REALIZATION INDEX AND ITS EFFECTS ON WASTE DISPOSAL: A MODELLING APPROACH

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1. INTRODUCTION

Increasing economic growth, purchasing power, and population as well as improving the standard of living have resulted in higher waste generation in Malaysia. Waste generation continues to grow to outstretch the available waste out of the limit. Thus, waste generation in Malaysia recently reached a crucial perspective, especially in terms of the amount and composition. Malaysian households produce 59776 tonnes of rubbish every day. That's almost 200 Boeing 747 planes stuffed all the way up with trash, every single day. The average Malaysian throws away 1.64kg of waste every day compared to the worldwide average of 1.2kg. Household waste has always been on rising. A study shows that solid waste generation in Malaysia has gone up 91% over the past decade [1], and the main reasons for this are urban development, higher salaries, and just a shift from how we use things as consumers. [2] On 17 March 2022, the population of Malaysia recorded was 33059083 people with a growth rate of an estimated 1.23% each year [3]. Although Malaysia's economy is developing rapidly, public concern and awareness are not evolving in parallel, and therefore participation towards sustainable waste management through the" Reduce, Reuse and Recycle" approach (3Rs) is severely lacking [4]. Waste disposal facilities, in general, are still lacking in Malaysia. Poor waste disposal contributes to climate change and air pollution and directly affects many ecosystems and species [5].

In Malaysia, waste disposal is a major environmental problem. Increasing waste quantity can cause many problems because improper practices with respect to waste management lead to pollution, resource degradation, and health problems for humans and animals. Besides that, no segregation from the source also has worsened the problem. Most Malaysian are still lacking the awareness and knowledge to do recycling among the other Malaysian community as well as being ignorant which also causes the problem to become more severe. Many people are also unaware of the individual actions they can take to help curb the problem.

By using our own idea with computer science concept and scientific skills, we have created a waste disposal model to simulate how does the realisation rate of consumers affects the waste disposed in Malaysia from year 2022 to 2050.

2. OBJECTIVES

Objectives of the experiment:

- To determine and statistically analyse waste disposed across the years.
- To estimate how does the realisation rate of consumers can affect the waste disposal in the future.

3. TOOLS & MATERIALS

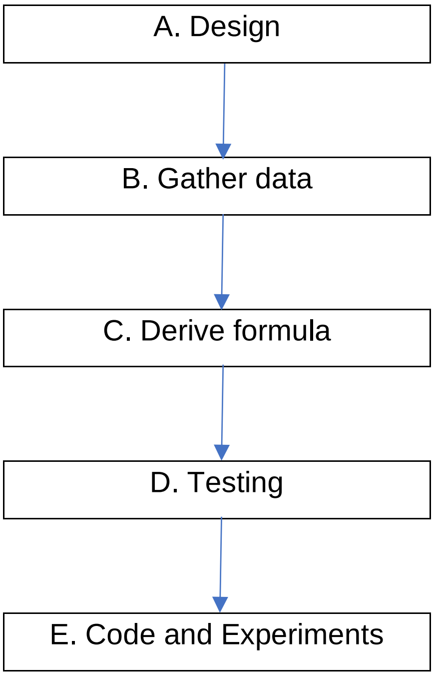
Vensim

Vensim is industrial-strength simulation software for improving the performance of real systems [6]. It is widely used in system dynamics modelling and analysis to simulate and predict the complex dynamic real-world outcome.

Google Colaboratory (Colab)

Colab, or "Colaboratory", allow us to write and execute Python code in the browser, with zero configuration required, access to high end GPUs free of charge and easy sharing [7]. This tool is extremely useful for our remote workflow due to current pandemic.

4. METHODOLOGY



A. Design

Before getting into the design of model, we had done tons of research on articles related and found an article on System Dynamic Modelling for Solid Waste Management in Lima Peru [8]. We inspired by this article that had the best methodology approach to what we wish to achieve in this experiment, so we implement some of the design method, which is the causal diagram to design our model. A causal diagram is the one that is connected by an arrow that shows the casual relationships and collaborations that variables have with each other [9]. It is worth mentioning that a correctly applied causal diagram is beneficial for the construction and analysis of a real system, since it can help in the planning and process of a system [8]. This causal diagram can be easily understood by anyone who are in or outside of the industry. The causalities to the waste disposed were figured out and drawn by using Vensim's Causal Diagram. The causal diagram we created was as shown in *Figure 4.1*.

We also found that for the population and realization of consumers were in stock-flow situations. A stock is accumulated over time by inflows and/or depleted by outflows, for example the number of populations at a certain time [10]. A flow changes a stock over time [10]. Usually, we can clearly distinguish inflow as adding to the stock, and outflow as subtracting from the stock [10]. Thus, we implement the stock-flow concept into our causal diagram before, and *Figure 4.2* was what we got.

