Policy Model of Waste Management - Modelling of Shanghai Municipal Solid Waste Management Regulations

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Abstract

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Wenhang Du

Waste management systems have always been considered complex. Scholars have studied waste management mostly from a macro perspective for a long time, considering waste management policies as a fraction of this complex system. This study presents the causal variables and feedback relationships related to waste management from the inside of the policy, using the macroscopic ideas of Environment-Based Design (EBD) and the system dynamics pictorial representation. The policy model developed in this thesis provides a graphical representation of the abstract policy language. The policy system model constructed based on the policy model further clarifies the linkage between policy and waste management systems. The way the policy really works is also clear from the analysis of the results, i.e., the policy controls the entire waste management system by controlling a subset of variables that affect other variables but are not affected by other variables. These variables can be divided into three categories: user-related variables, policy-related variables, and resource-related variables.

Along with the analysis of policy statements and the search for policy variables, this thesis investigates the process of policy generation and evolution. The general structure of the policy is linked to the responsibilities and work requirements of the various stakeholders within the policy based on three aspects: master plan, management hierarchy, and legal penalties. These structural maps will work together with the policy model to help policymakers further enhance the comprehension and improve the content of the policy in the future.

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Finally, I would like to thank the Bible. Before analyzing the policy, I first analyzed some chapters of the Bible. In the process of analyzing, I got many ideas and pondered. It helped me overcome the difficulties in my research and brought me a profound peacefulness.

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Abbreviations

EBD	Environment-Based Design
SD	System Dynamics
DYNAMO	Dynamic Model
MSW	Municipal Solid Waste
SMSWMR	Shanghai Municipal Solid Waste Management Regulations
CBA	Cost-Benefit Analysis
LCA	Life-Cycle Assessment
MCDM	Multi-Criteria Decision Making
WRAP	Waste Resource Allocation Program
WtE	Waste-to-Energy
MADM	Multi-Attribute Decision Making
MODM	Multi-Objective Decision Making
C&D	Construction and Demolition
MSWM	Municipal Solid Waste Management
ROM	Recursive Object Model
L	Level variable
R	Rate variable
A	Auxiliary variable
C	Constant variable
E	Exogenous variable
N	Initial value
S	Supplementary variable
T	Table variable
J	Past time point

K	Now time point
L	Future time point
JK	Past time period
KL	Future time period
FFM	Fine Farmers Market
FFSP	Fine Food Service Providers
FHO	Fine Hotel Operators
FC	Fine Companies
FI	Fine Individuals
FMRP	Fine Management Responsible Person
FWBAM	Fine Waste Business Activity Merchants
FWCC	Fine Waste Collection Companies
FWTC	Fine Waste Transport Companies
FWDC	Fine Waste Disposal Companies
DRP	Discipline Responsible Person
COD	Coefficient Of Determination
Dmnl	Dimensionless

1 Introduction

1.1 Municipal Solid Waste Background

As the world moves rapidly toward urbanization as an entirety, the amount of municipal solid waste (MSW) is also increasing. MSW is one of the most important by-products of urban lifestyles and is growing even faster than the rate of urbanization. Almost every municipality provides waste management services to its residents, while service levels, environmental impacts and costs vary enormously. The impact of waste management, as the most important municipal service and a prerequisite for other municipal services, is significant for the entire city. It is for this reason that governments and local authorities are actively seeking better solutions for municipal waste management [1]. Establishing relevant policies is the most direct way for the government to manage waste management issues [2]. As a result of political decisions, society has taken more action to find more sustainable solutions to waste management [3]. In June 2012, the United Nations Conference on Sustainable Development, as part of its main outcome document, 'The Future We Want', called on countries to develop and implement comprehensive national and local waste management policies, strategies, laws, and regulations [4]. In the Cambridge dictionary, policy is defined as 'a set of ideas or a plan of what to do in particular situations that has been agreed to officially by a group of people, a business organization, a government, or a political party' [5]. Blunkett advocated a new relationship between social science and government that would end the 'irrelevance' of social science to the policymaking process. Governments would rely on social scientists to 'tell us what works and why and what types of policy initiatives are likely to be most effective' [6]. To represent how existing policies have worked and have been implemented, policy models need to be developed for a specific policy to capture the full range of variables involved in a policy and the intricate causal relationships between them.

Municipal Solid Waste (MSW) is nonhazardous disposable materials generated by households, institutions, industries, agriculture, and sewage [7]. At present, the world produces about 3.5 million tons of waste every day and 1.3 billion tons every year, 54.02% of which comes from developing countries [1]. The total amount of waste generated in low-income countries is expected to more than triple by 2050. As of 2018, East Asia and the Pacific generated 23% of the world's waste, while the Middle East and North Africa region generated the least amount of waste in absolute terms at 6%. However, waste is growing fastest in Sub-Saharan Africa, South Asia, and the Middle East North Africa (MENA) region, where the total amount of waste generated is expected to approximately triple, double, and double, respectively, by 2050 [8]. China produced 190 million tons of MSW in 2004, making it the world's largest producer of MSW. That figure is expected to reach at least 480 million tons by 2030. No other country has experienced such massive and rapid growth in waste generation [9]. In the face of this pressure, China has invested considerable effort in municipal solid waste management [10]. China's first environmental sanitation plan, the National Eleventh Five-Year Plan on Urban Environment and Sanitization, was officially promulgated and implemented in 2006. Its overall objectives are to establish a rational waste collection, transportation, and treatment system, to promote the development of urban waste treatment towards reduction and resourcefulness; to improve the daily cleaning system in cities and towns; to promote the development of industrialized waste treatment, and to fundamentally establish an environmental sanitation system in China [11]. The 'Management Measure on Urban Waste', which came into effect on July 1, 2007, is the prototype of many specific municipal solid waste management regulations, from which city-specific solid waste management policies have been derived. This policy has had a profound impact on the development of municipal solid waste management regulations in many cities. It emphasizes waste reduction, resourcefulness, non-hazardousness, and producer responsibility. These principles have also become the core principles of waste management regulations in various cities in China [12]. On January 1, 2009, the Law on Circular Economy Promotion entered into force. The purpose of this law is to promote the development of circular economy, improve the efficiency of resource utilization, protect as well as improve the environment, and achieve sustainable development. It establishes a legal framework for waste reduction at source, reuse, and recycling [13]. From the overall planning and objectives of each policy, we notice that the policies related to waste management encompass almost the entire life cycle of waste, including the source of waste (i.e., the product before becoming waste), the generation of waste, the treatment of waste and the impact on the environment. There are many stakeholders involved, as well as human factors such as economic and demographic factors, and natural factors such as the geographical characteristics of different regions. The relationship between them is equally complex and dynamic. This thesis chooses the specific policy of Shanghai Municipal Solid Waste Management Regulations (SMSWMR) as an example and build a model by exploring the internal cause-effect relationship of variables in policy to reflect the way in which policy affects domestic waste management system.

1.2 Legal Background

Shanghai is the first city in China to implement municipal waste separation regulations [14]. Since 1996, Shanghai has carried out several domestic waste separation pilot rounds and became the first batch of domestic waste separation pilot cities in China in 2000. In 2018, Shanghai's daily domestic waste disposal volume was near 26,000 tons, and the average annual domestic waste generation exceeded 9 million tons, putting tremendous pressure on the environment and sustainable economic and social development [15]. The Shanghai Municipal Solid Waste Management Regulations became mandatory on July 1, 2019, and was adopted by the 15th Shanghai People's Congress, officially becoming a local law [16]. The regulation strengthen the supervision and punishment of irregularities in classification, which means that Shanghai waste classification officially steps into the era of rigid constraints [17].

1.3 Scope, Objective and Contribution

The scope of this thesis is defined within the context of the law, Shanghai Municipal Solid Waste Management Regulations, and the variables in the waste management system that are related to the variables extracted from the law. The variables involved in waste management systems are numerous and diversified, including economic variables, demographic variables, technological variables, capital variables, legal variables, educational variables, environmental variables, and energy variables. Each of these variables has complex interrelationships, for example, the demographic variables can be subdivided into total population, resident population, immigrant population, age structure, sex ratio, and birth & death rates. These variables can be further quantified by introducing more relevant variables such as the growth rate of the resident population. Almost all the variables included in the policy model are extracted from the policy, while the policy system model is based on the policy model with the addition of variables in the waste management system that are directly related to the policy, for example, in the demographic category, an additional variable of total population is added.

In this thesis, the research objective is extract variables from the policy and build a policy model to find out how the policy works. The specific steps are shown below:

1. Distill the work requirements and interrelationships of stakeholders in SMSWMR.
2. Sort out the main structure of SMSWMR.
3. Based on the policy text, extract the key information in the policy and further summarize it as independent variables.
4. Identify the goal to be achieved by the policy and refine it as the dependent variable.
5. Establish causal relationships between variables as described in the policy and fill in the relationships not described by the policy according to the variables' own characteristics.

6. Validate the reasonableness of the model.
7. Explore the ways soft data will be collected in the future.

The main contribution of this thesis is the extraction of variables from the policy and the construction of a policy model that reflects the causal relationship between different variables within the policy. The graphical structure of the policy and the policy system diagram are also created based on this core contribution.

1.4 Thesis Layout

The thesis is organized as follows: Section 2 provides an overview of previous research, from the overall study of municipal solid waste management to a review of policy research on waste management and the application of the system dynamics approach. Section 3 presents the research methodology, which mainly contains the introduction of EBD method and SD method. Section 4 presents a case study of waste management-related policies in Shanghai, containing details of the process. Section 5 discusses the strengths and weaknesses of the policy model and concludes.

2 Literature Review

A traditional research theme in the field of waste management has been focused on the development of tools and methods to help decision-makers make tactical decisions on waste management systems [18]. Most municipal waste management models identified in the literature are decision support models and can be classified into three main categories: models based on cost-benefit analysis (CBA), models based on life-cycle assessment (LCA), and models based on multi-criteria decision making (MCDM). Although many models recognize that environmental, economic, and social aspects must be considered for a sustainable waste management model, none of them consider all these three aspects simultaneously when applying the model [19]. Municipal waste policymakers need an integrated model to assist them in evaluating their current and future municipal waste management policies [20]. Modeling current policies can be a good way to link more aspects of waste management and provide a theoretical basis and guidance for the future improvement of current policies.

Most researchers model the entire waste management system or all information elements of a particular type of waste, showing the entire process or the whole life cycle of waste management at a macro level. With a holistic analytical understanding from the waste management system, the focus then shifts to conflict discovery and policy optimization and recommendations. This process of starting with the waste management system in its entirety and then focusing on policy has many advantages. Not only can it cover many aspects involved in different related laws, avoiding the absence of vital parts due to empirical reasons, which leaves the model with insufficient contents to display, but it can also combine with other academic system models better, using cross-disciplinary knowledge to present the model contents more adequately. However, the shortcomings of this macro-system approach to modeling, i.e., the inability to capture the full range of variables within the policy and the dynamic relationships among them, are revealed when evaluating a specific municipal waste management policy. The policy formulation process takes into account the different requirements of multiple stakeholders, and in order to develop policies, policy makers often combine conflicting goals into acceptable outcomes [21]. This is precisely why the perspective considered by the policy, i.e., the variables covered in the policy, may be drastically altered from the content of the variables in the traditional sense. By identifying the variables within regulations and the causal relationships between them, this study identifies the factors influencing the entire life cycle of waste management from within the law and demonstrates the way the law operates in the waste management system. This analytical approach can be extrapolated to other waste-related policies to help municipal waste policymakers evaluate their current and future municipal waste management policies on a case-by-case basis, thereby guiding and assisting future policy revision efforts.

2.1 MSWM models

As awareness of environmental protection has increased, models for municipal solid waste management have been developed over the past few decades. Truitt [22] developed a numerical computer simulation model of a complex urban mixed waste collection system in 1969. The model calculates the number of truck routes per day for each subarea as a function of household density, collection frequency, and collection truck haul distance. The model simulates the waste collection activity during the cycle according to the presence or absence of transfer stations. With this model, it is possible to investigate and compare the costs of alternate sites for final disposal sites and transfer station sites. The efficiency of proposed systems with different collection truck capacities and with or without auxiliary compaction equipment can also be investigated in terms of unit costs, overtime hours, and the number of units required to be transported. In the 1980s, the U.S. Environmental Protection Agency launched a computer project called the Waste Resource Allocation Program (WRAP), which greatly facilitated regional solid waste planning with its simple input requirements and clear outputs. Through planning algorithms, WRAP occasionally identified excellent solid waste management solutions that paved the way for future cost minimization studies. Perlack [23] developed a multi-objective planning model for the Boston sludge disposal problem in 1985, which included the objectives of net economic benefit, environmental impact, and impact variability. Systematic studies began to emerge gradually. Life cycle assessment (LCA) tools began to flourish in the 1990s, and are used to ensure that the assessment is comprehensive and covers the full range of "cradle-to-grave" impacts associated with the provision of a product or service [24]. The use of LCA in waste management significantly improves the holistic view of waste management, including waste flows and potential environmental impacts [25]. The application cases of LCA in waste management include many regions in the world. It contains the advantages of systematization, quantification, standardization and universality but also has the limitations of difficult data quality control, diverse product environmental impact, and difficult definition of environmental evaluation indicators [25-31].

Cost-benefit analysis models, as a tool for assessing economics, were also emphasized in the early 1990s [32-34]. Cost-benefit analysis is a method of assessing the value of a project by comparing the full costs and benefits of the project. As an economic decision-making method, cost-benefit analysis is used in planning decisions in government departments to find out how to obtain the maximum benefit at the minimum cost in investment decisions. It is commonly used to assess the value of public utility projects. The basic principle of cost-benefit analysis is to propose a number of options to achieve a certain expenditure goal, apply certain technical methods, calculate the costs and benefits of each option, and select the optimal decision option through comparative methods and based on certain principles. Yuan [36] applies cost-benefit analysis models to the management of the entire waste chain of construction and demolition waste. He emphasizes the dynamics and interrelationships of construction and development waste management practices and uses a system dynamics approach to analyze the cost effectiveness of this process. Tooraj assesses the economic and environmental aspects of waste management options, focusing on waste-to-energy (WtE) as a renewable resource. A social cost-benefit analysis of selected waste management options in the UK was conducted, focusing on specific waste management targets and carbon prices, and comparing them with coal-fired electricity. The results show that the cost-effectiveness increases substantially with an increase in the carbon price[37]. In addition, papers attempting to evaluate the effectiveness of MSW management systems by developing a comprehensive cost-benefit analysis (CBA) framework are numerous around the globe [36-38].

MCDM is also a common method to solve MSWM problems [41]. Multi-criteria decision making is divided into two categories, multi-attribute decision making (MADM) [42] and multi-objective decision making (MODM) [43], depending on whether the decision solution is finite or infinite. MCDM can judge, rank, and select multiple projects and assign weights to each impact factor of the project to help analyze the system dynamically as it examines the project. Asli [44] studied the various disposal technologies used worldwide and created different scenarios applicable to Turkey. Seven criteria were identified, and eight solid waste disposal scenarios were evaluated based on the input of experts in the field. Three different multi-criteria decision methods were used, and the most appropriate and feasible scenarios were identified. The results show the importance of recycling and landfill technologies in developing countries [45]. There are numerous applications of multi-criteria based decision-making in other aspects of MSW, such as the selection of energy recovery technologies [46], health care waste management methods [47], and bio-recycling management of municipal plastic waste [48].

2.2 MSWM Policies

Policy research on municipal solid waste management (MSWM) has been gaining attention from governments and researchers in the last two decades. Waste management policies are key to establishing effective and satisfactory waste management systems. However, waste policy development is hampered by a number of multifaceted and interrelated obstacles, particularly in developing countries, that further complicate the already complex task of waste management [49]. Potential problems in policy can arise in numerous ways, including weak institutional structures and lack of cooperation among stakeholders [49], lack of policy enforcement [50], waste transportation problems [2], and social and cultural background issues [51], etc.

There are also diverse perspectives on municipal solid waste management policy research. Mani and Singh's [52] analysis from the perspective of enacting the bill, combined with observations of the results of waste management implementation, found that many policies and programs failed to achieve their objectives due to a lack of clarity and awareness among stakeholders and poor implementation by regulators. Chris [53] considers the livelihoods of waste pickers in the context of municipal solid waste management policies. To investigate the socioeconomic status of waste pickers, including labor characteristics, household income, and poverty incidence, 146 semi-structured questionnaires were distributed to four communities near the landfill and 45 semi-structured interviews were conducted with key stakeholders. Findings indicated that hundreds of waste pickers were displaced by the project and that employment benefits from the project were unevenly distributed among the communities. After analyzing relevant management policies and practices, Hefa and Yuanan [54] concluded that policies have largely contributed to the production of dioxins. They recommend lowering dioxin emission standards, strengthening fly ash management, and enhancing enforcement to reduce dioxin emissions into the environment from municipal waste incineration. The perspective of policy analysis in this thesis, by contrast, is to present as much as possible the causal relationships among the components of the policies and to help various types of policy analysts to solve problems from different perspectives.

2.3 The Application of System Dynamics in Waste Management

System dynamics (SD) provides a transparent modeling approach because it can comprehensively model all the variables involved and the feedback loops, time delays, and linear and nonlinear interactions between the variables. Yücel and Miluska Chiong Meza [55] used the SD model to model the potential mechanisms to study the transition of waste management in the Netherlands. The intention is to explore the extent to which system dynamics as an approach enhances the understanding of transition dynamics in socio-technical systems. They argue that system dynamics is a promising approach that can explain the origin of complex dynamics based on interactive feedback loops, but it also has some shortcomings in the transition context, such as its inability to provide sufficient insight in every aspect of the system. Georgiadis and Vlachos [56] have analyzed the behavior of individual product supply chains through dynamic simulation models based on the principles of SD method for assessing the impact of environmental issues on long-term decisions and product demand for recycling remanufacturing activities. They concluded that system dynamics models can be used to obtain long-term estimates of system performance for a given strategy and to help analyze various scenarios by adjusting parameters. Using a system dynamics model, Xiao et al. [57] simulate the impact of various policies on the management of MSW in Shanghai from a dynamic and complex perspective, simulating the entire process of MSW production, sorting and collection, and final disposal in Shanghai. This waste management model will provide help and possibility to evaluate the impact of multiple policies on MSW management in more cities. Hao et al. [58] used a system dynamics approach to build a simulation model of Construction and Demolition (C&D) waste management in Hong Kong to help decision-makers and practitioners better understand the complexity of the information and the processes involved in managing C&D waste throughout the project life-cycle.

Traditionally, the purpose of modeling system dynamics is to study the problems of the system, to improve the study and understanding of the relationship between the feedback structure within the system and its dynamic behavior, and to conduct research to improve the behavior of the system. Initially, modeling requires a deep understanding of the principles and methods and a thorough understanding, investigation, and analysis of the object of study before proceeding. The most important policy analysis occurs after modeling.

2.4 Research Gap

Modeling of waste management systems and related studies for a specific type of waste management are numerous in the literature. For different purposes, researchers have used different methods, but all require experts with an extremely deep understanding of the relevant domain to successfully complete the modeling. Policies as an important tool for successful waste management achievement often appear in the final step of model utilization, i.e., using models to evaluate policies. Models that model policies and explore the causal relationships and modes of action within policies are never discussed and studied. It seems necessary for the policy to be given extra attention and analysis.

3 Methods

The Environment-Based Design (EBD) approach is the origin of the idea of modeling policies and is achieved by using the EBD approach in the modeling policy process. This method aims to identify the causal feedback within the policy to understand how the policy operates and how it affects the waste management system. The causal relationships are behind in the policy, which is unknown first. However, the policy and waste management system are known first. Therefore, this thesis adopted the Environment-Based Design (EBD) methodology, which first considers the environment in the analysis process [59]. In EBD, the environment of a product is everything except the product itself [59]. EBD regards everything in the universe as a product. The policy and waste management system are important environments for the causal feedback diagram, as shown in Figure 1 Environmental factors of policy causal feedback diagram. The two steps of determining the causal feedback diagram are responsible for extracting the variables and determining the causal feedback relationships, respectively. The causal feedback diagram is expressed by the system dynamics (SD) model to express the causal relationships between variables. In order to develop a simulation model, it is essential to transform the cause-effect diagram into a flow-stock diagram in order to clearly show the important stocks and flows. Before conducting a simulation, parameters and initial conditions must be estimated. These parameters can be estimated using statistical methods, market research data, similar product histories, expert opinion, and any other relevant data sources (quantitative or judgmental). The overall dynamics of the system depends on which feedback loops are dominant [60]. In this study, these dominant feedback loops will be uncovered in the objectives of the policy.

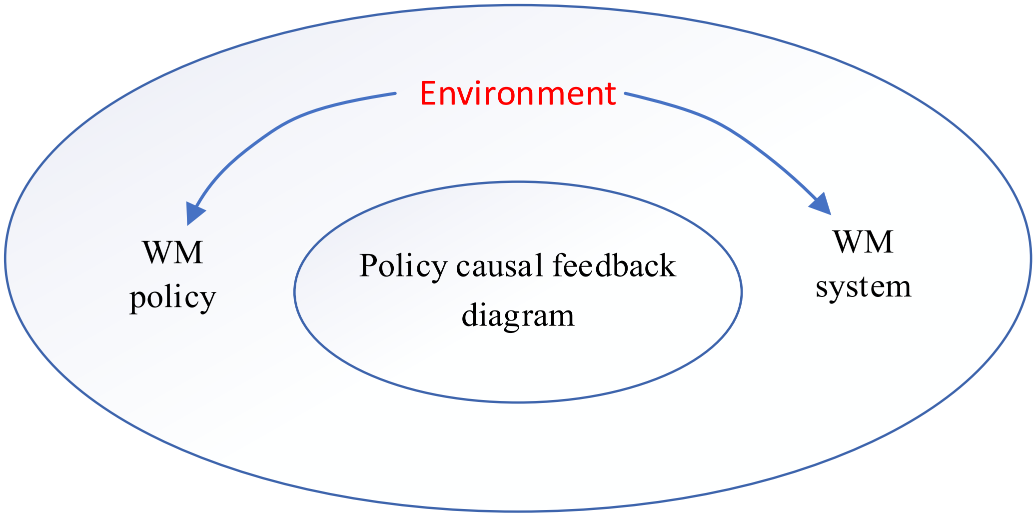

Figure 1 Environmental factors of policy causal feedback diagram

3.1 Modeling Strategy- Environment-Based Design (EBD)

Environment-based design (EBD) is a design methodology that looks firstly at the environment in the design process [59] [61]. The nature of design is shown by the recursive logic of design [62]. The recursive logic of design implies that the generation and evaluation of design solutions during the design process relies on design knowledge, and that design solutions determine the kind of design knowledge that can be used for the current design [61]. This is the co-evolutionary nature of the design process, in which design problems, design solutions, and design knowledge are updated simultaneously [61]. As shown in Figure 2 Environment-based design (EBD) [63], EBD includes three activities, which are environment analysis, conflict identification, and solution generation, during which design problem, design knowledge, and design solutions simultaneously and interdependently evolve as a part of the environment [63]. The product's environment can be defined in three dimensions, namely, environment types, life cycle events, and life cycle time [59]. In EBD, the sustainability-focused environment analysis method is called Environment-based life cycle analysis (eLCA) [63]. There are four kinds of environments in eLCA, which are natural, physical artifact (first built environment), digital artifact (second built environment), and human

[63]. Prior to writing this thesis, the author has done a detailed analysis of waste management issues using the EBD approach. It was found that policy is a rather important part of the built environment in waste management. In order to further explore the causal relationship within the policy, as well as to provide a reference and assistance to adjust the policy in the future, the author used the EBD idea as a basis and the SD model as a tool to build the policy model.

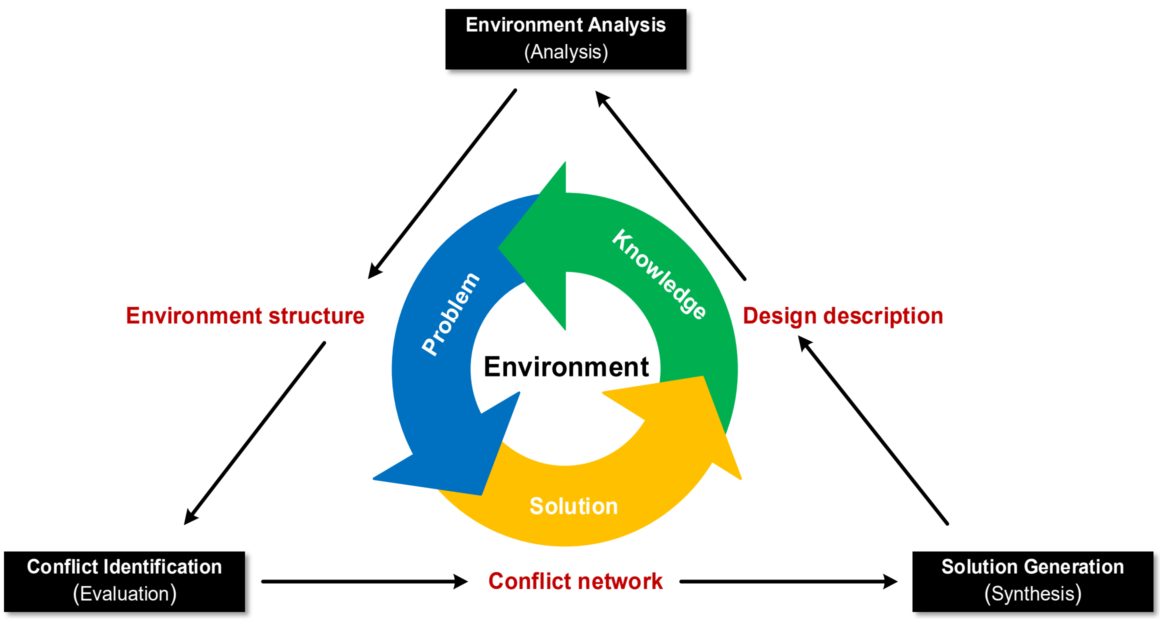

Figure 2 Environment-based design (EBD) [63]

3.1.1 Environment Analysis

Environment analysis is the first step in EBD, aiming to identify known environment components and their relationships between those components [61]. The input is the problem statement, and the output is the production environment. In the environment analysis, EBD provides two main tools, which are the Recursive Object Model (ROM) [64] and question asking [65]. ROM is a graphic language to represent objects and their relationships in terms of their semantic structure. EBD utilizes ROM analysis to process design problems, design knowledge, design solutions, and the evolution of product solutions. ROM diagram consists of two types of objects and three kinds of relations, as shown in **Error! Reference source not found.**.

Table 1 Elements of Recursive Object Model (ROM), adapted from [64]

Type			Graphic Representation	Definition
Object	Primitive objects		E_i^a	Everything in the universe is an object.
	Object structure		$\oplus E$	It is an object that includes at least two other objects in it.
Relations	Connection		E_i ■- - - l - - -▶ E_j	It is to connect two objects that do not constrain each other.
	Constraint		A ●—▶ E_i	It is a descriptive, limiting, or particularizing relation of one object to another.
	Predicate	Subject-verb	S_i ■— v	It describes an act of an object on another or that describes the states of an object.
		Verb/proposition-object	v/p —▶ O_j	

The right questions are a prerequisite for getting the right information and data. Zeng [59] had given the definition of the right question as the one asked in the right time about the right object with the right type (one of the 5W1H) and to the right resources. The order in which questions are asked should be considered first, and two basic rules of the EBD approach are used to address the questioning order, listed in Table 2 Rules for the right order of questions [65]. Based on the ROM diagram of a design statement, design questions can be generated using the EBD question generation template [65], as shown in appendix 1. Then eLCA can be used to analyze the life cycle of a product. The answers can be generated by the guideline of answering questions [59], as shown in appendix 2. As a part of the detailed description of the statement, the answers will be used to update the original ROM diagram. A complicated ROM diagram is usually generated after the environmental analysis. Since this part of the work is not the focus of this thesis, it will not be discussed in depth here.

Table 2 Rules for the right order of questions [65]

Rule1	Among all the candidate objects, the object with the most undefined constraints and predicates should be considered for questioning first.
Rule2	Before an object can be asked for a question, the objects constraining or predicating them should be asked.

3.1.2 Conflict Identification

Conflict identification is the second step in EBD, aiming to identify all potential conflicts from the updated ROM diagram using the interaction dependency network. A conflict is an insufficiency of resources for an environment object to produce a desired action on the product or to accommodate the product's response to its environment [59]. Interactions are associated with verbs in a ROM diagram [59], which can be classified into the independence interaction and the dependence-only interaction [63], as shown in Figure 3. Furthermore, if I_m depends on I_n, then I_m is a sufficient condition for I_n, and I_n is a necessary condition for I_m. The dependence relationship between interactions forms an interaction dependency network, which can be further used to identify conflicts. Each path between the independent and dependence-only interactions defines critical issues of a problem.

