School of Computing and Information Systems

IS 602 Spreadsheets Modelling for Decision Making

Recycling Rate Analysis for Singapore

Project Report (Group 2)

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Introduction

As of 2022, the overall recycling rate for Singapore was marked at around 57% [Reference: https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling]. While this is an impressive number, it is not enough. The Singaporean government has been ambitious as well as efficient in its waste management strategies. The government's strategy also included reducing the amount of waste sent to landfills. In 2022, approximately 40% of waste was sent for incineration and energy recovery, while the rest was landfilled [References: https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling]

The National Environment Agency (NEA) has also implemented the Net Zero Waste Masterplan, which is a comprehensive strategy that aims to reduce waste and increase recycling rates. The plan sets out various targets and initiatives to achieve a sustainable and zero-waste future.

One of the key targets outlined in the Zero Waste Masterplan is to achieve a recycling rate of 70% in Singapore by the year 2030. This is a significant increase from the recycling rate of around 57% in 2022.

In our data-driven analysis, we will attempt to investigate the trends in recycling rates and the % of waste recycled amongst other variables. This will be done on a category level such as plastic, food, paper etc. to understand the past and current recycling and waste numbers as well as the areas where a revamp of waste management strategies is required.

We will be creating an influence diagram to establish a model which conveys the overall recycling rate, and all the decisions and parameters impacting it. We will also perform the trade-off and sensitivity analysis to understand the impact of controllable and uncontrollable parameters on achieving the desired 70% recycling rate in Singapore by 2030.

Data Sources

Data Source Link	Data File	Variable	Description
https://www.towardszerowaste.gov.sg/resources/statistics/	• 2003-2016 Waste and Recycling Statistics • 2017-2020 Waste and Recycling Statistics • 2021 Waste Management and Overall Recycling Measures • 2022 Waste Management and Overall Recycling Measures	Waste type	Describes the waste category such as Food, Plastic etc.
		Waste Generated	It is the total waste generated in tons for the specific category
		Waste Recycled	It is total quantity of waste recycled in tons
		Recycling Rate	The recycling rate is the percentage of waste recycled for the categories

(DOS) | SingStat Table Builder – Indicators On Population	Indicators On Population, Annual	Total population	It contains the number of people living in Singapore for the particular year
https://tablebuilder.singstat.gov.sg/table/TS/M550001	International Visitor Arrivals by Inbound Tourism Markets, Monthly	International Visitor Arrivals by Inbound Tourism Markets	It contains the number of people visiting Singapore for tourism
https://www.mse.gov.sg/resource-room/category/2020-10-05-parliament-q-&-a-on-exports-of-recyclables/	Recyclable Exports Data	Total Recyclables Exported (tonnes)	It contains the Recyclable Exports market data in Metric Tonnes
https://tablebuilder.singstat.gov.sg/table/TS/M130591	NEA's Budget Data	Budget (Million SGD)	It contains the Budget allocated by NEA for Sustainability and the Environment
https://www.mse.gov.sg/files/resources/key-environmental-statistics-2023.pdf https://www.mse.gov.sg/files/resources/Key-Environmental-Statistics-2022.pdf https://www.mse.gov.sg/files/resources/Key-Environmental-Statistics-2021-Publication.pdf	Incineration Energy Data	Energy Produced	It contains the Energy produced from Incineration in MWh

Analyses & Computations

1. Estimates for Decision Input Variables

We have three decision input variables in our Model- Population of Singapore, Incoming tourists in Singapore and NEA Budget**.** We have used the Forecast Function in Excel to estimate all three variable calculations for years 2024 to 2030.

Decision Variable	Years Available	Years Forecasted	Reference In Workbook
Singapore Population	2001-2023	2024-2030	*2. Decisions & Parameters*
Incoming Tourists	2001-2023	2024-2030	
NEA's Budget	2008-2022	2023-2030	