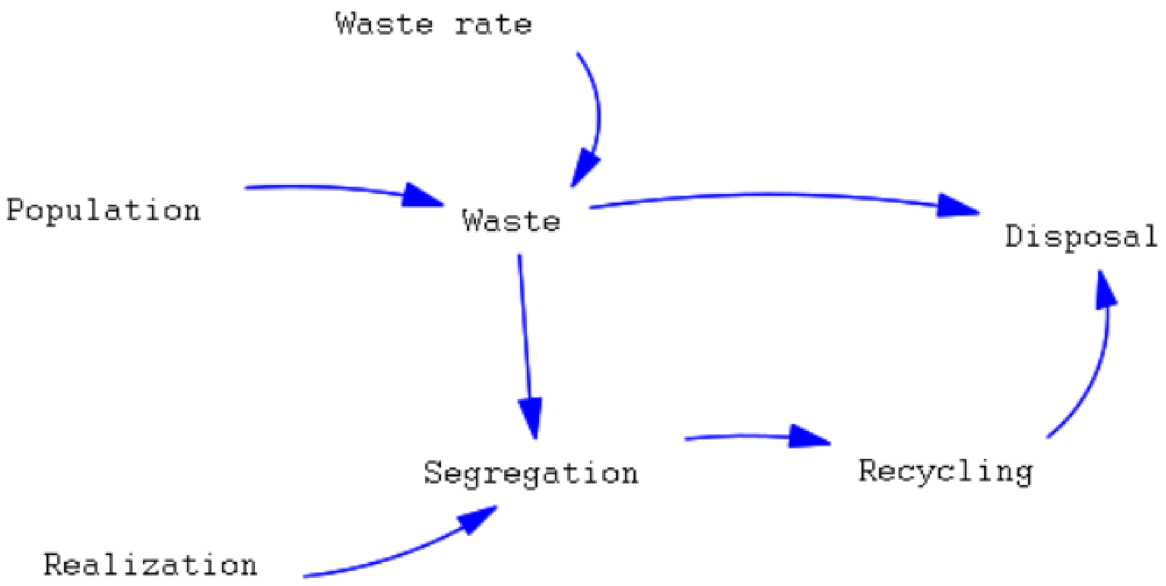


Figure 4.1: Waste Disposal Causal Diagram

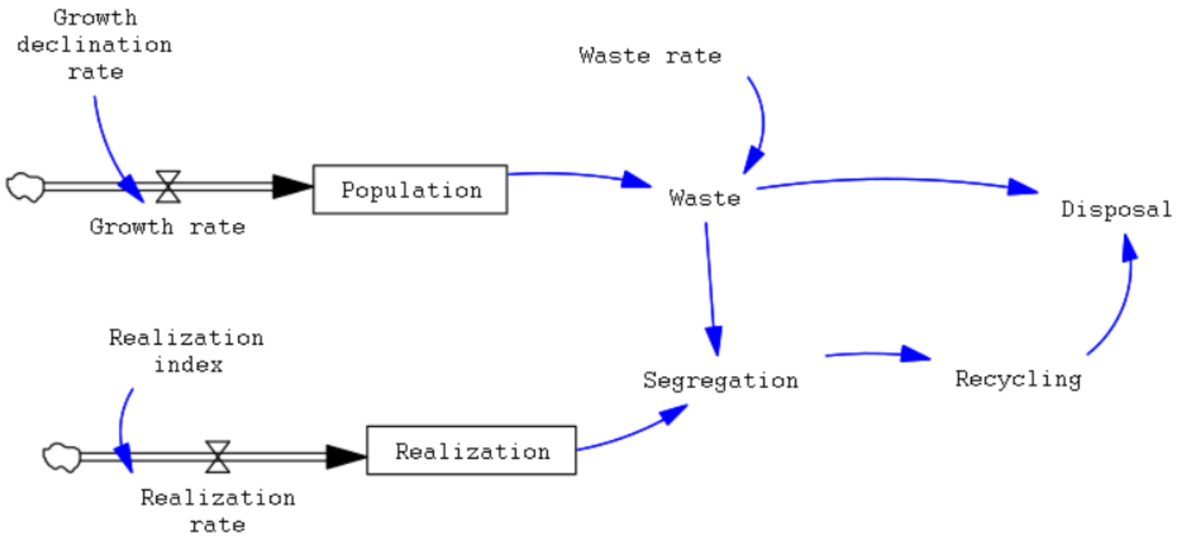


Figure 4.2: Waste Disposal Stock Flow Diagram

B. Gather Data

We then look for the suitable values and constants for all our variables from all sources online including journals, articles, websites, and figure out the equations related to them. However, we faced the challenge that there was no ready-made formula or value for the realization rate and realization of people yet we made this model from our own idea. So, we have to come out with our own equations and reasonable values to calculate the realization of people.

C. Derive Formula

We think that realization of something should be a sigmoid growth instead of a linear or exponential growth. Sigmoid growth is a growth that shows a S-shaped curve on the graph, where it displays certain phases consecutively; lag phase, exponential phase, linear phase, and lastly, plateau phase. The general sigmoid graph is as shown in *Figure 4.3*. Rose Hipkins and Bronwen Cowie had also published an article and mentioned that the s-curve can be used to describe and explain the pattern of introduction, rapid development, and ultimate maturity of new. They also mentioned that from slow beginnings and 'early adoption,' new technologies begin to diffuse across social settings. At a certain point, exponential growth occurs until the market is saturated, at which point the pace of uptake slows and stops [11].

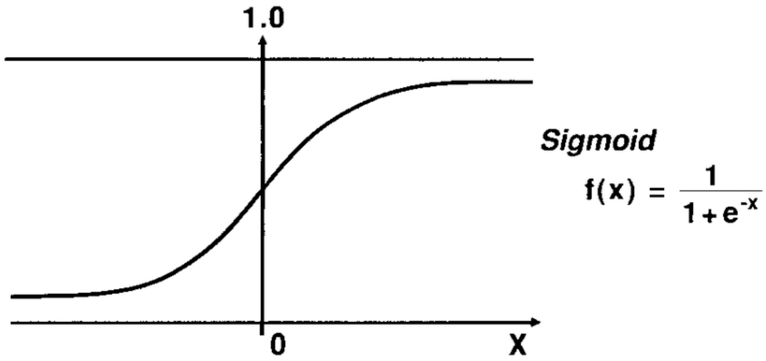


Figure 4.3: General Sigmoid Graph

This indeed gives fanatical support to our decision in using a sigmoid growth curve for the realization of people. By describing it as a metaphor, when a new idea was introduced to the world, fewer people will approach it because they aren't familiar or don't have trust in it yet, which forms the lower growth gradient at the start (lag phase). When these people prove that the concept works, they start to spread the idea and the majority begin to follow, leads to the higher gradient in middle (exponential phase and linear phase). However, there are always some people who lack in trust even though the idea may be the best approach or truth, so there is the decrease in gradient near the end (decelerating and approaching the plateau phase).