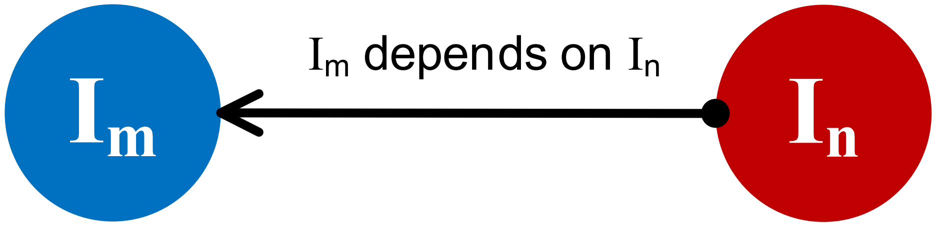

Figure 3 Dependency relation between two interactions [59]

3.2 Model Construction Tools- System Dynamics (SD)

The System Dynamics (SD) approach, a computer modeling method for designing policies and explaining the performance of complex systems, has gained popularity in waste management systems (WMS) since its introduction to study the feasibility and impact of implementing various waste management system practices and government policies [66]. The systems modeling approach was pioneered by Forrester in the 1960s and is used for long-term decision analysis of industrial management problems [67]. SD is a systems analysis approach that focuses on creating models of real-world systems and studying their dynamics. It provides an effective tool to understand these large-scale and complex management problems better. In an isolated view, a complex system may give a flawed impression that can lead to erroneous judgments; therefore, systems thinking should consider all interacting components that affect a complex system as much as possible [68]. The system dynamics modeling approach focuses on the understanding of feedback and feedforward relationships, and the construction of the model requires the analysts to construct relationships between various state variables [58]. It is able to deal with assumptions about the structure of a system in a rigorous way, especially monitoring the effects of changes in subsystems and their relationships. In addition, it is able to represent these changes and enable them to be communicated. SD is a proven method for studying and managing complex feedback systems [69]. The control-theoretic feedback concept of system dynamics is a well-suited technique for dealing with such complicated systems and will help to reveal the concept of feedback within policy and present the complex system of waste management in a more realistic way from a policy perspective. The nature of the system dynamics process is likewise an iterative process [70]. The components that constitute the system are two types, the variables, and the relationship between them. Systems are usually controlled by variables, and the nature and number of variables in a control system are difficult and unpredictable, with new variables being added as the system continues to evolve iteratively [70]. Much literature [67][71][72][73] is presented on how to develop and use system dynamics models. There are six important steps in the process of building the system dynamics model. Table 5 shows the contents of the six important steps in detail, and the specific steps of modeling are briefly described and discussed in the following sections. In this thesis, we use the process of system dynamics to find the variables needed to build the system from within the policy, and while accomplishing this goal of structuring the policy model, provide the foundation for a more comprehensive policy model in the future.

Table 3 Steps required to model and simulate complex systems based on systems thinking [68]

Serial number	Steps descriptions
1	Identify the problem.
2	Develop a dynamic hypothesis to explain the cause of the problem.
3	Create the elementary structure of a causal diagram.
4	Enrich the causal diagram with more information.
5	Convert the augmented causal graph to system dynamics flow graph.
6	Translate the system dynamics flow graph into Vensim programs or equations.

3.2.1 Problem Identification

In the Define the Problem phase, the modeler needs a clear mind to contemplate the expected results of the system dynamics model. A crisp and unambiguous statement of the problem will be of great help in the subsequent construction of the model. The boundary of the system should be defined first, and the boundary determines the scope of the study, which will also directly shape the scale of the succeeding development of the model. Figure 4 Waste Management Policy and Systems Research Boundaryillustrates the system boundary of this thesis's study, the polygonal outline indicates the multi-domain properties of the waste management system. Some of the variables included in the waste management policy are beyond the scope of the existing waste management system studies, but still within the radius of the broader concept of waste management system; in other words, the waste management system is a complex multi-disciplinary system, and the waste management policy can be understood as a snapshot of the local distinctiveness of this complicated system.

In this step, the boundaries of the system are clearly delineated as the problem is identified. The research question in this thesis can be summarized as the way in which policies play a role in waste management systems, then the boundary of the study is the waste management system involved in the policy under study. In order to clarify the boundaries more clearly, the SD approach considers that the feedback loops in the system should be considered as closed loops as much as possible. An attempt is made to include variables that are closely related and important to the purpose of the model. In the case of this study, this means including as many of the variables that are relevant to the variables extracted from the law as possible. Another point worth noting is that while encompassing all relevant variables, there is also a need to sift out excessive redundant details, and overly bloated models can pose considerable difficulties for the researcher.

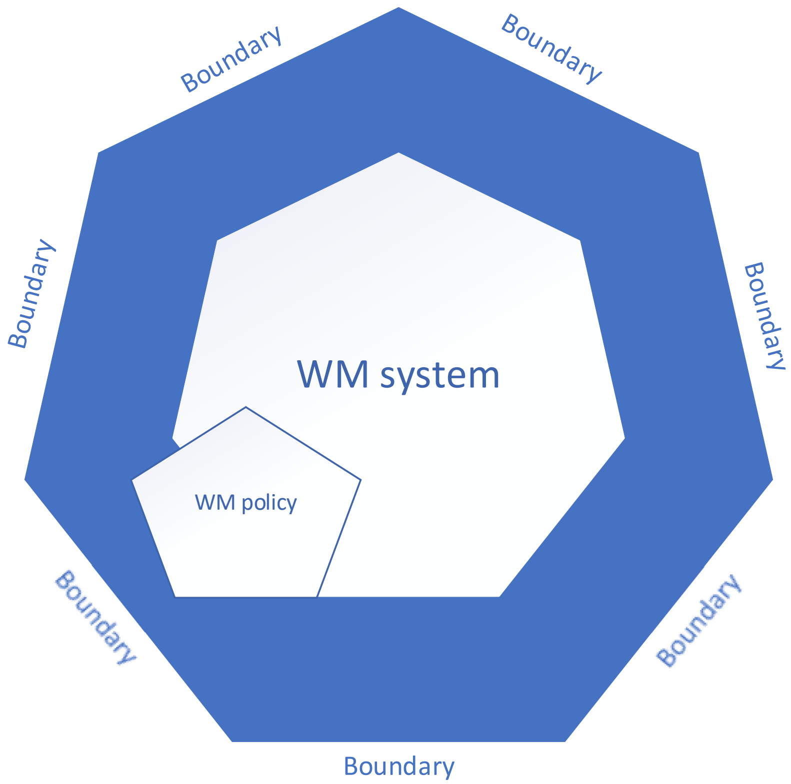

Figure 4 Waste Management Policy and Systems Research Boundary

3.2.2 Extracting Variables of Policy

This section represents the major difference from the traditional SD model construction process, where the dependent variables and many independent variables and related causal relationships are derived from laws and regulations. This section forms the main body of the subsequent model. Variables have a tremendous impact on the behavior of a system, and the number and properties of variables will continue to change as research continues to iterate. At this stage, the dependent variables within the policy and the relevant independent variables mentioned in the policy should be identified, and some of the apparently missing independent variables will be filled in through literature search to make the model presentation more comprehensive. As previously stated, the variables are the backbone of the policy model, and both independent and dependent variables can be uncovered from the policy. The variables that can affect the dependent variable can be called independent variables. The independent variables contain the variables revealed in the literature and in the policy, and the dependent variables will be transformed from the objectives expressed in the policy. SMSWMR, the target of analysis in this thesis, clearly describe the waste management objectives in Shanghai. Article 3 in SMSWMR indicates that Shanghai aims to achieve the reduction, resourcefulness, and harmlessness of domestic waste. The variable in domestic waste reduction is the amount of domestic waste generated. The variables in domestic waste resourceization are domestic waste resource utilization rate, domestic waste sorting and transportation capacity, and total domestic waste treatment capacity. The variables in domestic waste minimization include the total domestic waste treatment capacity, the domestic waste minimization rate, and environmental pollution level. These variables are the dependent variables of waste management in Shanghai, and the adjustment of these variables is the ultimate goal of urban waste management in Shanghai. The extraction process of the specific independent variables will be illustrated in detail in Section 4.2.2.

3.2.3 Dynamic Hypothesis

Dynamic hypotheses will be implemented once the problem is defined. Dynamic hypotheses are ideas about what structures might produce the corresponding behavior in the reference model [68]. The essence of dynamic assumptions is a conceptual model. Dynamic hypotheses can be formulated in various forms, statements of scenario hypotheses [74] or graphically represented using causal loop diagrams and further transformed into quantitative research hypothesis maps-stock flow diagrams. Hypotheses about reference patterns of system behavior usually rely on the author's observations, knowledge, and experience, and thus require a deep understanding of the system, while often facing revisions and adjustments [75]. Since the conceptual model of the simulation relies on patterns of behavior over a certain time horizon, upgrades or changes to the model are inevitable as time elapses. The variables will determine the model construction after the dynamic assumptions, and the relationship between the variables in this study is constructed and assumed through the policy formulation, which reduces the probability of errors for the next stage of simulating the dynamic assumptions, also known as simulation. The process of revealing the relationship of variables from policies will also be elaborated in the subsequent case studies. Although the model subsequently created also requires multiple rounds of adaptation, changes and iterations, the policy modeler will reach a higher state of understanding of the target policy, which will provide relatively referenceable suggestions for policy development.

3.2.4 Causal Loop Diagram (CLD)

The system boundary divides the variables into two types: variables inside the boundary are endogenous variables and variables outside the boundary are exogenous variables [68]. The structure of the system dynamics is illustrated by causal loop diagrams of the main feedback mechanisms, and all the dynamics arise from the interaction of two types of feedback loops: positive feedback loops and negative feedback loops. The causal loop diagram includes elements and arrows (called causal links) that connect these elements together in the same way, with a symbol (either + or -) on each link. (+) indicates that the direction of change of the two elements is in the same direction, while (-) indicates that the direction of change of the two elements is in the opposite direction [76]. If multiple links can form a loop, then a symbol should also be added in the center of the loop to indicate the different characteristics of the loop. A feedback loop is called a balanced feedback loop if the number of negative signs on all links on the loop is odd and can be denoted by the letter 'B' or the negative (-) sign. A feedback loop with an even number of negative signs on all links is called an enhanced feedback loop and can be denoted by the letter 'R' or by a positive (+) sign, as shown in Figure 5 and Figure 6. The causal loop diagram is used as a preliminary sketch of causal assumptions in the model development process, which can show the complex causal relationships within the model explicitly. Nouns or noun phrases should be used in causal loop diagrams, and when necessary, some gauges can be created to convey the desired meaning. Some of the gauges in this study are summarized from the policy.

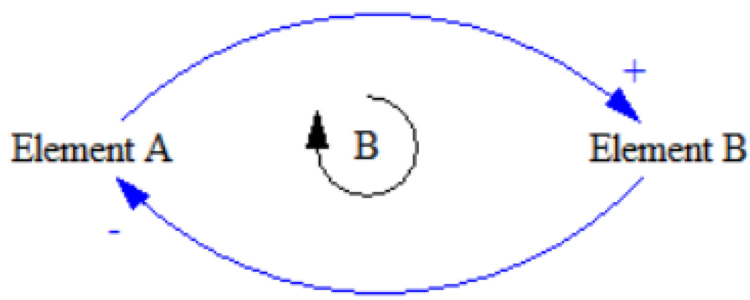

Figure 5 Basic balancing causal loop diagram (using the system dynamics software Vensim®)

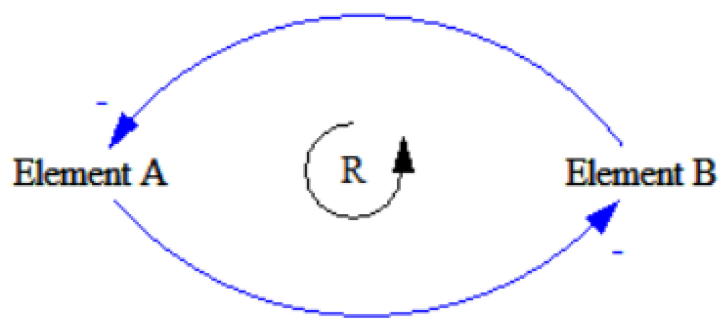

Figure 6 Basic reinforcing causal loop diagram (using the system dynamics software Vensim®)

3.2.5 Stock-Flow Diagram (SFD)

The fundamental weakness of causal loop diagrams is that they can only describe the basic aspects of the feedback structure and cannot represent the difference between variables of different nature. This weakness is addressed by stock-flow diagrams. The Stock-flow diagrams are usually developed after the cause-effect loop diagrams, and its most significant structures are stock and flow. Stock represents the state of the system at a certain point in time, while flow represents the activities or decisions that change the system. In the discipline of system dynamics, states are represented by levels and activities and decisions are represented by rates. The value of the state of the system changes with the activities and decisions, and the information about the state of the system can be fed back and used to change future activities and decisions [77]. In addition to stocks and flows, auxiliary variables and connectors are also essential components of the flow stock diagram, as shown in Figure 7. The mathematical mapping of the system dynamics stock flow diagram is achieved by a set of differential equations that are solved numerically by simulation. Technically speaking, all parts of the model can be represented by mathematical equations.

A level equation example is shown in (1):

$$Level(t) = level\ (t - 1) + (\Delta\ t)(rate\ A - rate\ B) \tag{1}$$

In Vensim modeling, the equation for the accumulated variables can be expressed as (2):

$$lvS(t) = S(t_0) + \int_{t_0}^{t} rate\ S\ (t)\ dt = S_{(t_0)} + \int_{t_0}^{t} [inflowS(t) - outflowS(t)]dt \tag{2}$$

$lvS(t)$ is the accumulation variable value at time t; $rateS(t)$ is the rate of change of this accumulation variable.

$rateS(t)$ can be expressed as (3):

$$rateS(t) = g[lvS(t), aux(t), exo(t), const] \tag{3}$$

aux(t) is the auxiliary variable at moment t; and exo(t) is the exogenous variable at moment t; const is the constant.

aux(t) can be expressed as (4):

$$aux(t) = f[lv(t), aux * (t), exo(t), const] \quad (4)$$

aux*(t) is the other auxiliary variables besides the auxiliary variables to be solved.

The above equations are the main variables equations in the Vensim model. The other components contain constants and exogenous variables. Constants usually only need to be assigned a fixed value directly, while exogenous variables affect other endogenous variables of the system but are not affected by the endogenous variables, so they are often a function of time t.

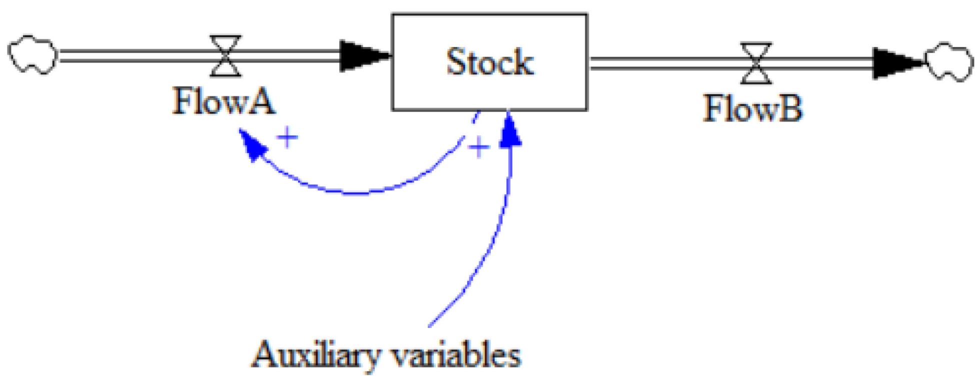

Figure 7 Basic elements of stock-flow diagram (using the system dynamics software Vensim®)

Frequently, there is a delay in the flow of material and information. This situation also has a unique form of expression in the stock flow diagram. Vensim software contains the DELAY1I function that can be used to express the delay, and DELAY1I takes the form of (5):

$$DELAY1I\ (input, delay\ time, initial\ value) \quad (5)$$

Expanded into a set of equations as (6):

$$DELAY1I = LV(t)/DT$$

$$LV(t) = LV(t_0) + \int_{t_0}^{t}[input(t) - DELAY1I]dt \quad (6)$$

$$LV\ (t0) = IV \times DT$$

LV(t) stands for State Variables; IV indicates the initial value; DT indicates the delay time.

If IV in equation is equal to the initial value of input, then DELAY1I can be simplified to DELAY1 in the form of (7):

$$DELAY1(input, delay\ time) \quad (7)$$

Vensim will calculate the initial LV values based on the system of equations (6) so that the inputs and DELAY1 are equal.

3.2.6 DYNAMO Equations

The DTNAMO language is named by combining the headers of the words DYNAmic and MOdel and is a modeling language for system dynamics. Its functionally fills the gap of SFD. In SFD, it is possible to see the variables in each information chain determined by several variables, but it is not possible to know the specific mathematical relationships between them. Therefore, the DYNAMO equation can be understood as an expression describing the specific mathematical relationships of the variables. The DYNAMO equation can also be understood as the formatting of the model, i.e., the transformation of an informal concept into a formal quantitative expression. Writing the model as an equation makes the model clearer and more useful in identifying and solving problems. The simpler the system under study, the less significant is the need for the DYNAMO equation, but in the complex system of waste management in this thesis, the specific relationships between variables can be accurately described only with the help of the DYNAMO equation. In order to represent the dynamics of the system, DYNAMO determines a time axis, which is divided evenly from the initial moment, with each step noted as a DT, as shown in Figure 8. The DYNAMO equation also requires a clear representation of moments. DYNAMO uses K for the present moment, J for the past moment and L for the future moment. Therefore, the JK time period is referred to as the past time period and the KL time period is referred to as the future time period, as shown in Figure 9.

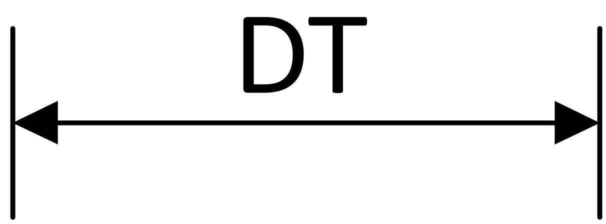

Figure 8 The length of time in the DYNAMO equation

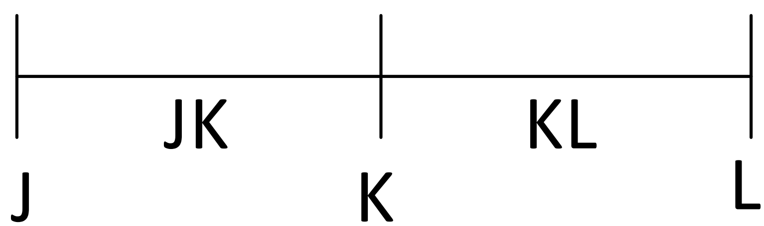

Figure 9 Moment representation in the DYNAMO equation

The basic rate equations can be expressed as the following 6 categories using Dynamo equations [78]. The RATE equation influenced by the constants within the system can be expressed as (8).

$$R\ RATE.KL = LEVEL.K * CONST \tag{8}$$

RATE is the rate variable; LEVEL is the level variable; CONST is the constant within the system.

The structure of the RATE change in the output of the state variable can be described by (9).

$$R\ RATE.KL = LEVEL.K/LIFE \tag{9}$$

LIFE is the lifetime of use or life span.

One representation of the rate in a negative feedback loop is shown in Equation (10).

$$R\ RATE.KL = \frac{GOAL.K - LEVEL.K}{ADJTM} \tag{10}$$

GOAL is the target state; ADJTM is the adjustment time.

CONST and LIFE in equation (8) and (9) can be replaced using auxiliary variable (AUX. K) that depends on other variables within the system, which will greatly improve the flexibility of the equations. As shown in (11) and (12).

$$R\ RATE.KL = LEVEL.K * AUX.K \tag{11}$$

$$R\ RATE.KL = \frac{LEVEL.K}{AUX.K} \tag{12}$$

AUX. K is the auxiliary variable.

In addition to the representation of the rate itself, the effect of certain factors on the rated rate can also be expressed by the equation as (13).

$$R\ RATE.KL = NORM.K + EFFECT.K \tag{13}$$

NORM is the rated rate; EFFECT is the effect of certain factors.

The most commonly used rate structure in system dynamics is (14).

$$R\ RATE.KL = NORM.K\ *\ EFFECT1.K\ *\ EFFECT2.K\ \ldots \tag{14}$$

The characteristic of this equation is to consider the rate as a certain nominal rate multiplied by a factor or multiplied by multiple factors, and this product is the value of the rate. The resulting rate may be higher or lower than the rated rate. If a factor has no effect on the rate, the value of 1 can be taken; if there is a facilitating effect, the value of $X>1$; if there is a weakening effect, the value of $0<X<1$ (X is the value of the influencing factor).

3.2.7 Parameter Estimation

The choice of parameters for system dynamics models is often the most common aspect of concern and misunderstanding. In fact, for the estimation of parameters, system dynamics has different requirements from statistics. The basic structure of the system dynamics model is information feedback, while the behavior of the feedback model is insensitive to parameter changes, and its model behavior patterns and results depend mainly on the structure of the model rather than the magnitude of the parameter values. Therefore, when running the model, the data that can be obtained by investigation or provided by the relevant departments and parties familiar with the system can be used directly; for parameters that cannot be obtained, the upper and lower limits of the parameters can be initially estimated according to the actual situation, and then confirmed by repeated modifications based on the system data.

3.2.8 Model Error Checking

Before the model runs, Vensim software provides model checking function, which is divided into two parts: one is the model structure checking, and the other is the variable unit checking.

Model Structure Checking

The main purpose of this part of the check is to verify that the model is complete and ready to run. There are two main types of errors: 1. The presence of variables not used in the model. 2. the internal equations of the model variables are reported in error. For the first type of problem, the causes may include problems such as the lack of a line between a variable and other variable or the lack of use of the variable in the internal equation of the variable connected to that variable. For the second type of problem, the causes may include state variables not assigned initial values or auxiliary variables not assigned or defined, etc.

Variables Dimension Checking

The units of the variables can be defined in Vensim software. Units are an indicator to check if the relationship of variables in the model is correct. Errors can arise for a variety of reasons, including but not limited to the failure to define the units of variables in the model and conflicting relationships between the units of variables in the model and the actual variables.

3.2.9 Model Correctness and Reliability Checking

It is meaningless to talk about the problem of model testing away from the purpose of modeling. In other words, the model is correct when it applies to the problem under study and models the described part in a way that is consistent with the actual system. The so-called correctness is not correct in an absolute sense but correct under a particular assumption. For example, the policy model constructed in this thesis is based on an important assumption that the policies modeled are correct, effective, reliable, and non-contradictory.

In the matter of validating the model, the system dynamics model differs from the typical model testing guidelines. It is not possible to pursue the testing of system dynamics models by statistical methods, e.g., goodness-of-fit tests, complex correlation coefficient estimation, etc. The reason why this cannot be done is that model checking of a system dynamics model is not a one-time procedure done after the model is built. Model checking is done throughout the iterative modeling process. The model is usually validated according to four aspects. (1) Suitability test of the model structure, which includes whether the bound size of the model is appropriate; whether the complexity of the bound is appropriate; and whether the structure of the model is sufficient for the problem under study, etc. (2) Model behavior suitability test, which contains the sensitivity of the parameters, and the sensitivity of the structure. Usually, the confidence of the model is high when the model is not overly sensitive to changes in parameters within a reasonable range and structural fine-tuning. (3) The model structure and actual system consistency test, including model appearance test and parameter test. The appearance test is to check whether the variables such as state and rate are arranged properly in the model. The parameter test considers whether the choice of parameters is justified or reasonable. Model behavior and actual system consistency check, in this case, it is concentrated on whether the behavioral model in the policy can be successfully represented.

4 Case Study

4.1 Background

Since 2004, China has surpassed the United States as the world's largest producer of waste [79], making it necessary to invest greater efforts in waste management to control the pollution and other serious consequences of municipal solid waste. Many cities in China are in the predicament of "waste siege", where the city is surrounded by piles of waste from the suburbs or the countryside [80]. China has made dramatic changes in all aspects of its waste management system and has invested considerable funds in environmental protection [81]. Since 2000, eight major cities in China have launched pilot programs for source separation and collection of municipal household waste, and Shanghai, as one of the eight pilot areas, has performed relatively favorably in terms of municipal household waste management [82].

4.1.1 Brief Introduction of Shanghai

Shanghai is the largest city in China and eighth largest city in the world. It has 24.88 million people as of 2020, making it also the most populous region in China [83]. Located in the Yangtze River Delta on the southeast China coast, Shanghai is the busiest container seaport in the world, as shown in Figure 10.

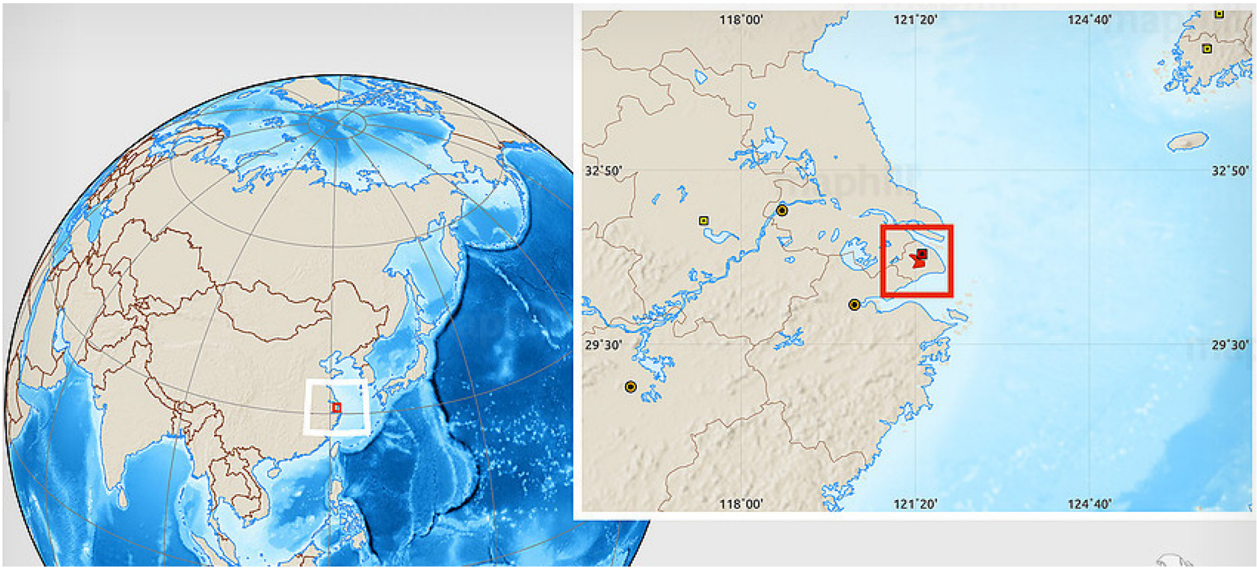

Figure 10 The Location of Shanghai (Produced by Maphill)

Shanghai is divided into 16 districts and 3 counties. There are 205 towns, 9 townships, 99 sub-district committees, 3,278 neighborhood committees and 2,935 villagers' committees in the city [84]. The massive population makes Shanghai's waste generation extremely high. The municipal household waste generation in Shanghai between 2000 and 2020 is illustrated in Figure 11. The tremendous and continuously rising waste generation has made both local and state highly concerned. If Shanghai's MSW classification is successful, then Shanghai's MSW classification policy will become an exemplary model and provide a benchmark and reference for other cities [15]. Because of the mandatory approach to waste management in Shanghai, waste generation declined significantly in 2020 (figure 11), but the effect is still limited. This was also a part of the inspiration for the origin of this study.

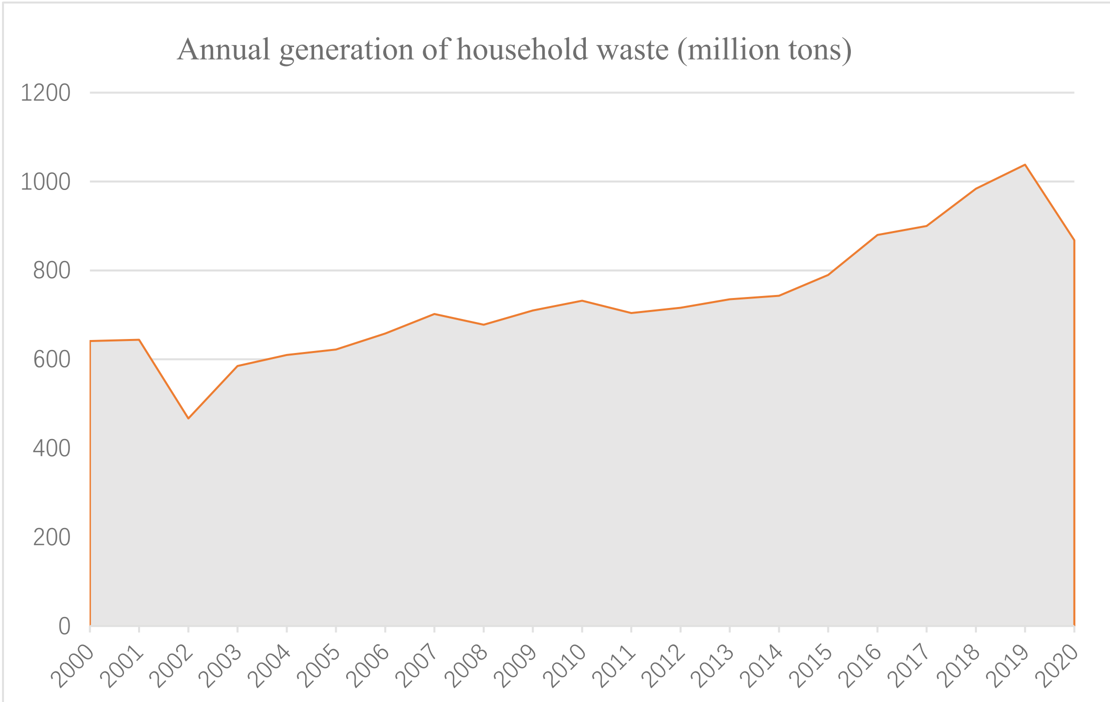

Figure 11 Shanghai municipal household waste generation (Data provided by Shanghai Greening and Amenities Administration) [83]

4.1.2 Important Time Nodes for Waste Management in Shanghai

The eight cities MSWM pilot program is not the first attempt of waste management in Shanghai. Since early 1995, a pilot community in Shanghai has been engaged in source separation and collection of waste by placing municipal solid waste separation containers in public places. Subsequently, a pilot program for source separation of municipal waste collection was initiated in 100 communities beginning in 2000. By 2006, more than 3,700 communities (3 million residents) were source separating MSW. In 2007, Shanghai officially adjusted the city's domestic waste to 4 categories: dry waste, wet waste, recyclables, and hazardous waste. This means that Shanghai's domestic waste disposal facilities will also follow and adjust in parallel. In 2010, Shanghai proposed a plan to minimize urban domestic waste, which also pushes Shanghai's waste management to a new level [85]. The important nodes of waste management development in Shanghai are shown in Figure 12.

