A system dynamics model for evaluating food waste management in Hong Kong, China

C.K.M. LEE, K.K.H. NG*, C.K. KWONG, S.T. TAY
Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, China
* Corresponding author
Address: Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong.
Tel.: +852 3400 3899; fax: +852 2362 5267
Email Address: ckm.lee@polyu.edu.hk (C.K.M. LEE), kkh.ng@connect.polyu.hk (K.K.H. NG), c.k.kwong@polyu.edu.hk (C.K. KWONG), szeting.tay@polyu.edu.hk (S.T. TAY)

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Abstract

Of landfilled municipal solid waste in Hong Kong, 33.2% is attributed to food waste. The government has set a waste reduction target to reduce by 40% the current food waste disposal at landfills by 2022 and has launched various policies and strategies to achieve this target. The Hong Kong Government is eager to control the utilisation level of food waste through various policies and the food waste conversion by a newly adopted Organic Waste Treatment Facility. In this study, the current landfill situation and the effectiveness of food waste policies are investigated using a system dynamics approach to study the dynamics and interrelationships in food waste management. The model is used to forecast the effectiveness of the food waste management in different scenarios. Among these scenarios, adopting Organic Waste Treatment Facility and implementing a quantity-volume-based charging scheme is examined. Although improvements are expected to be made after implementing these policies when compared to the current trends, the model output indicates that without any other new policy or action plan, it is difficult to achieve the objectives set by the government. Suggestions are made so as to improve the effectiveness of food waste management in the future.

Keywords: System dynamics modelling; Food waste management; Simulation; STELLA

1. Introduction

According to the United Nations Food and Agriculture Organisation report, about 1.3 billion tonnes of food is wasted or lost globally each year [1]. The value of food waste in developed countries and developing countries was roughly US$680 billion and US$310 billion respectively in 2017. Wastage of food waste can happen in all steps of the food supply chain such as the production and consumption stages [2, 3]. According to a research report, the food and drink wasted in UK households was around 7 million tonnes, with a retail value of approximately £12 billion, producing about 14 million tonnes of greenhouse gas emissions. In Africa, food waste causes losses of about US$2.7 billion yearly and 0.82% of South Africa's annual GDP [4]. Governments in Asian countries keep trying different methods to solve this problem. Concepts and frameworks like the life cycle assessment [5], '3Rs' (Reduce, Reuse, Recycle), waste hierarchy [6], polluter pays principle [7], extended producer responsibility, and Sustainable Consumption and Production (SCP) [8] are usually adopted in food waste management. The South Korean Government has implemented various policies, such as source reduction campaigns through public participation and recycling by source-separated collection of food waste, in order to promote food waste reduction and recycling, as food waste was banned from landfills in 2005. One of the source reduction campaigns in Korea was carried out by the Ministry of Environment in cooperation with the Ministry for Health, Welfare and Family Affairs, and the Ministry for Food, Agriculture, Forestry and Fisheries promoting food waste reduction by signing agreements with different sectors like restaurants, hotels and schools for voluntary cooperation in 2010 [9]. Moreover, the government promulgated a volume-based food waste fee system in 2013 in which households are required to pay based on the amount of food waste generated. In Taipei City, since 2003 the municipal government has run a programme throughout the city to collect and recycle food waste. Food waste can be divided into two types: raw food waste and cooked food waste [10]. Raw food waste like uncooked vegetables and fruit skins, and unprocessed meats, is processed by authorised composting factories to produce fertiliser, while cooked food waste such as leftovers, is handled by steaming at high temperatures to produce feed for local farmers. As a result, food waste recycling saved about 15% of household waste volume from incineration in 2008.

Food waste in Hong Kong has become a serious problem. The Hong Kong waste treatment and disposal statistics in 2015 compiled by the Environmental Protection Department [11] disclosed that the daily amount of municipal solid waste (MSW) from domestic, industrial and commercial sources disposed of at landfills was 10,159 tonnes. Furthermore, 3,382 tonnes of food waste was disposed of at landfills, which contributed the greatest proportion (33.2%) of MSW. Landfilling is not a sustainable way to deal with food waste, as food waste in landfills will further generate greenhouse gases, wastewater, and rapid depletion of the finite landfill space that imposes a heavy burden on the environment [12, 13]. Currently, a small amount of food waste is processed by industrial operators or the composting facilities of the Environmental Protection Department (EPD) at Kowloon Bay, Hong Kong for recycling to alleviate the problem, while there is a large amount of food waste that is still sent to the insufficient landfills. Consequently, the three existing strategic landfills will reach capacity within a very short time [14].

The EPD promulgated a comprehensive action plan in May 2013 named "Hong Kong Blueprint for Sustainable Use of Resources 2013 – 2022" aiming at reducing waste through increased social mobilisation, coupled with appropriate policies and legislation. In 2014, the Environment Bureau (ENB) published "A Food Waste and Yard Waste Plan for Hong Kong (2014-2022)", which set the goal of reducing by 40% the food waste disposal at landfills by 2022, using 2011 as the base year. More specifically, the amount of food waste disposed of in landfills needs to be reduced from around 3,600 tonnes a day (1,314,000 tonnes a year) to around 2,160 tonnes a day (788,400 tonnes a year) over eight years. Apart from the waste reduction plan, various programmes and educational campaigns have been initiated and supported by the government in order to promote recycling, source separation and food waste reduction in different sectors, for example, the "Food Waste Recycling Partnership Scheme" in 2010, "Help-desk Service of Food Waste Recycling Projects in Housing Estates" in 2011, and "Food Waste Reduction Programme" in 2012. The government is going to implement a quantity-based MSW charging scheme in the next few years in order to change the public's consumption and disposal behaviour [15].

The outcome of the recent food waste management policies and programmes is questionable. On the basis of the audit report on food waste management by the Audit Commission [16], the average amount of food waste treated at the Kowloon Bay Pilot Composting Plant in Hong Kong is below the expected level, which is not fully utilised. Industrial operators claim that support from the government is insufficient [17]. Hence, this paper aims to analyse the food waste management in Hong Kong using a System Dynamics (SD) approach and then forecast the effectiveness of the current food waste management scheme. The prediction from the model provides insightful ideas for strategic planning of food waste in Hong Kong by combining the complexity of the food waste generation, reduction, recycling, treatment and management process.

In this paper, the effectiveness of the food waste policies and recycling performance are analysed. The following research questions were addressed: [RQ1] Can Hong Kong achieve the food waste reduceion target by adopting Organic Waste Treatment Facility (OWTF) within the scheduled time? [RQ2] What is the level of food waste generated with the adoption of food waste volume-based charging scheme? [RQ3] What are the effects of food waste reduction and the estimated landfill capacities by the proposed scenarios? Regarding the suggested research questions, the prediction of food waste performance is investigated using the SD approach in order to estimate the possible outcome of the landfill capacities and food waste reduction affecting food waste generation.

The organisation of this paper is summarised as follows: Section 2 describes the basic methods and concepts adopted, including system dynamics along with relevant studies in regard to food waste management. The construction and validation of the model are described in Sections 3 and 4 respectively. The results and discussion of the applied policy in Hong Kong are presented in Sections 5 and 6 respectively. Finally, conclusions are presented in Section 7.

2. Literature

2.1. Food waste management

The challenge of food waste management includes food waste prevention, preservation and food waste treatment. Various methods have been proposed by recent publications. Salemdeeb, et al. [18] developed a life cycle assessment model for food waste prevention. Papargyropoulou, et al. [19] illustrated the food waste prevention in the hospitality sector. Fujii and Kondo [20] further investigated the food waste framework using decomposition analysis. Several papers have focused on food waste reduction and the environmental impact [21], social factors [22], material flow analysis [23] and energy preservation methods [24].

2.2. System dynamics

System Dynamics (SD), introduced by Jay Forrester in 1960, is a thinking model and simulation method to support the study of dynamic behaviour in complex systems [25]. According to Forrester [26], SD can analyse the complexity, non-linearity and feedback loop structures that are inherent in physical and non-physical systems. In other words, it can analyse the relationship between various factors, obtain information on the feedback structure, function and behaviour of the system and simulate quantitative data [27]. Therefore, SD is usually adopted when studying the relationships in the behaviour of a system over time and its underlying structure and decision rules so as to provide an easier way to understand the overall system and work out different relevant policy scenarios to manage the system's dynamic evolution mechanism [28, 29]. Applications of SD have been applied in different areas including urban waste management [30-32], construction waste management [33], electronic components recycling [34], packaging waste management [35], agricultural systems [27], business systems [36], care systems [37-39], ecological systems [40, 41], environmental systems [42], political decision-making systems [43] and social-economic systems [44]. Stella® is one of the dynamic modelling systems which have achieved broad recognition as its user-friendly iconographic interface simplifies the development of dynamic systems [45].

2.3. Studies related to SD for food waste management

There are many system assessment tools for decision support in waste management, for instance, cost-effectiveness analysis, environmental auditing, environmental impact assessment, life-cycle costing, material flow analysis, policy assessment [46], risk assessment, strategic environmental assessment, and substance flow analysis. Scholars can apply these assessment tools to offer policy-relevant and consistent results which are all based upon a simplified perception of reality expressed in the form of assumptions and uncertainties [47]. System dynamics modelling is one of the assessment instruments providing a useful modelling approach since the dynamic behaviour of all processes among all related variables can be comprehensively modelled. Modellers can use the SD approach to establish feedback loops, time delays, and both linear and nonlinear interactions of variables in all processes in integrated waste management in real-life situations [48].

One of the common applications of SD is in Municipal Solid Waste Management (MSWM) for forecasting waste generation. Dyson and Chang [49] constructed a SD model for predicting the solid waste generation in an urban environment with high potential for economic growth. Kollikkathara, et al. [50] employed SD modelling to evaluate the generation of waste for the Newark urban region in the US, landfill capacity, and the expenditure on related policies. Besides waste prediction, SD has been used to review the performance of waste policies. [51] used a system dynamics model to evaluate the potential impact of construction and demolition waste policies so as to propose how the government can improve the recycling system. The SD model has been used to predict municipal solid waste generation in developing countries and plan sustainable MSWM [52]. In addition to being used to support MSWM policy analysis, the results have indicated that SD models can offer a better understanding of the dynamic interactions and interdependencies of the key concerns of MSWM processes. Sudhir, et al. [53] applied a system dynamics model to capture the dynamic nature of the interactions between different components in the MSWM system. A model focused on generation, transportation and collection of MSW and the related economic and environmental effect of MSW was developed by Wang [54] in order to cope with an integrated waste management system.

Although many scholars have applied SD in solid waste management, they seldom use it when evaluating food waste management. Using system dynamics modelling can provide a whole picture of the effectiveness of the current food waste management policies for future waste generation by assessing the interrelation between different variables in the food waste management system.

3. Model development

In this research, a SD approach was considered to evaluate the effectiveness of food waste management in Hong Kong. The measurement of the effectiveness of the food waste management in Hong Kong considered the reduction gap in food waste disposal compared with the goal of the government for 2022. Stella® was used as the platform to design the dynamic model. In this section, the major variables that affect the effectiveness of food waste management are first identified and a causal loop diagram is constructed based on these variables and relationships. Then, the integrated causal loop diagram is converted into a stock flow diagram.