The general sigmoid function is:

$$S(x) = \frac{1}{1 + e^{-x}}$$

Hence, based on the sigmoid function, the realization formula that we formed was:

$$R(t) = \frac{1}{1 + 15e^{-\frac{t}{n}}} = \frac{1}{1 + 15e^{-t(r)}} \qquad 4.1$$

And when $n = 1$, the realization sigmoid graph was as shown:

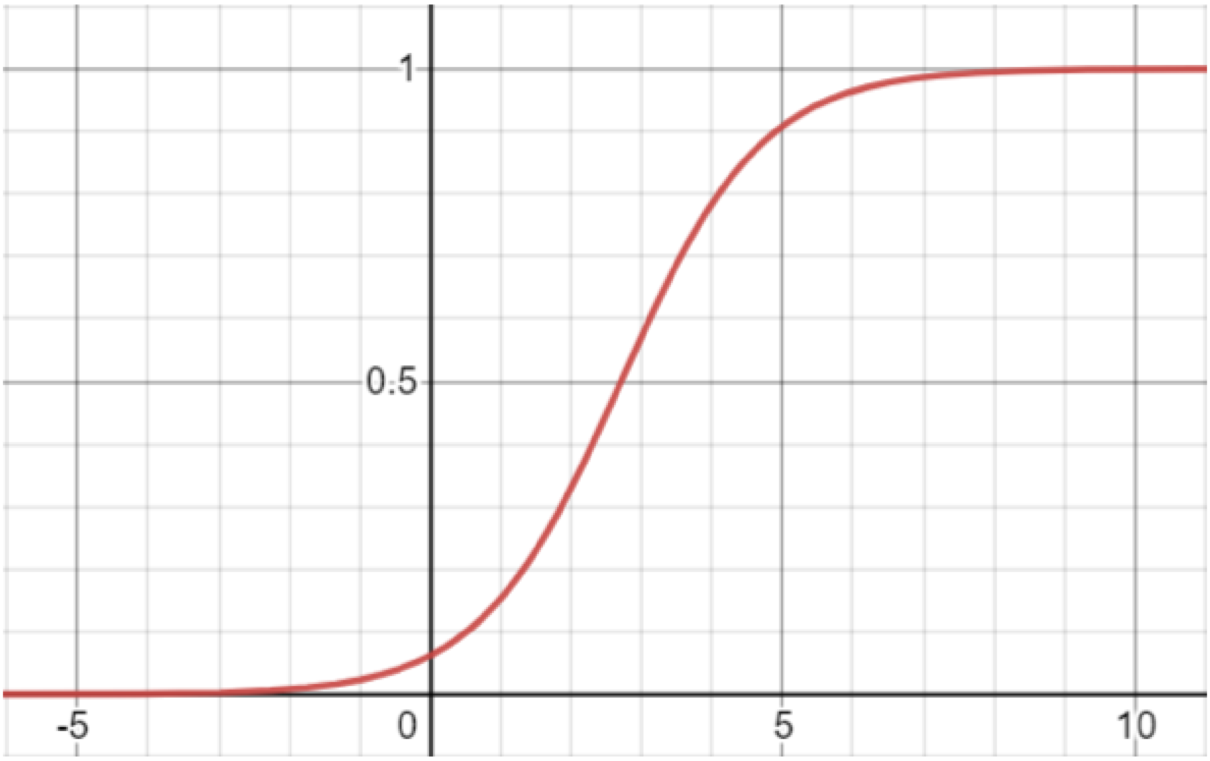


Figure 4.3: Realization Sigmoid Graph

where:

$R(t)$ – the expected cumulative percentage of growth in realization at time, t, range from 0 to 1

n – the realization index which $1n$ means it takes $1e$ years or 2.71 years to reach 50% of growth in realization of people.

r – the realization rate which means how fast is the growth of realization of people.

The realization rate, r was calculated by taking the inverse of realization index, n:

$$r = \frac{1}{n} \tag{4.2}$$

The other values and formulae were shown in *Table 4.1* and *Table 4.2*.

Table 4.1: Values

No.	Variable	Value	Unit
1.	Initial Year	2022	year
2.	End Year	2050	year
3.	Growth declination rate	0.04	people/year/year
4.	Growth rate	0.0123	people/year

5.	Population	33059083	people
6.	Waste rate	1.64	kg/people/day
7.	Initial realization	0.3	Dmnl (dimensionless)
8.	Realization index	10	year

Table 4.2: Formulae

No.	**Formula**	
1.	Year length = End Year – Initial Year	year
2.	Realization rate = 1 / Realization index	1/year
3.	Growth rate = Growth rate * (1 - Growth declination rate)	people/year
4.	Population = Population * (1 + Growth rate)	people
5.	Realization = Initial realization + (1 – Initial realization) / (1 + 15 * exp (- current year * Realization rate)	Dmnl
6.	Waste = population * Waste rate * 365	kg
7.	Recycling = Waste * Realization	kg
8.	Disposed = Waste - Recycling	kg

D. Testing

The values and formulae were then implemented into our Vensim model for testing to make sure everything works accordingly to what it supposed to be. The reason we test it in Vensim before it was directly transformed into code was that it enables us to quickly identify any problem presence in our calculations and provided a causal tracking tool to check where the problem began and apply quick fix on them.

E. Code and Experiments

We implement all the working calculations into Colab platform. The reason that Colab had been chosen for our modelling tool was the easy sharing feature and collaborative workflow provided to us, especially in the current situation. Besides, Colab uses Python as their programming language which has one of the largest libraries including the math and plotting modules that we required. The code in Cola can be split into cells and text that can be added in between them, making it visually neater and comprehensible.

The full code of this experiment can be found on our Colab notebook file [12].

There are 2 experiments that we did on this model. First experiment was to determine and statistically analyse how does the waste disposed across the years at the realization index, n of 10. Second experiment was to estimate how does the realization rate of people can affect the waste disposal in the future.

To set up for both experiments, the modules needed in Code Cell 1, some general variables in Code Cell 2 and functions in which will be used in both experiments were imported and defined at the beginning of the model. General variables and functions mean these variables and functions were been used in both experiments. Then we calculate and plot the dataset for population for 2022 to 2050 as this dataset were being used for both experiments too.

Code Cell 1: Import Modules and Packages

```
import math
import matplotlib.pyplot as plt
```

Code Cell 2: Define General Variables

```
INIT_YEAR = 2022
END_YEAR = 2050
year_length = END_YEAR - INIT_YEAR
GROWTH_DECLINATION_RATE = 0.04
growth_rate = 0.0123
population = 33059083 #as of 17/3/2022
WASTE_RATE = 1.64
x_year = []
y_population = []
y_realization = []
y_waste = []
y_recycle = []
y_disposed = []
```

Code Cell 3: Define General Functions

```
def Year():
  global x_year
  for i in range(year_length + 1):
    x_year.append(i + INIT_YEAR)

def P(): #population
  global y_population, growth_rate, population
  for i in range(year_length + 1):
    y_population.append(population)
    population += population*growth_rate
    growth_rate *= 1-GROWTH_DECLINATION_RATE
```

```
    print(x_year[i], "\t", round(y_population[i]))

def R(year, realization_rate): #realization
  return INIT_REALIZATION + (1-
INIT_REALIZATION)/(1+15*math.exp(-year*realization_rate))

def W(population): #waste created
  return population * WASTE_RATE * 365

def Rc(waste, realization): #recycled
  return waste * realization

def D(waste, recycle): #disposed
  return waste - recycle
```

Experiment 1

On this experiment, we wanted to find out how does the waste, waste recycled and waste disposal changes across years when we had a fix realization index of $n = 10$. Realization index, $n = 10$ means it takes 27.1 years to increase realization by 50% from its initial realization value, which we set it as 0.3, means about 30% of people already realize and act on the recycling effort. The experiment began by defining the realization index and rate in Code Cell 4.