2. Estimates for Parameters Input Variables:

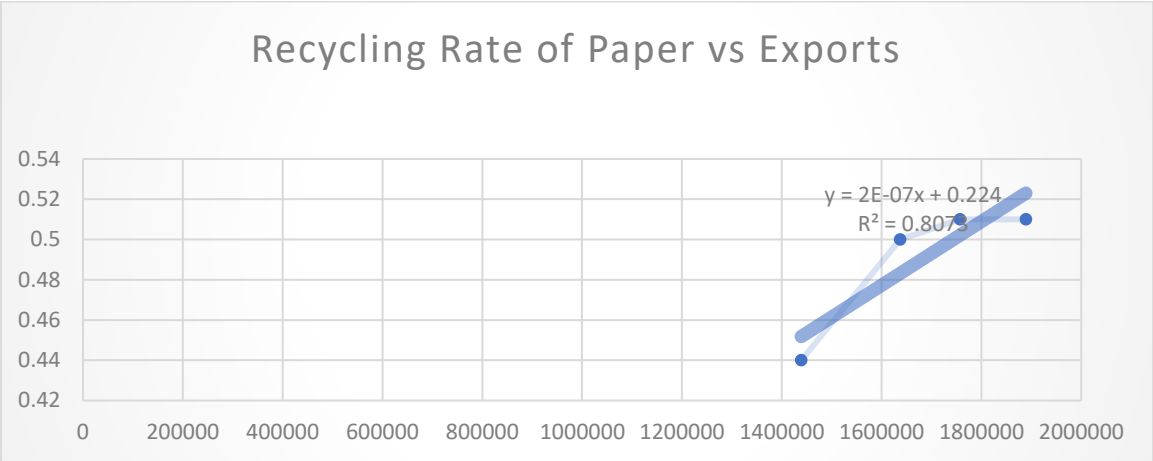
We have considered Recyclables Export Market as an uncontrollable input variable in our model. The Data was available from 2015- 2019, and we estimated the Market Exports for the years 2020 to 2030 using Forecast Function in Excel. (Please refer *2. Decisions & Parameters* In Modelling Worksheet for details)

3. Intermediate Calculations for Consequence Variables:

3.1 Calculations of Recycling Rate of Paper

Recycling Rate for Paper and Export Market (tonnes) data was available for the Years 2015-2019. We observed a linear trend between Recycling rate of Paper and Exports as shown in Fig below. This trend was represented by the equation:

$$y = 2e - 07x + 0.2240$$



Assuming this linear rate of increase, we estimated the recycling rates for Paper from 2020-2030. (Please refer *3. Consequence Variables* in Modelling Worksheet for details)

3.2 Calculations of Recycling Rate of Food

Recycling Rate for Food and NEA's Budget (Million SGD) data was available for the Years 2008-2022. We also had determined the Budget for years 2022-2023 using the Forecast function (Section 1). Since, we are dealing with Budget Allocation data, we assumed that it would take at-least 3 years to utilise the budget and possibly improve the Recycling Rate of Food. With this assumption we obtained the summary statistics below for Budget over 3 timeframes (Current Year, Year-1 and Year-2).

We then used these statistics along with previously estimated NEA Budget data to calculate the Recycling Rate for Food. (Please refer *3. Consequence Variables* in Modelling Worksheet for details)

	Coefficients
Intercept	0.091837003
Budget (Current Year- - Million SGD)	1.99623E-05
Budget (Year-1)	3.12689E-05
Budget (Year-2)	3.76581E-05

4. Intermediate Calculations for Secondary Performance Variables:

4.1 Estimates for Waste Generated across Categories

Forecast Function in Excel to estimate all three variable calculations for years 2024 to 2030. In our model, we have considered Population of Singapore and Incoming tourists to be a major contributor to waste generated across categories. To validate our assumption, we obtained the statistics summary for Population and Tourists across categories. To standardize the scales, we first converted Population and Tourists into Population_Normalized and Tourists_Normalized values respectively using the Standardize function in Excel. For the categories- Food, Plastic, Metal and other, we obtained p-values < 0.05 and were able to use the statistics obtained for estimating the waste generated from years 2023-2030.

ANOVA-Food					ANOVA-Metal				
	df	*SS*	*MS*	*F*		*df*	*SS*	*MS*	*F*
Regression	2	1.846E+11	9.23E+10	35.9486065	Regression	2	1.16374E+12	5.8187E+11	21.8134556
Residual	17	43648384910	2567552054		Residual	17	4.5347E+11	2.6675E+10	
Total	19	2.28248E+11			Total	19	1.61721E+12		
	Coefficients	*Standard Error*	*t Stat*	*P-value*		*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	745350.612	13940.77009	53.4655264	2.1936E-20	Intercept	1394214.09	44934.21131	31.0278973	2.0804E-16
Tourists Normalized Value	4339.39435	15246.69448	0.28461214	0.77937922	Tourists Normalized Value	92055.0635	49143.4969	1.87318912	0.07834117
Population Normalized Value	125268.664	16107.01115	7.77727554	5.3494E-07	Population Normalized Value	270110.619	51916.48939	5.20279052	7.1849E-05