3.1. Causal loop diagram

The causal loop diagram visualises how different variables in a system are interrelated. It gives a general overview of the SD model. The proposed casual loop diagram is shown in **Fig. 1**. There is a causal link from one variable to another. Each arrow shows the effect of one variable on another because of it having either positive or negative polarity, marked as "+" and "-" respectively [55]. There is a positive polarity link if any two linked variables that have a relationship change in the same direction, and vice versa. A complete loop appears when the causal arrow links connect variables together. A reinforcing loop (R) occurs if an equal number of the same polarity arrow links exist, which indicates a variation of any variables that are eventually influenced in a positive way. Oppositely, a balancing loop (B) occurs if there are an unequal number of the same polarity arrows, which indicates a variation of any variable that is eventually influenced in a negative way. There are two balancing loops and one reinforcing loop in the diagram. Feedback loops B1 and B2 show that the increase of initialising the waste reduction plan and programmes drive a decrease of the waste generated by the household, commercial and industrial sector respectively. Feedback loop R1 indicates that the increase of the amount of collected waste leads to increased expenditure on food waste management.

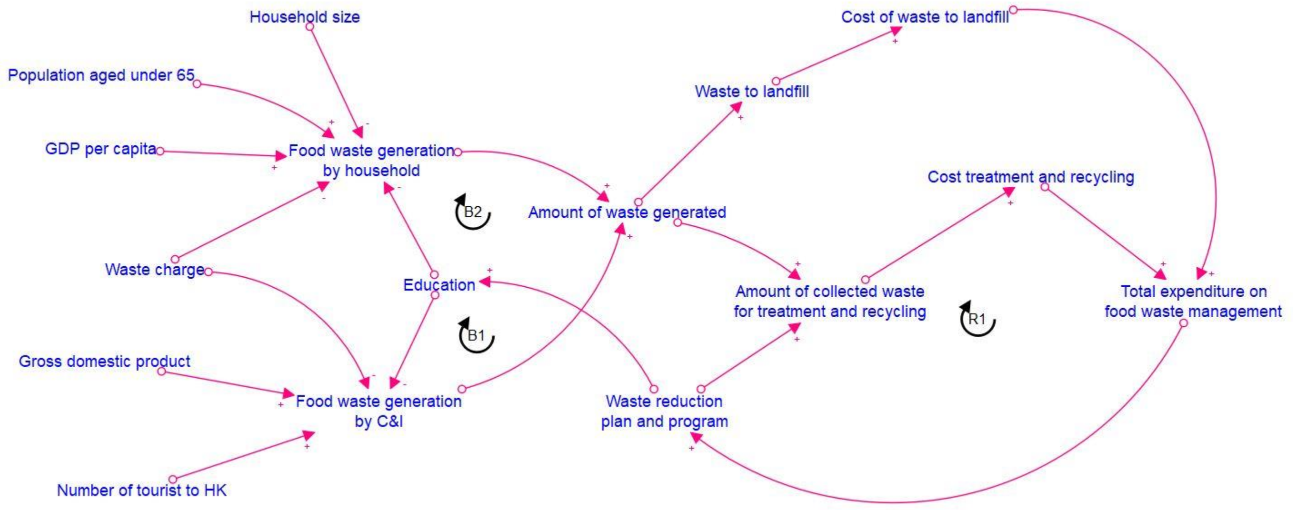

Fig. 1. Causal loop diagram of the food waste management system

3.2. Stock and flow diagram

The integrated causal loop diagram is transformed into a quantitative model, called the stock and flow diagram, to simulate the performance of each sector. The stock flow diagram involves three main elements, which are stock, flow, and converter. The stock is the element that indicates the state of the model. The flow is the element that can be defined as a time function. The flows show the variations of the stocks. For instance, flow-in raises the main element in the model, and flow-out reduces the main element in the model. The converters are auxiliary variables that allow a better visualisation of the variables that are affecting the behaviour of the flows. The connector, which is a transmitter, is connected between elements by an arrow [25]. The basic elements that can be found in the stock flow diagram are illustrated in **Fig. 8** of **Appendix A**.

After the design of the causal loop diagram of food waste management system is constructed as shown in **Fig. 1**, it is converted and transformed into a comprehensive stock and flow diagram as shown in **Fig. 9** of **Appendix A.** This model consists of four sub-models including food waste generation, waste treatment and recycling, landfilling and government expenditure.

3.2.1. Food waste generation sector

Fig. 2 shows a diagram of the food waste generation sector. The source of generation of food waste is mainly divided into two sectors: Domestic, and Commercial and Industrial (C&I) [15]. From the literature, there are various variables that influence the waste generation in each field, as shown in **Table 2** of **Appendix B**.

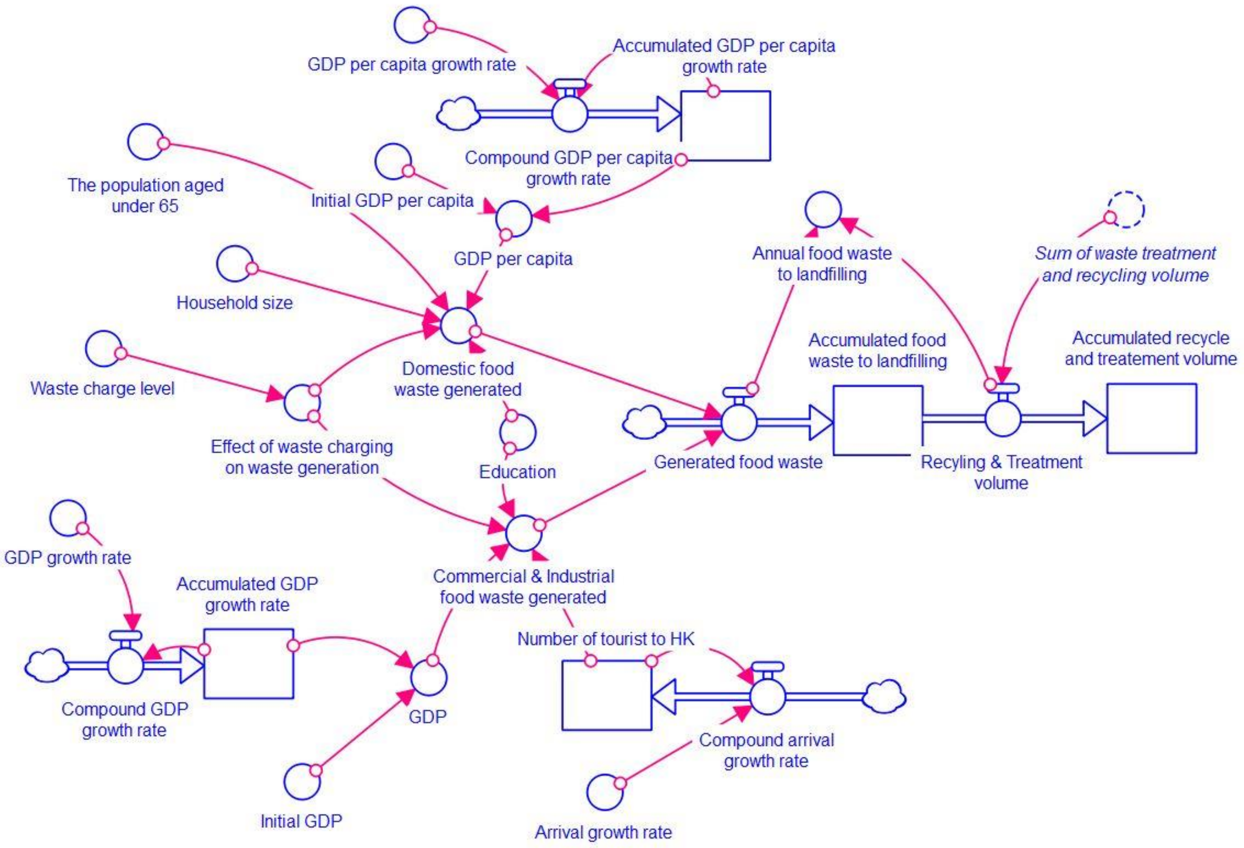

Fig. 2. Food waste generation sector

As for household food waste, various studies and researchers have found that the amount of food waste generated per person strongly depends on the household size [56-58]. The amount of food waste generated per person reduces with increasing family size. Also, domestic food waste generation is affected by the waste consumers' age. People aged 65 or over are found to produce significantly less food waste than the rest of the population [59-62]. Income has been found to have a positive linkage with domestic food waste generation. Higher income households tend to waste more than low-income households [61, 63]. In order to account for the income factor in regard to food waste generation, Jörissen, et al. [56] suggested using GDP per capita instead of GDP.

Education and waste charging policies are factors that tend to minimise waste generation. Education herein means the programmes and activities that are organised by the government. Examples of these types of programmes and activities include the Food Wise Hong Kong Campaign, advertising, competitions, etc. Education has been shown to be an essential component in enhancing awareness of waste generation [56] and encouraging public participation in recycling programmes [64]. Waste charging is a common economic instrument that has a direct impact on waste generation [65, 66] and recycling behaviour [64, 67, 68]. The Hong Kong Government intends to introduce a waste charging system [15]; hence, the impact of waste charging on food waste generation by households is also considered in the model.

As mentioned by the Director of Environmental Protection [69], C&I food waste has a correlation with the rising GDP and number of tourists coming to Hong Kong. According to a survey conducted by Oxfam Hong Kong [70], companies usually discard their surplus food. They face the difficulties of limited resources to handle their surplus food in a better manner, like food donation and recycling and the waste charging system might increase the burden on handling the waste. Similar to household food waste, education also plays an important role in minimising waste generation in the C&I food waste sector. Examples of educational aspects in the C&I sector are the Green Lunch Charter, Food Wise Eateries and Food Wise Hong Kong Campaign, etc.

3.2.2. Waste treatment and recycling sector

Apart from landfilling, there are other ways to treat food waste in Hong Kong, as shown in **Fig. 3**. The OWTF and the Kowloon Bay Pilot Composting Plant are facilities operated by the Hong Kong Government to recycle food waste from domestic and C&I to recover energy and nutrients. The OWTF applies a biological process of anaerobic digestion and composting to convert food waste into biogas as renewable energy and compost. For anaerobic digestion, it consists of three phases which are enzymatic hydrolysis, acid formation and gas production. The organic matter in the food waste will be broken down by the microorganisms to produce biogas through these processes. When the anaerobic digestion is completed, the residues can be used for the production of compost for agricultural applications. The first OWTF was opened in 2017 and an expanded OWTF will be ready to operate a few years later. Housing estates, which have participated in the Food Waste Recycling Project, have their own on-site composters to treat food waste. Moreover, some private operators recycle their waste for composting or animal feed. The government subsidises the OWTF in order to support it to enlarge the scale of its recycling throughput. South China Reborn Resources (Zhongshan) Company Limited in EcoPark, one of the supported entities, has signed an agreement to guarantee food waste recycling. Alternatively, food donation is also an option to handle the surplus food.