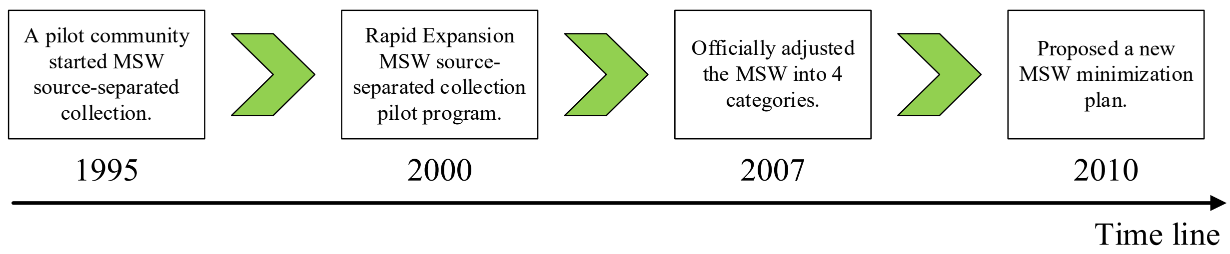

Figure 12 The important nodes of waste management development in Shanghai [85]

4.1.3 Development of Waste Management Systems and Policies in Shanghai

Both the central and local governments in China have made several attempts to promote municipal domestic waste separation policies, but due to many factors such as psychological resistance of residents, insufficient amount of facilities, and poor coordination among various government departments, municipal domestic waste separation cannot be considered successful [57]. The Shanghai Municipal Household Waste Separation System regulates the behavior of dumping household waste in Shanghai, China. It requires citizens and various organizations and institutions to separate waste according to a specific set of separation standards and convert and dispose of waste in a separate manner to achieve the goal of waste reduction. Table 4 lists the changes in the number of sanitation facilities in Shanghai from 2000 to 2020. It is worth noting that there is a decreasing trend in the number of domestic waste collection points in 2001, 2019, and 2020. The decrease in 2001 could be due to the consolidation of waste collection points, while in 2019 and 2020, it is likely due to the implementation of the SMSWMR to eliminate some unsupervised household waste collection points.

Table 4 Number of sanitary facilities in Shanghai [83]

Year	Household waste collection point (pcs)	Waste bins (pcs)
2000	22 470	23 189
2001	17 694	24 672
2002	26 787	29 517
2003	27 814	31 272
2004	28 649	34 571
2005	28 388	39 539
2006	29 812	44 888
2007	29 538	47 739
2008	29 965	56 485
2009	30 584	67 465
2010	30 645	74 658
2011	30 648	78 213
2012	31 625	82 454
2013	32 018	98 266
2014	32 122	98 857
2015	32 209	94 310
2016	32 257	81 246
2017	32 247	86 246
2018	31 319	80 360
2019	29 811	62 554
2020	28 104	55 309

Shanghai's household waste separation system first began in 1990, when the city began collecting and disposing of waste glass and waste batteries separately [86]. Since 2002, Shanghai has been implementing the "one city, two systems" for waste separation, with the presence or absence of waste incineration plants as the key to differentiate the different systems [87]. In areas served by waste incineration plants, the four categories of incinerable waste, non-incinerable waste, glass waste and hazardous waste will be implemented, while in areas not served by waste incineration plants, the categories of incinerable and non-incinerable waste will be replaced by compostable and non-compostable waste. In 2005, the Shanghai Municipal People's Government promulgated the government regulation "Shanghai Measures for Promoting the Separation and Reduction of Domestic Waste", which established the current system of four classifications of waste in the form of government regulations and formal penalties. In 2007, Shanghai's waste separation standards were again adjusted regionally. Different regions implement different waste separation standards according to their specific local conditions [88]. The specific approach is divided into three categories: 1,000 pilot residential areas implement a four-way separation of recyclable waste, food waste & other waste, waste glass and hazardous waste; public places implement a two-way separation of recyclables and other waste; and 1,000 pilot companies using a three-way separation of recyclables, hazardous waste, and other waste. In 2008, Shanghai Municipal People's Government promulgated the "Shanghai Municipal Domestic Waste Collection and Disposal Management Measures" to regulate the collection and disposal of municipal domestic waste in Shanghai and began to implement a domestic waste charging system [89]. Beginning in 2010, Shanghai's legislative and administrative authorities began to study legislation for a waste separation system. In same year, Shanghai started to implement the four methods of separating dry waste, wet waste, recyclable waste and hazardous waste, which is also the current method of waste separation in Shanghai [87]. In 2014, the Shanghai Municipal People's Government issued the "Shanghai Measures to Promote the Separation and Reduction of Domestic Waste", which formally legislated the current four-point waste separation method, replacing the previous one [90]. In the same year, Shanghai formulated the "Shanghai Domestic Waste Classification Catalogue and Related Requirements" to refine waste classification standards and specific requirements. This bill was replaced in April 2019 by the "Shanghai Household Waste Separation and Disposal Guidelines" [91]. In May 2019, the Shanghai Municipal Bureau of Urban

Management Administration and Law Enforcement issued the "Shanghai Municipal Regulations on Investigation and Punishment of Illegal Acts of Domestic Waste Classification", and in Article 3 of this law, the penalties and objects of punishment for domestic waste classification management are described in detail [92]. The “Shanghai Municipal Solid Waste Management Regulations” was passed by the 15th Shanghai Municipal People's Congress, formally becoming a local regulation, and became mandatory on the same year, July 1, 2019 [16]. The timeline of Shanghai's waste management system and policies is shown in Figure 13.

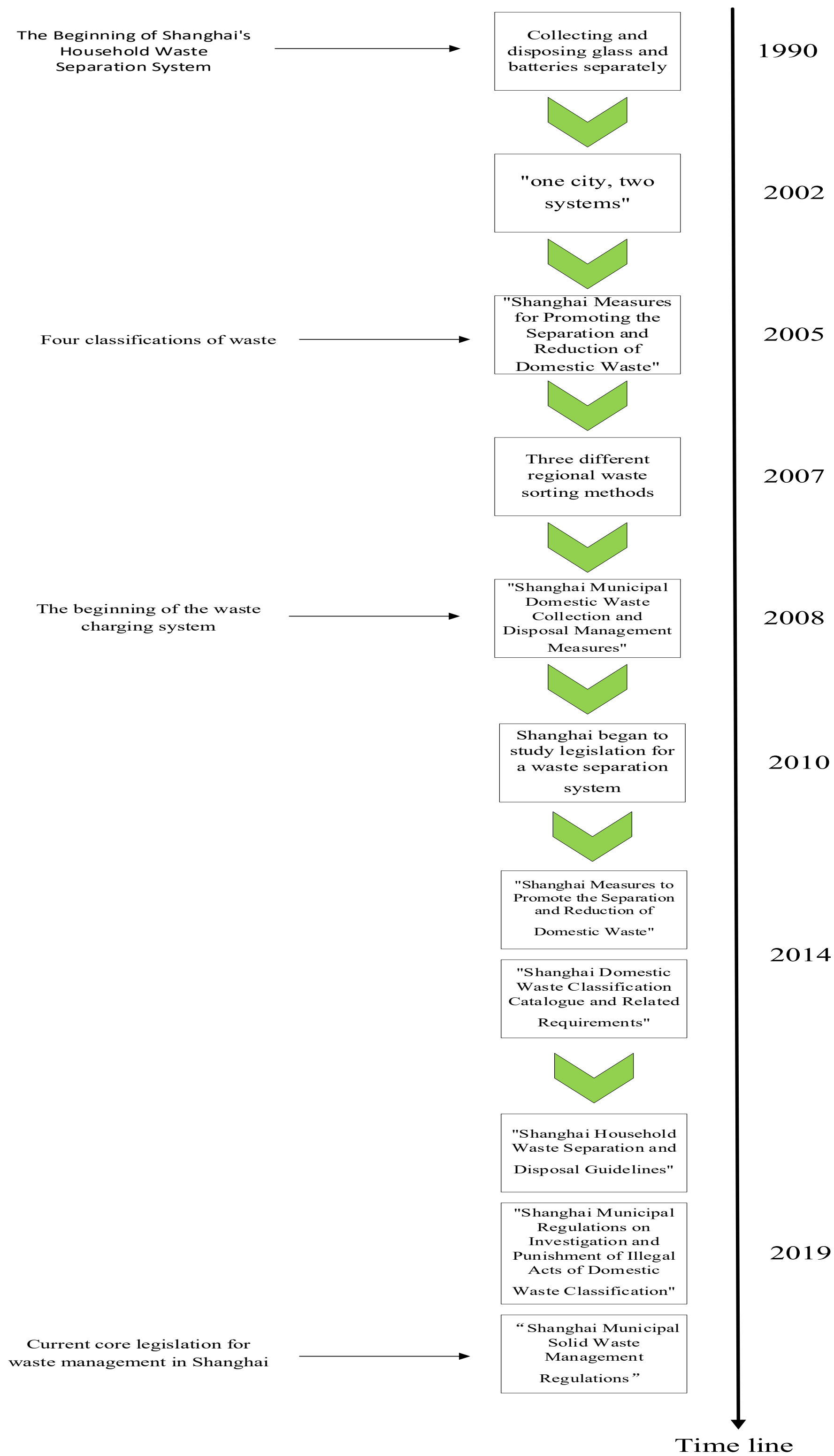

Figure 13 The timeline of Shanghai's waste management system and policies

4.2 The Shanghai Municipal Solid Waste Management Regulations

"Shanghai Municipal Solid Waste Management Regulations" is a local regulation proposed by the Shanghai Municipal People's Government and considered, adopted and promulgated by the Shanghai Municipal People's Congress. On February 22, 2017, the thirty-fifth meeting of the Standing Committee of the 14th Shanghai Municipal People's Congress adopted the Legislative Work Plan of the Standing Committee of the Shanghai Municipal People's Congress for 2017. This means that the legislative preparatory work for the Shanghai Municipal Solid Waste Management Regulations has officially begun. Subsequently, the "Legislative Work Plan of the Standing Committee of the Shanghai Municipal People's Congress for 2018" was adopted at the second meeting of the Standing Committee of the 15th Shanghai Municipal People's Congress on February 24, 2018. This event marked the formal inclusion of this law in the legislative work plan of the NPC Standing Committee. Since September 25, 2018, the Standing Committee of the Shanghai Municipal People's Congress and the 15th Shanghai People's Congress have been reviewing this bill repeatedly. It was formally adopted at the second session of the 15th Shanghai People's Congress on January 31, 2019 and signed and published by the Bureau of the session on the same day. This regulation is currently in effect in Shanghai. A large number of leaflets about this law are circulating in Shanghai, and a variety of innovative promotional designs are being collected simultaneously. The case study in this thesis is based on this statute and is modeled from a legal perspective to explain the mechanics of how this statute works in the context of waste management.

4.2.1 Internal Structure of Law

Shanghai Municipal Solid Waste Management Regulations are divided into 10 chapters and 65 articles. The key information it conveys can be divided into 4 parts. The relationship between them can be represented in Figure 14. The master plan section is the basis for the subsequent content of this law and is the necessary landing point for the rest of this bill to be promoted. Stakeholders' responsibilities and work requirements are the most important part of this bill. The large number of connections contained in this section form a network of relationships that link organizations and individuals through responsibilities and requirements. This network is overseen by a detailed management hierarchy that ensures that the content of each department's responsibilities can be reported and monitored. Legal penalties are the final line of restraint on the behavior of various stakeholders, and the specific number of fines can serve as a deterrent and warning to both individuals and companies.

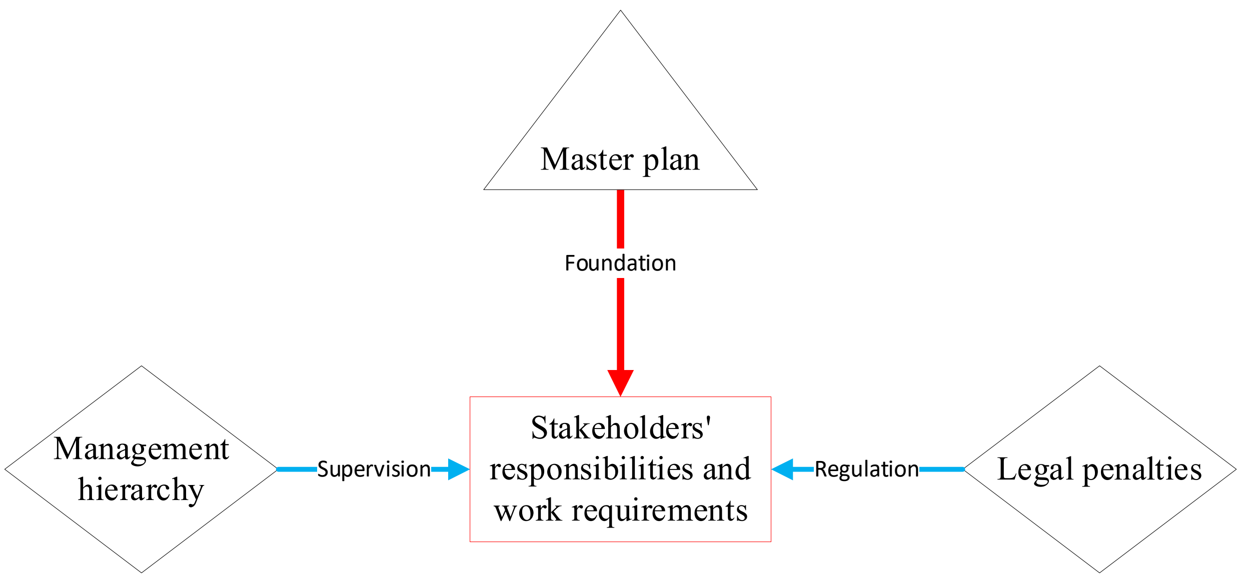

Figure 14 Structural relationship of key information in each part of Shanghai Municipal Solid Waste Management Regulations

Master plan

The first part of the key information is the master plan. The master plan contains the legislative basis and legislative objectives of this law. They are: 1. Strengthen the city's domestic waste management. 2. Improve the living environment. 3. Promote urban management. 4. Maintain ecological security. 5. protect sustainable economic and social development. On this basis, the law introduces and specifies six principal aspects: working principles, definitions of each type of waste, charging principles, establishment of a sorting system, specific objectives, and scope of application. This part is concentrated in the first chapter of this law and is the ideological basis for the realization of the subsequent actions of this law. The details of the master plan structure are shown in Figure 15.

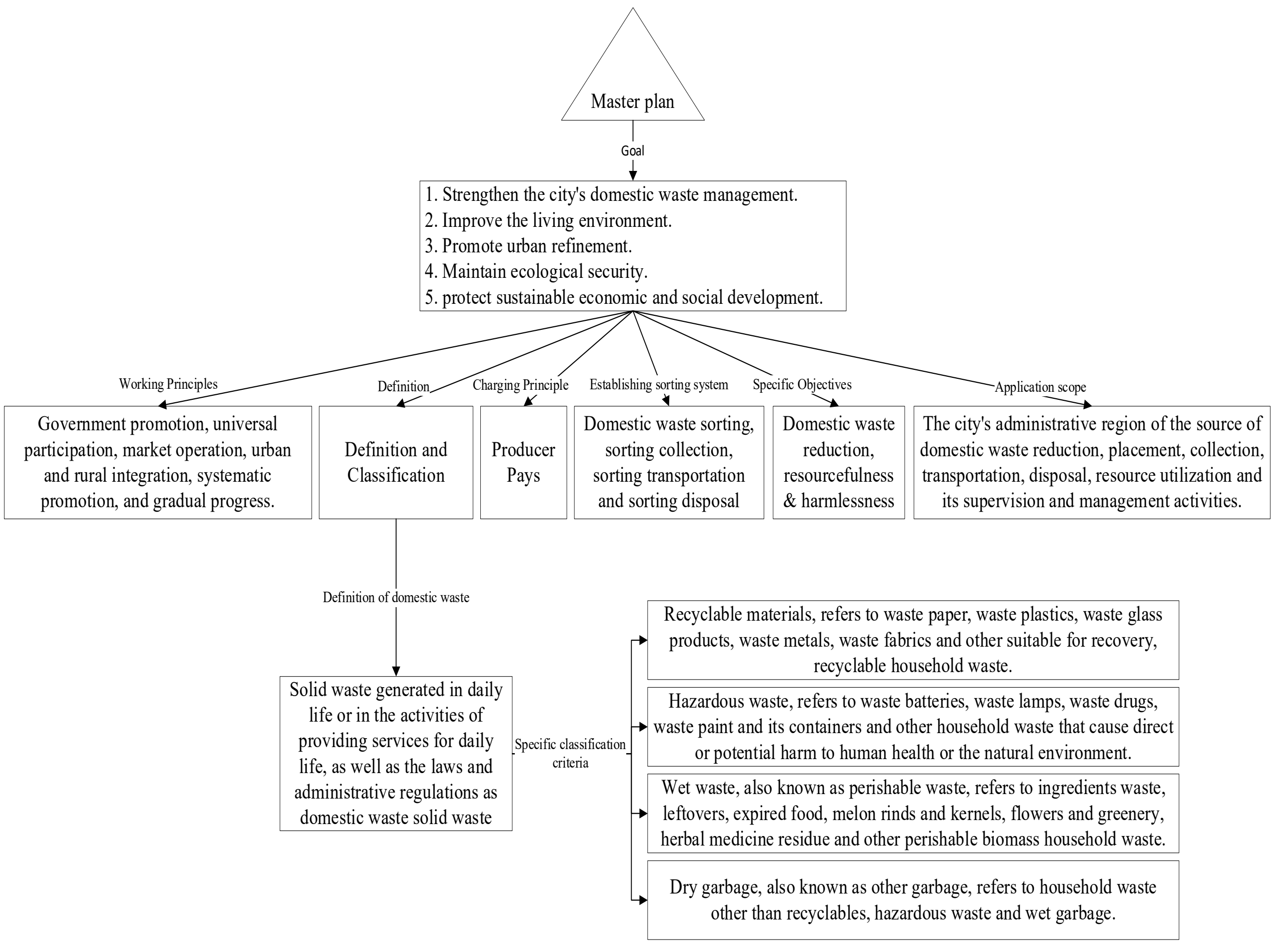

Figure 15 The master plan structure of SMSWMR

Stakeholders' responsibilities and work requirements

The second part of the key message is the stakeholders' responsibilities and work requirements. This section also describes the relationship between the different stakeholders. It includes various governmental management organizations, related enterprises and factories, individual companies, merchants, and individuals, etc. Figure 16 shows the relationship network diagram between stakeholders. The core part of the relationship network is the individual, that is, the product user, the consumer, or can be understood as the producer of waste. The rest of the relationships between the various social components and individuals are made according to the description of the relationships in the law. From Figure 16, it can be seen that the essence of the whole network diagram interrelationship is actually the management, constraint and guidance of different perspectives of individual producing waste according to the perspective of waste life cycle. Municipal supervision department oversees and manages the products produced by the product producers with the aim of controlling the waste generation from the source. The purchasing trends of state-owned enterprises (SOEs) and party and government agencies can likewise serve as a social driver, which also aims to control the source of waste.

For individuals, sorting waste and learning how to sort waste is the only workload. However, the operation of seemingly simple things is not easy, these two things will engage almost all the remaining social resources. Producers, news media, volunteer organizations and people responsible for waste management start from the perspective of personal waste separation awareness through announcements, repeated advocacy, appeals and guidance. Construction companies provide the infrastructure, while recycling operators provide financial subsidies so that individuals can get money while having bins for separated waste. Restaurants and hotels no longer offering disposable merchandise are forcing individuals to change their habits. The city management enforcement department is the bottom line for individual sorting behavior to be conducted or not, and fines become the punishment for those unwilling to comply.

Together, government departments and companies that recycle and transport waste make up the second half of the waste lifecycle in the network of relationships. In this part, each government department plays the lead function. The companies are monitored, promoted, and supported by the governmental departments through service agreements signed with them.

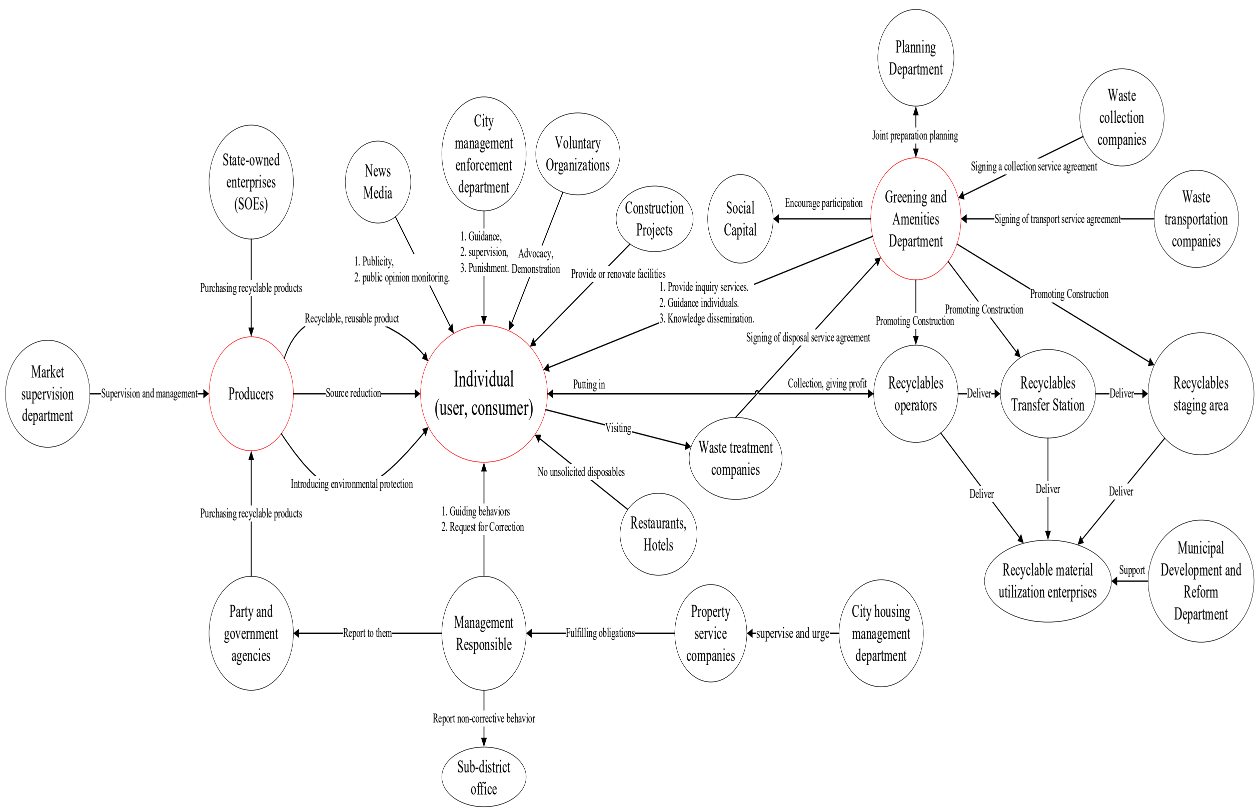

Figure 16 Stakeholders' relationship network

Circles indicate stakeholders; Arrows indicate actions; The direction of the arrow is the direction of application; Source reduction for producers is mainly through material and design solutions; Producers advocate environmental protection to consumers mainly through the packaging usage perspective; Sub-district office is an official who works with local residents and report to higher government authorities; Joint preparation of waste transfer, disposal and recycling facilities planning by the planning department and the greening and amenities department; Social capital is encouraged to participate in the construction of municipal recyclables collection and transportation facilities.

Management hierarchy

The third part of the key message is the management hierarchy. The tiers shown in Figure 17 are the main tiers and departments of waste management in Shanghai, such as housing and urban-rural construction, commerce, finance, planning, economic information technology, education, civil affairs, agriculture and rural areas, science and technology, health, culture and tourism, market supervision, postal services, and institutional affairs management departments will also implement the Shanghai Municipal Solid Waste Management Regulations in accordance with their respective responsibilities, which are omitted for the sake of simplicity of the diagram. Each management level is divided according to whether there is an encompassing relationship between jurisdictions. The city administrative district contains the district level. Municipal governments are responsible for establishing systems and developing plans. Each district government, in turn, implements measures in accordance with the plan. Township people's governments and sub-district offices are responsible for the implementation of the daily waste management of the areas under their jurisdiction, such as household waste sorting, sorting barging and related sorting and collection. The above responsibilities are the main role of the government and offices at all levels in the management of municipal solid waste in Shanghai, and other duties are carried out together with the main duties in accordance with the law. Clear hierarchy and segregation of duties can increase efficiency and accuracy for specific problem solving, reporting, feedback, and auditing.

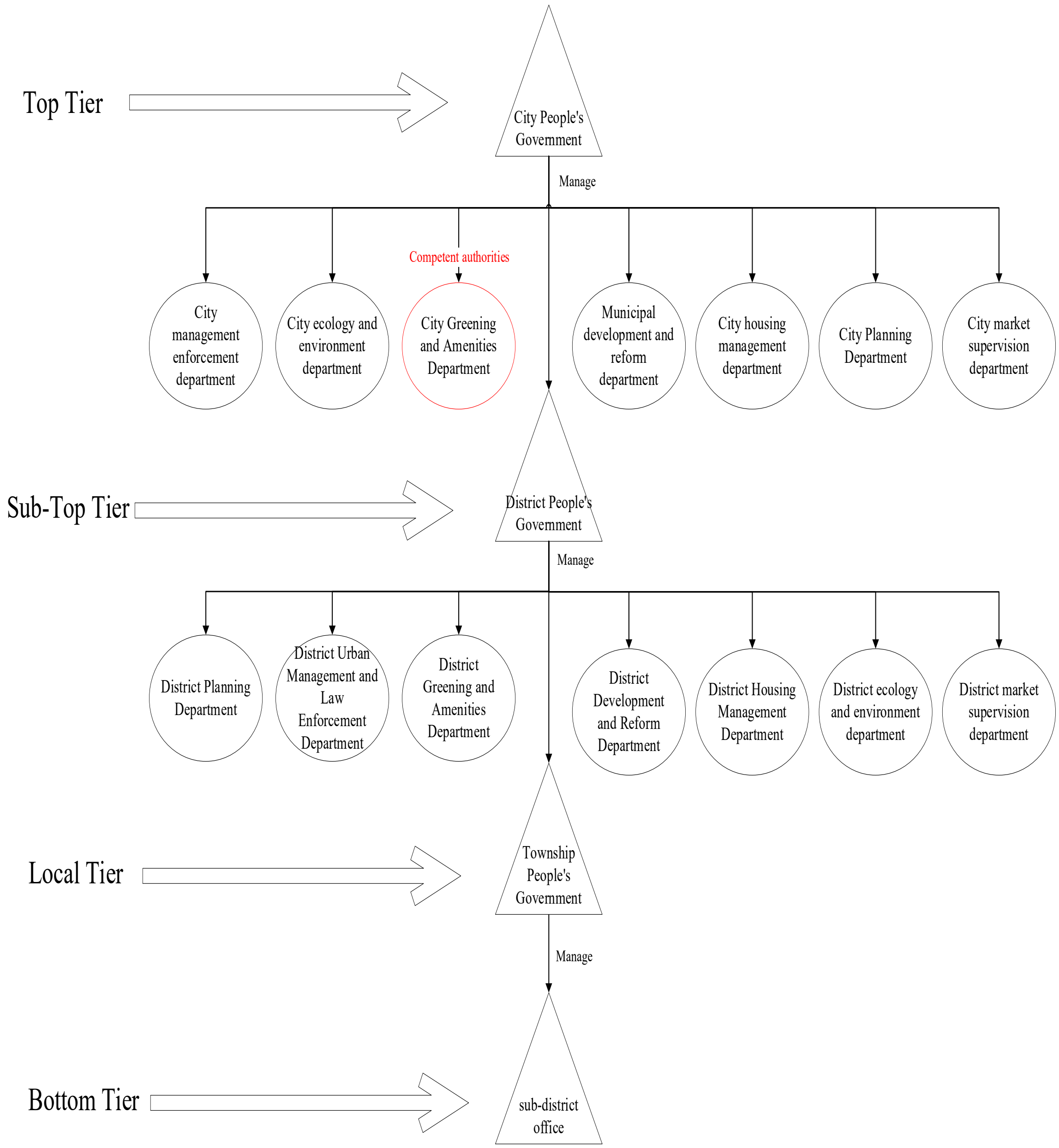

Figure 17 Shanghai waste management hierarchy

Legal penalties

The fourth part of the key message is the legal penalties. The content of the Shanghai Municipal Solid Waste Management Regulations on specific measures of punishment is mostly grouped in Chapter 9. It involves 4 types of punishment departments, 11 types of objects to be punished, and

7 types of punishment measures, the specific corresponding situation is shown in Figure 18. In general, the penalties are lighter for individuals and small business operators, and heavier for businesses engaged in waste collection, transportation, and disposal-related activities.