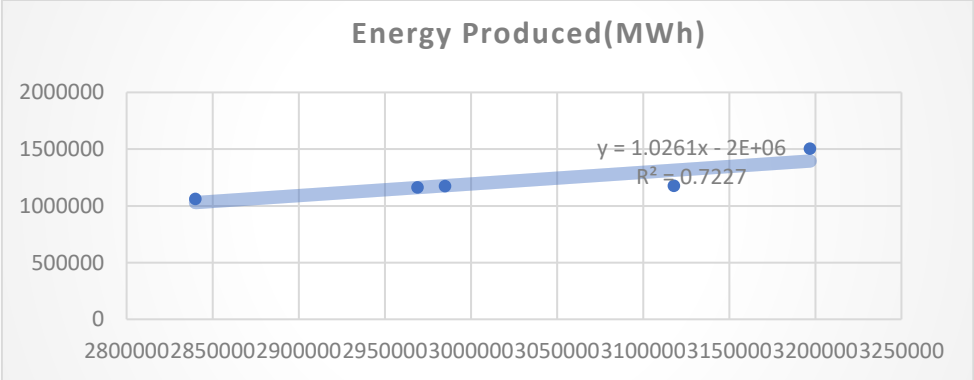
ANOVA-Plastic					ANOVA-Others				
	df	*SS*	*MS*	*F*		*df*	*SS*	*MS*	*F*
Regression	2	2.15223E+11	1.0761E+11	31.1103597	Regression	2	6.78947E+12	3.3947E+12	70.6935424
Residual	17	58803491192	3459028894		Residual	17	8.16348E+11	4.802E+10	
Total	19	2.74027E+11			Total	19	7.60582E+12		
	Coefficients	*Standard Error*	*t Stat*	*P-value*		*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	845382.706	16180.95802	52.2455287	3.2404E-20	Intercept	3137906.41	60289.31072	52.0474754	3.4552E-20
Tourists Normalized Value	-31162.218	17696.73568	-1.76090204	0.09623073	Tourists Normalized Value	338587.522	65937.01032	5.13501477	8.2692E-05
Population Normalized Value	145789.482	18695.29944	7.79818922	5.1594E-07	Population Normalized Value	563405.582	69657.60095	8.08821398	3.1427E-07

For Paper, we used discrete data resampling of the historic data for waste generated from paper (2003-2023 data) to estimate waste generated from paper for years 2024-2030 (Please refer to *4. Secondary Perf Variables* in Modelling Worksheet for details)

4.2 Calculation for Energy Produced from Incineration

The data for Energy produced from Incineration (MWh) and Non-recycled waste was available for the years 2018-2022. We observed a linear trend between the Energy produced and non-recycled waste as shown in Fig below. This trend was represented by the equation:

$$y = 1.0261x - 2e + 06$$



Assuming this linear rate of increase, we estimated the recycling rates for Paper from 2023-2030. (Please refer *4. Secondary Perf Variables* in Modelling Worksheet for details)

5. Computation of Performance Variable:

5.1 Overall Recycling Rate

The primary performance variable in our dataset is the Overall recycling rate. This is calculated as Ratio of Overall Waste Recycled/ Overall Waste generated. In our dataset, we have categorized source of waste generated into 5 broad categories- Food, Plastic, Paper, Metal and Others (Scrap, Construction & Demolition etc.). We estimated the waste generated (outlined in section 4 above) and Recycling Rates across categories (outlined in section 3 above) for years 2023-2030. For Metals, since the Recycling rate is 99%, we assumed it would remain the same till 2030 as there is minimal scope of improvement in the recycling rate.

Using the recycling rates and waste generated, we calculated the waste recycled first by categories and then subsequently, on an overall level to obtain the Overall Recycling Rate. (Please refer *5.As-is Analysis- Perf Variable* in Modelling Worksheet for details). Using this model, we determined that Overall Recycling Rate of Singapore is expected to be 58% by year 2030.