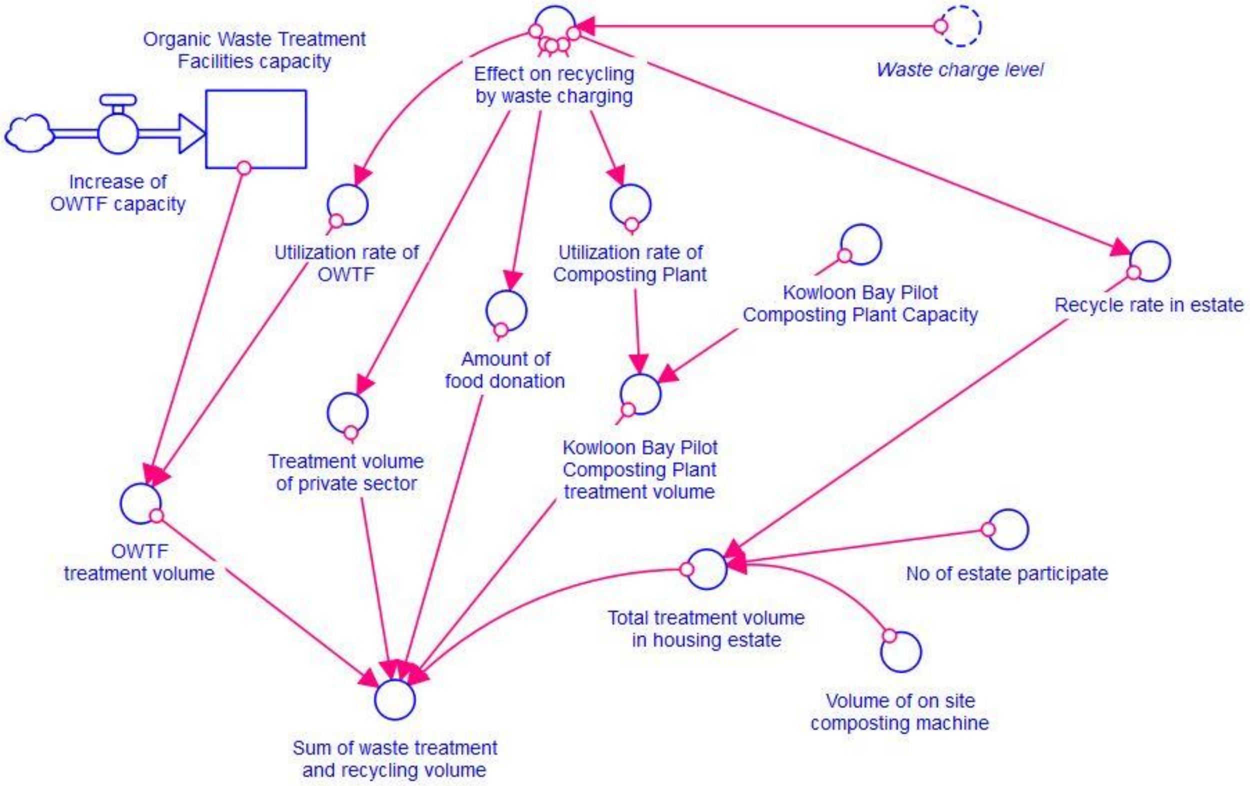

Fig. 3. Waste treatment and recycling sector

3.2.3. Landfilling sector

As shown in **Fig. 4**, this sector provides specific information about the utilisation of landfills. Hong Kong has three sites: the West New Territories (WENT) Landfill, South East New Territories (SENT) Landfill and North East New Territories (NENT) Landfill. Collected food waste is disposed of at these landfill sites. The SENT Landfill has accepted only construction waste since 6 January 2016, and has made an application to expand the landfill’s capacity. In this model, the expansion of landfills is not considered as the expected completion time is beyond the forecasting period.

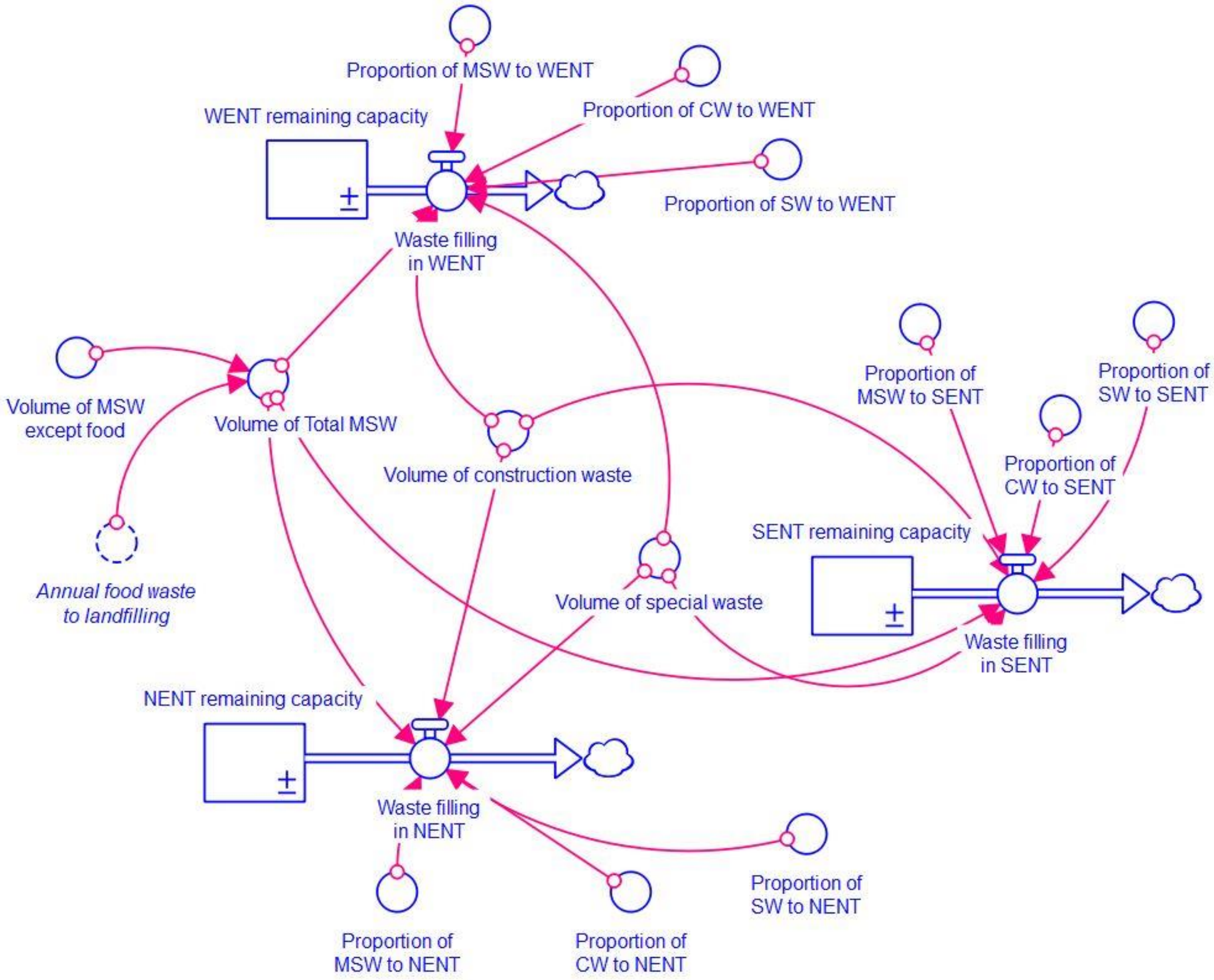

Fig. 4. Landfilling sector

3.2.4. Government expenditure sector

Fig. 5 shows the government expense involved in food waste management. The overall expenditure over the simulation period was simulated. The expenditure can be classified into four categories: the operation cost of the government's treatment facilities (Kowloon Bay Pilot Composting Plant and OWTF), subsidies for treatment and recycling in the private sector, expenses for education and expenses for disposing of food waste in landfills.

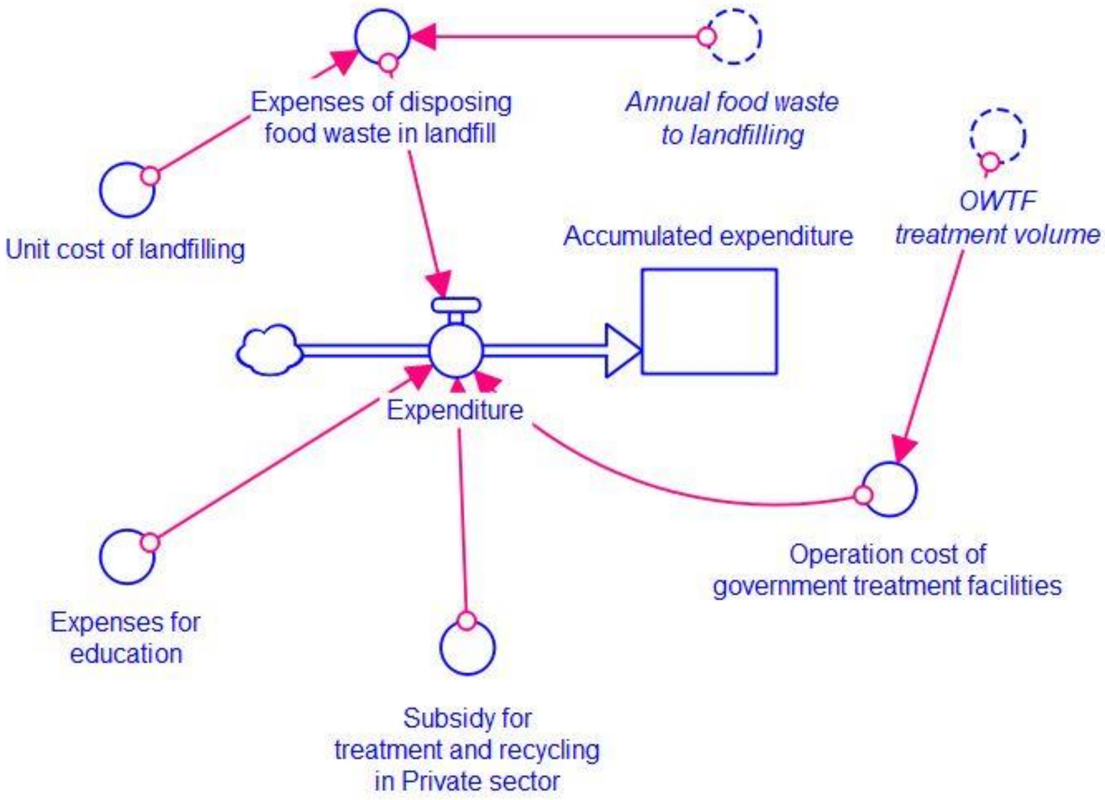

Fig. 5. Government expenditure sector

4. Model validation

In order to make sure that the model is appropriate, model validation was carried out. There are some criteria to objectively validate the result of a SD model. The parameter settings in the SD model are presented in **Table 4** (see **Appendix C**) Barlas [71] and Coyle [72] further elaborated and extended the criteria into a number of steps and guidelines to build confidence in the SD model. If the model fulfils these criteria, it can be stated that the model is valid. The validation steps proposed by Coyle [72] were adopted in this study in order to build up confidence.