Code Cell 4: Define Realization Index & Rate for Experiment 1

```
REALIZATION_INDEX = 10
REALIZATION_RATE = 1.0/REALIZATION_INDEX
INIT_REALIZATION = 0.3
```

The realization for each year based on realization rate in Code Cell 5, waste created for each year based on populations in Code Cell 6, waste recycled for each year based on waste created and realization in Code Cell 7, and waste disposed for each year based on waste created and waste recycled in Code Cell 8 were calculated by using the function defined in

Code Cell 3 and using looping. The data sets were plotted into graphs. The result was shown by combining dataset of waste created, waste recycled and waste disposed into a single dataset and graph so that we can see how waste recycled affects waste disposed and their relationships can be clearly seen.

Code Cell 5: Calculate Realization for Each Year

```
for i in range(year_length + 1):
  y_realization.append(R(i, REALIZATION_RATE))
  print(x_year[i], "\t", round(y_realization[i], 5))
plt.plot(x_year, y_realization)
plt.xlabel("Year")
plt.ylabel("Realization")
plt.title("Graph of Realization against Year")
```

Code Cell 6: Calculate Waste Created for Each Year

```
for i in range(year_length + 1):
  y_waste.append(W(y_population[i]))
  print(x_year[i], "\t", round(y_waste[i]))
plt.plot(x_year, y_waste)
plt.xlabel("Year")
plt.ylabel("Waste Created (kg)")
plt.title("Graph of Waste Created against Year")
```

Code Cell 7: Calculate Waste Recycled for Each Year

```
for i in range(year_length + 1):
  y_recycle.append(Rc(y_waste[i], y_realization[i]))
  print(x_year[i], "\t", round(y_recycle[i]))
plt.plot(x_year, y_recycle)
plt.xlabel("Year")
plt.ylabel("Waste Recycled (kg)")
plt.title("Graph of Waste Recycled against Year")
```

Code Cell 8: Calculate Waste Disposed for Each Year

```
for i in range(year_length + 1):
  y_disposed.append(D(y_waste[i], y_recycle[i]))
  print(x_year[i], "\t", round(y_disposed[i]))
plt.plot(x_year, y_disposed)
plt.xlabel("Year")
plt.ylabel("Waste Disposed (kg)")
plt.title("Graph of Waste Disposed against Year")
```

Experiment 2

On this experiment, we wanted to find out how does the realization index and rate affects the waste disposed. The realization index, n was set to 10 datasets of $n = 5$ to 14 as it is our manipulated variable and this range of value were more realistically reflect to real life scenarios. As the value of year only determine the amount of population and did not affect much in the result trend, it was set as constant of 2040 as it was randomly selected in between our test year from 2022 to 2050.

The variables were defined in Code Cell 9. The dataset of realization rate was then calculated accordingly to each of the realization index. The dataset of waste disposed for each realization index were then calculated based population on the year 2040 and its waste recycled in Code Cell 10. The graph of realization index and realization rate against waste disposed were plotted.

Code Cell 9: Define Variables for Experiment 2

```
TARGET_YEAR = 2040
YEAR_INDEX = TARGET_YEAR - INIT_YEAR
x_count = 10 # number of data sets
INIT_n = 5 # first realization index value
n = [] # realization index
rr = [] # realization rate
disposed = []
```

Code Cell 10: Calculation of Realization Index, Realization Rate and Waste Disposed

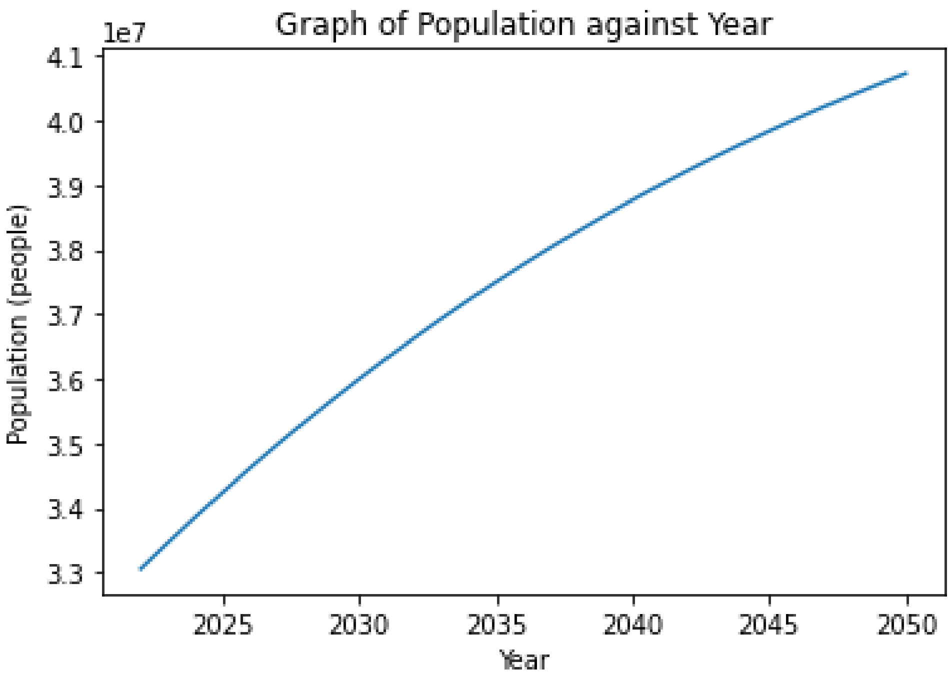
```
for i in range(x_count):
  n.append(INIT_n + i)
  rr.append(1/n[i])
  realization = R(YEAR_INDEX, rr[i])
  waste = W(y_population[YEAR_INDEX])
  recycled = Rc(waste, realization)
  disposed.append(D(waste,recycled))
  print(n[i], "\t", round(rr[i],2), "\t", round(disposed[i]))
```