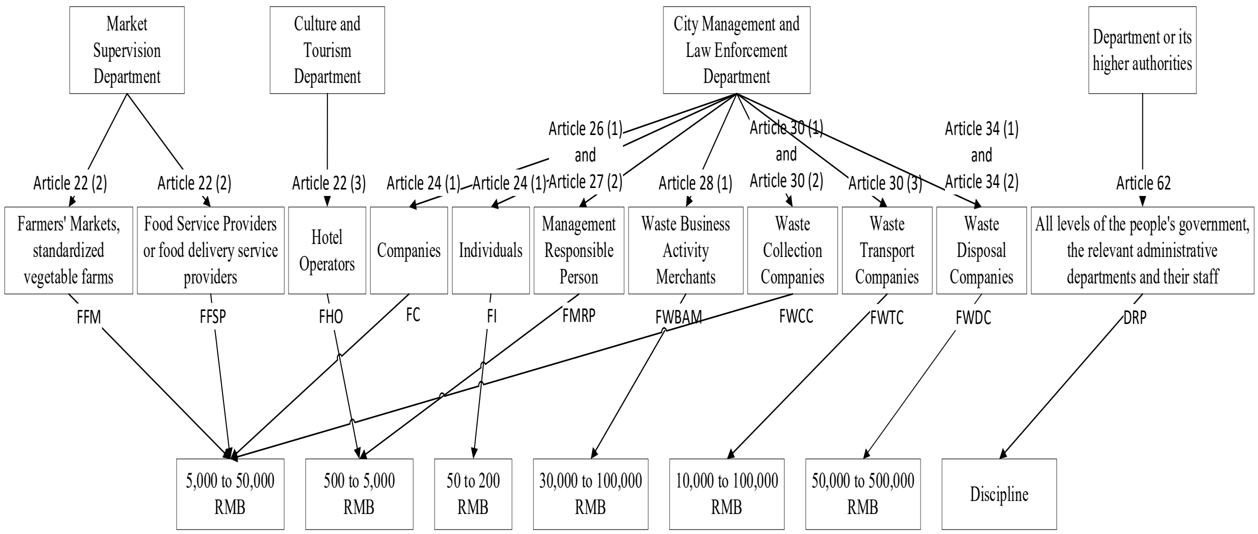

Figure 18 Shanghai Municipal Solid Waste Management Regulations Punitive Measures (The specific information in the figure is explained in the next paragraph)

FFM (Fine Farmers Market) is to fine farmers' markets and standardized vegetable farms not in accordance with the standard configuration of wet waste in situ treatment facilities; FFSP (Fine Food Service Providers) is to fine food service providers or food delivery service providers proactive provision of disposable chopsticks, spoons and other tableware to consumers; FHO (Fine Hotel Operators) is to fine hotel operators proactive provision of disposable daily necessities to consumers in guest rooms; FC (Fine Companies) is to fine companies failure to put household waste into the appropriate collection containers; FI (Fine Individuals) is to fine individuals mixing hazardous waste with recyclables, wet waste and dry waste, or mixing wet waste with recyclables and dry waste; FMRP (Fine Management Responsible Person) is to fine management responsible person not set up in accordance with the requirements of the collection containers, facilities, and uncategorized barge (The full title of the management responsible person is the management responsible person for the classification of household waste placement); FWBAM (Fine Waste Business Activity Merchants) is to fine waste business activity merchants unauthorized hazardous waste, wet garbage, dry garbage business collection, transportation, and wet garbage, dry garbage business disposal activities; FWCC (Fine Waste Collection Companies) is to fine waste collection companies not using special vehicles, ships, not clearly marked categories of household waste transported, not sealed transport or not installed online monitoring system, mixed collection and transport of household waste that has been sorted, or hazardous waste, industrial solid waste, construction waste, etc. mixed into household waste (FWCC may result in the revocation of the waste collection company's domestic waste operation service license); FWTC (Fine Waste Transport Companies) is to fine waste transport companies not in accordance with the requirements to transport domestic waste to eligible transfer sites; FWDC (Fine Waste Disposal Companies) is to fine waste disposal companies failure to maintain normal operation of domestic waste disposal facilities and equipment, affecting the timely disposal of domestic waste, failure to dispose of domestic waste in accordance with the requirements of classification (FWDC may result in the revocation of the waste disposal company's domestic waste operation service license); DRP (Discipline Responsible Person) is to discipline responsible person (a) Failure to perform the source reduction of domestic waste and classification of placement, collection, transportation, disposal, utilization of supervision and management responsibilities in accordance with the provisions. (B) Failure to implement the construction of domestic waste disposal facilities in accordance with the requirements. (C) Not investigated and handled in accordance with the law after receiving relevant complaints and reports. (D) Other dereliction of duty, abuse of power, favoritism and corruption.

4.2.2 Extraction Variables from the Policy

The extraction of variables in the policy is a summary of the purpose and intent expressed in the various parts of the policy. A short process of extracting the dependent variables from the policy is given in Section 3.2.2. The five dependent variables extracted are the key variables in this case, which reflect the target that the policy maker is trying to achieve. The independent variables in the policy can be divided into two categories according to the number of research. The first category has been studied extensively, for example, Shigemi [93] mentions the dependence of waste generation on consumption structure, and the legal provisions that are closely related to the variable of consumption structure can also be found in SMSWMR. As shown in Figure 22. Another category of variables has been studied in a small amount and it is difficult to find the same or similar variables in other literature. Such variables are mentioned in law texts and have a non-negligible impact on the events in the waste management life cycle. The author summarizes this type of variables and try to represent and express these variables by other variables in the subsequent quantification process. This type of variables such as product-related variables, which contains product design solutions, product production materials, product packaging design solutions, and product packaging production materials. Figure 24 illustrates the product-related variables in the Shanghai Municipal Solid Waste Management Regulations. The author extracted a total of 19 independent variables from the Shanghai Municipal Solid Waste Management Regulations, as shown in Figure 19-34. The red circle at the center bottom of the image is the name of the extracted variable, the surrounding or upper part is the law text related to this variable, and the outermost or uppermost number represents the specific section of the relevant law text that appears in the Shanghai Municipal Solid Waste Management Regulations.

The variable shown in Figure 19 are the regional economic distribution, mainly extracted from Article 52. As economic development levels vary from region to region in Shanghai, some commercially centralized areas do not have sufficient waste disposal capacity, while the economies of areas with stronger waste disposal capacity need to be further improved. Therefore, the environmental compensation system implemented in Shanghai for inter-regional disposal of domestic waste has partially channeled funds from domestic waste exporting areas to domestic waste importing areas. This initiative will balance the distribution of regional economies and in such a way that it will also contribute to a further increase in waste disposal capacity in waste-importing regions, leading to additional improvements in economic conditions.

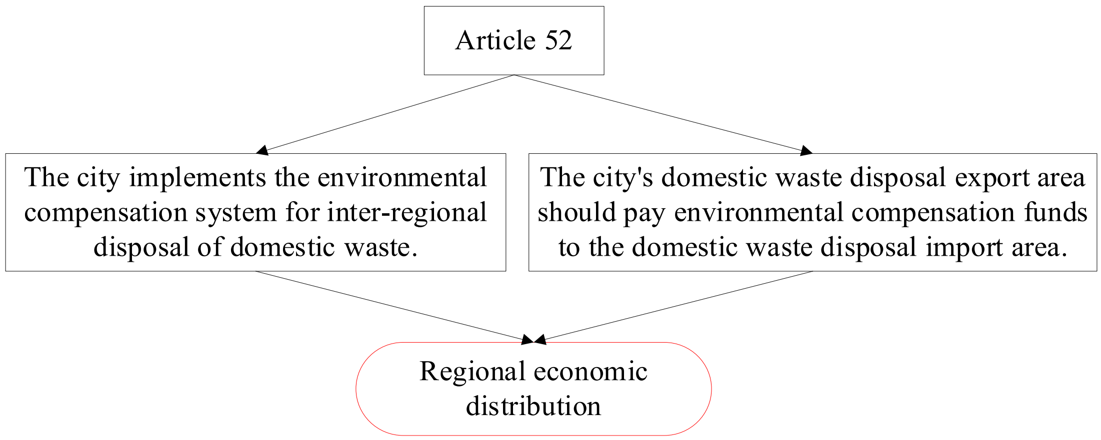

Figure 19 Embodiment of the reginal economic distribution variable in SMSWMR

The variable shown in Figure 20 are fuel structure and are mainly extracted from Article 39. The impact on the urban fuel structure is an important target for waste management, occurring in the later stages of the waste management life cycle, during the waste disposal phase. The heat generated by waste incineration can reduce the city' s dependence on coal and other fossil fuels. Waste incineration produces slag and fly ash along with waste treatment, and these derivatives can be utilized as fertilizer resources, etc.

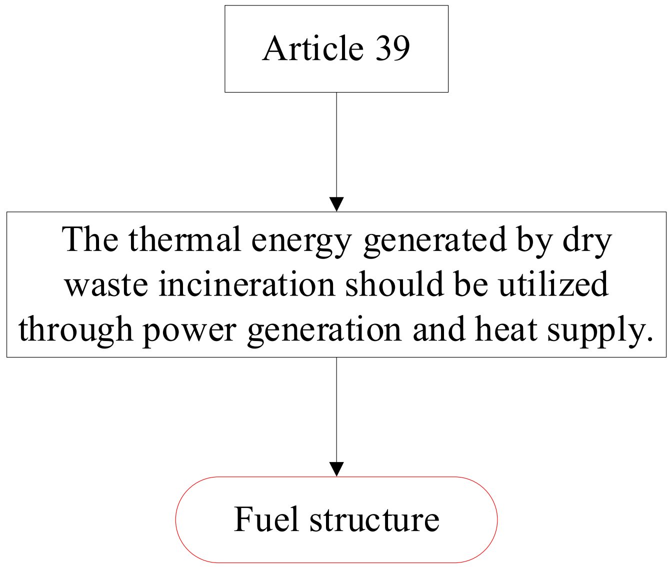

Figure 20 Embodiment of the fuel structure variable in SMSWMR

The variable shown in Figure 21 is compensation for recyclables, extracted from Articles 24 and 42. There are two types of compensation measures. The first is financial compensation measures (Article 24), which will significantly improve disposable income per capita for the impoverished. For the poverty-stricken who rely on recycling collection for their livelihood, this law provides employment opportunities or a way to earn money. These individual waste collectors play an important role in the waste collection and sorting process. The compensation measures will also be closely related to the educational guidance within the waste management system, and the quality audit of recyclables can further enhance the learning effect of waste collectors. The point redemption and other methods in Article 42 are likewise a recyclable compensation measure. Unlike Article 24, this type of compensation will work better for people who are not sensitive to economic factors, and it also adds a degree of playfulness to waste separation and recycling.

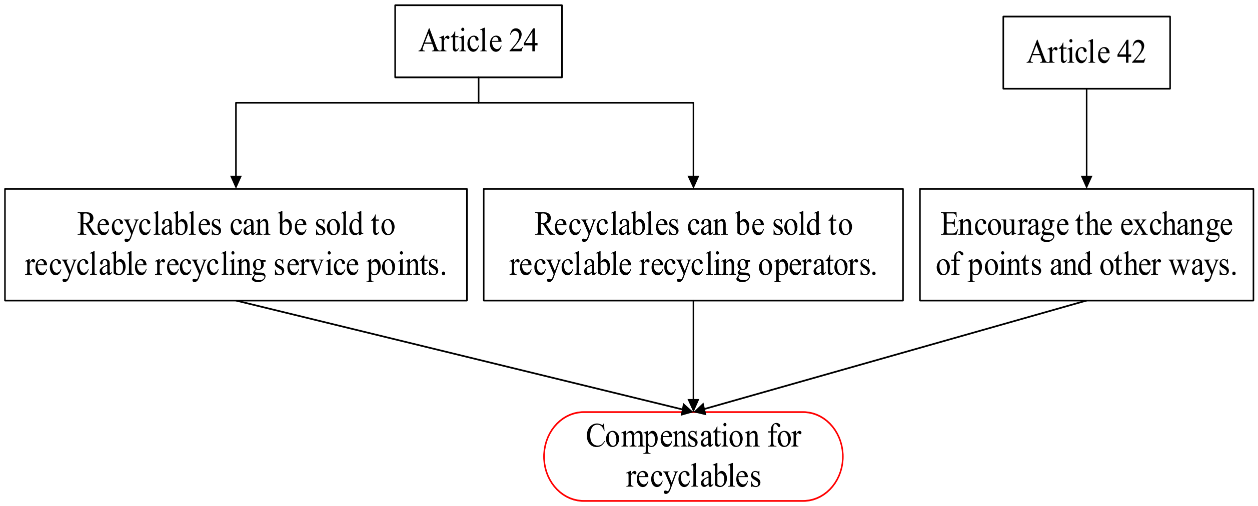

Figure 21 Embodiment of the disposable income per capita variable in SMSWMR

The variable shown in Figure 22 is the consumption structure. The mention of consumption structure in Shanghai Municipal Solid Waste Management Regulations is multi-faceted. The purpose of Article 19 is to change the consumer consumption habits of the packaging. The use of electronic waybills, eco-friendly boxes and recycling of courier boxes has enabled residents to downgrade their consumption in the packaging section. From a life-cycle perspective of waste management, this is a way to control the generation and composition of waste at the source by changing the consumption structure. Article 20 requires clean vegetables on the market for fruit and vegetable production bases, farmers' markets, standardized vegetable farms and supermarkets. This requirement is to reduce the generation of wet waste at the source of purchase by consumers. This action will cause consumers to spend a little more on vegetables and fruits, but is beneficial for waste management in the long run. The change in the consumption structure of the government and related authorities is mainly manifested in government procurement. The details of this part are elaborated in Article 21. This change is beyond a mere change in the type of products consumed; it also plays a leading role in the consumption habits of society. The stakeholders targeted in Article 22 are divided into three main categories, namely, individuals, food service providers and hotel operators. Individuals should choose to buy recyclable products as a way to control waste at its source. As for the encouragement of individuals to trade spare items online or offline, it is to reduce the final amount of disposal of waste from the perspective of reusing them. For restaurants and hotels, not offering disposables also serves to control waste generation at the source. The support and encouragement of government departments for wet waste resource utilization products mentioned in Article 38 is intended to change the consumption structure of fertilizer-related products and shift the consumption related to them to the purchase or use of commodities that are derived from waste. Article 42 mentions another change in government spending, in addition to the individual point redemption method mentioned earlier, namely the purchase of waste management-related services from social organizations. This adjustment in government consumption will promote the conversion or addition of waste management-related services by all kinds of organizations in society and improve the general waste management capability of society. In brief, the variable of consumption structure is reflected in various aspects of this regulation. Unlike the traditional understanding of an upgrade or downgrade in consumption due simply to an increase or decrease in disposable income, the adjustment of consumption structure in this law focuses more on the transformation of consumption, i.e., requiring and recommending the purchase of goods different from previous categories.

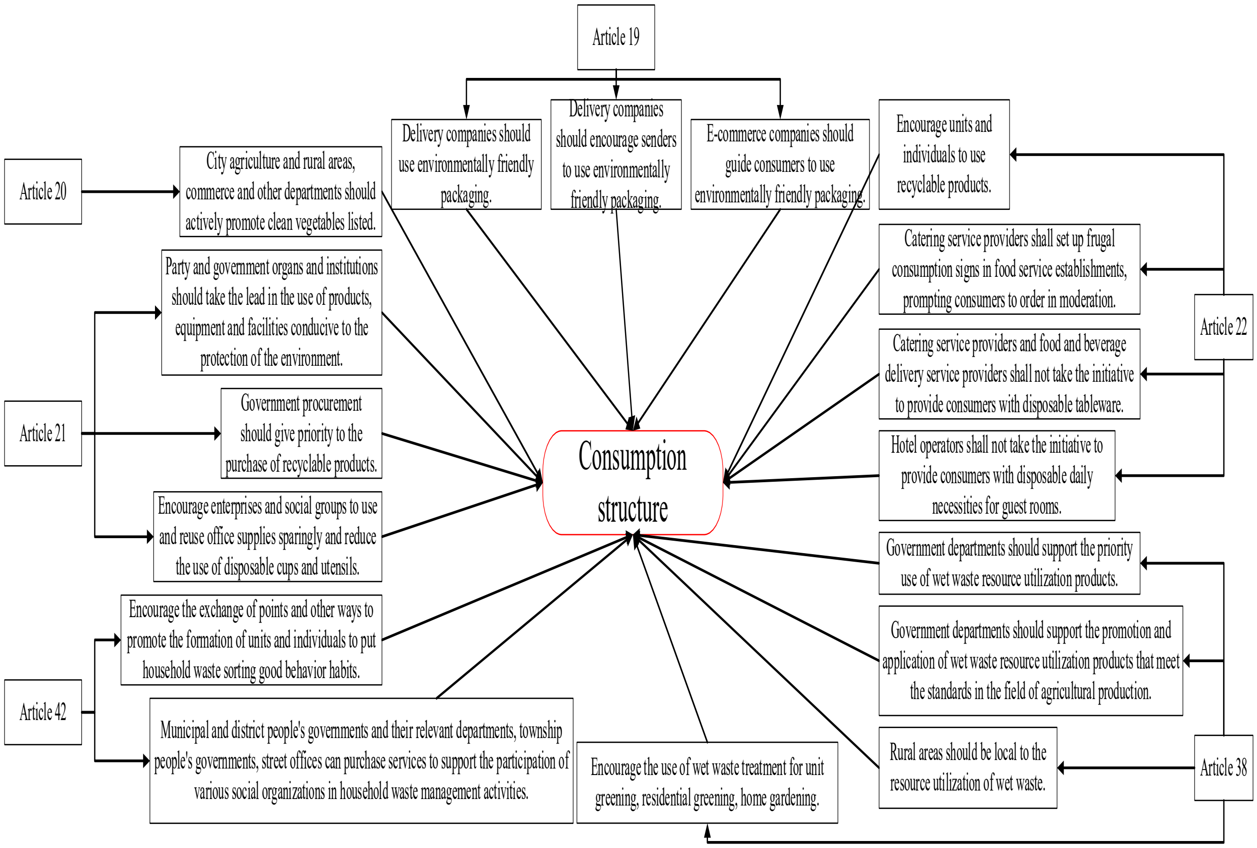

Figure 22 Embodiment of the consumption structure variable in SMSWMR

The variables shown in Figure 23 are the number of facilities. The variable of facility amount is critical in both the collection and disposal of domestic waste. Insufficient sorting and collection facilities will prevent citizens from carrying out sorting activities, while insufficient disposal facilities will lead to a substantial amount of waste going to landfill. Article 13 is the requirements of this law for the relevant government departments. They are required to take actions in the construction of domestic waste treatment facilities in the scope of their respective capabilities. City and district greening and amenities departments as the competent authorities, responsible for the development of annual plans for domestic waste disposal facilities and to organize the implementation. City and district development and reform, planning and other departments are cooperating with them to incorporate the funds and land required for the plan into the annual investment plan and annual land supply plan, respectively. Article 13 provides the basis for the realization of subsequent laws related to waste disposal facilities from the perspective of government departments. For the construction of domestic waste collection facilities, the project constructor has a great responsibility. Article 14 is for the construction of facilities matching the project requirements. City and district greening and amenities departments also need to promote and encourage the construction of urban recyclables-related facilities in accordance with Article 15. This provision will improve the city's recyclables recycling capacity. Article 20 of the bill proposed to farmers' markets and standardized vegetable farms in situ wet waste treatment facilities configuration requirements. Article 26 of the bill is the specific requirements for each management responsible person in the setting of household waste separation and collection containers. For the promotion of the construction of equipment clusters such as the circular economy industrial park, Article 35 of the bill also gives the relevant requirements.

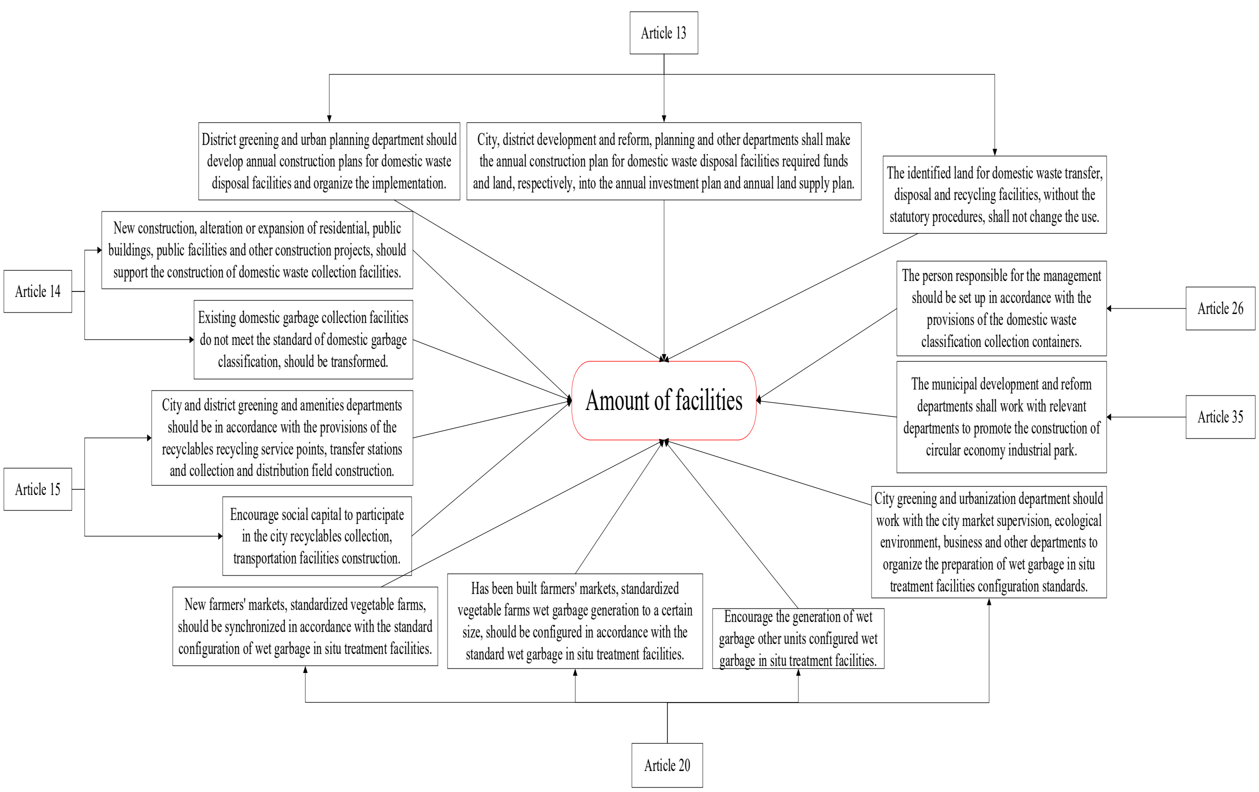

Figure 23 Embodiment of the amount of facilities variable in SMSWMR

Figure 24 contains four variables, which are product design solution, product packaging design solution, product production materials and product packaging production materials. These are product-related variables that act at the initial stage of the waste management lifecycle. Legal constraints on these variables can pre-empt the type and amount of waste that may be generated before the goods are manufactured. The main principles of product design stipulated in Article 17 are less waste generation and recyclability. From design to production should be throughout these two principles, the choice of easily degradable non-toxic and non-hazardous materials will make subsequent waste disposal much less difficult. The control of product packaging is similar to that of products, with material and volume remaining the two most important factors. Article 18 regulates the packaging of product companies, with emphasis on reduction, while Article 19 focuses on the environmental management of packaging materials for courier companies and other companies that rely on express delivery, such as e-commerce companies.

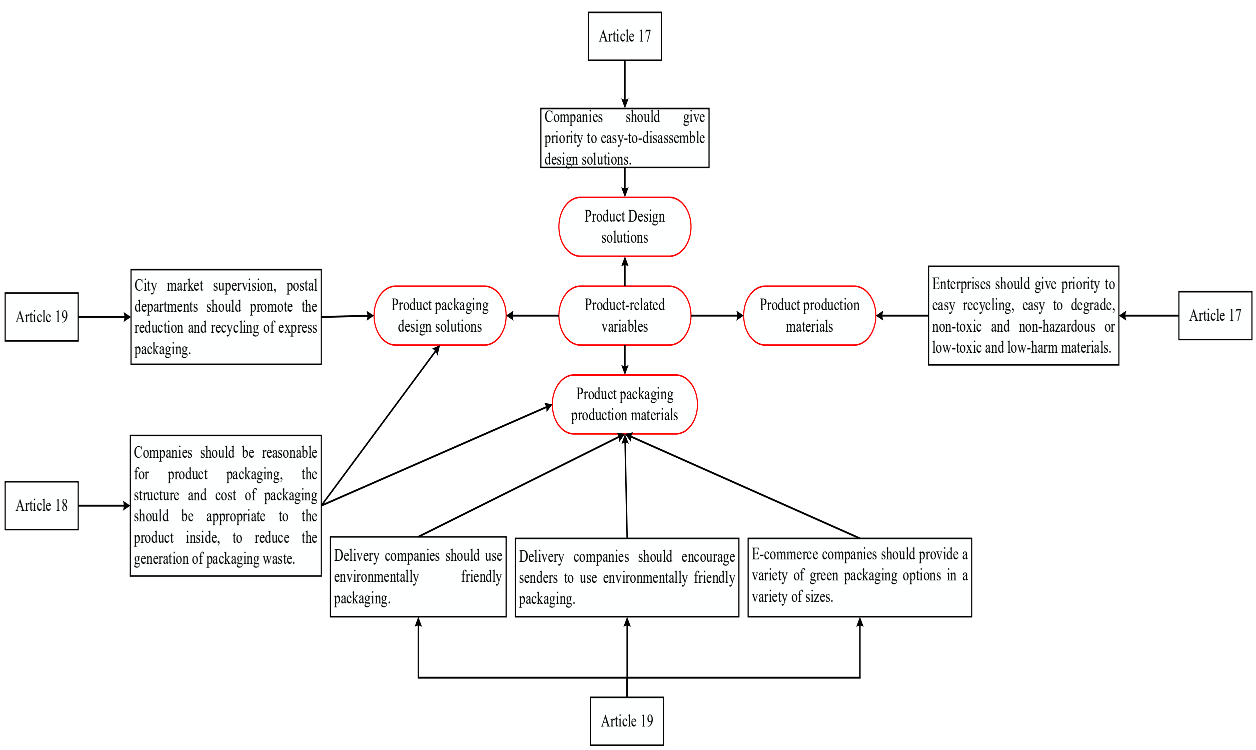

Figure 24 Embodiment of product-related variables in SMSWMR (including product design solutions, product packaging design solutions, product production materials, product packaging production materials)

The variables contained in Figure 25 is the intelligence level. The increased level of intelligence will greatly improve the efficiency of waste separation, collection, transportation, disposal and management operations. Article 10 of this bill shows the attitude of Shanghai towards intelligent development. The city supports departments and companies to develop and apply new technologies, materials and equipment in the whole life cycle management of waste. This has an extremely important role in encouraging and guiding the sustainable and innovative development of urban waste management. For government departments, waste management techniques also need to keep up with the times. Article 50 of this law requires the relevant government departments to establish an information system for the whole process of waste management and to integrate the collection and transportation activities of separated domestic waste into the urban grid management. Such an increased level of intelligence plays an important role and helps in the supervision and evaluation work of the relevant government departments.