1) The causal loop diagram must relate to the statement of the problem.

Fig. 1 in Section 3.1 illustrates the causal loop diagram of food waste management in Hong Kong, considering waste generation, waste treatment and recycling, and government expenditure. Thus, it is considered that the causal loop diagram effectively describes the problem statement. The value of these variables can be acquired from information in research papers, reports or governmental regulations. **Table 3** (See **Appendix C**) lists the sources of data.

2) The relationship of the equation in the stock flow diagram should be consistent with the

relationship portrayed in the causal loop diagram.

The casual loop diagram in **Fig. 1** consists of both a proportional and inversely proportional relationship among the variables, which is related to the equation in the stock flow diagram in **Fig. 9** of **Appendix A**. Therefore, if the relationship of the equation in the stock flow diagram is inconsistent with the relationship portrayed in the causal loop diagram, infeasible results will be obtained.

3) The behaviour of the model must reasonably represent the real system.

The proposed model was set to run from the year 2011 to 2014 so as to compare the actual annual waste sent to landfills (tonnes per year), as illustrated in **Table 1**. It can be noticed that the mean percentage error

and absolute mean percentage error of the annual waste sent to landfills is below 5%, which is a similar outcome compared to the actual result. The results of the validation suggest that the proposed model can accurately forecast the results of changes in the variable.

Table 1

Statistical comparison of annual waste sent to landfills

Year	Simulated annual waste sent to landfills (tonne)	Actual annual waste sent to landfills (tonne)	Difference (tonne)	Absolut percentage error (%)
2011	1,221,256	1,308,160	86,904	6.64
2012	1,249,073	1,218,005	-31,068	2.56
2013	1,275,375	1,331,520	56,145	4.22
2014	1,299,529	1,328,965	29,436	2.21
			Mean percentage error	2.63
			Absolute mean percentage error	3.91

4) The model should behave properly even when it is subjected to extreme conditions.

Taking the variable OWTF treatment volume of waste treatment in the recycling sector as an example, the variable can be influenced by the Organic Waste Treatment Facility capacity, and the utilisation rate of the OWTF. Since the OWTF is a new food waste treatment facility in Hong Kong, the actual utilisation rate cannot be clearly identified. Thus, the utilisation rate of the OWTF was determined by referring to the utilisation rate of the Kowloon Bay Pilot Composting Plant, which is 0.47. The utilisation rate of the OWTF can range from 0 to 1. By using different utilisation rates of the OWTF, the result of the treatment volume will be different as shown in **Fig. 10** of **Appendix E**.

The first case scenario concerns using a utilisation rate of 0.1, the second case scenario concerns using a utilisation rate of 0.47 and the third case scenario concerns using a utilisation rate of 0.9. We can observe that the treatment volume of the OWTF in tonnes per year can have variance by using different utilisation rates. The performance of the sum of the waste treatment and recycling volume will also be affected due to the change in treatment volume of the OWTF as a result. Other variables in the model can be analysed in a similar way. The outcomes of the above checking ensure that the proposed model can sensibly mirror the actual food waste management. Therefore, it can be concluded that the model performs as per the real situation accurately.

5) Sensitivity analysis

Sensitivity analysis is one of the validation tests to detect whether the model is sufficiently sensitive to contribute any major differences when changing the value of the parameters. Besides, it can validate whether the parameter is reasonable if the model behaves as expected from observations. Since the GDP and the number of tourists coming to Hong Kong are significant in regard to food waste generation from the regression analysis in Section 3.2.1, the sensitivity of the model was further examined using these parameters. The values for GDP and the number of tourists coming to Hong Kong were extracted from the lowest and highest based on the 10-year historical data. Among the figures in **Appendix E**, the higher the GDP, the more the food waste generation. Similarly, the higher the number of tourists coming to Hong Kong, the lesser the food waste generation. Moreover, increased GDP and number of tourists coming to Hong Kong can result in an obvious change in food waste generation. This demonstrates that the model is sensitive and the parameters are reasonable.

5. Scenario analysis of food waste management in Hong Kong

The previous section illustrates the validation process for this SD model and guarantees the reliability of the model. The model was employed to simulate the performance of food waste management in Hong Kong firstly without any significant management policy changes. This base run can comprehensively forecast the amount of food waste disposed of in landfills and the expenditure on handling food waste if no food waste management policy is implemented, such as quantity-based MSW charging scheme and operating the OWTF, etc. Alternative food waste treatments were included in the simulation, for a better comparison of different management policy scenarios.

Table 5 (see **Appendix E**) shows that the annual food waste sent to landfills has increased continuously which implies that more food will be consumed and disposed of. Consequently, the increased annual food waste sent to landfills will lead to increased expenditure on food waste management including around 98% on handling food waste in landfills. The result shows that if the government does not improve its waste management policy, the food waste problem will be become more serious as the amount of food waste sent to landfills will rise rapidly. In addition, the total handling fee for food waste is projected to increase in the future.

The three strategic landfills' remaining capacity is displayed in **Fig. 12**, **Fig. 13** and **Fig. 14** (see **Appendix E**). The disposal of municipal solid waste and special waste has been prohibited since 2016; such waste is disposed of in the remaining two landfills. The slope of the lines for the remaining two landfills show that both of them have become burdened since 2016. Besides, the SENT landfill and

WENT landfill will be saturated in 2020 and 2024 respectively and the negative remaining capacity shows the required additional area to handle the excess waste. Consequently, the government needs to spend more money and find more area for handling waste, which does not practically solve the root cause.

5.1. Scenario development

According to the food waste reduction plan proposed by the Environment Bureau, three policy scenarios were selected for analysis of the effectiveness of dealing with food waste. The purpose of these scenarios was to compare how the policy can reduce the amount of food waste and expenses for handling food waste.

(a) In scenario 1 (S1), the OWTF was chosen to recycle the food waste. The OWTF aims to minimise the amount of landfill disposal through recycling organic waste and changing it into useful products for energy recovery. The first OWTF started to operate in 2017 and handles 200 tonnes of food waste per day (73,000 tonnes per year) and the second OWTF is scheduled to commence operations in 2021 and will deal with 300 tonnes of food waste per day (109,500 tonnes per year).

(b) Scenario 2 (S2) reflected that a quantity-volume-based charging scheme will be introduced in 2019. Waste charging is an effective way that not only reduces the amount of waste generated but also increases the recycling rate. By referring to the experience in Taipei and South Korea, the waste charge level is set to be HKD0.11/L to achieve a positive effect on waste reduction and waste recycling.

(c) In scenario 3 (S3), a mixed effect of scenarios 1 and 2 was evaluated, the aim of which was to examine the effectiveness of food waste management by implementing the two policies together. It was expected that the result of implementing multiple policies would be distinctive compared to scenario 1 and scenario 2.

The simulated result of waste generated and the government expenditure on food waste management for each scenario is shown in **Fig. 6** and **Fig. 7** respectively. **Fig. 10** and **Fig. 11** of **Appendix D** show more detailed results for each scenario. The simulated results of waste generated, Government expenditure and OWTF treatment volume are presented in **Table 6**, **Table 7** and **Table 8** correspondingly (see **Appendix D**).