5. RESULT

Pre-experiment

Table 5.1: Table of Population on Each Year

No.	Year	Population
1	2022	33059083
2	2023	33465710
3	2024	33860873
4	2025	34244709
5	2026	34617368
6	2027	34979015
7	2028	35329822
8	2029	35669975
9	2030	35999666
10	2031	36319094
11	2032	36628466
12	2033	36927993
13	2034	37217891
14	2035	37498377
15	2036	37769673
16	2037	38032002
17	2038	38285586
18	2039	38530651
19	2040	38767418
20	2041	38996112
21	2042	39216953
22	2043	39430161
23	2044	39635954
24	2045	39834545
25	2046	40026149
26	2047	40210973
27	2048	40389223
28	2049	40561102
29	2050	40726808



Graph 5.1: Graph of Population against Year

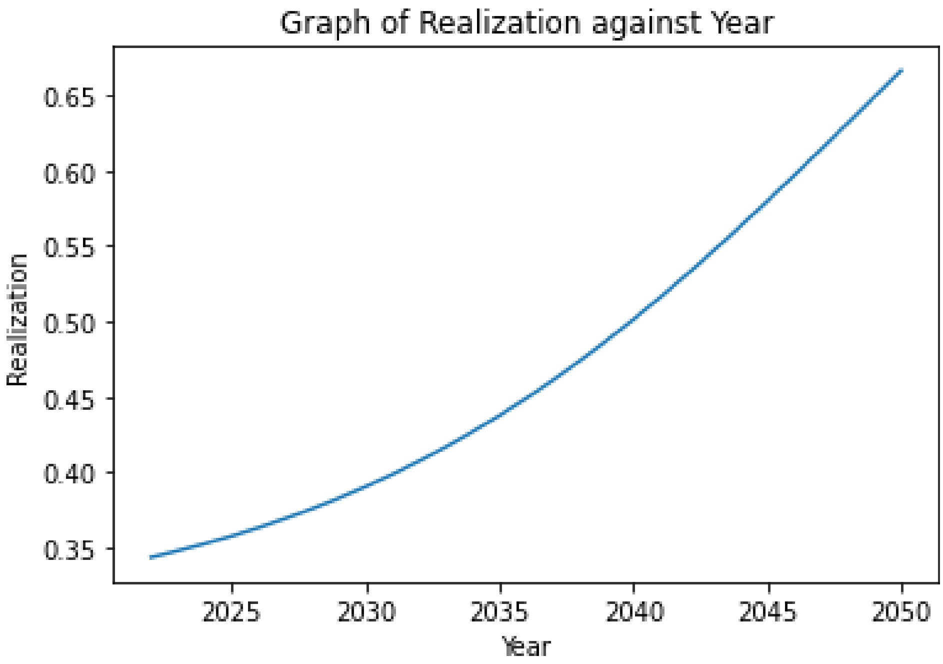
From Table 5.1 and Graph 5.1, the population were increasing across each year with slight declination. This was reflected to the saturation of population in a fix area of land.

Experiment 1

Table 5.2: Table of Realization on Each Year

No.	Year	Realization
1	2022	0.34375
2	2023	0.34804
3	2024	0.35271
4	2025	0.35779
5	2026	0.36332
6	2027	0.36932
7	2028	0.37582
8	2029	0.38285
9	2030	0.39044
10	2031	0.39861
11	2032	0.40739
12	2033	0.41680
13	2034	0.42686
14	2035	0.43758

15	2036	0.44897
16	2037	0.46103
17	2038	0.47376
18	2039	0.48715
19	2040	0.50118
20	2041	0.51581
21	2042	0.53102
22	2043	0.54675
23	2044	0.56296
24	2045	0.57957
25	2046	0.59651
26	2047	0.61372
27	2048	0.63111
28	2049	0.64859
29	2050	0.66608

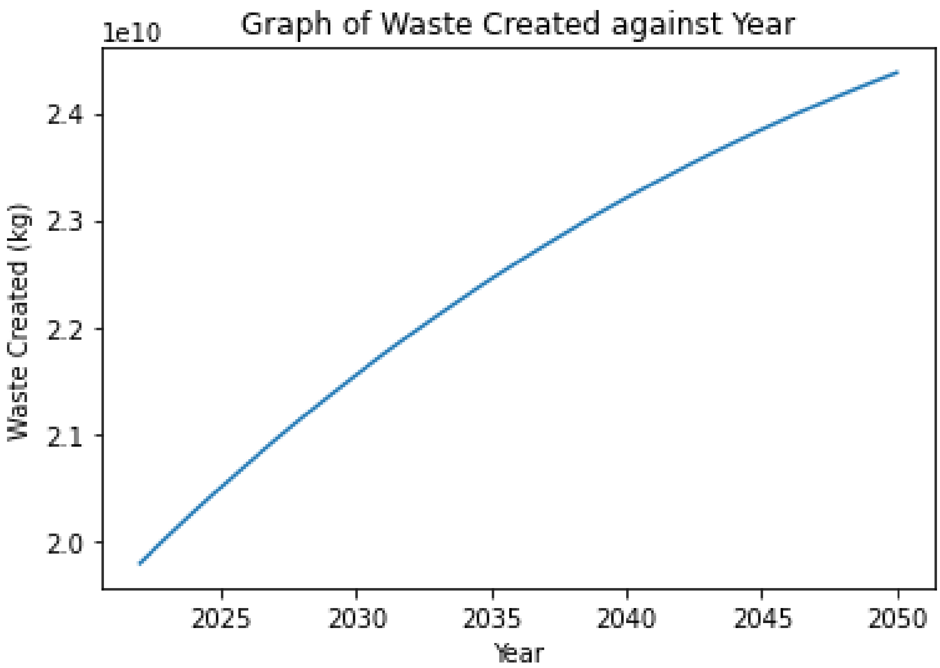


Graph 5.2: Graph of Realization against Year

From Table 5.2 and Graph 5.2, the realization of people increase exponentially in between years of 2022 and 2050 when realization index, $n = 10$. This coincides with the exponential region in our realization sigmoid graph Figure 4.3 at year 2050, so the declination growth of realization was not shown in this graph yet.