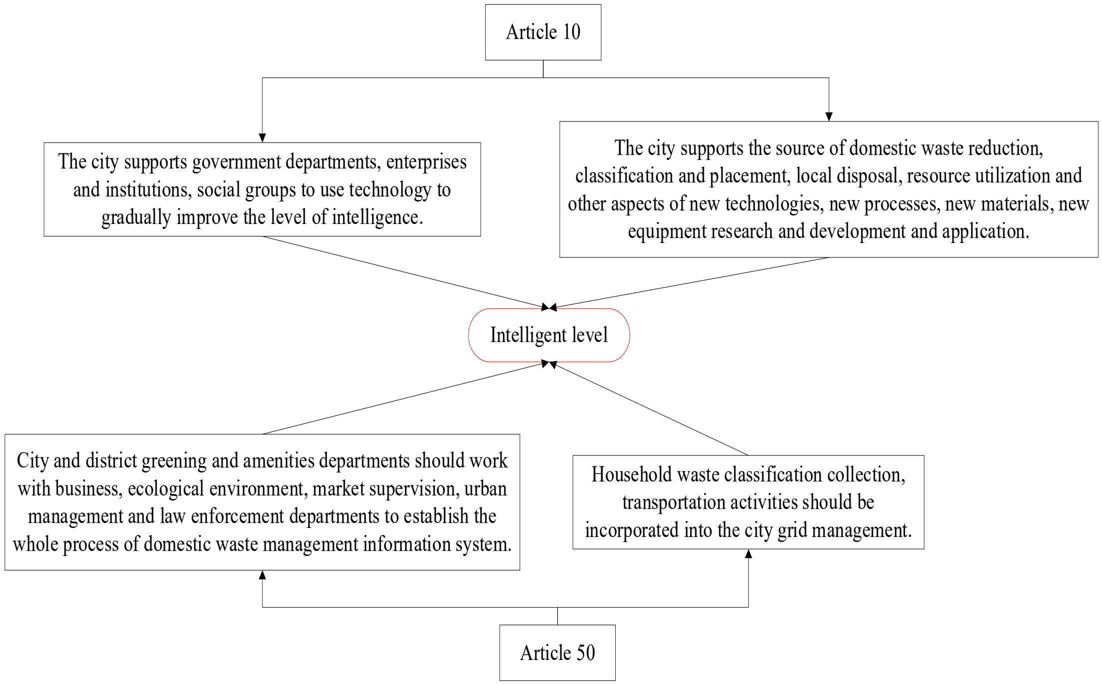

Figure 25 Embodiment of the intelligent level variable in SMSWMR

The variables included in Figure 26 are the legal force. As a law, the effectiveness of it is reflected and strengthened by various disciplinary measures. In this law, many ways exist to improve the force of the law embodied. Article 18 clearly mentions that the city and district market supervision departments should do a good job in the supervision and management of product packaging reduction. Such a duty requirement written in the bill will inevitably attract the great attention of the market regulators, which will inadvertently increase the binding legal force. The same way of mentioning the specific duties required of a particular department appears several times in this bill, including the market supervision department, the postal department, etc. Another characteristic way to strengthen the effectiveness of the law is to implement the system of "responsible person for the management of household waste separation". Article 25 of this law not only mentions the implementation of this provision, but also gives a detailed description of the way to determine the person responsible for the management, including the way to define the person responsible for the management of various departments, companies, social organizations, residential communities, public places and other locations. For companies or places where the person responsible for management cannot be ascertained, township people's governments and street offices will be responsible for confirming. The advantage of this system is that any site or location that is found in trouble with waste management has a person responsible for it. The clear delineation of responsible persons will increase the motivation and rigor of those responsible for collecting and separating waste in their areas, which will lead to the rapid adoption of this law in all areas. The third way in which this bill increases legal binding is by providing a clear place to report and who to report to. For different objects should go to the place of reporting and the events that should be reported are mentioned several times in this law. For example, in Article 25, the person responsible for management can report to the local township people's government or street office for those who refuse to correct their behavior of putting out waste. Whistleblowing is a prerequisite for enabling further financial or other penalties to be imposed, which increases the basic voice of those responsible for managing waste management incidents. The fourth way to improve the legal effect is to require operational collection, transportation and disposal companies to obtain relevant business service licenses in accordance with the law, and to sign relevant service agreements with government greening and amenities departments. This section appears in Article 28 of the Law, using both licenses and service agreements to strengthen the regulatory powers of government departments over waste management-related companies, as licenses can be revoked, and service agreements can be used as a basis for penalties. In addition to this, the approval procedures required by the Law for other waste management-related companies also belong to this category of enhancing legal force. The fifth way to improve the effectiveness of the law is to introduce a system of social supervisors for domestic waste management. This part is described in Article 46 of this bill. The system of social supervisor of domestic waste management is a characteristic system of waste management in Shanghai as well as the system of responsible person of domestic waste classification and management. Domestic waste management social supervisors elected by the city and district greening and amenities departments facing the whole society, they will participate in the supervision of the whole process of domestic waste management. The proposed supervisor system will also further facilitate the advancement of individual reporting of any violations of domestic waste management regulations. The sixth and most direct way in which this law strengthens the legal force can be divided into three categories. The first category is combined with another act, the Shanghai Social Credit Regulations, which imposes credit penalties on violators of domestic waste management regulations, as detailed in Article 54 of this law. The second category is the direct imposition of fines, articles 56, 57, 58, 59, 60, 61 of this law are different ways of punishment for different objects and events. The third category is administrative sanctions against the supervisors and directly responsible persons of the administration, with specific information in Article 62 of this Act. A brief summary of the contents regarding the enhancement of legal force can be found in Table 5.

Table 5 Enhancement measures for legal force

Serial number	Brief description of the action
1	Clarify responsibilities
2	Management responsible person system
3	Provide reporting methods
4	Operators need to apply for permits and sign agreements
5	Social supervisor system
6	Credit penalty
	Monetary fine
	Administrative sanctions

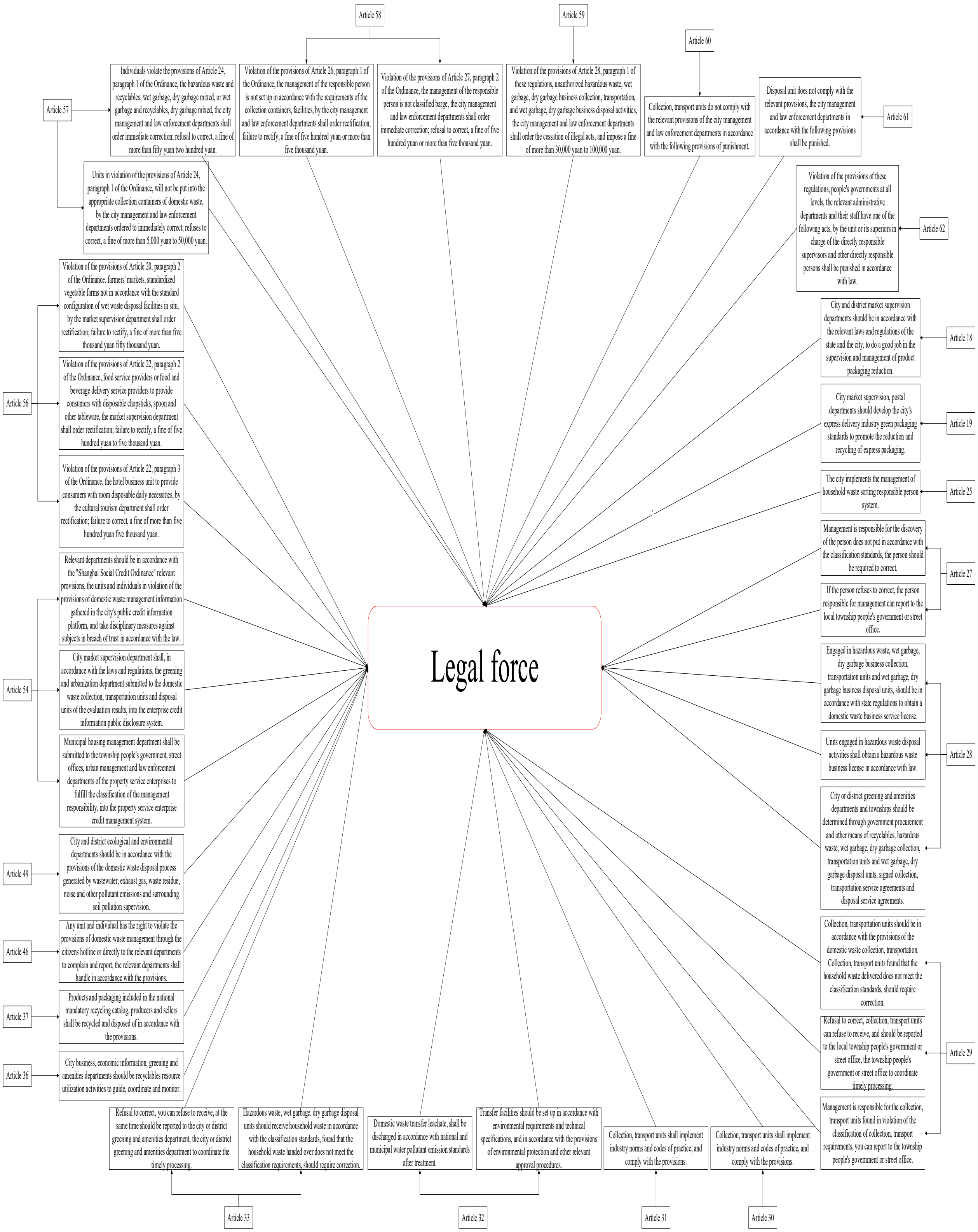

Figure 26 Embodiment of the legal force variable in SMSWMR

The variables included in Figure 27 are government support for recyclables. The impact of government support for recyclables on waste management systems is extraordinary. Because the recycling of recyclables involves a large number of general publics, it makes this support policy directly affects a large population base, and the financial support is related to economic factors, which is beneficial to social and economic development. Article 31 is mainly about the work of the relevant departments in the construction of recyclables recycling system tasks. Article 35 shows the clear support attitude of this bill for recyclables recycling projects. Article 37 imposes recycling and disposal requirements on producers and sellers, which are relatively more efficient and likely to be reused by producers and sellers of their own waste compared to other companies and enterprises.

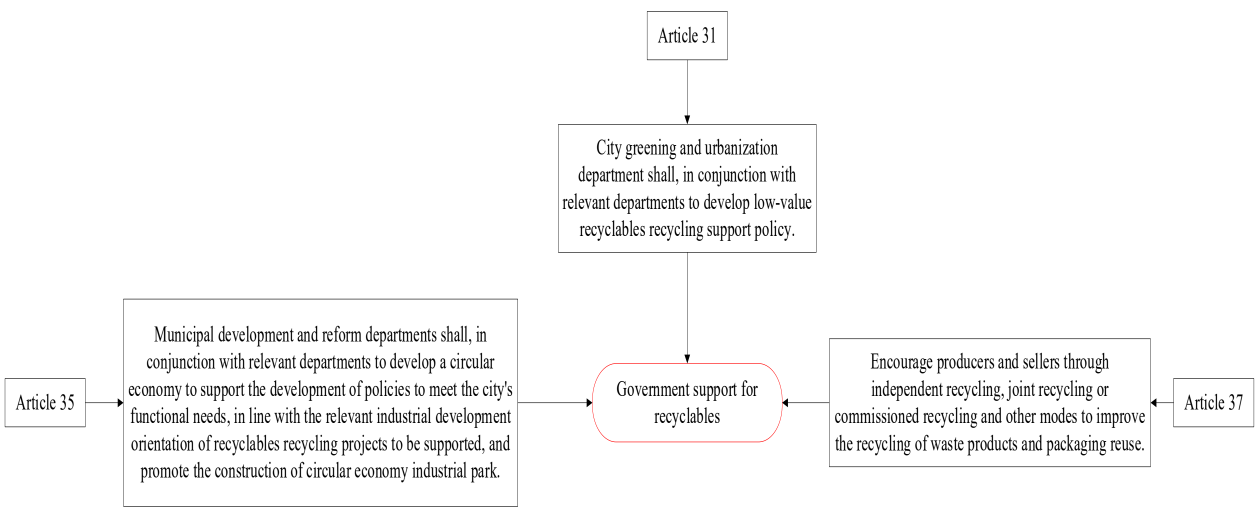

Figure 27 Embodiment of the support for recyclables variable in SMSWMR

The variable included in Figure 28 is the clarity of responsibility allocation. As mentioned earlier, a clear allocation of responsibility goes a long way in enhancing the force of the law. Article 7 of this Act regulates the principle of payment for waste, namely who produces who pays. Another aspect that needs to be clarified in the bill is the responsibilities of the various government departments and the companies involved. The responsibilities of the government and related departments are mentioned in Articles 16, 23, 31 and 38, while the responsibilities of companies and individuals are stated in Articles 24, 30, 34 and 36 from different perspectives.

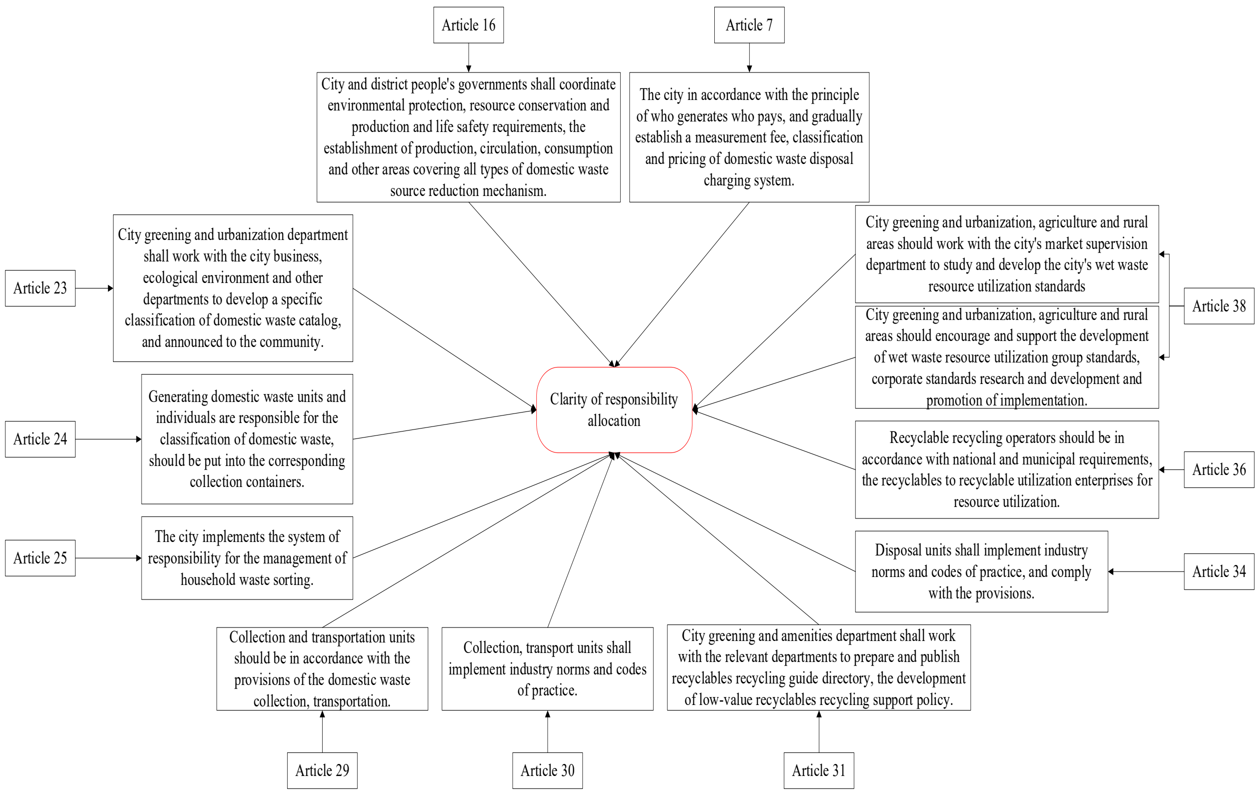

Figure 28 Embodiment of the clarity of responsibility allocation variable in SMSWMR

The variable included in Figure 29 is clarity of provision. Clarity of provision can be understood as whether the approach to an event in the law is clear enough to be understood. For example, Article 33 of this bill provides for the classification and disposal of different types of waste. Hazardous waste shall be disposed of by high temperature treatment, chemical decomposition, etc. for harmless disposal; wet waste shall be disposed of by biochemical treatment, biogas producing, composting, etc. for resource utilization or harmless disposal; dry waste shall be disposed of by incineration, etc. for harmless disposal. Article 63 is the detailed regulations on the placement, collection, transportation and disposal of domestic waste. Article 64 is the industrial solid waste, dangerous waste placement, collection, transportation and disposal regulations, this part is not explicitly described, but gives the categories of regulations should be looked for.

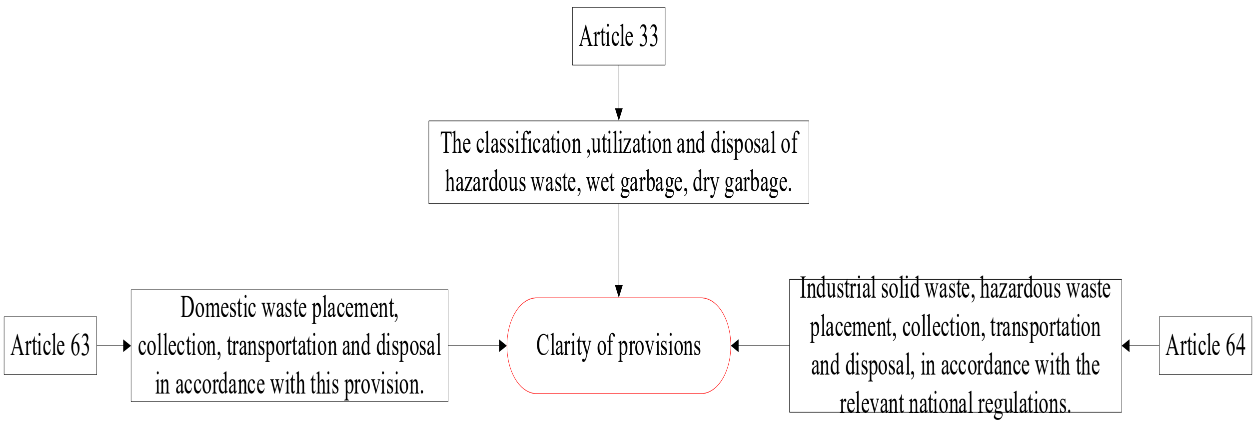

Figure 29 Embodiment of the clarity of provisions variable in SMSWMR

The variable included in Figure 30 is social engagement. Social participation is especially important for the implementation of the policy. This law also refers in several places to the encouragement and mobilization of different people. Article 7 encourages companies and individuals to actively participate in green living initiatives. Article 23 targets the relevant departments and requires them to publish a specific catalog of waste classification to the community to increase the possibility of public participation. Article 36 requires the relevant departments to guide, coordinate and supervise the recyclables resource utilization activities, which is the government's guidance on the way to cooperate with social participation activities. Articles 40-47 are the specific programs of this bill on how to promote the participation of the whole society in the management of domestic waste from various angles, including education bases, practical activities, public opinion supervision, task allocation, innovative forms, industry training, civilized selection, complaints and reports, recognition and rewards, and many other methods. Generally speaking, community involvement is an important aspect of the bill's emphasis, and a poorly involved community will not be able to achieve excellent waste management.

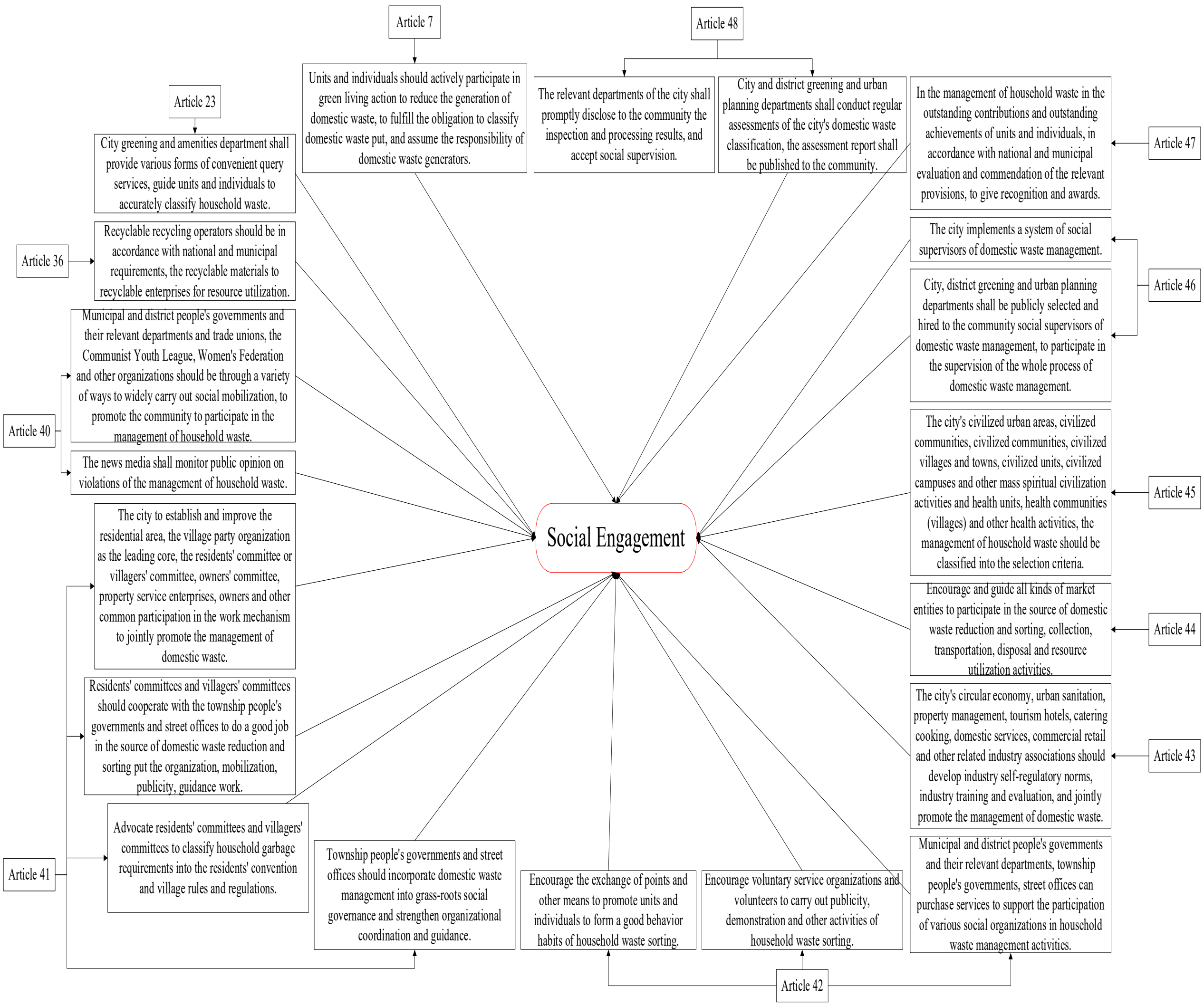

Figure 30 Embodiment of the social engagement variable in SMSWMR

The variable included in Figure 31 is the knowledge level of domestic waste. This part is different from what is commonly referred to as variables, education, or knowledge level, and cannot be measured simply by education. Awareness of domestic waste reduction, sorting, and resource utilization is only related to the level of knowledge of domestic waste. In this regard, there are various ways of promoting it in this bill. Article 9 gives the people's governments at all levels in Shanghai the task of disseminating knowledge to the residents. Article 23, Article 27 and Article 40 also set out the requirements and instructions for the tasks that should be achieved by the relevant departments.

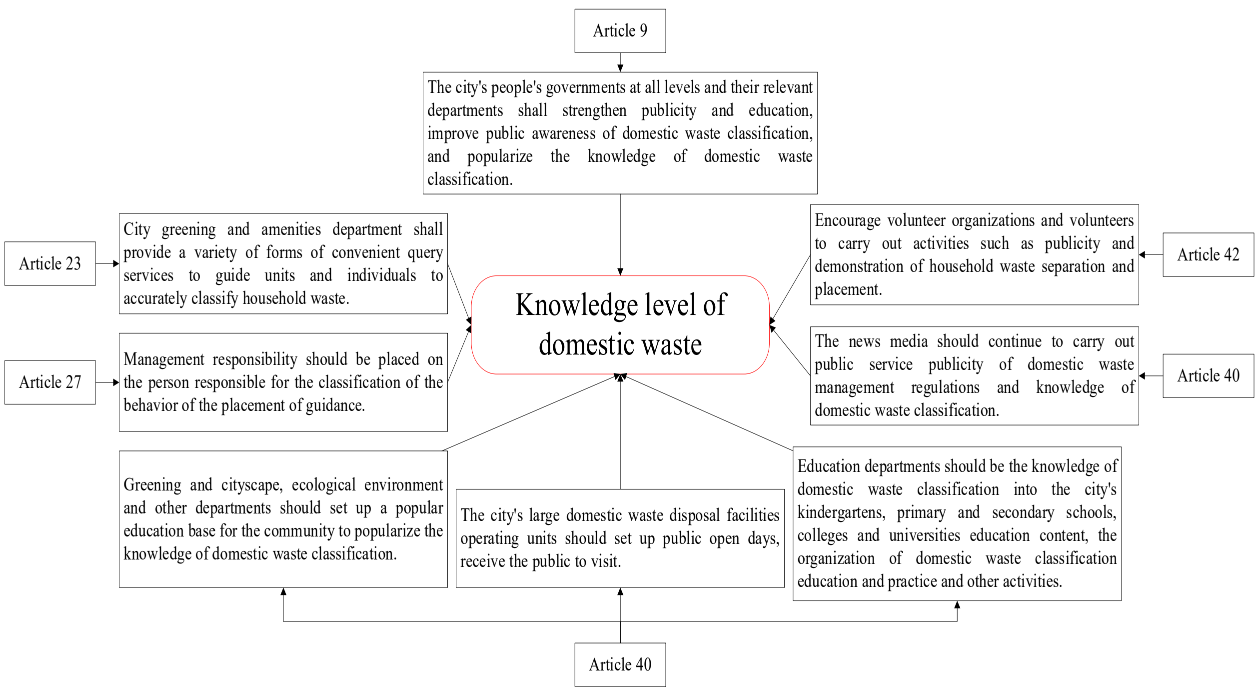

Figure 31 Embodiment of the knowledge level of domestic waste variable in SMSWMR

The variables included in Figure 32 are domestic waste disposal behavior. This is a typically important but difficult to quantify variable. Domestic waste disposal behavior can be influenced by several variables such as social participation, level of waste knowledge, and also restricted by legal penalties. Articles 27, 29 and 33 are all corrective requirements and reporting measures for different improper waste disposal behaviors.

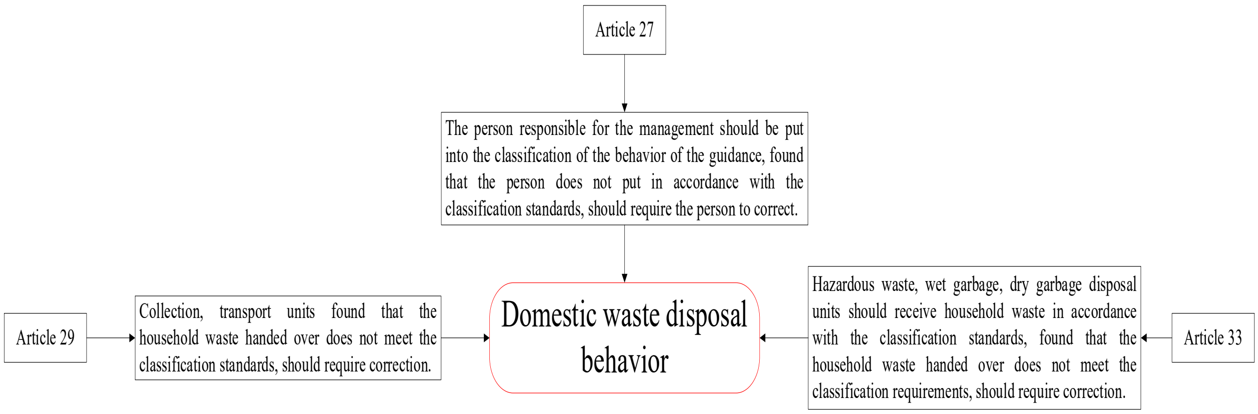

Figure 32 Embodiment of the sorting behavior of domestic waste disposal variable in SMSWMR

The variable included in Figure 33 is the emergency handling capability. Emergency handling capacity is a safeguard measure for a city's waste management in order to prevent emergencies. Article 51 requires the city and district greening and amenities department's ability to handle emergencies and requires them to be the department that should be reported in the event of an emergency, e.g., collection or transport failures.

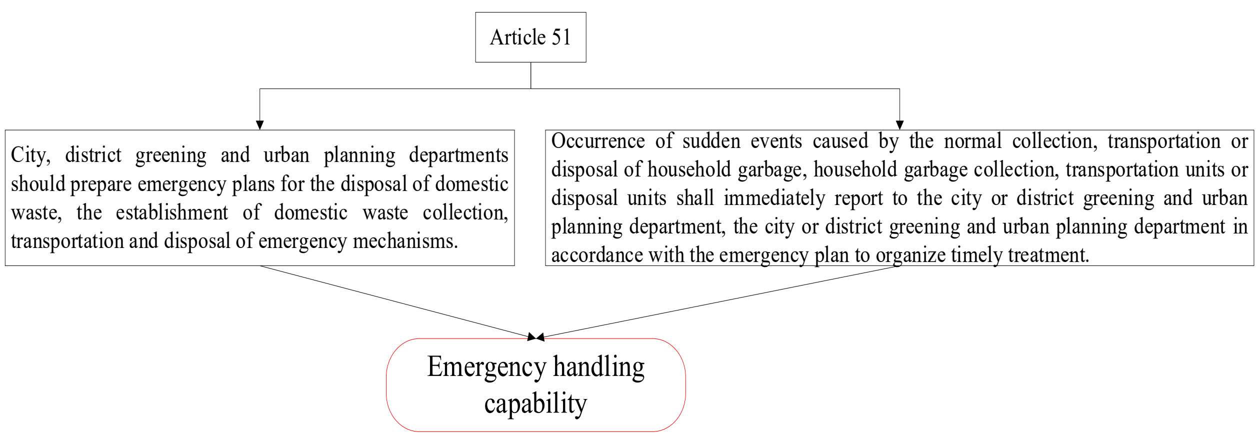

Figure 33 Embodiment of the emergency handling capacity variable in SMSWMR

The variable included in Figure 34 is performance evaluation. Performance evaluation has a feedback effect as a means of evaluating the status of domestic waste management. Enhanced performance evaluation will have a positive effect on the motivation of governments and departments at all levels. Article 45 is related to the evaluation criteria while Article 53 is associated with the assessment content.