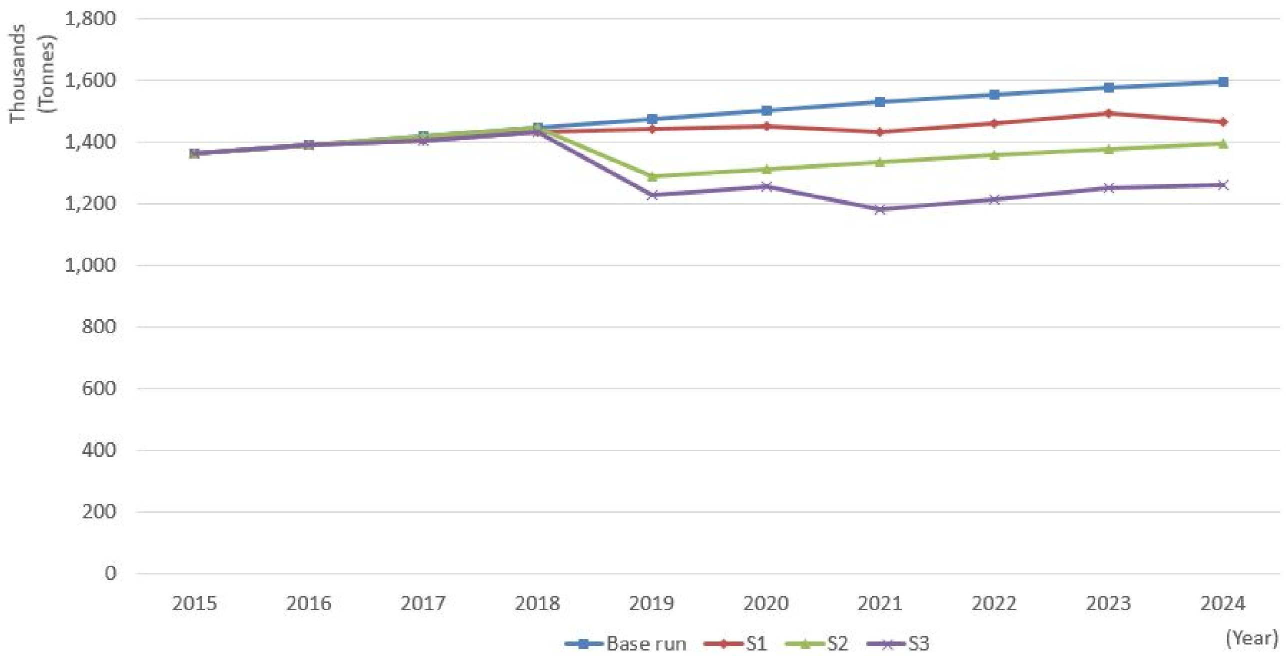

Fig. 6. Simulated result of waste generated for each scenario

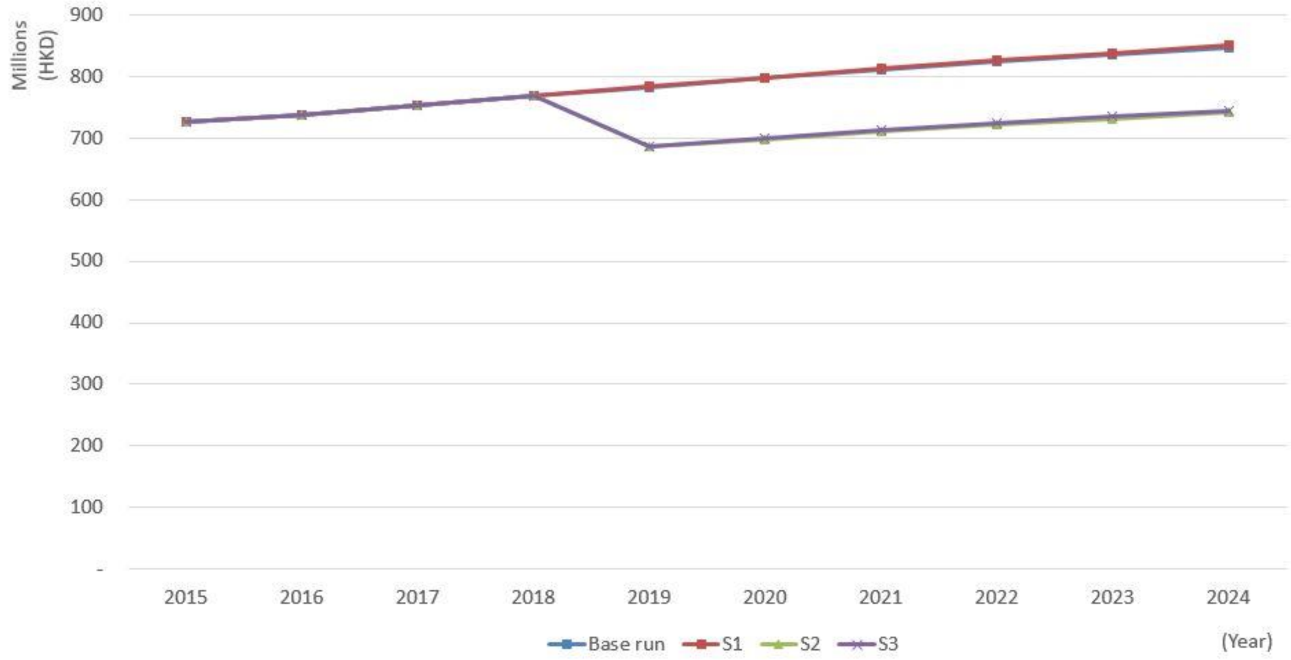

Fig. 7. Simulated result of the government expenditure for each scenario

5.2. Result and analysis

Compared to the base scenario, scenario 1 exhibited the smallest improvement (3.46%) in reducing the annual amount of food waste sent to landfills. Although adopting the OWTF to recycle food waste will contribute to recycling from an average of 27,700 tonnes per year from 2017-2020 to 100,700 tonnes per year from 2021-2024 as shown in Appendix E, the growth rate of the dumping of food waste is the same as the base run, as a result. The recycling rate is not high enough to handle the large amount of food waste, while the total expenses for waste management in scenario 1 have increased by 0.17% due to the operation cost of government treatment facilities. It can be concluded that adopting the OWTF to recycle food waste will slightly reduce the volume of dumping, which cannot effectively alleviate the problem.

In scenario 2, it can be noted that the amount of food waste sent to landfills can be reduced by 4.58%, which is better than scenario 1. Besides, there will be a significant drop in 2019 due to the waste charge implementation. However, the amount of waste sent to the landfills will again increase because of economic growth. The total expenses for waste management decreased by 7.72% as there is less waste dumping in landfills directly in contrast to the base run's situation. The result shows that the waste charge policy is more effective than adopting the OWTF, and the net increase in expenses can be used to implement the other policy to reduce food waste.

The result of scenario 3 shows a 5.11% decrease in the annual amount of food waste sent to landfills. The mixed policy can achieve a more effective reduction of food waste. Although the expense on waste management is slightly greater than in scenario 2 due to the operation cost of government treatment facilities, the effectiveness of handling food waste is distinctive compared to scenarios 1 and 2.

6. Discussion

The base run and three policy scenario results provide an insight into the effectiveness of food waste management in Hong Kong. The food waste management system is complex, including numerous variables, that are interrelated with each other. It can be observed that adopting the OWTF to recycle food waste (Scenario 1), introducing quantity-volume-based charging (Scenario 2) and multiple policies of adopting the OWTF and introducing waste charging (Scenario 3) can reduce the amount of food waste sent to landfills compared to the base run. Although the cost of implementing waste charging is neglected in this model, the benefits of waste charging can probably eliminate the negative effect of the additional cost of waste management. Among the three policy scenarios, scenario 3 has the most effective impact since it has the smallest amount of food waste sent to landfills as it not only increases the amount of recycled food waste but also lowers the waste generation. However, the target amount of food waste sent to landfills by the government is 788,400 tonnes a year by 2022. By evaluating the impact of the policy proposed by the government on waste monitoring, it is unlikely to reach the waste reduction target within the scheduled time if no new policies or modifications of the existing policies are planned.

7. Conclusion

Food waste has become a priority in regard to waste management in Hong Kong. The Hong Kong

Government has made a great deal of effort to manage food waste through recycling campaigns, promotion and education, etc. In order to understand the effectiveness of the actions taken by the government, System Dynamics (SD) modelling is used to illustrate how food waste can be better managed by the government. From a review of the literature, most of the recent research papers have focused on using SD models to forecast MSW rather than food waste in particular. During SD model development, the major variables that influence food waste management, including food waste generation, collection and treatment, landfilling and expenditure are identified. Model validation provides confidence in the model in that the model can reflect the actual system. Through conducting a series of scenario analyses, the SD model has shown its ability to provide an experimental platform to model and evaluate the effectiveness of different management policies.

The effectiveness of the food waste management in Hong Kong has been investigated, and it is found that the recent policies such as implementation of the OWTF cannot fulfil the waste reduction target within the scheduled time. Thus, education is another tool to prevent waste and increase the recycling rate. Similar to waste charging, education changes the waste producers' behaviour through raising their awareness of the negative impact of the disposal of food waste and being responsible for the environment. Examples of these types of initiatives include advertising, school programmes, training, and competitions. Thus, citizens will be more willing to reduce waste generation and recycle waste. If the Hong Kong Government can allocate more resources to educating the public, together with the implementation of a waste charge scheme and the OWTF, the waste reduction target set by the government may be achieved.

In this study, some of the major variables that influence food waste management have been identified, but not assessed and discussed, since they are abstract or not publicly available. For example, several surveys conducted by private research organisations have mentioned that cost is the major concern of restaurants in dumping food scrap in landfills directly, or through recycling, but it is difficult to link the cost of handling waste to the amount of waste generated directly, as the data are difficult to collect. Moreover, education is also a major variable in the waste generation and recycling dimension, but it is not easily quantified and difficult to relate to government expenditure on education. Therefore, this model uses a constant value provided by the government to evaluate the effect on the waste generation in C&I and domestically without connecting to the expenditure on education. In future development, surveys can be conducted to better understand how the factors contribute to waste generation and recycling. Improving the model's accuracy and capability to reflect the real-life situation through analysing and updating more data from more case studies is a future recommendation.

Appendix A. Structure of the stock flow diagram in the model

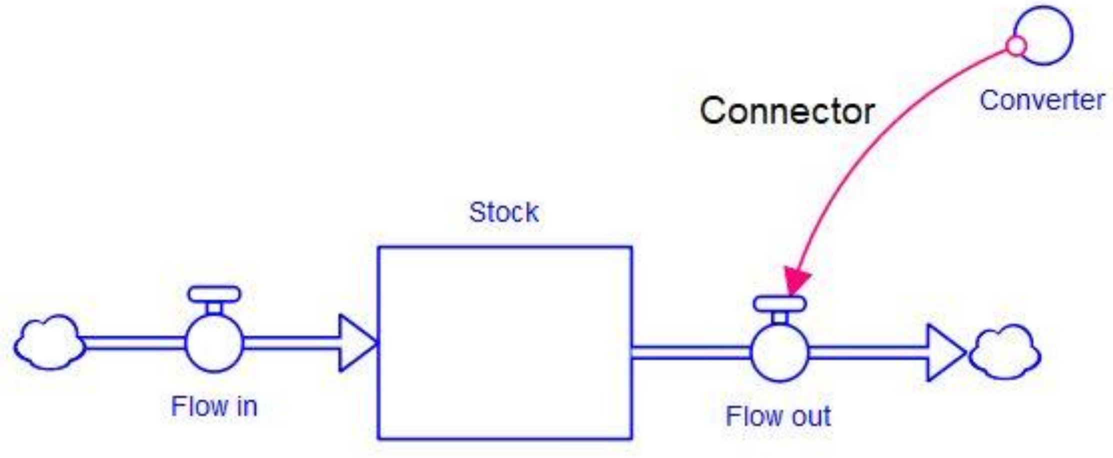

Fig. 8. Basic elements in the stock flow diagram

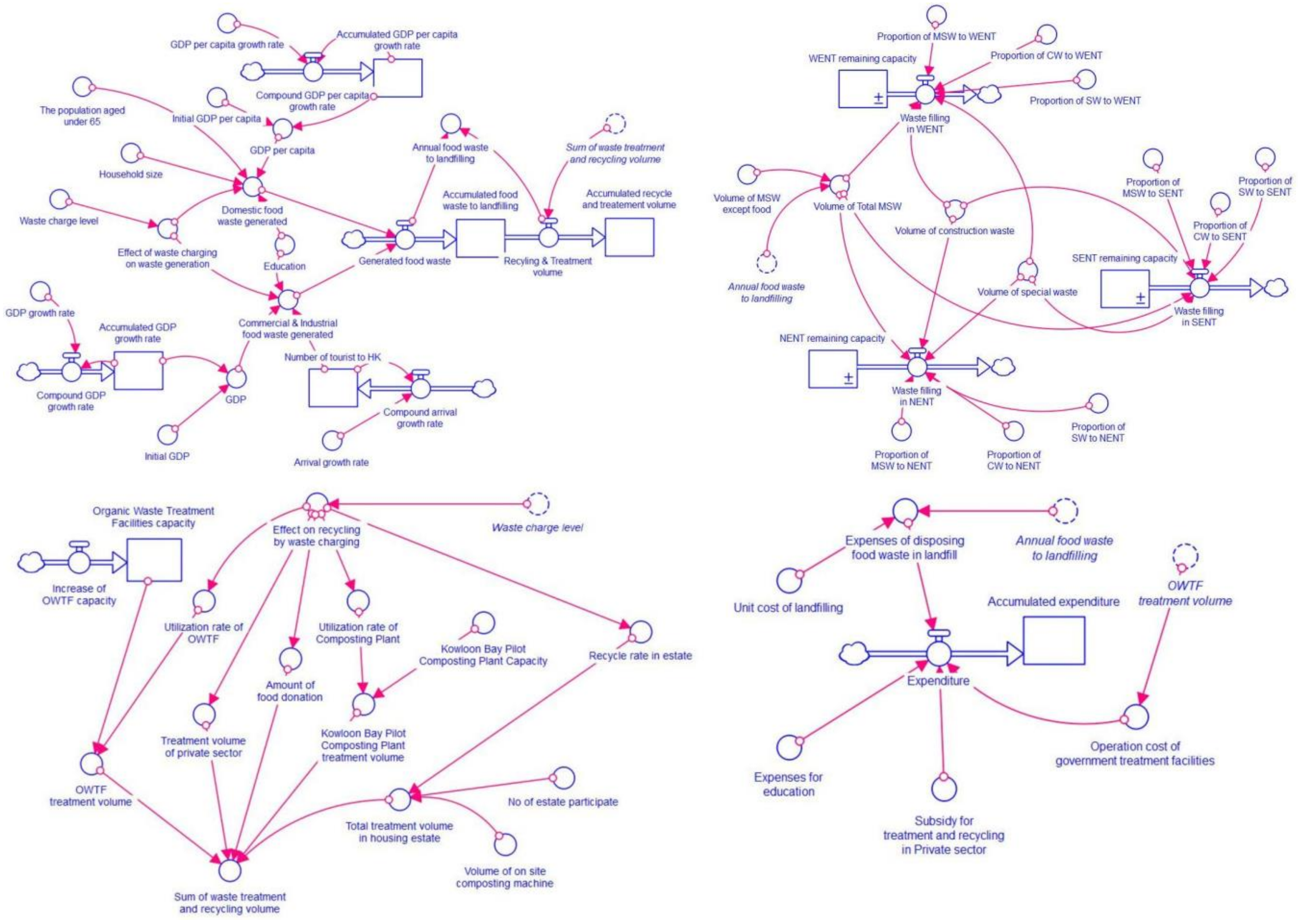

Fig. 9. Structure of the system dynamics model for food waste management from each sub-model