Table 5.3: Table of Waste Created on Each Year

No.	Year	Waste Created
1	2022	19789167084
2	2023	20032573839
3	2024	20269118471
4	2025	20498882712
5	2026	20721956735
6	2027	20938438244
7	2028	21148431604
8	2029	21352047029
9	2030	21549399814
10	2031	21740609617
11	2032	21925799786
12	2033	22105096729
13	2034	22278629337
14	2035	22446528440
15	2036	22608926309
16	2037	22765956194
17	2038	22917751905
18	2039	23064447426
19	2040	23206176558
20	2041	23343072602
21	2042	23475268068
22	2043	23602894413
23	2044	23726081808
24	2045	23844958924
25	2046	23959652753
26	2047	24070288436
27	2048	24176989127
28	2049	24279875862
29	2050	24379067455



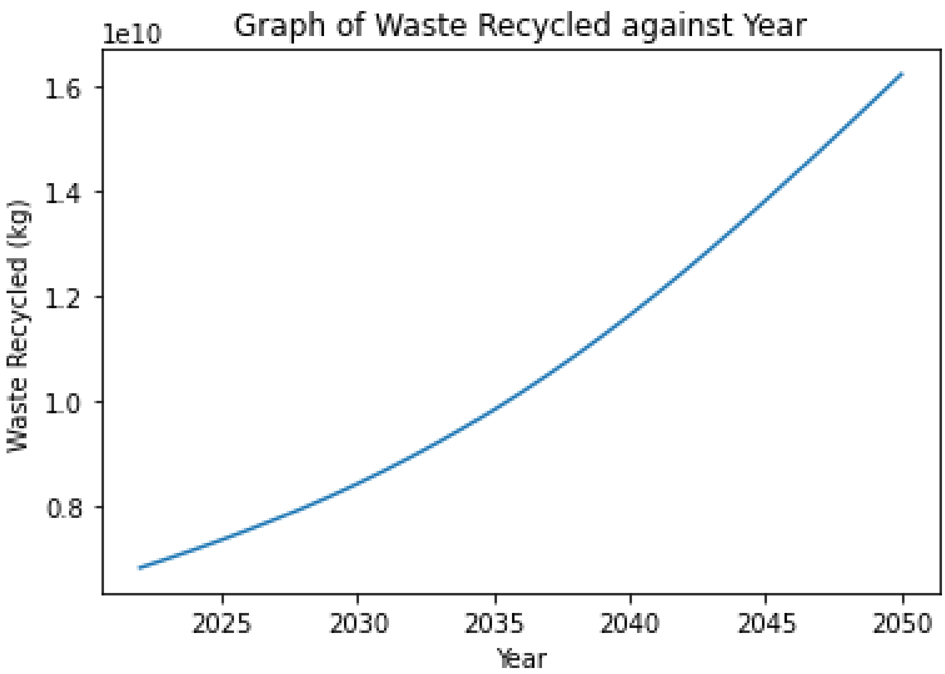
Graph 5.3: Graph of Waste Created against Year

From Table 5.3 and Graph 5.3, the waste created increase with year, which had the same trend with population as it only affected by the population in our formula.

Table 5.4: Table of Waste Recycled on Each Year

No.	Year	Waste Recycled
1	2022	6802526185
2	2023	6972046485
3	2024	7149060538
4	2025	7334348938
5	2026	7528720104
6	2027	7733003545
7	2028	7948041423
8	2029	8174678246
9	2030	8413748575
10	2031	8666062646
11	2032	8932389929
12	2033	9213440690
13	2034	9509845763
14	2035	9822134880
15	2036	10150714028

16	2037	10495842490
17	2038	10857610375
18	2039	11235917571
19	2040	11630455194
20	2041	12040690633
21	2042	12465857326
22	2043	12904950287
23	2044	13356728259
24	2045	13819723097
25	2046	14292256651
26	2047	14772465030
27	2048	15258329690
28	2049	15747714366
29	2050	16238406498

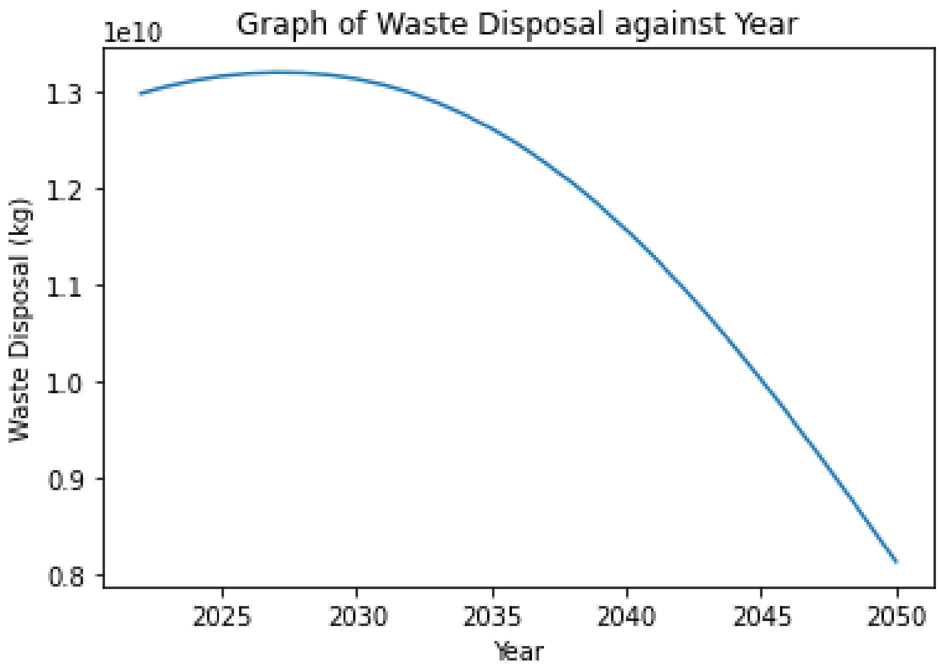


Graph 5.4: Graph of Waste Recycled against Year

From Table 5.4 and Graph 5.4, the waste recycled increase exponentially across the year. This was due to realization of people were increase exponentially as well, thus directly affected the waste recycled.