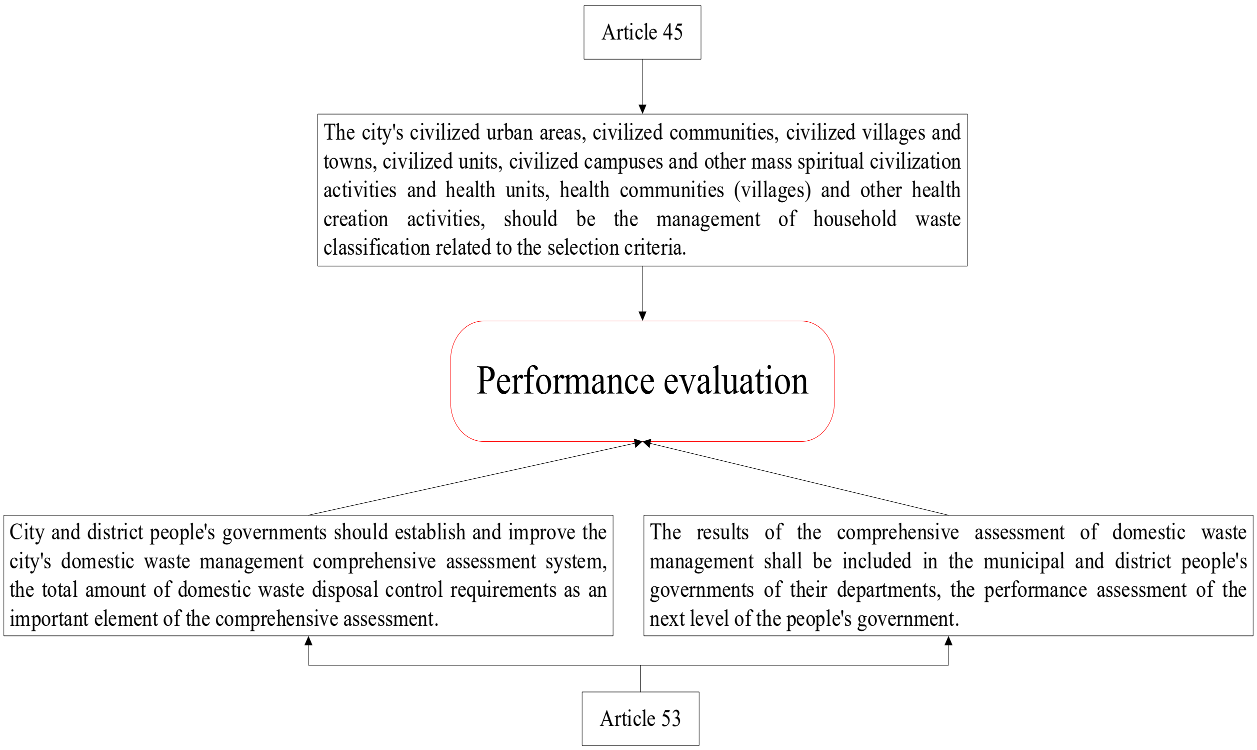

Figure 34 Embodiment of the performance evaluation variable in SMSWMR

4.3 Modeling of the Policy

4.3.1 Problem Description

The problem of waste management is a typical interdisciplinary problem, involving knowledge of economics, mathematics, statistics, environmental science, demography, psychology and many other disciplines. The BUSINESS DYNAMICS book mentions several times that one should never model a system, in other words, one should never and cannot answer all questions within a model [75]. In conjunction with some previous research done by the author in the field of waste management, the focus of this thesis is on the modeling of a policy. As mentioned earlier, the internal causality and action mechanisms of policy as an important built environment for waste management are unknown. Therefore, the problem defined in this thesis is to identify the causal relationships and points of action within the policy, to understand the fulcrum of the policy to pry the boulder of waste management, and to explore the way the policy really works. Before modeling the waste management policy in Shanghai, there are three important basic assumptions, which are

1. The content of the policy is correct, effective, comprehensive, and non-contradictory.
2. There is causal relationship between components and structures within the policy, containing both positive and negative feedback relationships. For example, there is a negative feedback relationship between controls on merchants offering disposable goods and dry waste generation; the stricter the controls, the less dry waste is generated.
3. Policy control of the waste management system is accomplished through three types of variables within the control system, which are user-related variables, policy-related variables, and resource-related variables.

4.3.2 Dynamic Hypothesis

The dynamic assumption is a conceptual model. The idea of dynamics is concentrated in the structural conception of the model, i.e., the ability of policy to control waste management. In combining the life cycle perspective of waste, the type of sub-blocks of variables will be distinguished and linked according to the different status of the waste (from cradle to grave). For the policy model to be developed in this thesis, the endogenous structure of the model is all the variables proposed within the policy. The system boundary of the model is the policy of Shanghai Municipal Solid Waste Management Regulation. In conjunction with the scope of the policy coverage mentioned in Section 3.2.2, other variables associated with the variables extracted from the policy will be included in the policy system model, most of which are commonly and frequently mentioned in the literature. The policy system model is constructed based on the policy model to reflect the linkage between policy and other variables of the waste management system. The structure and variable diagrams of the different sub-blocks in the policy model are shown in Figure 35.

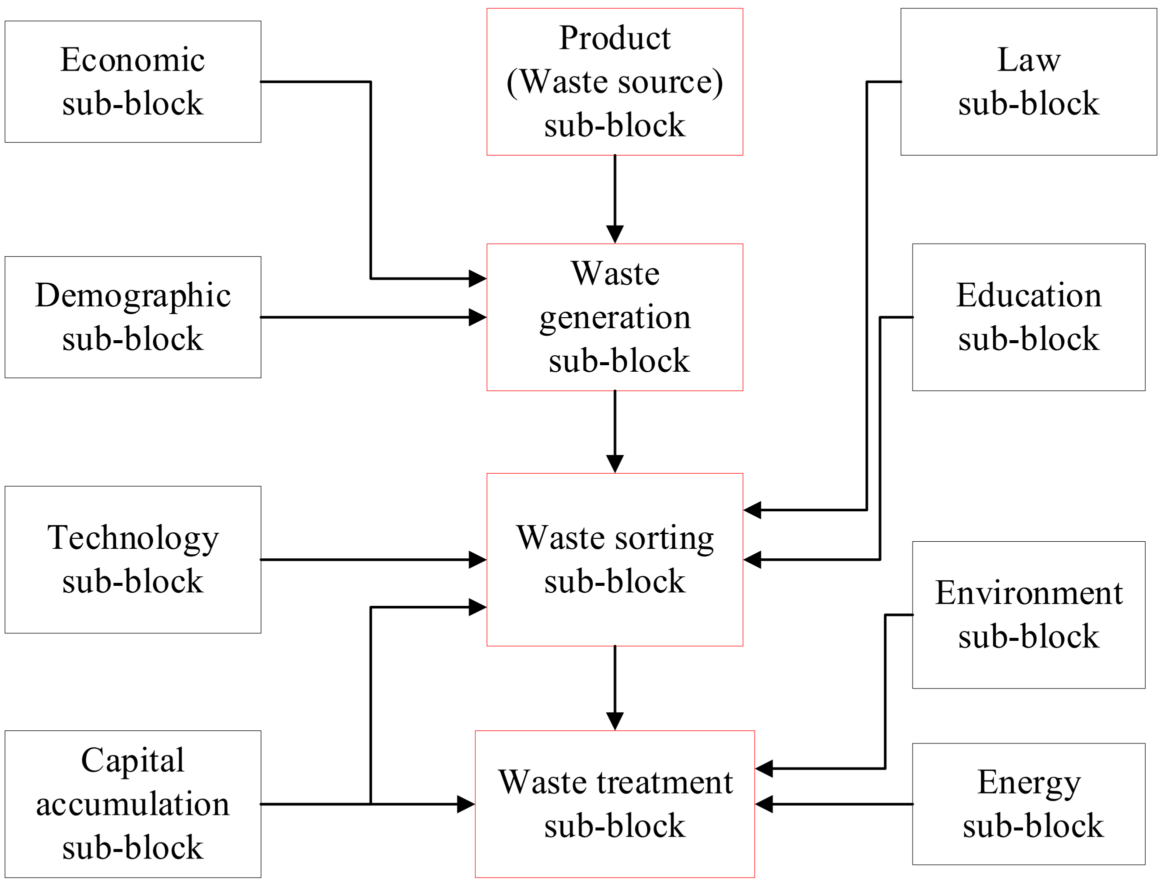

Figure 35 Shanghai policy model sub-block structure

The structural diagram of the Shanghai Policy Model contains a total of 12 main sub-blocks: product (waste source) sub-block, waste generation sub-block, waste sorting sub-block, waste treatment sub-block, economic sub-block, demographic sub-block, technology sub-block, capital accumulation sub-block, law sub-block, education sub-block, environment sub-block, energy sub-block. The first four sub-blocks (in the red box) are the simplified waste lifecycle sub-blocks. The rest of the unmentioned sub-blocks include transportation sub-block, etc. The transportation sub-block has a very important position in the process of urban collection and disposal of waste, but there is no separate section in the Shanghai Municipal Solid Waste Management Regulations that discusses this section. Penalties for transportation companies appear in the section on punishment measures, which deals with transportation but places more emphasis on legal clarity and legal force. For the sake of simplifying the model, this section is no longer established as a separate sub-block. A main focus of the assessment of domestic waste sorting and collection capacity is the number of trucks, and variables related to truck shortage issues are included in this section as representative embodiments of the missing transportation sub-block. The sub-blocks in Figure 35 are interconnected through the coupling between variables. Each sub-block has a unique feedback mechanism within itself, and the variable components and causal relationships within each sub-block are briefly described below.

Product (waste source) sub-block

The crucial variable in the source sub-block of waste is the waste content in the product. The moment the product is produced it is decided what type of waste will be generated, therefore the amount and type of waste that will be generated in the future can be seen in the product. The material of the product and the packaging material of the product are the two independent variables extracted from the policy, and the changes in these two independent variables are positively correlated with the waste content in the product. Similarly, the product design solution and the product packaging design solution are also independent variables extracted from the policy, and both of them also have positive effects on the material. Simply because the optimization of the design solution is accompanied by the simultaneous optimization of the product and the materials in the product packaging. At the same time, the waste content in the product has a negative feedback moderating effect on the design solution, constantly regulating the design solution to a waste-appropriate level. This adjustment process will not continue to intensify but will slowly seek to reach a suitable level of product waste content. The causal loop diagram of product sub-block in both policy and policy system model as shown in Figure 36. The two balancing feedback loops contained therein will effectively and dynamically regulate the waste content of the product and the product packaging.

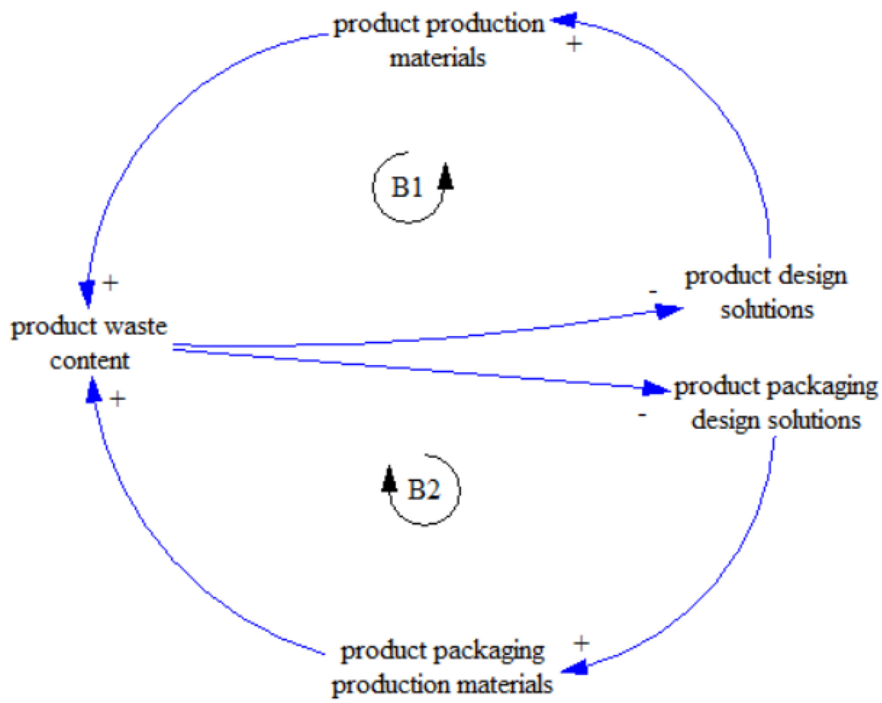

Figure 36 Product (waste source) sub-block causal loop diagram in both policy and policy system model

Waste generation sub-block

The amount of domestic waste generated is the dependent variable in Shanghai's municipal solid waste management regulations. Since the regulations divide Shanghai's waste into four categories, the author introduced four variables: dry waste generation, wet waste generation, recyclables generation, and hazardous waste generation in order to clearly show the impact of each waste variable on the total amount of waste. These four variables all have a positive effect on the total amount of domestic waste generated. The waste content of the product is a variable introduced from the product sub-block, as this variable is closely associated with the waste production sub-block. Optimization of the waste content of the product as described above refers to better design and production for the product itself and the packaging, with the aim of reducing the dry waste of the product while improving the recyclable properties of it. Therefore, the waste content of the product is positively correlated with the number of recyclables generated and negatively correlated with the amount of dry waste generated. The consumption structure is as described in 4.2.2, where actions such as the marketing of clean vegetables will have a reducing effect on the amount of wet waste generated. As the consumption structure continues to improve, the amount of recyclables will keep increasing and the amount of dry waste will keep decreasing. The waste generation sub-block causal loop diagram in policy model is shown in Figure 37.

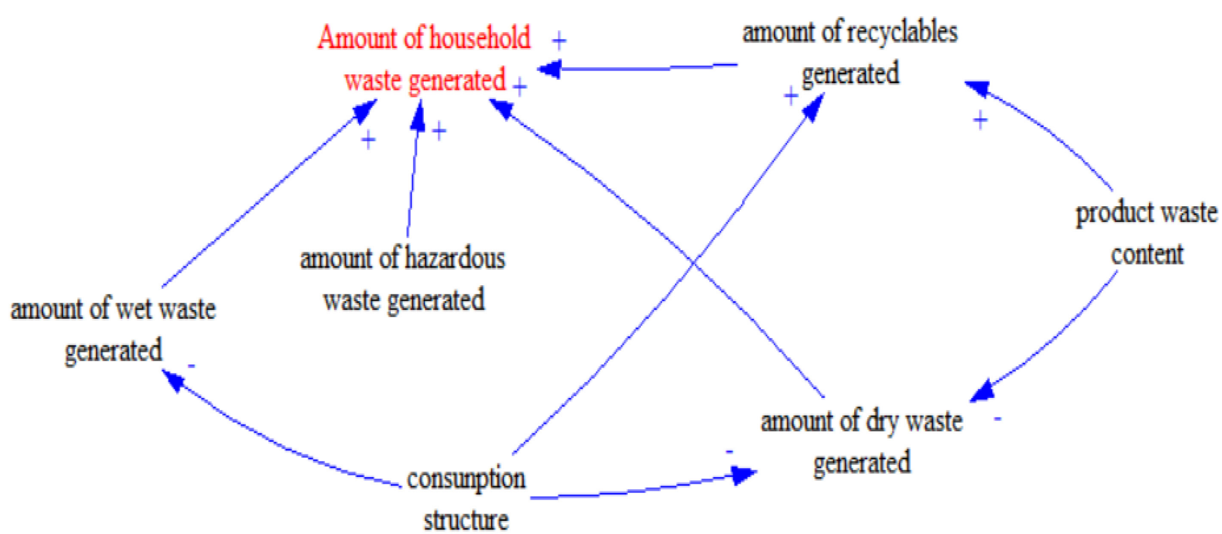

Figure 37 Waste generation sub-block causal loop diagram in policy model

The waste generation sub-block is greatly and positively influenced by the economy and population, and positively influences the waste sorting sub-block, as shown in Figure 38. Gross Domestic Product (GDP) is positively correlated with per capita consumption expenditure, which will positively affect per capita waste generation and thus directly lead to changes in total domestic waste. An increase or decrease in population will also inevitably produce a change in waste production in the same direction. It is worth noting that population and GDP are not directly mentioned in the SMSWMR.

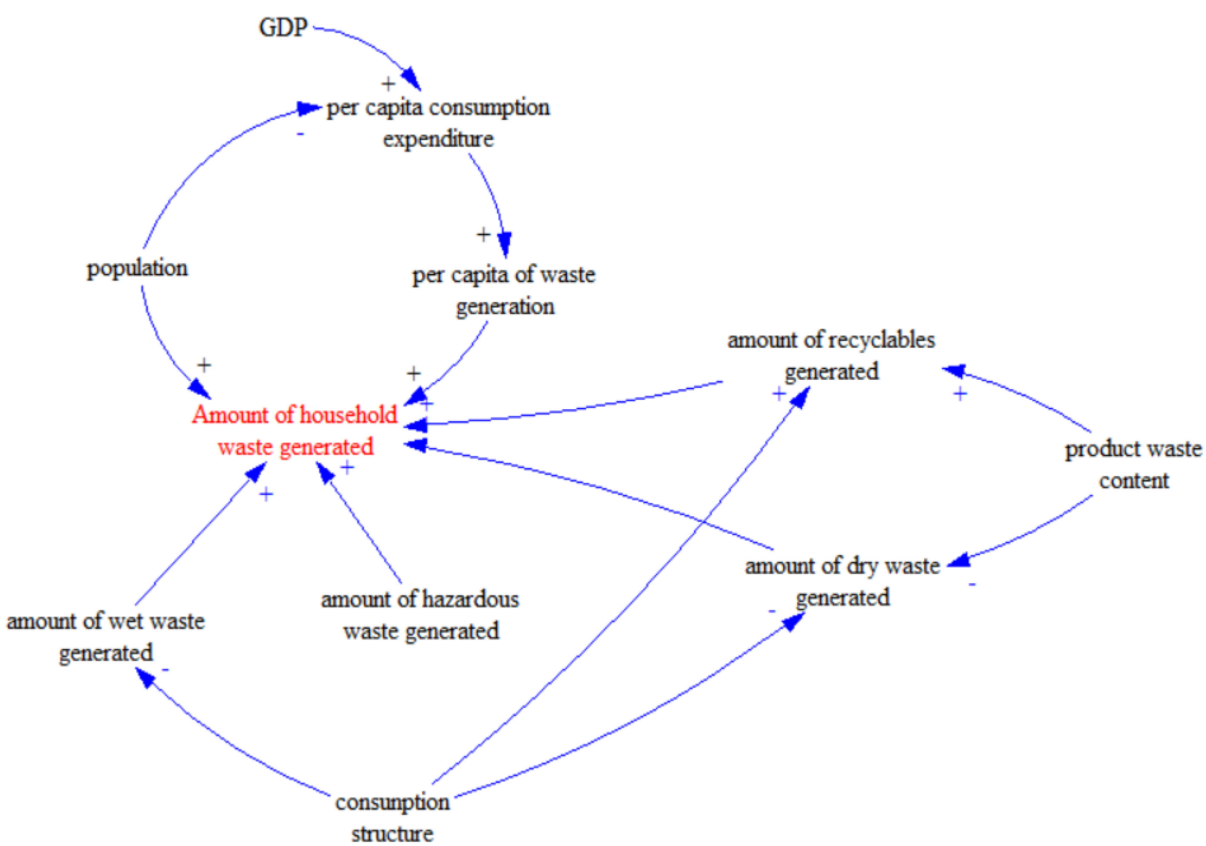

Figure 38 Waste generation sub-block causal loop diagram in policy system model

Waste sorting sub-block

The waste separation sub-block is the core section about citizen behavior. It is influenced in multiple ways by the law sub-block, education sub-block, technology sub-block and capital accumulation sub-block. As shown in Figure 39, the dependent variable for this component is household waste sorting and collection capacity. The dependent variable in this sub-block is mainly positively influenced by the level of intelligence and the number of facilities. Emergency handling capacity and performance evaluation also contribute positively to the household waste sorting and collection capacity. Both domestic waste disposal behaviors and social engagement were positively affected by the compensation for recyclables variable, the knowledge level of domestic waste variable, and the legal effect variable. Legal force is one of the very policy-specific variables that increases with clarity of responsibility allocation and clarity of provisions, and is positively stimulated by performance evaluation, which is further adjusted and strengthened as performance evaluation is enhanced. At the same time, the direct impact of legal force on the behavior of government and citizens forms the most crucial part of this sub-block.

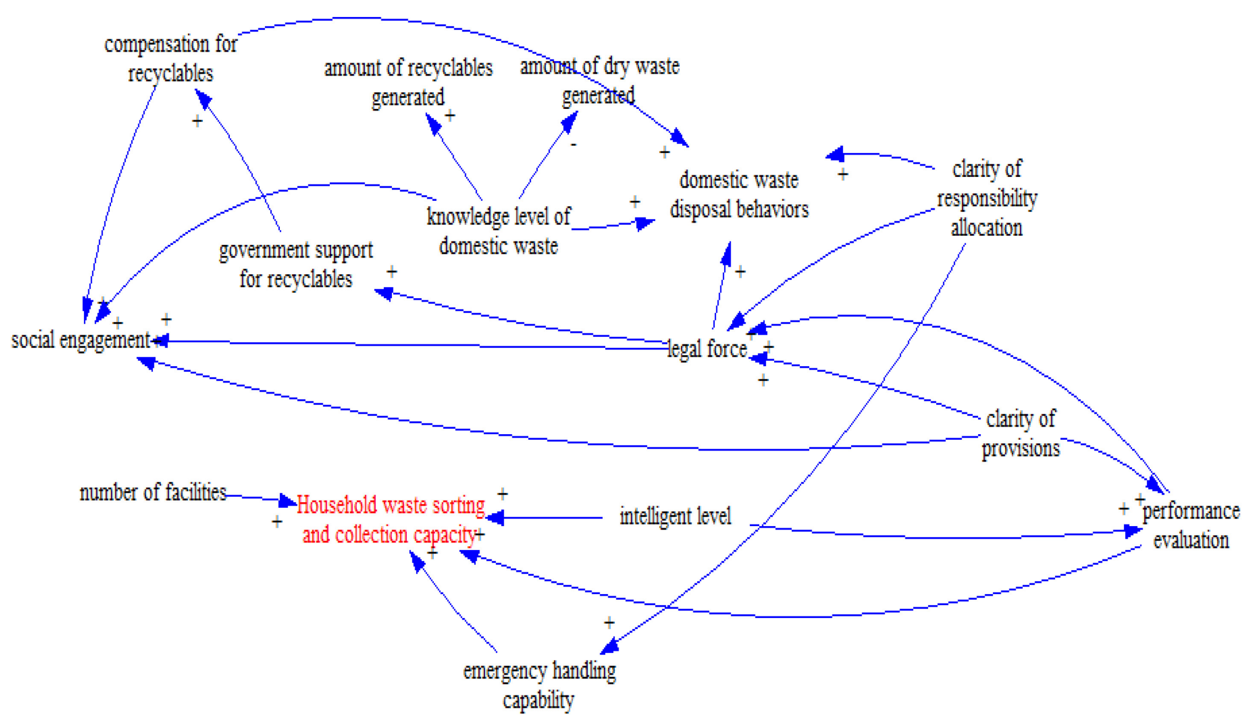

Figure 39 Waste sorting sub-block causal loop diagram in policy model

In the waste sorting sub-block of policy system model, as shown in Figure 40. The biggest difference from the causal loop diagram of the variables presented from the policy only is the inclusion of the funds variable and the social concern variable. The funds variable is an inseparable topic in municipal solid waste management and plays an extremely important role in the process of municipal waste separation and collection. It can be said that the amount of funding determines the quality of municipal solid waste management to a great extent. However, in the Shanghai Municipal Solid Waste Management Regulations, there are hardly any requirements for the amount of funds and depiction to the requirements on how the funds are allocated and used, so it is impractical to extract the corresponding funds variables. The funds variable is influenced by the government's support for recyclables. Although also influenced by other government investments in waste management, they are not covered in this paper since they have little relevance to this bill. The number of available trucks is an indicator of waste transport capacity, but this part will increase the financial pressure on municipal waste management. The shortage of trucks increases the funds required and thus has a negative impact on the amount of funds. Public concern is the livelihood factor of waste management, which is not easy to express in the policy. Public concern has a catalytic effect on social engagement, the variable extracted from the bill. As public concern rises, so does public pressure, which in turn has a positive impact on performance evaluation.

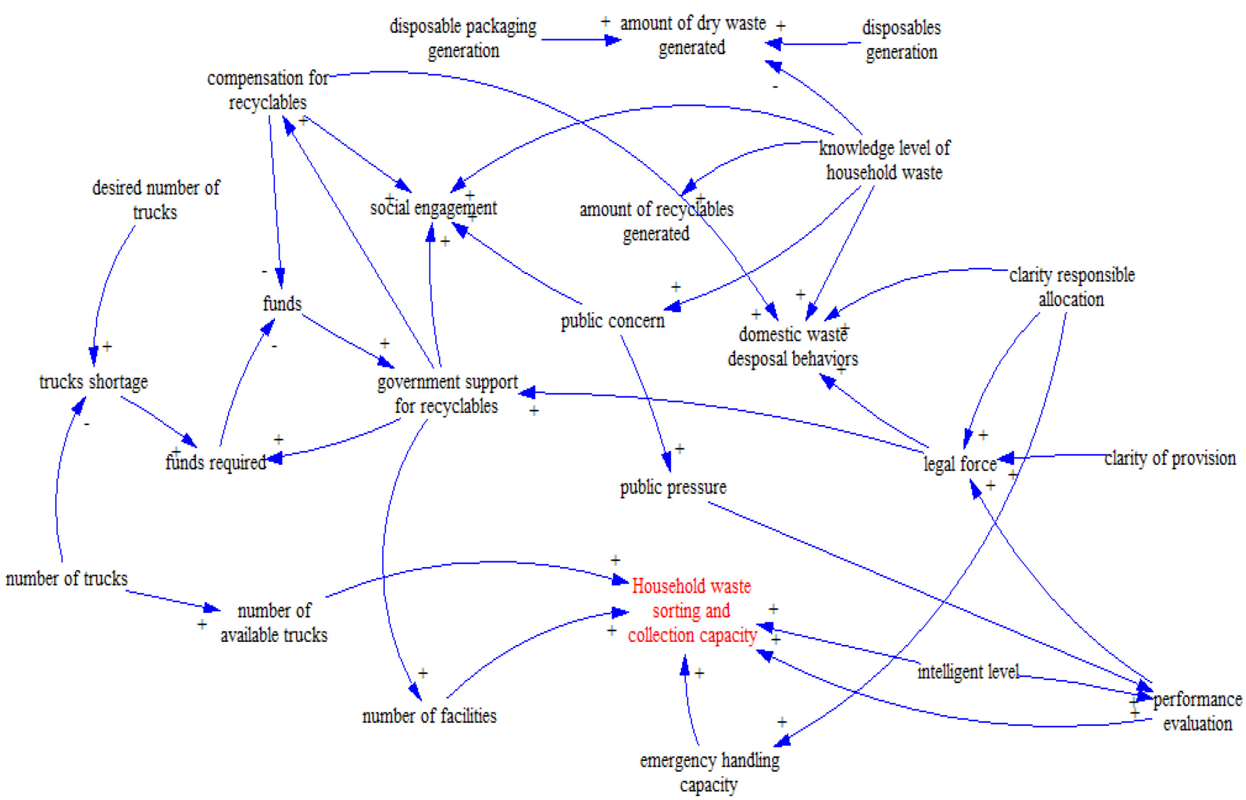

Figure 40 Waste sorting sub-block causal loop diagram in policy system model

Waste treatment sub-block

The waste treatment sub-block is the final part of the waste management lifecycle, as shown in Figure 41. This part contains three dependent variables extracted from the objectives in the Shanghai Municipal Solid Waste Management Regulation, which are resource utilization rate, total household treatment capacity, and harmless disposal rate of household waste. The energy structure is the concentration of the energy sub-block in the policy. The incineration of waste will not only increase the rate of harmless disposal, but also enhance the resource utilization rate of waste. Meanwhile, the product of waste incineration can also be used as fertilizer for adequate re-utilization of resources. The capital accumulation sub-block is mainly reflected in the number of equipment, which is the epitome of capital accumulation in this bill, and more details about it will be elaborated in the later section. It is obvious that the level of technology can directly improve the waste treatment capacity, and the improvement of the management level by technology mentioned in this bill will improve the monitoring effect of the performance evaluation, and thus improve the indicators of the three dependent variables.