Appendix B. Variables affecting food waste generation

Table 2

Variables affecting food waste generation

Fields	Variables
Domestic food waste	Household size Population aged under 65 Gross domestic product per capita Waste charge Education level
C&I food waste	Number of tourist to Hong Kong
	Gross domestic product (GDP)
	Waste charge
	Education level

Appendix C. Parameters used in the simulation model

Table 3

Source of data

Subsystem	**Variables**	**Unit**	**Source**
Landfilling	WENT remaining capacity	tonnes	Environment Bureau [14]
	SENT remaining capacity	tonnes	Environment Bureau [14]
	NENT remaining capacity	tonnes	Environment Bureau [14]
	Volume of MSW expect food	tonnes/year	Environmental Protection Department [73]
	Volume of construction waste	tonnes/year	Environmental Protection Department [73]
	Volume of special waste	tonnes/year	Environmental Protection Department [73]
	Proportion of MSW to WENT	%	Environmental Protection Department [73]
	Proportion of MSW to SENT	%	Environmental Protection Department [73]
	Proportion of MSW to NENT	%	Environmental Protection Department [73]
	Proportion of CW to WENT	%	Environmental Protection Department

			[73]
	Proportion of CW to SENT	%	Environmental Protection Department [73]
	Proportion of CW to NENT	%	Environmental Protection Department [73]
	Proportion of SW to WENT	%	Environmental Protection Department [73]
	Proportion of SW to SENT	%	Environmental Protection Department [73]
	Proportion of SW to NENT	%	Environmental Protection Department [73]
Government Expenditure	Unit cost of landfilling	$/ton	Audit Commission [16]
	Expenses for education	$/year	Audit Commission [16]
	Subsidy for treatment and recycling in Private sector	$/year	Public Accounts Committee [69]
	Operation cost of government treatment facilities	$/year	Audit Commission [16], Legislative Council Secretariat [74]
Waste Treatment and Recycling	Increase of OWTF capacity	tonnes	Audit Commission [16]
	Kowloon Bay Pilot Composting Plant Capacity	tonnes/year	Audit Commission [16]
	Utilisation rate of OWTF	%	Audit Commission [16]
	Utilisation rate of Composting Plant	%	Audit Commission [16]
	Amount of food donation	tonnes/year	The Conservancy Association [75], Food Angel [76]
	Treatment volume of private sector	tonnes/year	Legislative Council Secretariat [77], Allied Environmental Consultants Ltd. [78]
	Recycle rate in estate	%	Audit Commission [16]
	No of estate participate		Audit Commission [16]
	Volume of on site composting machine	tonnes/year	Audit Commission [16]
	Effect on recycling by waste charging	%	Korea Ministry of Environment [79]
Food Waste Generation	Household size		Census and Statistics Department [80]
	The population aged under 65		Census and Statistics Department [80]
	Waste charge level	$/L	Korea Ministry of Environment [79],

			Department of Environmental Protection [81]
	Initial GDP per capita	$	Census and Statistics Department [82]
	GDP per capita growth rate	%	Census and Statistics Department [82]
	GDP growth rate	%	Census and Statistics Department [82]
	Initial GAP	$	Census and Statistics Department [82]
	Arrival growth rate	%	Census and Statistics Department [83]
	Number of tourist to HK		Census and Statistics Department [83]
	Education	%	Environmental Protection Department [73]
	Effect of waste charging on waste generation	%	Korea Ministry of Environment [79]

Table 4

Parameter setting in the System Dynamics model

Subsystem	**Variables**	**Value**
Landfilling	WENT remaining capacity	23365825
	SENT remaining capacity	5131830
	NENT remaining capacity	15551480
	Volume of MSW expect food	2241465
	Volume of construction waste	1438830
	Volume of special waste	413910
	Proportion of MSW to WENT	IF time>2015 then 0.729 else 0.533
	Proportion of MSW to SENT	if time >2015 then 0 else 0.269
	Proportion of MSW to NENT	if time > 2015 then 0.271 else 0.198
	Proportion of CW to WENT	0.149
	Proportion of CW to SENT	0.736
	Proportion of CW to NENT	0.116
	Proportion of SW to WENT	if time >2015 then 0.779 else 0.529
	Proportion of SW to SENT	if time >2015 then 0 else 0.321
	Proportion of SW to NENT	if time > 2015 then 0.221 else 0.150
Government	Unit cost of landfilling	520

Expenditure	Expenses for education	10450000
	Subsidy for treatment and recycling in Private sector	2609640
	Operation cost of government treatment facilities	2870000+546*OWTF__treatment_volume
Waste Treatment and Recycling	Increase of OWTF capacity	if time = 2016 then 73000 else if time = 2020 then 109500 else 0
	Kowloon Bay Pilot Composting Plant Capacity	500
	Utilisation rate of OWTF	(if time > 2016 AND time < 2019 then 0.2 else if time > 2018 then RANDOM(0.4,0.75) else 0) *(1+Effect_on_recycling_by_waste_charging)*0
	Utilisation rate of Composting Plant	RANDOM(0.4,0.75)*(1+Effect_on_recycling_by_waste_charging)
	Amount of food donation	1510*(1+Effect_on_recycling_by_waste_charging)
	Treatment volume of private sector	(if time <2015 then 4320 else if time =2015 then (4320+3600) else (4320+700*12))*(1+Effect_on_recycling_by_waste_charging)
	Recycle rate in estate	RANDOM(0.1,0.15)*(1+Effect_on_recycling_by_waste_charging)
	No of estate participate	37
	Volume of on site composting machine	18.3
Food Waste Generation	Household size	2.9
	The population aged under 65	86.9
	Waste charge level	0
	Initial GDP per capita	311835
	GDP per capita growth rate	0.048
	GDP growth rate	0.056
	Initial GAP	2.39712E+12
	Arrival growth rate	0.1
	Number of tourist to HK	60838836
	Education	0.1