Table 5.5: Table of Waste Disposed on Each Year

No.	Year	Waste Disposed
1	2022	12986640899
2	2023	13060527354
3	2024	13120057933
4	2025	13164533774
5	2026	13193236632
6	2027	13205434699
7	2028	13200390181
8	2029	13177368783
9	2030	13135651240
10	2031	13074546972
11	2032	12993409857
12	2033	12891656039
13	2034	12768783574
14	2035	12624393560
15	2036	12458212281
16	2037	12270113704
17	2038	12060141531
18	2039	11828529855
19	2040	11575721364
20	2041	11302381969
21	2042	11009410742
22	2043	10697944126
23	2044	10369353548
24	2045	10025235827
25	2046	9667396102
26	2047	9297823406
27	2048	8918659437
28	2049	8532161497
29	2050	8140660957



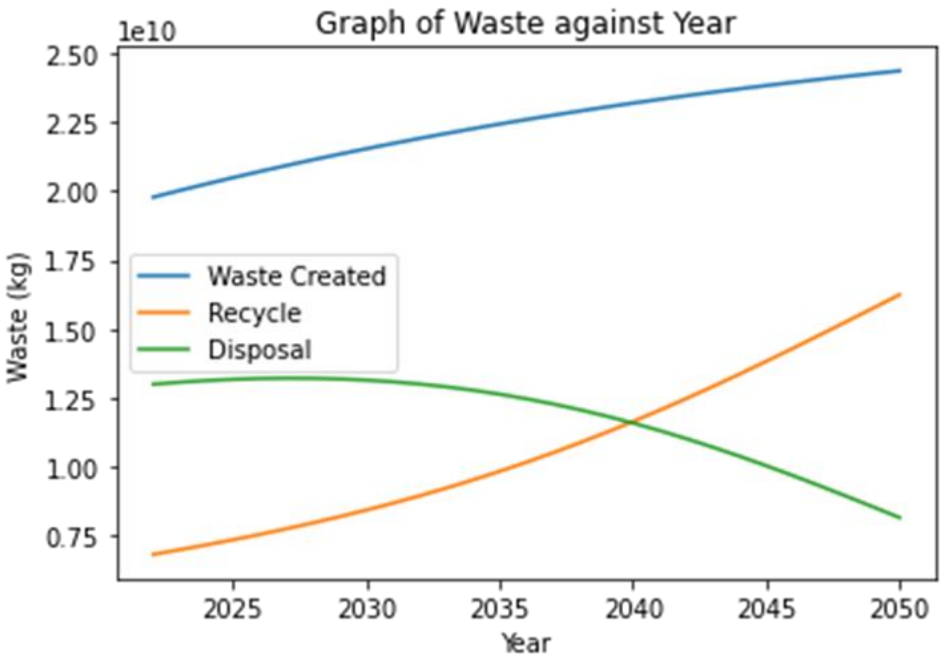
Graph 5.5: Graph of Waste Disposed against Year

From Table 5.5 and Graph 5.5, the waste disposed was increase initially but decrease exponentially. This was because of realization of people increase leads to increase in recycling effort, thus the yearly waste disposed were reduced.

Table 5.6: Table of Waste Created, Waste Recycled and Waste Disposed on Each Year

No.	Year	Waste Created	Waste Recycled	Waste Disposed
1	2022	19789167084	6802526185	12986640899
2	2023	20032573839	6972046485	13060527354
3	2024	20269118471	7149060538	13120057933
4	2025	20498882712	7334348938	13164533774
5	2026	20721956735	7528720104	13193236632
6	2027	20938438244	7733003545	13205434699
7	2028	21148431604	7948041423	13200390181
8	2029	21352047029	8174678246	13177368783
9	2030	21549399814	8413748575	13135651240
10	2031	21740609617	8666062646	13074546972
11	2032	21925799786	8932389929	12993409857
12	2033	22105096729	9213440690	12891656039
13	2034	22278629337	9509845763	12768783574

14	2035	22446528440	9822134880	12624393560
15	2036	22608926309	10150714028	12458212281
16	2037	22765956194	10495842490	12270113704
17	2038	22917751905	10857610375	12060141531
18	2039	23064447426	11235917571	11828529855
19	2040	23206176558	11630455194	11575721364
20	2041	23343072602	12040690633	11302381969
21	2042	23475268068	12465857326	11009410742
22	2043	23602894413	12904950287	10697944126
23	2044	23726081808	13356728259	10369353548
24	2045	23844958924	13819723097	10025235827
25	2046	23959652753	14292256651	9667396102
26	2047	24070288436	14772465030	9297823406
27	2048	24176989127	15258329690	8918659437
28	2049	24279875862	15747714366	8532161497
29	2050	24379067455	16238406498	8140660957



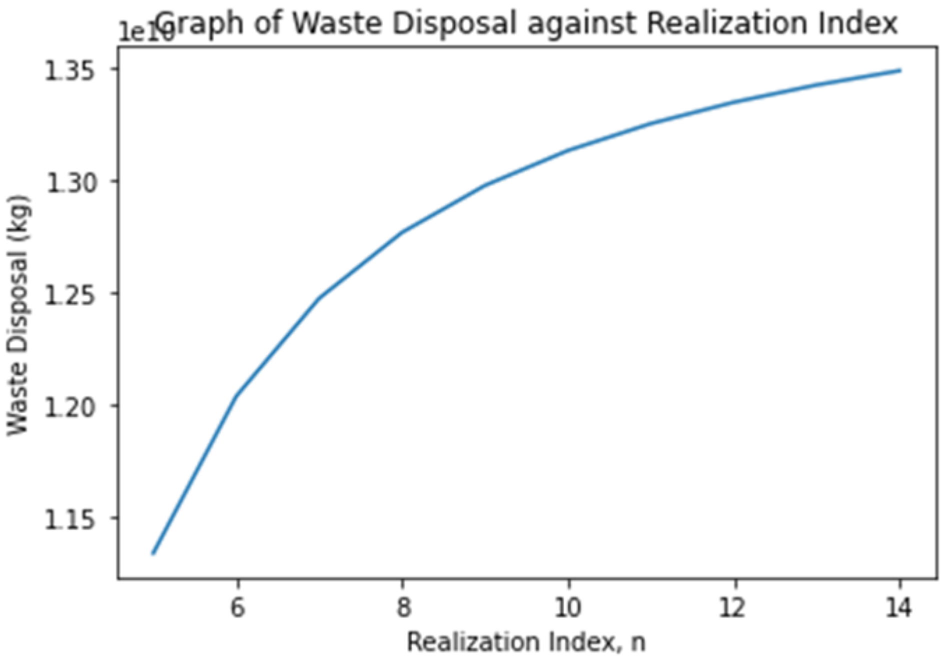
Graph 5.6: Graph of Waste Created, Waste Recycled and Waste Disposed against Year

By combining the datasets into one, we get the result of this experiment by visualising the trend of waste recycled and disposed in the future if we have the realization index, $n = 10$.