5.2 Improvement Opportunities for Overall Recycling Rate

From our Analysis in Section 5.1, we were able to determine that overall recycling rate in Singapore will be 58% by 2030. This is nowhere near the target of 70% as set by National Environmental Agency in its Zero-waste Masterplan. (Reference- https://www.towardszerowaste.gov.sg/zero-waste-masterplan/)

We tried using Solver to determine how can the government target improvements in recycling rate on a category level (across Food, Paper, or Plastic) to arrive at the desired Recycling Rate of 70%. (Please refer *6. Solver Analysis* in Modelling Worksheet for details)

Solver suggested a significant increase in the recycling rate of plastic to at least 50% to achieve the targeted overall Recycling rate of 70% by 2030. It also suggested that the current levels of paper recycling rates need to be maintained if not improved further to supplement the recycling rates and achieve the targeted number.

Results and Insights

- Overall Recycling Rates from 2023 to 2030 are likely to remain in the same range as they were in the last few years between 57 and 61%.

- It has been observed that paper recycling rates might decrease due to increasing digitalization and reduced demand for recycled paper overseas (e.g., China and Vietnam). To overcome this challenge, Singapore needs to find new markets where recycled paper can be exported. This can also be supplemented by increasing the market size for recycled goods within Singapore.

- Plastic Recycling rates have largely stagnated due to the saturation of plastic recycling infrastructure facilities and low demand for recycled plastic goods. While investments in research for improving the recycling rates of plastic have been made, there has not been a breakthrough leading to a significant increase in the recycling rate of plastic. Major breakthroughs in the form of technological advancements and innovative policy decisions are needed to improve plastic recycling rates.

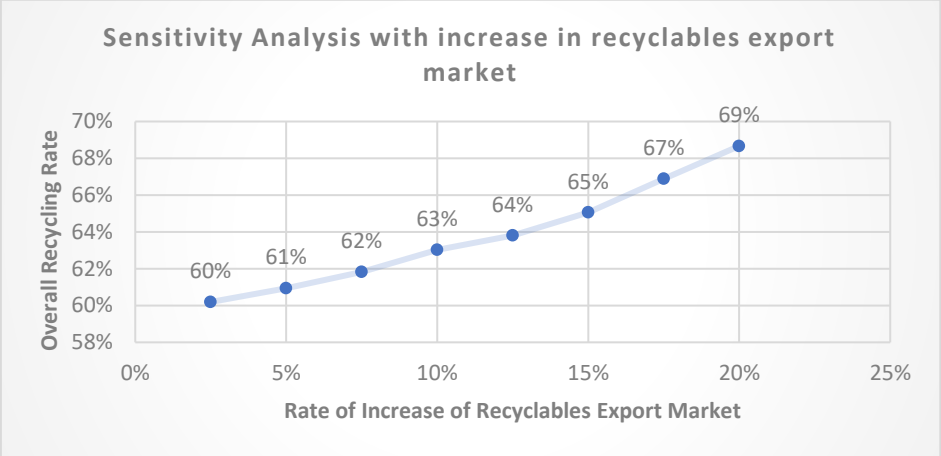
- Currently, food recycling rates have been seen to increase with the increase in NEA Development Expenditure over a three-year time window. However, the rate of increase in food recycling rates is very low compared to the investment made. There needs to be a significant improvement in food recycling infrastructure to have a higher increase in food recycling rates with lower investments.

- Germany and South Korea have achieved high recycling rates in plastic and food respectively through policies and innovative strategies. Countries like Germany and South Korea can be used as case studies to figure out strategies to improve the overall recycling rate.

Sensitivity Analysis

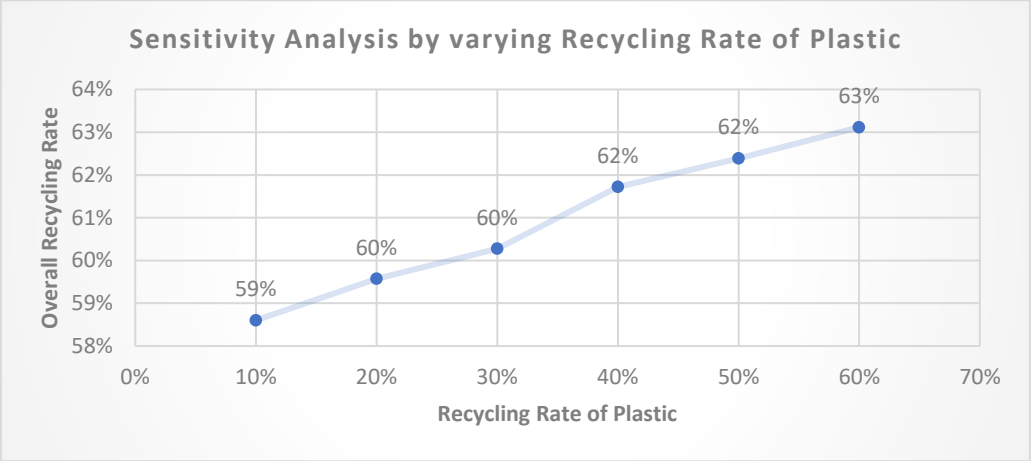
1. Sensitivity Analysis 1- What if there is a steady increase in the Export Market between 2023 and 2030?