Appendix D. The results for model analysis

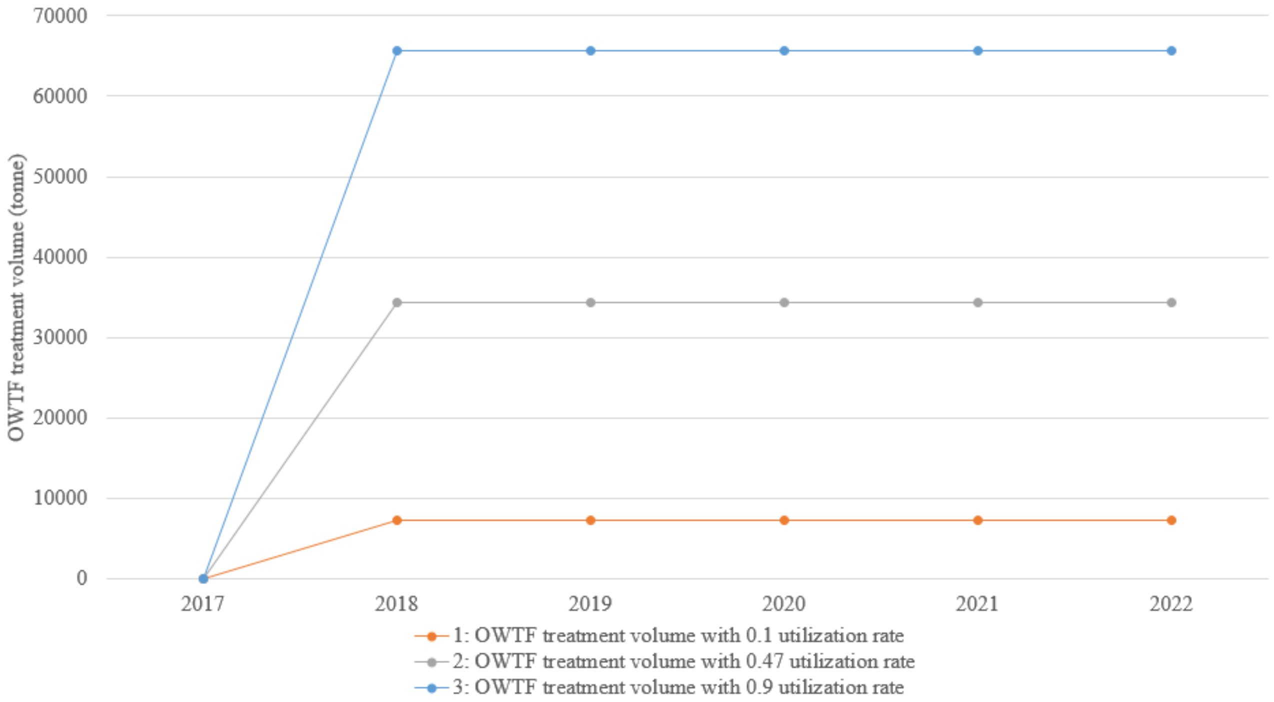

Fig. 10. The result of OWTF treatment volume with different utilization rate

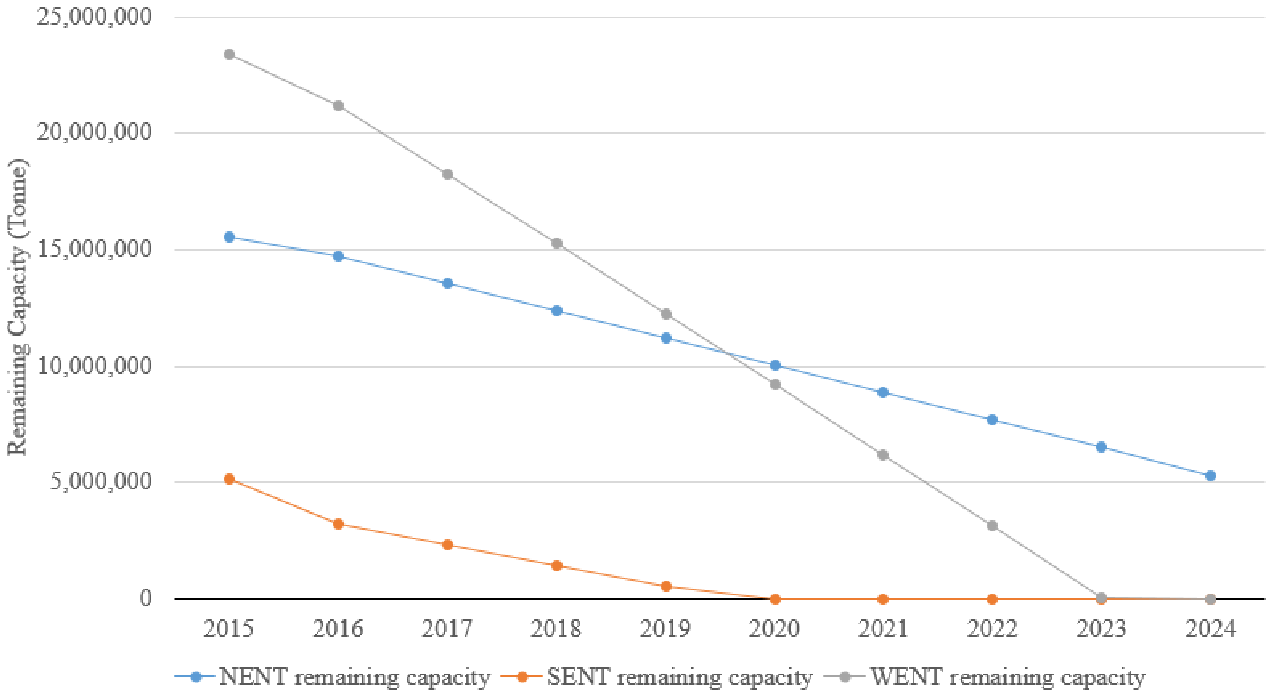

Fig. 11. The situation of the three strategic landfills' remaining capacity

Table 5

Simulated result of annual food waste sent to landfills and annual expenditure on food waste management in 2015 – 2024

Year	Annual food waste sent to landfills (tonne)	Annual expenditure on food waste management (HKD)	Expenses for disposing of food waste in landfills (HKD)
2015	1,364,673	725,559,406	709,629,766
2016	1,388,915	738,165,577	722,235,937
2017	1,417,801	753,186,271	737,256,631
2018	1,446,390	768,052,522	752,122,882
2019	1,474,573	782,707,672	766,778,032
2020	1,501,724	796,826,171	780,896,531
2021	1,528,142	810,563,606	794,633,966
2022	1,553,086	823,534,553	807,604,913
2023	1,576,322	835,617,149	819,687,509
2024	1,597,481	846,619,774	830,690,134
Total	14,849,108	7,880,832,701	7,721,536,301

Table 6

Simulated result of waste generated for each scenario by year

Year	Base run	S1	S2	S3
2015	1,364,673	1,364,577	1,364,551	1,364,603
2016	1,388,915	1,388,926	1,388,812	1,388,967
2017	1,417,801	1,403,175	1,417,878	1,403,200
2018	1,446,390	1,431,751	1,446,464	1,431,773
2019	1,474,573	1,441,921	1,287,497	1,229,001
2020	1,501,724	1,452,708	1,311,415	1,256,260
2021	1,528,142	1,431,966	1,334,394	1,180,008
2022	1,553,086	1,458,819	1,356,148	1,213,421
2023	1,576,322	1,494,325	1,376,509	1,251,442
2024	1,597,481	1,466,897	1,395,185	1,261,485
Total	14,849,108	14,335,064	13,678,852	12,980,160
%[a]		3.46%	4.58%	5.11%

Table 7

Simulated result of the government expenditure for each scenario by year

Year	Base run	S1	S2	S3
2015	725,559,406	725,509,475	725,496,169	725,523,286
2016	738,165,577	738,170,904	738,111,977	738,192,565
2017	753,186,271	753,552,033	753,226,055	753,565,228
2018	768,052,522	768,411,576	768,090,887	768,423,260
2019	782,707,672	783,549,475	685,427,924	686,923,937
2020	796,826,171	798,175,674	697,865,504	699,309,486
2021	810,563,606	813,012,105	709,814,484	713,842,947
2022	823,534,553	825,972,220	721,126,491	724,855,109
2023	835,617,149	837,741,743	731,714,226	735,004,788
2024	846,619,774	850,012,205	741,425,847	744,927,798
Total	7,880,832,701	7,894,107,410	7,272,299,565	7,290,568,404
%[b]		-0.17%	7.72%	7.49%

Table 8

Simulated result of the OWTF treatment volume for scenario 1

Year	Organic Waste Treatment Facilities capacity (tonne)	OWTF treatment volume (tonne)	Utilisation rate of OWTF
2015	0	0	0
2016	0	0	0
2017	73,000	14,600	0.2
2018	73,000	14,600	0.2
2019	73,000	58,450	0.8
2020	73,000	55,173	0.76
2021	182,500	154,413	0.85
2022	182,500	142,759	0.78
2023	182,500	125,138	0.69
2024	182,500	133,747	0.73

Appendix E. Sensitivity analysis

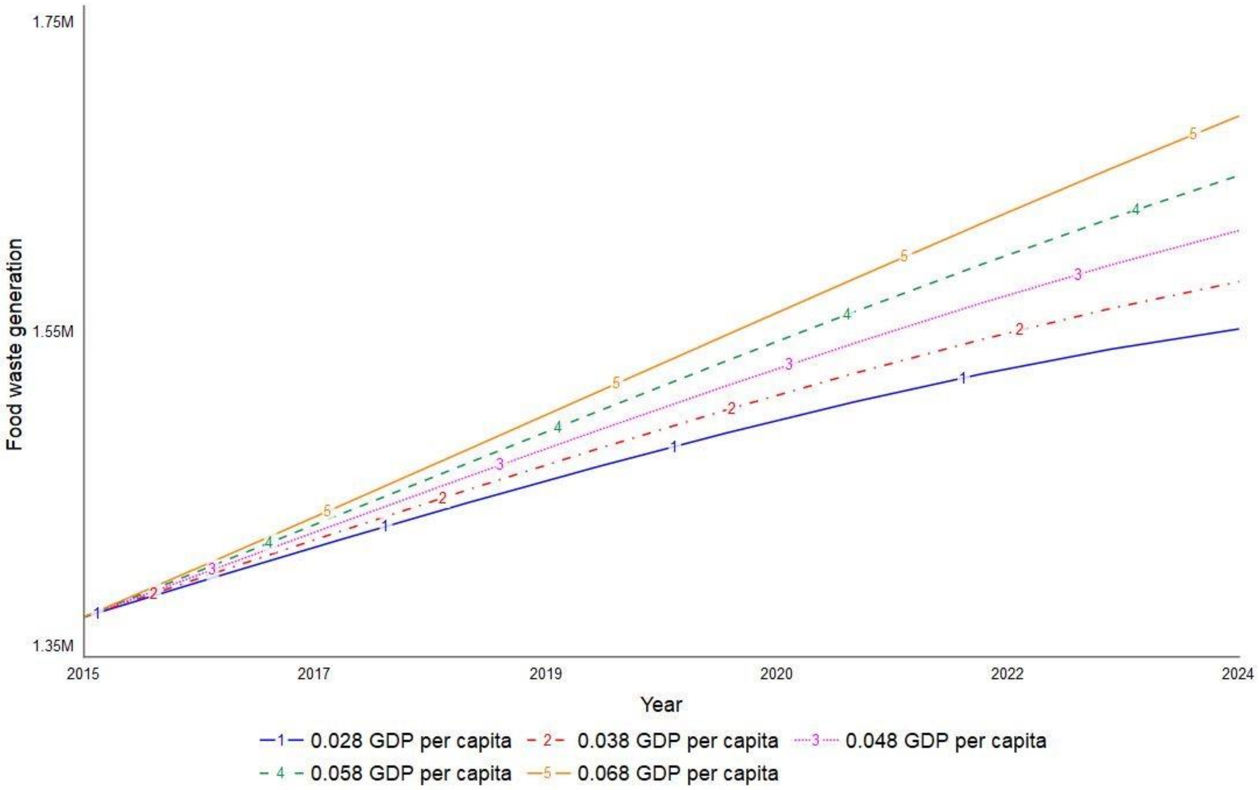

Fig. 12. Simulated result for the food waste generation with various GDP per capita

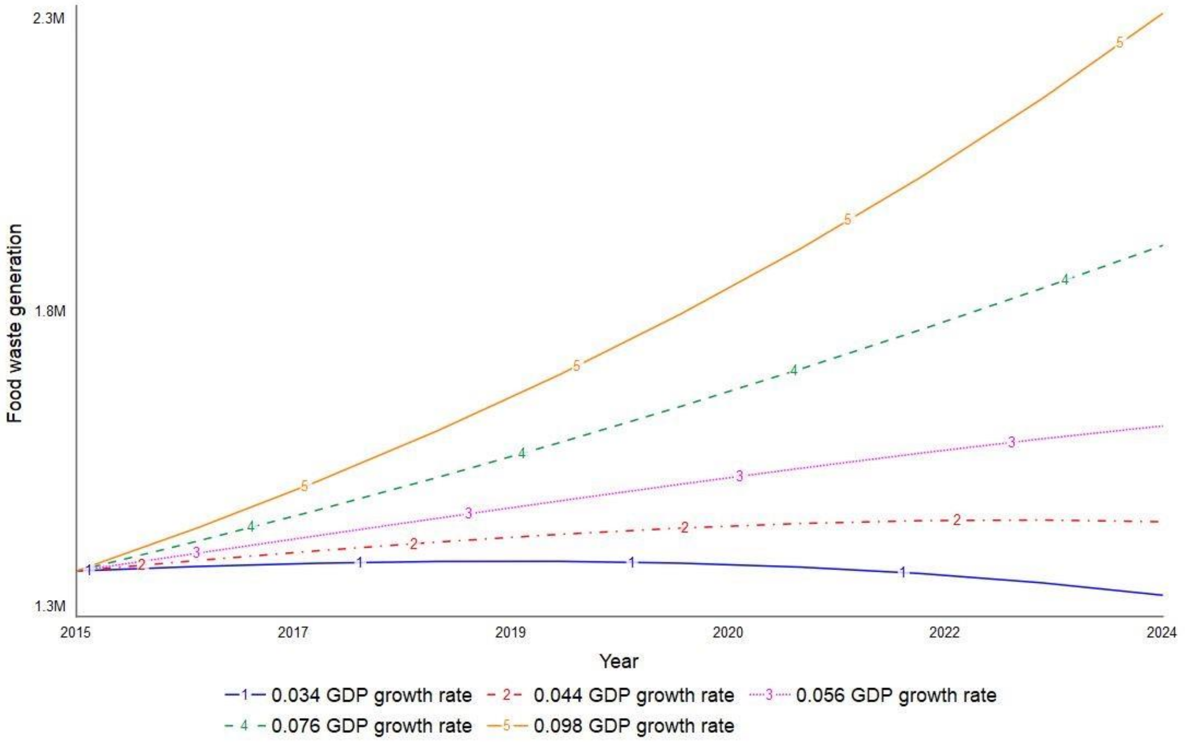

Fig. 13. Simulated result for the food waste generation with various GDP growth rate