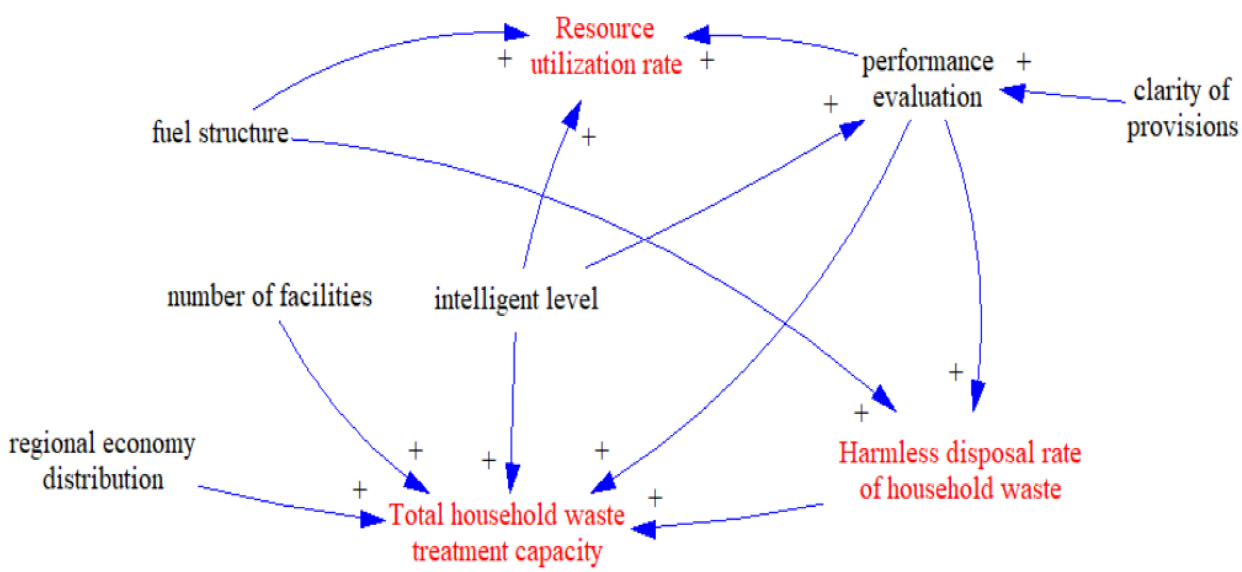

Figure 41 Waste treatment sub-block causal loop diagram in policy model

The environmental sub-block has an impact on the waste disposal sub-block in the policy system model, and more environmentally relevant variables will be mentioned below. In this component, environmental compensation funds are included as variables related to both the economy and the environment, and it has a positive effect on the regional economy distribution. The environmental compensation funds had been mentioned in this bill, but no specific policies and implementation programs were addressed, so it was only placed in the policy system model as one of the influencing factors affecting the regional economy distribution. This is illustrated in Figure 42.

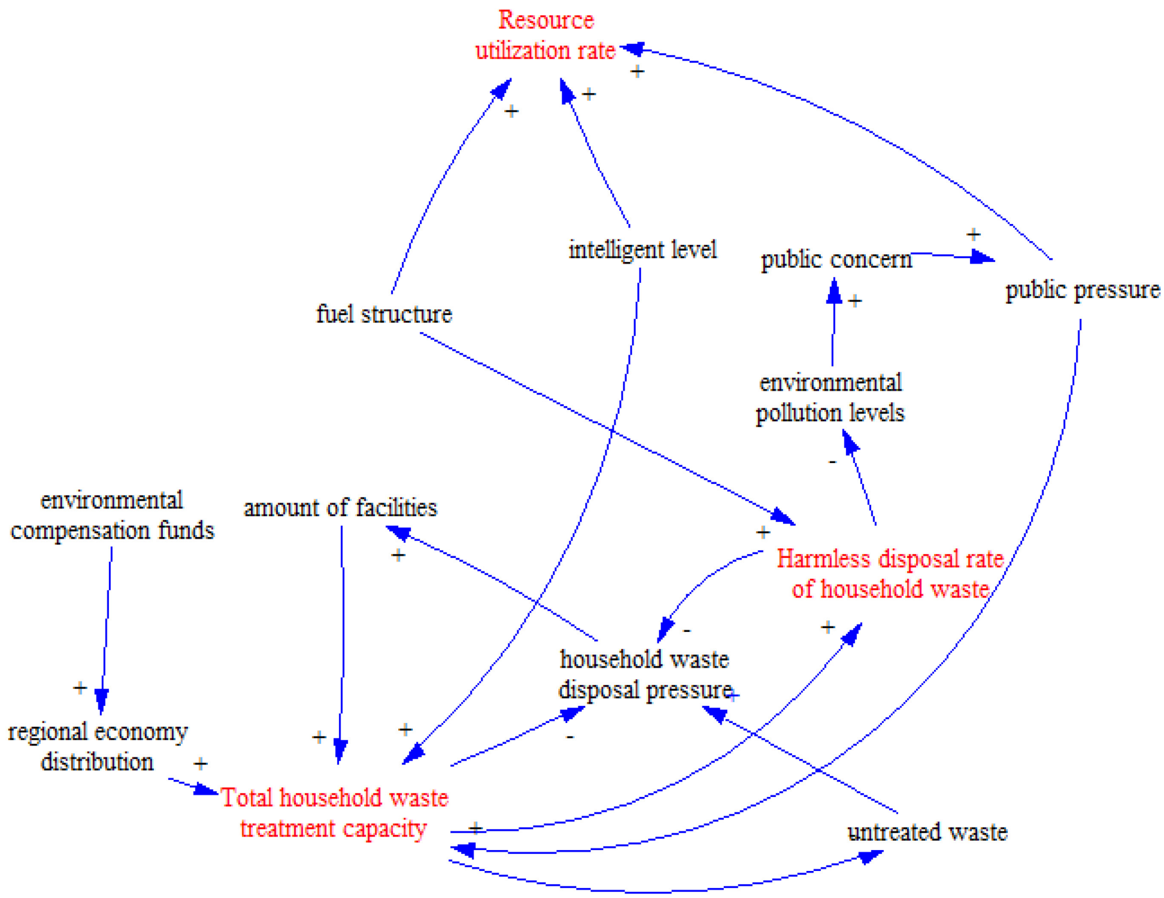

Figure 42 Waste treatment sub-block causal loop diagram in policy system model

Economic sub-block

The economic variables extracted from the policy contain regional economic distribution, compensation for recyclables and consumption structure. The enhance of the reginal economy distribution means the areas that do not dispose of waste will pay a fee to the areas that dispose of waste, which will help the economy of the areas that dispose waste. In such a model, the waste treatment capacity of the waste treatment area will be further enhanced, resulting in an increase in the total capacity to treat domestic waste. The increase in consumption structure has a catalytic effect on social engagement, and similarly, the increase in social engagement further optimizes the consumption structure, thus forming a reinforcing loop for the continuous increase in both social engagement and consumption structure. Government subsidies for recyclables also have a positive effect on both. The two portions of the relationship are illustrated in Figure 43.

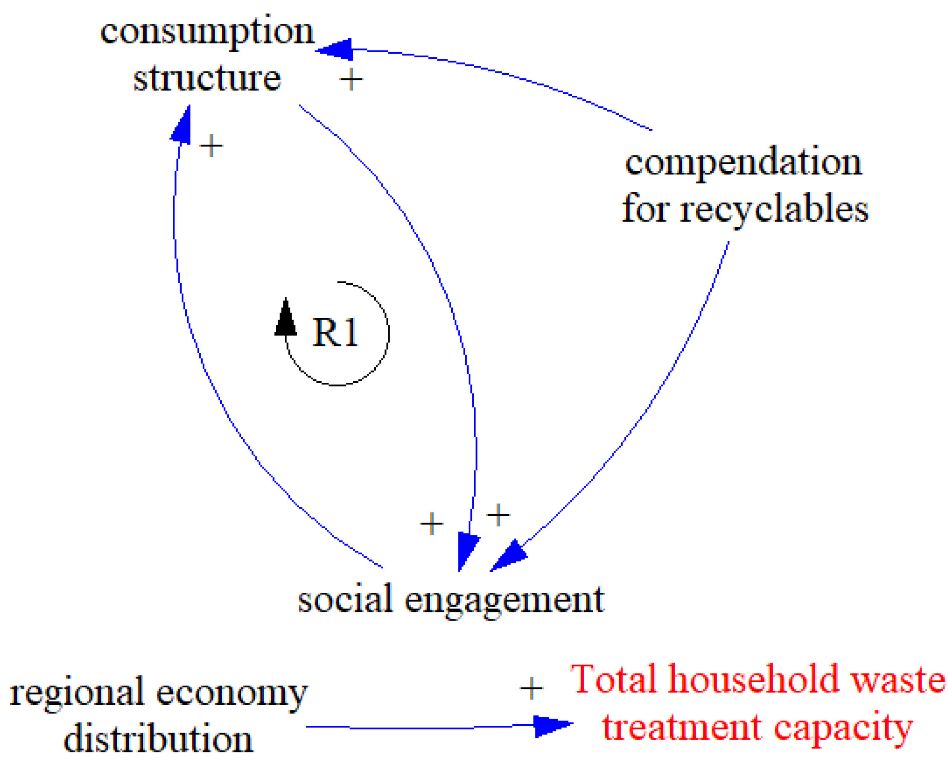

Figure 43 Economic sub-block causal loop diagram in policy model

Figure 44 shows the causal expression of the economic sub-block in the policy system model, where the relevant funds are influenced by the GDP, which is transmitted to eventually affect the MSW treatment capacity.

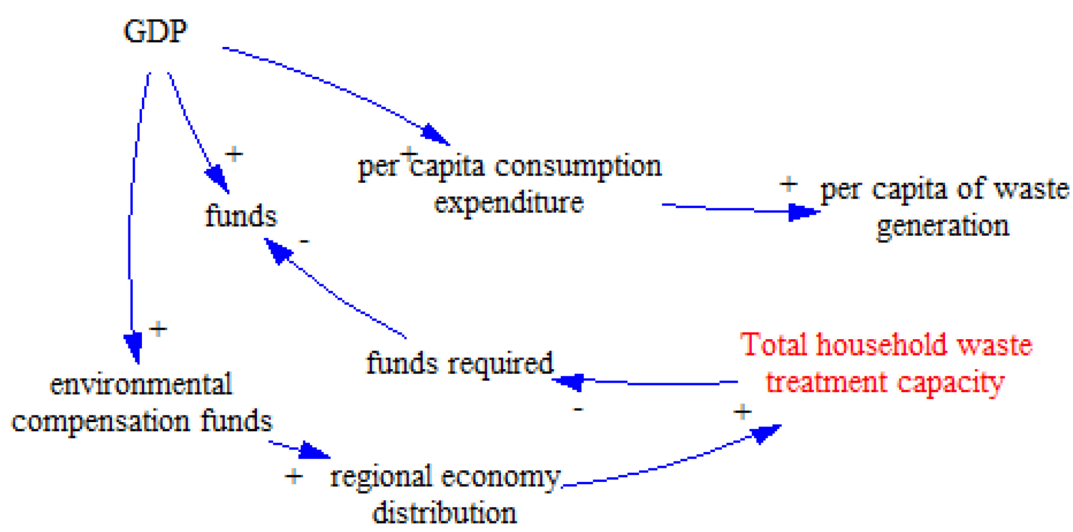

Figure 44 Economic sub-block causal loop diagram in policy system model

Demographic sub-block

The population sub-block is not a part of the policy model but is mentioned in the policy system model as an important component that affects waste production. Typically, the population sub-block consists of four components: population age structure, life expectancy, number of births and birth control. The age of the population can be divided into several age groups according to infancy, youth, middle age and old age. Average life expectancy is influenced by four factors: food, social welfare, pollution, and overcrowding. The number of births is governed by both the maximum number of births a woman can have and the desired number of births, while fertility control depends on the government's population policy [78]. In this thesis, population is only presented as a solitary variable in the policy system model.

Technology sub-block

Technology-related variables in the Shanghai Municipal Solid Waste Management Regulations only have intelligent levels. In waste management systems, the level of science and technology can be further refined into the level of industrial science and technology and the level of agricultural science and technology. The level of technology is a dimensionless indicator and is influenced by the level of education, technology introduction and investment in science and technology. These variables are not included in the policy system model since they are not obviously directly related to the policy model.

Capital accumulation sub-block

As mentioned above, the capital accumulation sub-block is mainly reflected in the number of facilities in the policy model. In the policy system model, the number of trucks can also be attributed to this component. In the waste management system, total asset is one of the core state variables, which is influenced by capital investment, fixed assets under construction and asset formation rate. These variables are not mentioned in this policy, so they are not discussed in this paper.

Law sub-block

The most prominent variable in the law sub-block is the legal force, as shown in Figure 45. Legal constraints as the last line of defense for waste management has a punitive and deterrent effect. Unclear regulations or unclear allocation of responsibilities have a huge impact on the prestige of the law. Therefore, as the provisions continue to be clear and the allocation of responsibilities gradually become more specific, the binding force of the law will also continue to increase. With the increase of legal force, those who are directly affected can be divided into two categories, one is governmental behavior, and the other is citizens' behavior. The government and its related departments will enhance the degree of fulfillment of relevant duties while the behavior and social participation of citizens will also be raised.

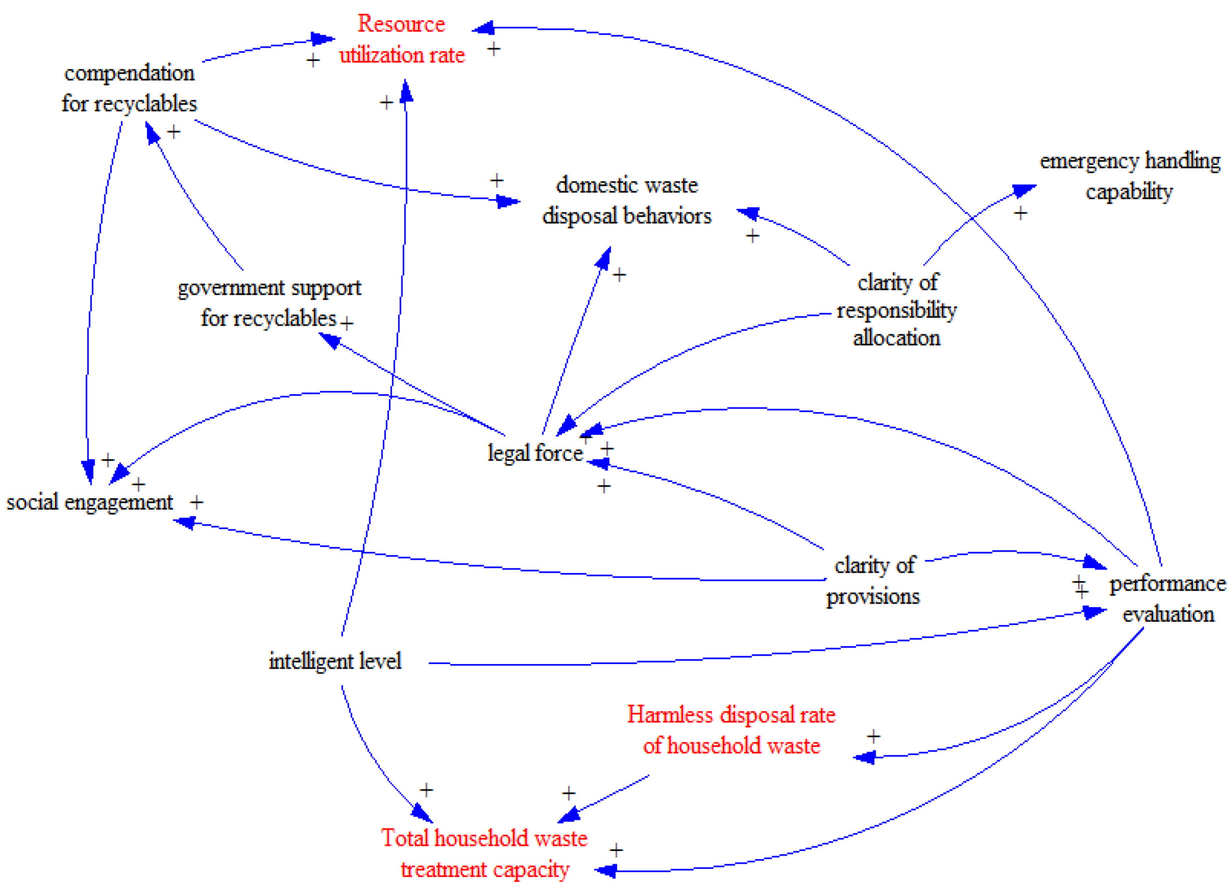

Figure 45 Law sub-block causal loop diagram in policy model

Education sub-block

The level of education is reflected in the policy as the level of knowledge of domestic waste, which is not directly related to the level of education in a strict sense. The level of education in the traditional sense is positively influenced by social consumption and contributes similarly positively to the level of technology and production capacity. However, in the Shanghai Municipal Solid Waste Management Regulations, only the variable knowledge level of domestic waste is mentioned, so this variable will represent the only variable modeled in the education sub-block in relation to the waste management system.

Environment sub-block

Environmental issues are mentioned in the Shanghai Solid Waste Management Regulations only in the section on environmental compensation in different areas, and there is no description of any implementation scheme related to them, so it is too far-fetched to draw environmental and economic issues from them. However, environmental issues play an important role as an unavoidable part in waste management system, and some variables related to the policy model are presented in the policy system model described in Figure 46. In brief, the core variable of the environment sub-block is the level of environmental pollution. Although all other types of waste have a positive effect on the environmental pollution level, the effect of hazardous waste is the most significant. For the sake of model simplicity only the positive effect of hazardous waste on environmental pollution level is retained. In the waste management system, the state variable environmental pollution level is a dimensionless variable. It is affected by the decontamination rate and the incidence of pollution. The contamination decontamination rate mitigates the level of contamination, while the level of decontamination capacity depends on the number of facilities. The pollution purification rate is also related to the purification time, and improved technology, which means improved technology, can also shorten the purification time of pollution. Since the above variables have a weak relationship with the variables in this method, they are not further encompassed in the policy system model.

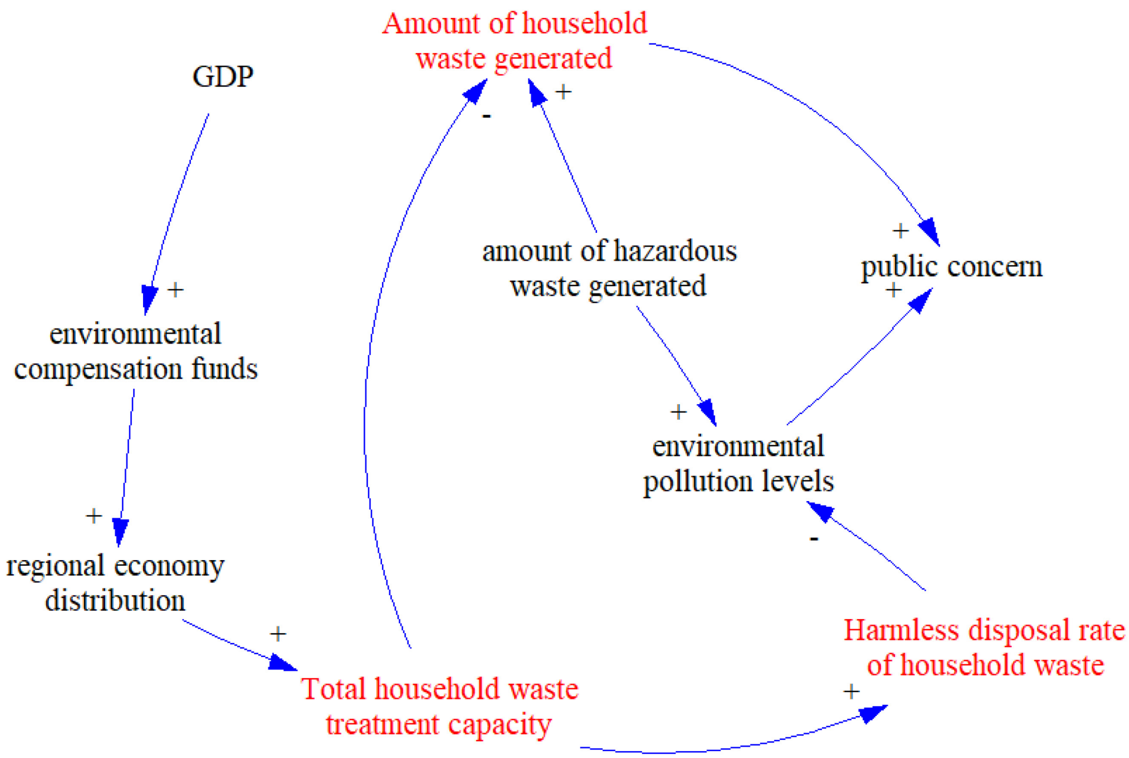

Figure 46 Environment sub-block causal loop diagram in policy system model

Energy sub-block

The energy sub-block of the SMSWMR is mainly manifested in the fuel structure. Burning waste can generate heat to replace fossil fuels which can save a considerable amount of energy. The products of combustion can be resourcefully utilized, greatly reducing the amount of landfill required, while increasing the resource utilization rate and the harmless disposal rate of domestic waste. Energy applications in waste management systems include waste incineration and wet waste composting, biogas production, etc. There are still concerns in many countries and regions about using waste to generate energy due to technical and emission issues.

4.3.3 Constructing Causal Loop Diagram (CLD)

Figure 47 shows the policy model of waste management in Shanghai. Almost all of the variables in the model are extracted from the policy. The causal relationships between the variables are derived from the nature of the variables themselves and the descriptions in the policy, as described in 4.3.2 for each sub-block.

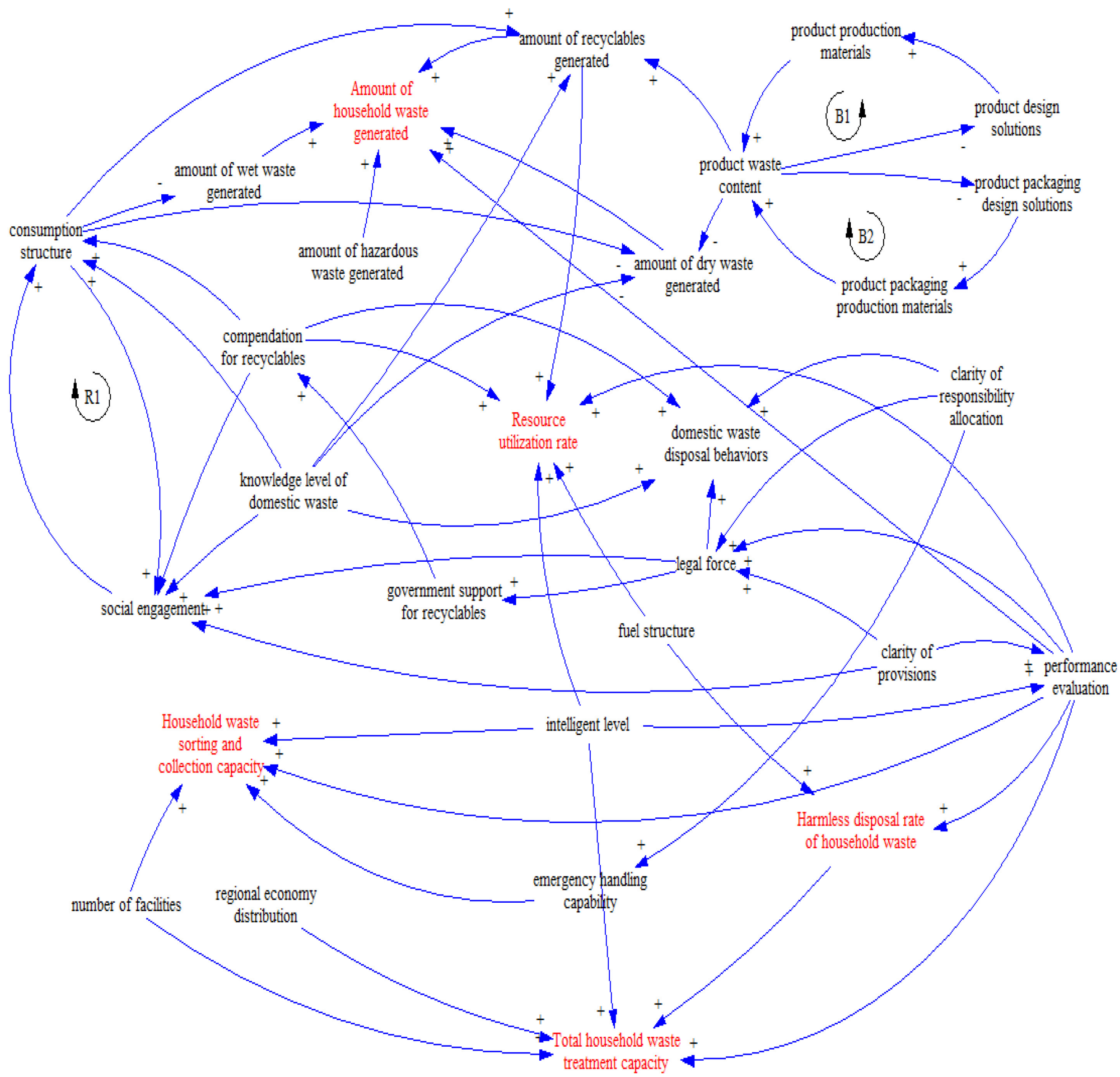

Figure 47 SMSWMR Policy Model

Figure 48 shows the Shanghai waste management policy system model. Based on the Shanghai policy model, some variables in the waste management system that are directly related to the policy model variables are added to make the connection between the policy model and the waste management system clearer. Certainly, there are more variables in the waste management system model, and it is unrealistic to include them all, so only the most directly related variables are included for the sake of model readability. The specific structure within the model is described in Section 4.3.2.

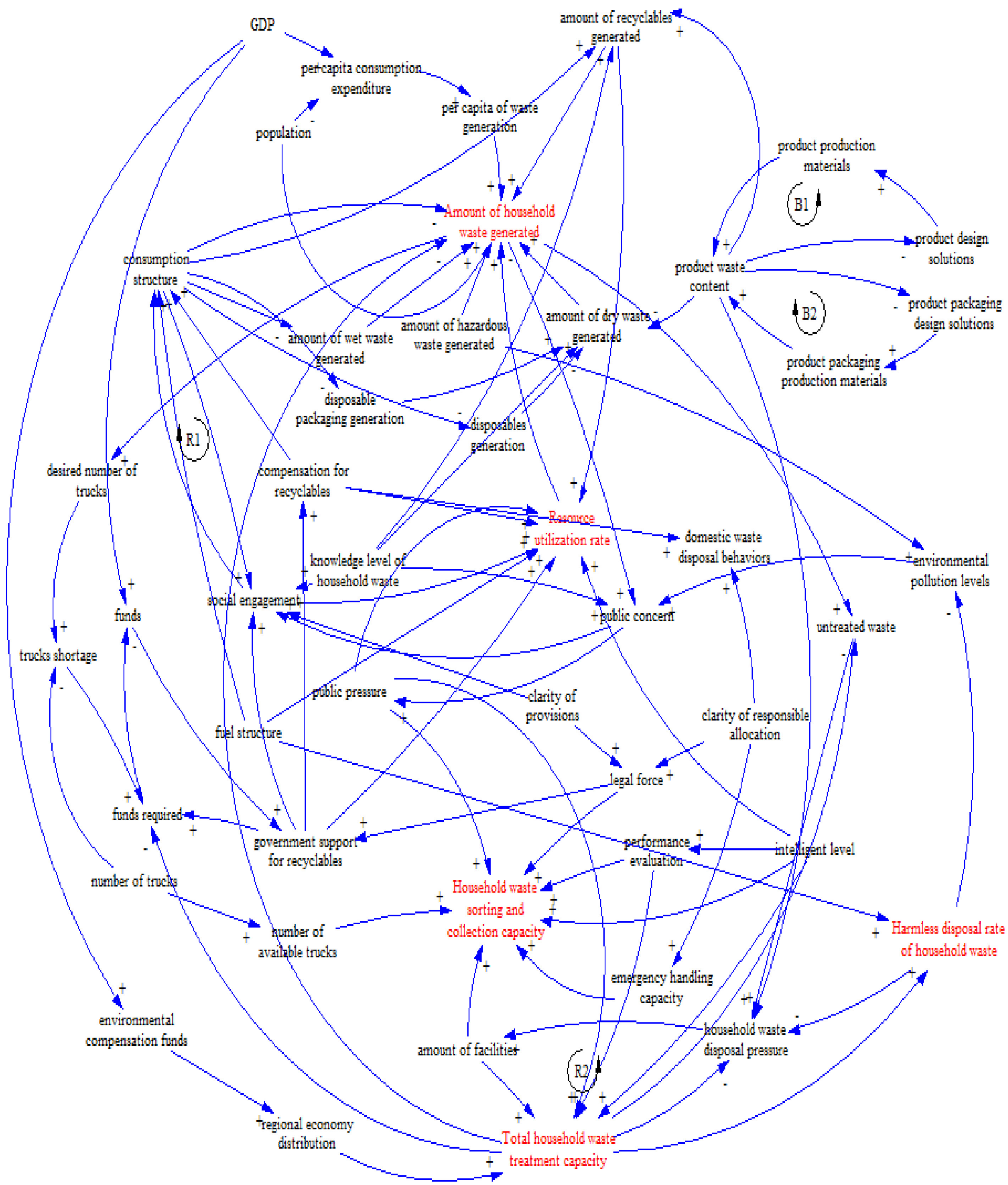

Figure 48 SMSWMR Policy System Model

4.3.4 Conversion to Stock-Flow Diagram (SFD)

The primary problem encountered in the transformation process from CLD to SFD is how to distinguish existing variables. The "snapshot experiment" is a useful way to make the distinction [78]. Just imagine stopping time in the system under study and freezing the amount of change in all flows, as if using a camera to capture the physical process in the system (the essence of the process is to remove the rate variables). The quantities that already exist in the snapshot can be defined as state variables, where the quantities that change very slowly or are essentially constant over the range of the system's time axis can be regarded as constants. If an integral variable is changing rapidly relative to the time coordinate of the model, then it is considered as an auxiliary variable. A stock-flow diagram of the policy system model was constructed using notation in the Vensim software, as shown in Figure 49.