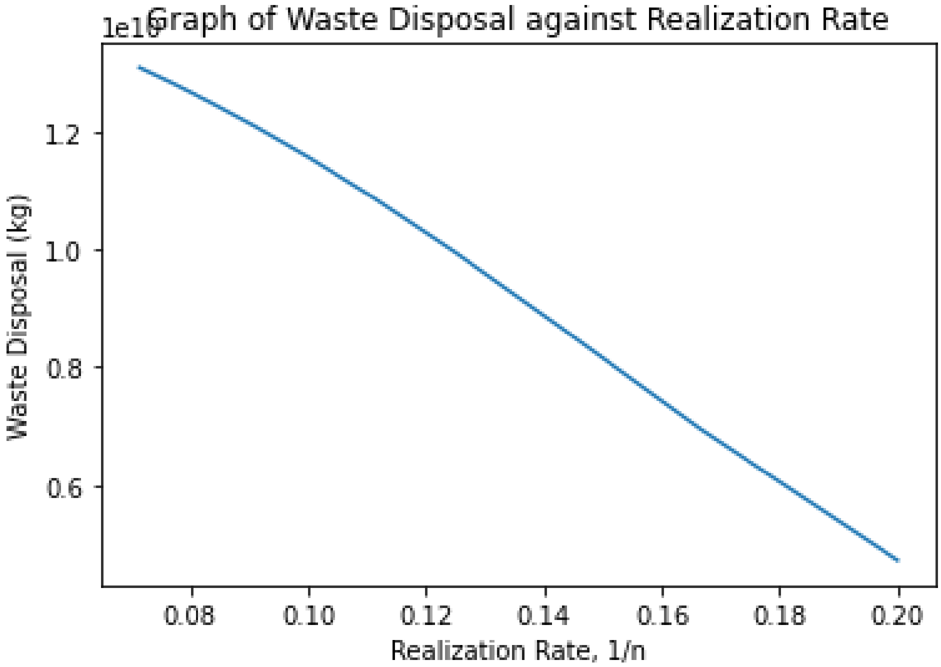
Experiment 2

Table 5.7: Table of Realization Index, Realization Rate and Waste Disposal

No.	Realization Index	Realization Rate	Waste Disposal
1	5	0.20	4722348671
2	6	0.17	6944880291
3	7	0.14	8676131878
4	8	0.12	9950485234
5	9	0.11	10883212440
6	10	0.10	11575721364
7	11	0.09	12100681267
8	12	0.08	12507378235
9	13	0.08	12828996837
10	14	0.07	13088122230



Graph 5.7: Graph of Waste Disposal against Realization Index



Graph 5.8: Graph of Waste Disposed against Realization Rate

From Table 5.7, Graph 5.7 and Graph 5.8, higher realization index gives higher waste disposal, and higher realization rate gives lower waste disposed. This means, a lower waste disposal shows that people are realizing the issue at a faster rate.

6. CONCLUSION

From the results of experiment 1 when realization index, $n = 10$, the realization of people increase exponentially in between years of 2022 and 2050, waste created increases with population, waste recycled increases exponentially and waste disposed was increase initially but decrease exponentially. In experiment 2, we saw that higher realization index gives higher waste disposed, and higher realization rate gives lower waste disposed. This experiment can vividly emphasize to us that throughout the upcoming years, there will be more population and so is the waste. With that, the realization rate of people must increase with a higher rate to reduce waste disposal. The increase in waste disposal has contributed to increases in environmental pollution such as air pollution, land pollution, garbage solution, beach solution, and plastic pollution. Malaysia itself contributes emissions given its significant use of coal and natural gas. However, the use of hydropower has expanded in the 21st century, and other potential energy sources such as solar power and biomass are being explored. To conclude, this experiment provides us an opportunity to study waste disposal in Malaysia across the years. We should let people around us realize and act on this issue as soon as possible to let our planet reaches the net-zero waste target within the least number of years.

7. FUTURE RECOMMENDATION

The model is highly compatible as its variables are manipulatable to help organisations to statistically analyse on waste disposal in a smaller or more specific groups instead of analyse on the whole nation, for example it can be narrowed down to genders, races, age groups, and so on. Besides, it can even be used as the base model on most reality research fields as it features the sigmoid function which is crucial in representing the growth.

We see a brilliant potential in the development of this model, in where more factors can be included in our basic causal diagram and make it more relevant to reality, which can lead to more precise and accurate data.

Circular economy is a sustainable model of production and consumption model that ensures sustainable growth over time. With the circular economy, we can drive the optimization of resources, reduce the consumption of raw materials, and recover waste by recycling or giving it a second life as a new product. The aim of the circular economy is therefore to make the most of the material resources available to us by applying three basic principles: reduce, reuse, and recycle. In this way, the life cycle of products is extended, waste is used and a more efficient and sustainable production model is established over time. The idea arises from imitating nature, where everything has value and everything is used, where waste becomes a new resource. In this way, the balance between progress and sustainability is maintained.

One of the benefits of circular economy is to protect the environment. It reduces CO_2 emissions, minimises the consumption of energy natural resources, and reduces waste generation. Other than that, circular economy benefits the local economy. It can benefit the local economy by encouraging production models based on reuse of nearby waste as raw material. Apart from that, circular economy drives employment growth. It stimulates the development of a new, more innovative, and competitive industrial model, higher economic growth, and more employment. Lastly, circular economy promotes resource independence. The reuse of local resources can lead to less dependence on imported raw materials and position Malaysia to better address emerging resources scarcity issues in the future.

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