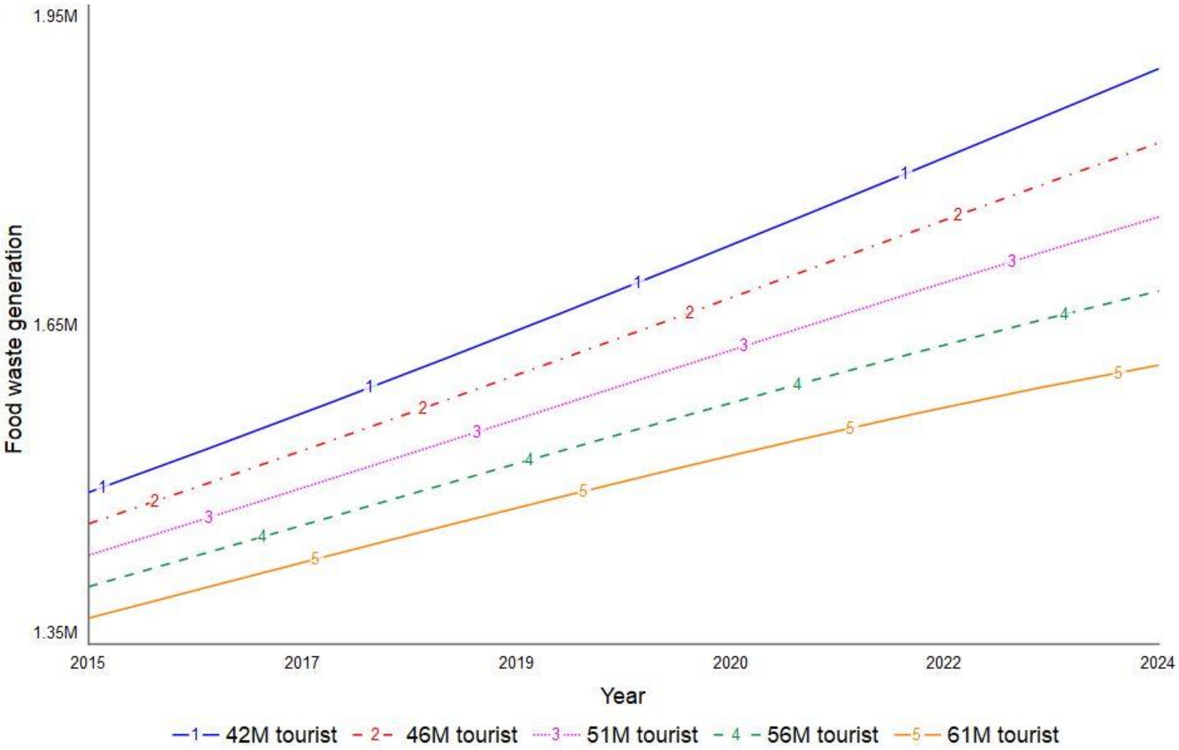

Fig. 14. Simulated result for the food waste generation with various total number of tourists to Hong Kong

Appendix F. Model equations

Accumulated_expenditure(t) = Accumulated_expenditure(t - dt) + (Expenditure) * dt

INIT Accumulated_expenditure = 0

INFLOWS:

Expenditure = Operation_cost_of__government_treatment_facilities+Expenses_of_disposing_food_waste_in_landfill+Expenses_for__education+Subsidy_for__treatment_and_recycling_in_Private_sector

Accumulated_food_waste_to_landfilling(t) = Accumulated_food_waste_to_landfilling(t - dt) + (Generated_food_waste - Recyling_&_Treatment_volume) * dt

INIT Accumulated_food_waste_to_landfilling = 0

INFLOWS:

Generated_food_waste = Domestic_food__waste_generated+Commercial_&_Industrial_food_waste_generated

OUTFLOWS:

Recyling_&_Treatment_volume = Sum_of_waste_treatment_and_recycling_volume

Accumulated_GDP_growth_rate(t) = Accumulated_GDP_growth_rate(t - dt) + (Compound_GDP_growth_rate) * dt

INIT Accumulated_GDP_growth_rate = 1

INFLOWS:

Compound_GDP_growth_rate = CGROWTH(GDP_growth_rate*100)*Accumulated_GDP_growth_rate

Accumulated_GDP_per_capita_growth_rate(t) = Accumulated_GDP_per_capita_growth_rate(t - dt) + (Compound_GDP_per_capita_growth_rate) * dt

INIT Accumulated_GDP_per_capita_growth_rate = 1

INFLOWS:

Compound_GDP_per_capita_growth_rate = CGROWTH(GDP_per_capita_growth_rate*100)*Accumulated_GDP_per_capita_growth_rate

Accumulated_recycle_and_treatement_volume(t) = Accumulated_recycle_and_treatement_volume(t - dt) + (Recyling_&_Treatment_volume) * dt

INIT Accumulated_recycle_and_treatement_volume = 0

INFLOWS:

Recyling_&_Treatment_volume = Sum_of_waste_treatment_and_recycling_volume

NENT_remaining_capacity(t) = NENT_remaining_capacity(t - dt) + (- Waste_filling__in_NENT) * dt

INIT NENT_capacity = 15551480

OUTFLOWS:

Waste_filling__in_NENT = Volume_of_Total_MSW*Proportion_of__MSW_to_NENT+Volume_of_construction_waste*Proportion_of__CW_to_NENT+Volume_of_special_waste*Proportion_of__SW_to_NENT

Number_of_tourist_to_HK(t) = Number_of_tourist_to_HK(t - dt) + (Compound_arrival_growth_rate) * dt

INIT Number_of_tourist_to_HK = 60838836

INFLOWS:

Compound_arrival_growth_rate = Arrival_growth_rate*Number_of_tourist_to_HK

Organic_Waste_Treatment_Facilities_capacity(t) = Organic_Waste_Treatment_Facilities_capacity(t - dt) + (Increase_of__OWTF_capacity) * dt

INIT Organic_Waste_Treatment_Facilities_capacity = 0

INFLOWS:

Increase_of__OWTF_capacity = if time = 2016 then 73000 else if time = 2020 then 109500 else 0

SENT_remaining_capacity(t) = SENT_remaining_capacity(t - dt) + (- Waste_filling__in_SENT) * dt

INIT SENT_capacity = 5131830

OUTFLOWS:

Waste_filling__in_SENT = Volume_of_Total_MSW*Proportion_of__MSW_to_SENT+Volume_of_construction_waste*Proportion_of__CW_to_SENT+Volume_of_special_waste*Proportion_of__SW_to_SENT

WENT_remaining_capacity(t) = WENT_remaining_capacity(t - dt) + (- Waste_filling__in_WENT) * dt

INIT WENT_capacity = 23365825

OUTFLOWS:

Waste_filling__in_WENT = Volume_of_Total_MSW*Proportion_of_MSW_to_WENT+Volume_of_construction_waste*Proportion_of_CW_to_WENT+Volume_of_special_waste*Proportion_of_SW_to_WENT

Amount_of_food_donation = 1510*(1+Effect_on_recycling_by_waste_charging)

Annual_food_waste__to_landfilling = Generated_food_waste-Recyling_&_Treatment_volume

Arrival_growth_rate = 0.1

Commercial_&_Industrial_food_waste_generated = (-178305.208350143-0.00693714382616583*Number_of_tourist_to_HK+4.55977914502194E-07*GDP)*(1-Education-Effect_of_waste_charging_on_waste_generation)

Domestic_food__waste_generated = (0.887506*GDP_per_capita+757709.9)*(1-Effect_of_waste_charging_on_waste_generation-Education)-Household_size*0-The_population_aged__under_65*0

Education = 0.1

Effect_of_waste_charging_on_waste_generation = if Waste_charge_level =0 then 0 else if time <2019 then 0 else (0.114492550133199+0.173145005706119*Waste_charge_level)

Effect_on_recycling_by_waste_charging = if Waste_charge_level =0 then 0 else if time <2019 then 0 else (0.140801692895453-0.26306882535519*Waste_charge_level)

Expenses_for__education = 10450000

Expenses_of_disposing_food_waste_in_landfill = Unit_cost_of_landfilling*Annual_food_waste__to_landfilling

GDP = Initial_GDP*Accumulated_GDP_growth_rate

GDP_growth_rate = 0.056

GDP_per_capita = Initial_GDP_per_capita*Accumulated_GDP_per_capita_growth_rate

GDP_per_capita_growth_rate = 0.048

Household_size = 2.9

Initial_GDP = 2397124000000

Initial_GDP_per_capita = 311835

Kowloon_Bay_Pilot_Composting_Plant_treatment_volume = Utilisation_rate_of_Composting_Plant*Kowloon_Bay_Pilot__Composting_Plant_Capacity

Kowloon_Bay_Pilot__Composting_Plant_Capacity = 500

No_of_estate_participate = 37

Operation_cost_of__government_treatment_facilities = 2870000+546*OWTF__treatment_volume

OWTF__treatment_volume = Utilisation_rate_of__OWTF*Organic_Waste_Treatment_Facilities_capacity

Proportion_of_CW_to_WENT = 0.149

Proportion_of_MSW_to_WENT = IF time>2015 then 0.729 else 0.533

Proportion_of_SW_to_WENT = if time >2015 then 0.779 else 0.529

Proportion_of__CW_to_NENT = 0.116

Proportion_of__CW_to_SENT = 0.736

Proportion_of__MSW_to_NENT = if time > 2015 then 0.271 else 0.198

Proportion_of__MSW_to_SENT = if time >2015 then 0 else 0.269

Proportion_of__SW_to_NENT = if time > 2015 then 0.221 else 0.150

Proportion_of__SW_to_SENT = if time >2015 then 0 else 0.321

Recycle_rate_in_estate = RANDOM(0.1,0.15)*(1+Effect_on_recycling_by_waste_charging)

Subsidy_for__treatment_and_recycling_in_Private_sector = 2609640

Sum_of_waste_treatment_and_recycling_volume = Amount_of_food_donation+Kowloon_Bay_Pilot_Composting_Plant_treatment_volume+OWTF__treatment_volume+Total_treatment_volume_in_housing_estate+Treatment_volume_of_private_sector

The_population_aged__under_65 = 86.9

Total_treatment_volume_in_housing_estate = No_of_estate_participate*Recycle_rate_in_estate*Volume_of_on_site__composting_machine

Treatment_volume_of_private_sector = (if time <2015 then 4320 else if time =2015 then (4320+3600) else (4320+700*12))*(1+Effect_on_recycling_by_waste_charging)
Unit_cost_of_landfilling = 520
Utilisation_rate_of_Composting_Plant = RANDOM(0.4,0.75)*(1+Effect_on_recycling_by_waste_charging)
Utilisation_rate_of__OWTF = (if time > 2016 AND time < 2019 then 0.2 else if time > 2018 then RANDOM(0.4,0.75) else 0)*(1+Effect_on_recycling_by_waste_charging)*0
Volume_of_construction_waste = 1438830
Volume_of_MSW__except_food = 2241465
Volume_of_on_site__composting_machine = 18.3
Volume_of_special_waste = 413910
Volume_of_Total_MSW = Volume_of_MSW__except_food+Annual_food_waste__to_landfilling
Waste_charge_level = 0

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