In our analysis, we determined that the Recyclables Export market has a direct bearing on the Recycling rate of paper. Currently, the export market has been decreasing due to countries like China closing their borders for recyclable goods. This scenario assumes that if there is a steady increase in the export market due to some other countries/avenues that Singapore can find for its recyclable exports, how will this impact the recycling rate of paper and subsequently impact the overall recycling rate. (Please refer to *7. Sensitivity Analysis* for details). We performed this analysis assuming a 2.5% rate of increase in export market from 2022 to 2030. This did not result in any significant improvements in the overall recycling rate (58%). We also used a data table to determine the Overall recycling rate by varying rate of exports. The resulting trend is as shown in figure below:



2. Sensitivity Analysis 2- What if there is a technological Breakthrough leading to a significant improvement in Recycling Rate of Plastic?

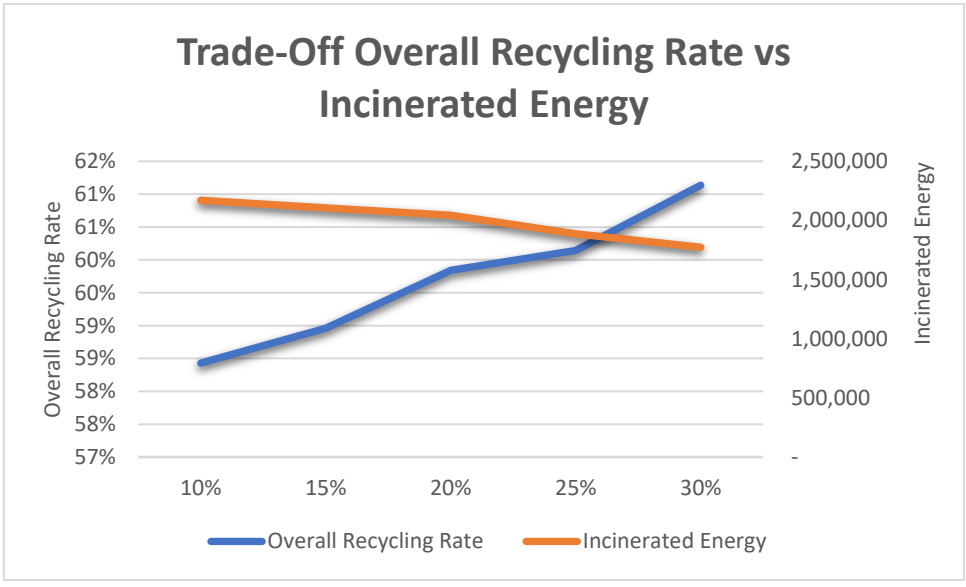
This scenario gauges the impact on the Overall Recycling rate of Singapore in the year 2030 if Singapore can find a technological breakthrough or implement recycling infrastructure to significantly improve the recycling rate for Plastic specifically. (Please refer to *7. Sensitivity Analysis* for details). We performed this analysis assuming improvement of 10% recycling rate in 2023 which is constant till 2030. This did not result in any significant improvements in the overall recycling rate (58%) by 2030. We also used a data table to determine the Overall recycling rate for varying recycling rate of plastic. The resulting trend is as shown in figure below:



