	Ranking (Rating Scale: 1-5)							
	Waste Accumulated	Total Emission	Employment	NPV	IRR	Annual Net Benefit	Total Rating	Rank
Status Quo	1	1	4	0	0	0	6	4
Scenario 1: Ban on Waste Burning	2	2	4	2	2	2	14	3
Scenari0 2: Recycling and Composting	3	4	4	3	5	3	22	2
Scenario 3: Creation of Recycling Center	4	5	5	4	4	4	26	1

The results of the scenario analysis provide a clear basis for selecting the most effective waste management policy for the Municipality of Argao. Among the alternatives, maintaining the status quo is not a viable option, as it leads to unmanageable waste accumulation, high greenhouse gas emissions, and foregone economic opportunities. Similarly, implementing a ban on household waste burning alone may yield environmental benefits and a relatively low investment requirement with initial costs estimated at only Php 100,000 to Php 250,000 to fund the IEC campaigns and enforcement mechanisms (Department of Environment and Natural Resources, 2022), but the financial assessment shows a negative net present value and annual losses, which makes it unsustainable in the long run as a standalone measure.

Recycling and composting stand out as a practical starting point. With a modest investment requirement of about Php 500.000 and Php 1.5 million for bins, household training, and logistics, this scenario offers substantial reductions in waste volume and carbon emissions while delivering positive economic returns. The high internal rate of return (69.6%) demonstrates that small-scale interventions can be both environmentally sound and financially rewarding (Husna et al., 2023; Manea et al., 2024). Despite these costs, they show strong positive returns, with NPVs exceeding Php 5 million over ten years, driven by household participation and compost/recyclable sales. This makes household-level recycling and composting a strong entry strategy, especially for resource-constrained municipalities.

However, the creation of a municipal recycling center emerges as the most strategic single intervention. Despite requiring higher capital outlays ranging from Php 5 million to Php 10 million , this scenario generates the largest employment impact, supports compliance with Republic Act 9003, and produces an impressive net present value of ₱13.2 million (*Asian Development Bank Annual Report 2021*, 2022; Iqbal et al., 2022). The facility not only diverts a significant portion of waste from the landfill but also establishes a sustainable revenue stream from recovered materials, providing long-term resilience for local waste management systems (Hall et al., 2024).

When considered collectively, the combined scenario demands an investment of Php 7-12 million, integrating both community and infrastructure programs (Hall et al., 2024). This integrates a ban on burning, household recycling and composting, and a recycling center—achieves the highest overall rating. It maximizes waste diversion, reduces emissions, and secures both economic and social benefits. With a projected NPV of ₱15.9 million and nearly 10,000 jobs generated, this integrated strategy although more resource-intensive, it offers the most comprehensive pathway to sustainability producing both environmental and economic gains (World Bank (Washington, District of Columbia), 2019).

4. CONCLUSIONS

The scenario analysis highlights the urgent need for a stronger and more effective waste management strategy for the Municipality of Argao. Continuing with the status quo is not a viable path forward, as it would certainly result in growing waste volumes, increased greenhouse gas emissions, and missed economic opportunities for the community. Likewise, a sole focus on banning household waste burning, while environmentally beneficial, is financially unsustainable given its negative net present value and recurring annual losses.

Among the policy alternatives, household recycling and composting emerge as a practical and affordable first step. With relatively low investment requirements, this approach can significantly reduce both waste volume and carbon emissions while generating positive financial returns. The impressive internal rate of return (69.6%) indicates that even small-scale, community-based interventions can produce meaningful environmental gains and measurable economic value. This makes it an ideal entry point for municipalities with limited resources seeking to enhance compliance with national waste management policies.

The establishment of a municipal recycling center stands out as the most impactful single measure. Although it demands greater capital investment, this option yields the highest employment generation, strengthens compliance with Republic Act 9003, and delivers a robust net present value. More importantly, it ensures the long-term stability of waste management system by creating a steady revenue stream from recovered materials and diverting a substantial share of waste away from the landfill.

When implemented as a comprehensive package, the combined scenario—which merges a ban on burning, household recycling and composting, and the construction of a municipal recycling center, achieves the highest overall performance. This integrated approach maximizes waste diversion, lowers emissions, and creates both economic and social value for the community.

In view of these findings, it is recommended that Argao adopt a phased implementation strategy: begin with household recycling and composting to engage the community and deliver quick, visible results, then scale up by investing in a municipal recycling center. This progressive approach ensures alignment with national policy goals, mitigates environmental risks, and produces sustained economic benefits for the municipality. Further, the LGUs must allocate sufficient funding, build proper infrastructure, and encourage community participation to ensure its success. Economic incentives should also be integrated into waste reduction efforts, as the study highlights that households can generate revenue from recycling and composting. LGUs should establish buy-back programs for recyclables, offer tax incentives for waste-conscious households, and support businesses using recycled materials to enhance economic viability.

Despite the study's valuable insights, several limitations are considered. One limitation is its geographical scope, as the research focuses solely on the rural municipality of Argao, Cebu, Philippines. This may limit the universality of the findings to other regions with different socio-economic and environmental conditions. The study also does not fully account for the contributions of informal waste pickers and recyclers, who play a significant role in waste recovery in developing countries. Further exploration of their economic impact is necessary. Likewise, the policy implementation challenges remain a concern, as the study does not fully address the political, financial, and bureaucratic barriers that may hinder the practical execution of these policies at the local government level.

In conclusion, the study underscores the importance of implementing robust waste management policies prioritizing recycling and composting, supported by community engagement and economic incentives. By adopting such strategies, rural municipalities like Argao can achieve sustainable waste management, reduce environmental impact, and enhance economic and social well-being. Future research should also address the limitations of this study and explore more comprehensive, context-specific waste management models to improve policy effectiveness and ensure sustainable household waste management in rural municipalities.

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