Trade-off Analysis

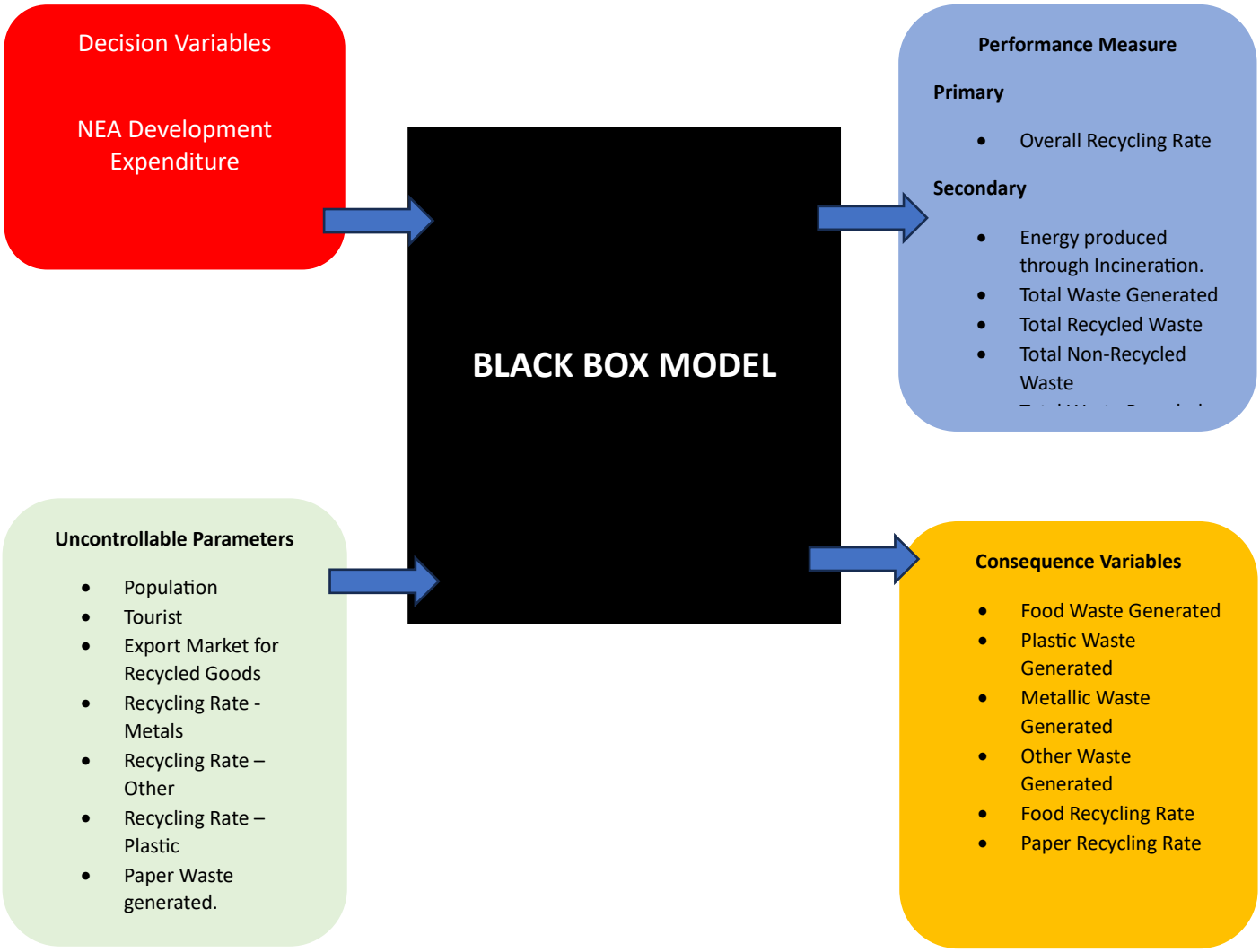
What if the NEA Development Expenditure increases significantly at a constant rate between 2023 and 2030?

In our analysis, we found that the observable impact of NEA Development Expenditure on the Food recycling rate is in a 3-year window period, subsequently impacting the Overall recycling rate. The non-recycled waste is used to generate energy through incineration, implying that if we improve the recycling rate, the recycled waste increases, which in turn decreases the amount of non-recycled waste. This is likely to reduce the energy generated through incineration. This analysis attempts to examine the scenario if the NEA Development Expenditure increases at a constant rate, how will the overall recycling rate and energy have generated through incineration trade-off against each other. We also used a data table to determine the Overall recycling rate and Total energy generated through incineration by varying rate of increase of NEA budget. (Please refer to *8.Tradeoff Analysis* for more details).The resulting trade-off between them is as shown in figure below:



Appendix

Black Box Diagram



Influence Diagram