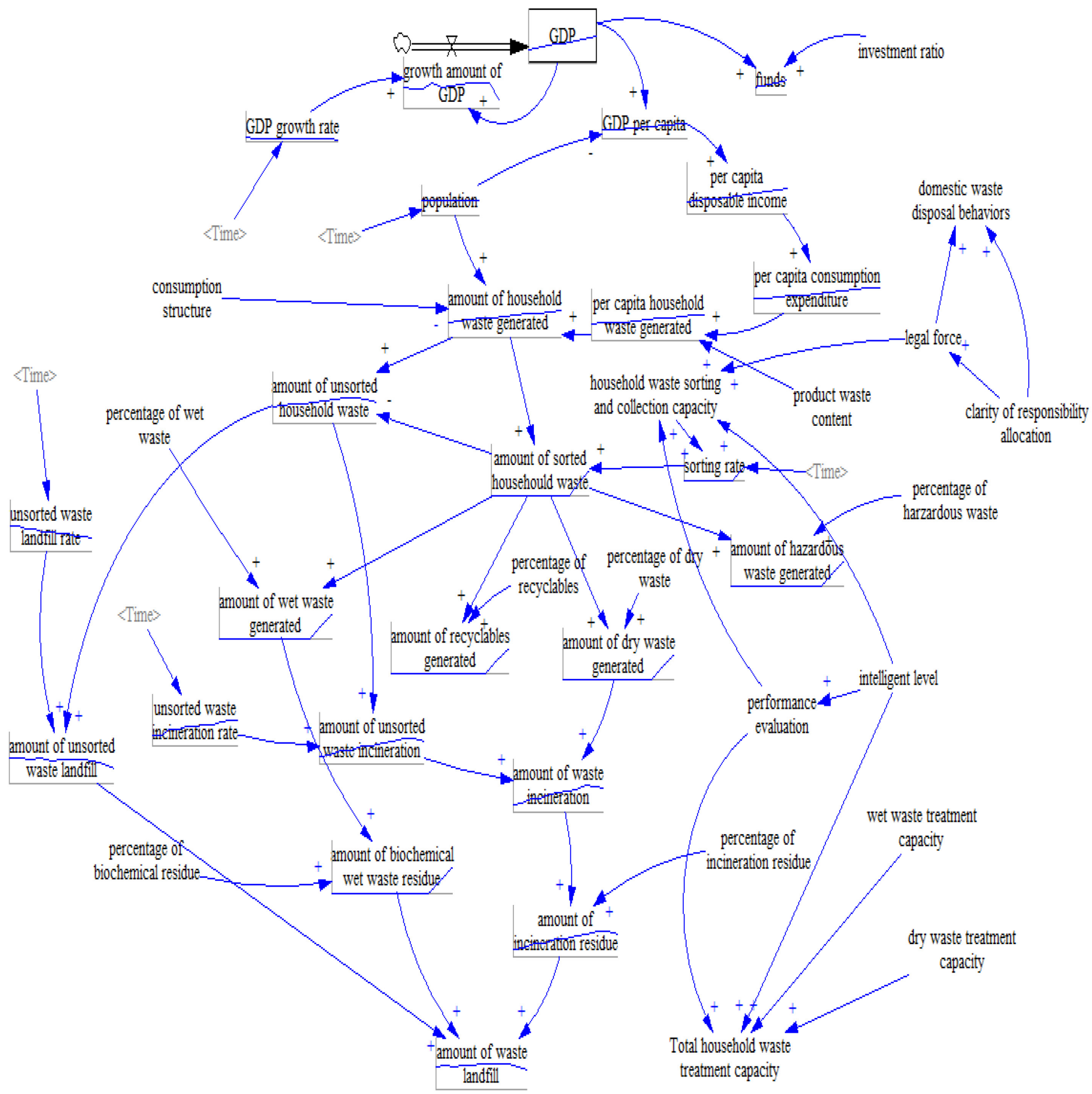

Figure 49 Stock and flow diagram of the policy system model

The variables in Figure 49 do not fully include all the variables in the policy model, as some variables cannot be quantified by finding reliable data at this stage. However, Figure 49 adds some variables that are not mentioned in the policy model, such as separating out different domestic waste treatment capacities, with the aim of helping to quantify total household waste treatment capacity. Table 6 shows the specifics of the variables, variable values, variable types and units in Figure 49.

Table 6 Variables and values of the CLD diagram

No.	Variables and values	Variable type	Unit
1	C INITIAL TIME = 2010 (The initial time for the simulation.)	Constant	Year
2	C FINAL TIME = 2020 (The final time for the simulation.)	Constant	Year
3	C SAVEPER = TIME STEP	Constant	Year
4	C TIME STEP = 1 (The time step for the simulation.)	Constant	Year
5	A Amount of biochemical wet waste residue = Amount of wet waste generated * Percentage of biochemical residue	Auxiliary	Ton
6	A amount of dry waste generated = Amount of sorted household waste * Percentage of dry waste	Auxiliary	Ton
7	A Amount of hazardous waste generated = Amount of sorted household waste * Percentage of hazardous waste	Auxiliary	Ton
8	A Amount of household waste generated = Population * Per capita household waste generated * Consumption structure	Auxiliary	Ton
9	A Amount of incineration residue = Amount of waste incineration * Percentage of incineration residue	Auxiliary	Ton
10	A Amount of recyclables generated = Amount of sorted household waste * Percentage of recyclables	Auxiliary	Ton
11	A Amount of sorted household waste = Sorting rate * Amount of household waste generated	Auxiliary	Ton

12	A Amount of unsorted household waste = Amount of household waste generated - amount of sorted household waste	Auxiliary	Ton
13	A Amount of unsorted waste incineration = Unsorted waste incineration rate * Amount of unsorted household waste	Auxiliary	Ton
14	A Amount of unsorted waste landfill = Unsorted waste landfill rate * Amount of unsorted household waste	Auxiliary	Ton
15	A Amount of waste incineration = Amount of dry waste generated + Amount of unsorted waste incineration	Auxiliary	Ton
16	A Amount of waste landfill = Amount of biochemical wet waste residue + Amount of incineration residue + Amount of unsorted waste landfill	Auxiliary	Ton
17	A Amount of wet waste generated = Amount of sorted household waste * Percentage of wet waste	Auxiliary	Ton
18	C Clarity of responsibility allocation = 1 (Estimated based on the assumptions made in this paper for the policy.)	Constant	Dmnl
19	C Consumption structure = 0.7 (A rough estimate based on what is described in the literature [93])	Constant	Dmnl
20	C Domestic waste disposal behaviors = 0.95 * clarity of responsibility allocation * legal force (Estimates based on current waste disposal behavior in Shanghai [94])	Auxiliary	Dmnl
21	C Dry waste treatment capacity = 7.7745e+06 (Calculated using daily processing capacity multiplied by 365 days [94])	Constant	Ton/Year
22	A Funds = GDP * Investment ratio (The funds refer to environmental related funds, which are considered as the original funds for waste management in this paper)	Auxiliary	CNY
23	L GDP = INTEG (Growth amount of GDP, 1.79154e+12) [94]	Level	CNY

24	A GDP growth rate = WITH LOOKUP (Time, ([(2010,0) - (2020,0.12)], (2010,0.102),(2011,0.083),(2012,0.075),(2013,0.097),(2014,0.071),(2015,0.07),(2016,0.069),(2017,0.07),(2018,0.068),(2019,0.06),(2020,0.017))) [94]	Auxiliary	1/Year [0,1]
25	A GDP per capita = GDP/population	Auxiliary	CNY/Person
26	A Growth amount of GDP = GDP * GDP growth rate	Auxiliary	CNY/Year
27	A Household waste sorting and collection capacity = 1 * Legal force * Performance evaluation * Intelligent level (Parameters are estimated by sufficient capacity)	Auxiliary	Dmnl
28	C Intelligent level = 2 (Approximate projections based on the literature [95])	Constant	Dmnl
29	C Investment ratio = 0.291 (Use the proportion of environmental-related investments)	Constant	Dmnl
30	A Legal force = 1.5 * Clarity of responsibility allocation (Estimates based on expected legal effects)	Auxiliary	Dmnl
31	A Per capita consumption expenditure = 0.5532 * Per capita disposable income + 7399.96, R^2 (COD) = 0.99241 (The calculation equation is derived by ordinary least squares, which means that the factors of the optimal function are discretized to calculate the government data of Shanghai from 2016 to 2020. The square of R represents the confidence level. COD is Coefficient of determination.)	Auxiliary	CNY/Person

32	A Per capita disposable income = 0.5052 * GDP per capita - 7779.74, R^2 (COD) = 0.9737 (Calculation method same as the 31)	Auxiliary	CNY/Person
33	A Per capita household waste generated = (7.8106e-06 * per capita consumption expenditure + 0.0598) * product waste content, R^2 (COD) = 0.9768 (Calculation method same as the 31)	Auxiliary	Ton/Person
34	C percentage of biochemical residue = 0.12 [96]	Constant	Dmnl
35	C Percentage of dry waste = 0.037 [57]	Constant	Dmnl
36	C Percentage of hazardous waste = 0.0009 [57]	Constant	Dmnl
37	C Percentage of incineration residue = 0.3 [97]	Constant	Dmnl
38	C Percentage of recyclables = 0.335 [57]	Constant	Dmnl
39	C Percentage of wet waste = 0.6334 [57]	Constant	Dmnl
40	A Performance evaluation = 1.2 * intelligent level (Estimation of performance evaluation effects through literature [98])	Auxiliary	Dmnl
41	A Population = WITH LOOKUP (Time, ([(2010,2.2e+07)-(2020,2.6e+07)] ,(2010,2.30266e+07),(2011,2.35553e+07),(2012,2.398e+07),(2013,2.448e+07),(2014,2.467e+07),(2015,2.457e+07),(2016,2.467e+07),(2017,2.466e+07),(2018,2.475e+07),(2019,2.481e+07),(2020,2.488e+07))) [94]	Auxiliary	Person
42	C Product waste content = 1e-05 (By roughly estimating the price level and waste production factors in Shanghai)	Constant	Ton/CNY
43	A Sorting rate = WITH LOOKUP (Time * household waste sorting and collection capacity, ([(2010,0) -(2020,1)], (2010,0),(2011,0),(2012,0),(2013,0),(2014,0),(2015,0),(2016,0),(2017,0),(2018,0),(2019,0.15),(2020,0.3))) [57]	Auxiliary	Dmnl

44	A Total household waste treatment capacity = (Dry waste treatment capacity + Wet waste treatment capacity) * Performance evaluation * Intelligent level	Auxiliary	Ton/Year
45	A Unsorted waste incineration rate = WITH LOOKUP (Time,([(2010,0)-(2020,1)],(2010,0.24),(2011,0.25),(2012,0.37),(2013,0.37),(2014,0.46),(2015,0.46),(2016,0.48),(2017,0.5),(2018,0.56),(2019,0.59),(2020,0.62))) [57]	Auxiliary	Dmnl
46	A Unsorted waste landfill rate = WITH LOOKUP (Time, ([(2010,0)-(2020,1)],(2010,0.76),(2011,0.75),(2012,0.63),(2013,0.63),(2014,0.54),(2015,0.54),(2016,0.52),(2017,0.5),(2018,0.44),(2019,0.41),(2020,0.38))) [57]	Auxiliary	Dmnl
47	C Wet waste treatment capacity = 2.01845e+06 (Calculated using daily processing capacity multiplied by 365 days [94])	Constant	Ton/Year

4.3.5 Model Validation

As mentioned in Section 3.2.9, the inspection of the model does not occur only after the model is completed, but during the process of developing the model. In the process of building the causal loop model, the analysis and construction of the model structure is a way of performing model validation. Further, for qualitative policy models, the nature of the variables themselves and the descriptions in the policy are strong evidence of the model structure. As for the quantitative SFD diagram, the structure of the model first needs to be checked using the Vensim software, with the aim of preventing errors in the model's structure itself and the content of the internal formulas, with the test results passing, as shown in Figure 50. This model testing approach only guarantees that the model syntax is error-free.

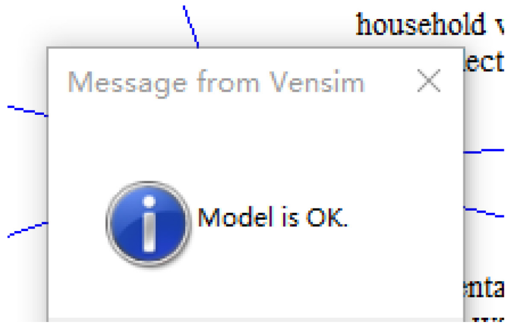

Figure 50 Vensim model checking result

Since the relationships between the variables in SFD are all from the CLD diagram, there is no need to prove the contents of each sub-block separately again. The data sources in the model consist of three parts, which are official data from the Shanghai government, data from the literature, and parameters inferred from the authors' experience. The time axis of the SFD model was selected from 2010 to 2020, as shown in Figure 51-53. From the results, the self-fitting parameters have no significant effect on the other variables and the overall trend remains the same as before the parameters intervened, but this SFD model cannot predict the future because the exact values of the parameters and the relationship with the variables are still unclear.

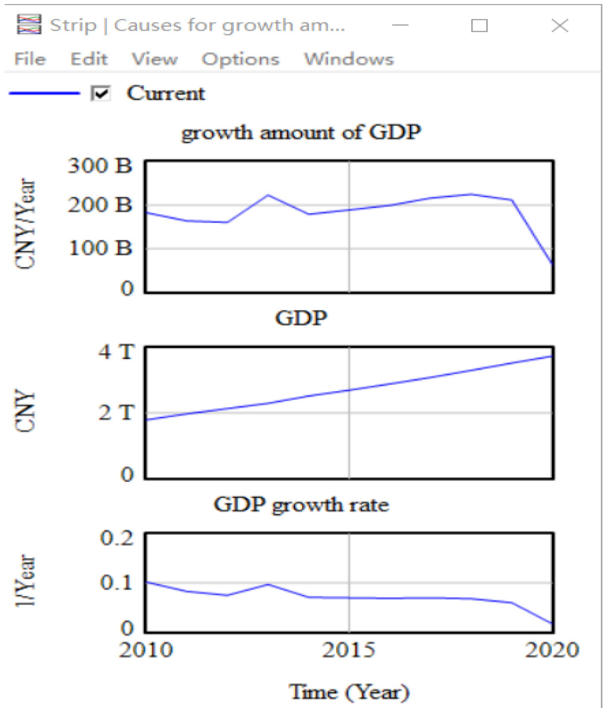

Figure 51 Results of economic-related data

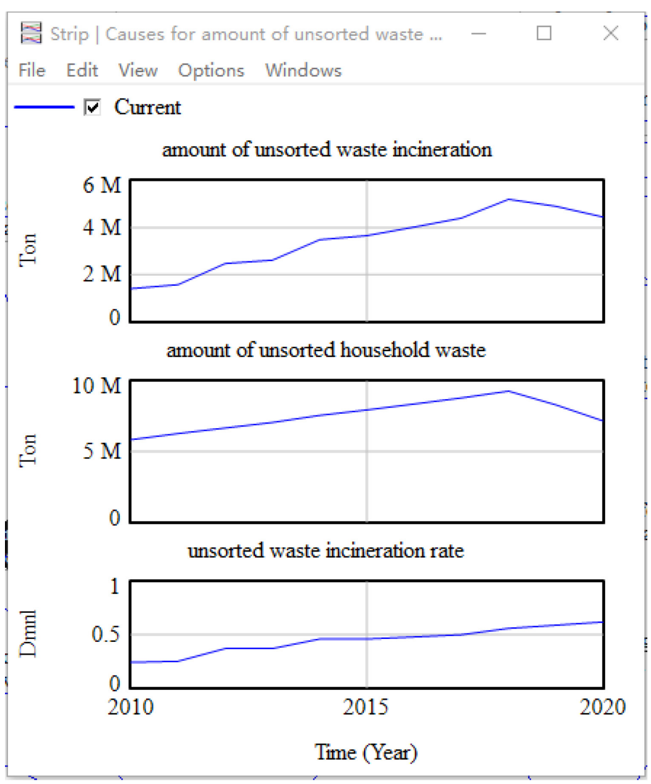

Figure 52 Results of waste incineration-related data

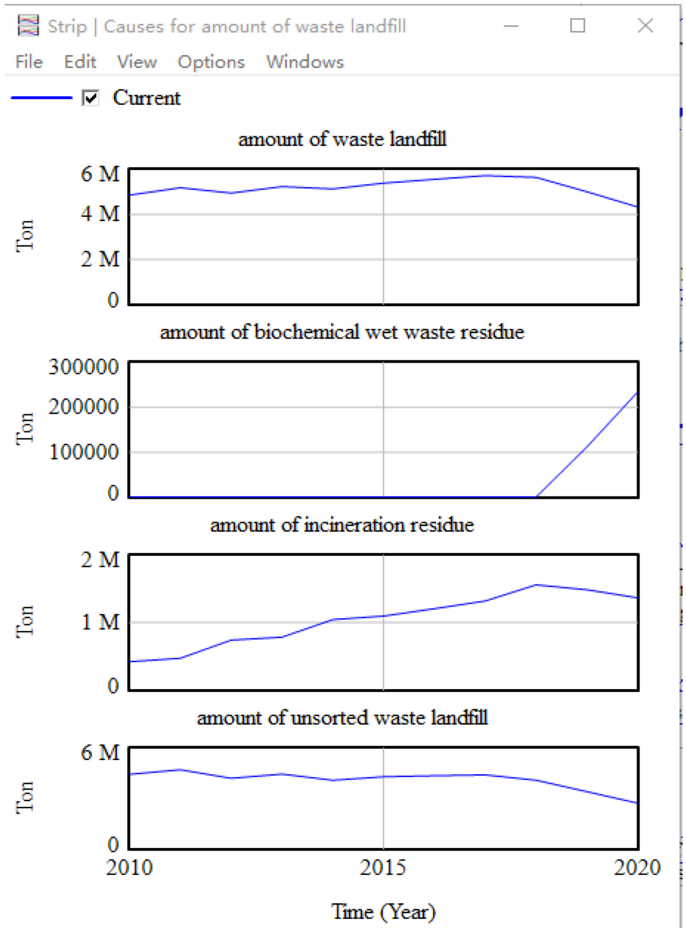

Figure 53 Results of waste landfill-related data

4.3.6 Results Analysis

In the policy model of Figure 47, it is evident that the variables can be divided into three categories based on their relationship with other variables. The first category of variables is those that are influenced only by other variables and do not affect other variables, which are mostly dependent variables extracted from the policy. Since the dependent variable is the goal that the policy wants to achieve, it is reasonable to have such a characteristic. The second type of variables are those that affect other variables while also being affected by other variables. These variables mostly have the effect of transmitting the effects caused by the previous variable and can be understood simply as intermediate variables in the policy model. The third type of variables are the variables that we want to find, i.e., those that only affect other variables and are not affected by other variables, and these are the triggers by which policy manipulates the entire policy model as well as the overall waste management system.

In the policy model of Shanghai Municipal Solid Waste Management Regulations, there are eight variables in the third category, all of which only affect other variables and are not affected by other variables. Since the variable of amount of hazardous waste generated is not proposed from the policy but is a refinement of the total amount of household waste generated, this variable will not be discussed in depth here. The other seven variables are 1- clarity of responsibility allocation, 2- knowledge level of domestic waste, 3- fuel structure, 4- clarity of provisions, 5- intelligent level, 6- number of facilities, 7- regional economy distribution, as shown in Figure 54. By screening these variable types, they can be divided into three categories, which are user-related variables (containing 2, 5), policy-related variables (containing 1, 4, 6, 7), and resource-related variables (containing 3). The way the policy operates is to precisely control the relevant variables of the user, policy, and resource to regulate the whole waste management system.

For the quantitative model SFD, within the economic sub-block, the growth rate of GDP continues to slow down, which leads to a gradual decrease in the amount of GDP growth and in the long run, the growth of disposable income per capita of the population will also continue to slow down. Since the average spending of residents is proportional to the average disposable income of residents, then the spending of residents will also decelerate going forward. Coupled with the government's encouragement for the change of consumption structure and the promotion of several waste recycling bills, there is a great possibility that the waste generated by residents' consumption will be further reduced in the future. The data shows that the government intends to increase the proportion of waste incinerated and seeks to reduce the amount of waste going to landfill. This trend will greatly contribute to the harmless treatment and resource utilization of dry waste, and will reduce soil pollution and the need for landfill sites, as well as improve the energy structure to some extent. It can also be seen from the data that the biochemical treatment of wet waste is gradually being paid attention to, and with the progressive establishment of wet waste treatment equipment, the wet waste treatment capacity will also be significantly enhanced. Wet waste can produce biogas and further optimize the energy structure, which belongs to the category of resource utilization. Dry waste incineration and wet waste biochemical treatment will also work together to have a positive impact on landfills, and from the data, the number of landfills will gradually decrease.

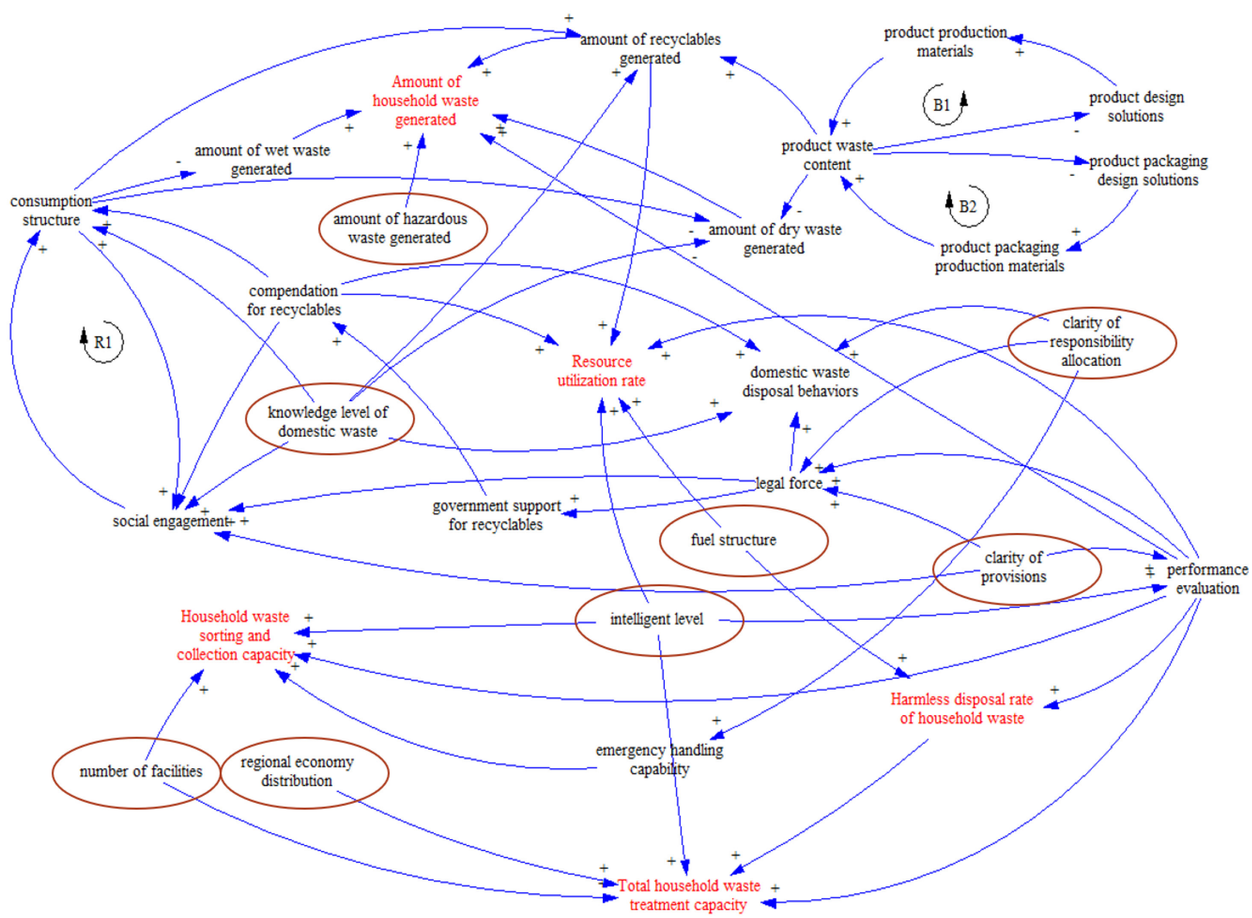

Figure 54 Variables that affect other variables only and are not affected by them (circled in red)

5 Discussion and Conclusions

5.1 Discussion

As environmental issues become increasingly emphasized worldwide, the significance of waste management has gradually emerged. Numerous researchers have contributed to the modeling of waste management systems. Their models are generally macroscopic, taking the perspective of the whole system of waste management, where policy as one of the influencing factors is considered as only a small part of the complex waste management system. This thesis differs from previous studies on waste management systems by considering the waste management environment before studying waste management issues based on EBD, which leads to an in-depth discussion of waste management policies. Rather than a small part of the model, this thesis takes the most important policy environment in waste management as the basis for building the model, and carefully explores the independent and dependent variables in the policy. With the help of ROM diagrams in the EBD approach, understanding statements, stakeholders' actions and responsibilities, and the framework of the policy can be distilled, allowing the policy content to be visualized from multiple perspectives.

In terms of the model's utility, the potential for the policy model's use is enormous, benefiting from its comprehensive content, abundant information coverage, and diverse management perspectives. Because of the specificity of the process of policy designation, the study of the way policy works will help policy makers and decision-makers to have a better understanding of the aspects covered and the way the policy operates, which will help to modify the policy in the future.

The policy system model is constructed by linking the policy model to the sub-blocks in the waste management system. This model would deepen the connection between the policy model and the waste management system. At the same time, the progressive improvement of the policy system model can also reveal aspects and relationships that are not covered in the policy and can further uncover problems that arise from the absence of certain objects and relationships in the policy.

5.2 Limitations

The core of this thesis is the policy model. The two key components of the policy model are the variables and the variable relationships, and the limitations associated with these two will be discussed first, followed by the limitations of the policy system model and the quantification issues.

1. The problem of variable extraction in the policy. Due to the abstract and incomprehensible nature of the policy, many difficulties were encountered in the extraction process of the policy, and the summarization process of the variables went through several iterations, but the problem of classification accuracy still exists. There is still much potential for improving the accuracy of variable extraction in different statements, and further research is necessary to continue subdivision, expression, and refinement of variables. The authors will invite multiple experimenters to interpret the same policy and adjust the variable content by comparing the results obtained by them.
2. The level of refinement of the relationships between variables in the current model could be further enhanced. The author believes that there are still intermediate variables that play a transmission and moderating role in the relationship between many variables that directly interact with each other, and these variables need to be further explored in the policy.
3. The policy system model has missing content in each sub-block. Although the focus of this thesis is not on the policy system model, the sub-blocks of the policy system model appear to be incomplete at this stage. There are still many variables that are not considered in

comparison to a well-established waste management system model, and the aspects that are not considered may reveal missing elements in the policy.

4. The problem of quantification of abstract variables. In the SFD model of this thesis, the skeletal structure of the policy model is quantified, while many related but relatively abstract variables cannot be quantified because no data can be found or there is no way to know the exact relationship with other variables. This poses a significant obstacle to both the in-depth study and the predictive power of the SFD model. A possible solution that comes to the forefront is to try to represent the abstract variables in terms of quantifiable variables and then derive the parameter values with the highest confidence through simulation of the system behavior, but the possibility of implementing this process still needs to be further examined.

5.3 Conclusions

This paper uses EBD to model Shanghai's waste management policies using an Environment-based thinking approach. By studying and mining the policy, 19 independent variables were extracted from the regulations in the policy, and 5 dependent variables were extracted from it according to the objectives of the policy. There are two main ways of constructing relationships between variables in a policy model, one is based on a direct description of the policy and the other relies on the variables' own characteristics. After finding the information about the variables and their relationships, the policy model is partitioned into 12 sub-blocks to build the holistic model. In the partitioning process, more variables in the waste management system are also considered, forming a more comprehensive policy system model based on the policy model and further strengthening the connection between the policy model and the waste management system. The model's block division approach is based on the life cycle of the waste and the connections between the sub-blocks and other sub-blocks within the life cycle. As a result, the policy model and the policy system model based on the policy model are built simultaneously.

The policy model reveals the complex causal relationships within policies and provides a graphical representation of the abstract policy language. In the policy model, the positive and negative feedback relationships between variables can be clearly identified using the direction of arrows. Furthermore, the hypothesis about the way in which the policy controls the waste management system is verified by extracting variables that affect only other variables. Based on the three environments of EBD, natural, human, and built environment, at the beginning of the model, the author assumed that the way policy controls the waste management system is by controlling these three types of variables. User-related variables correspond to the human environment; policy as the most important built environment in the policy model, policy-related variables correspond to the human environment; and resource-related variables correspond to the natural environment. The study of the policy model reveals that there are eight variables that only affect other variables and are not affected by other variables. After ignoring one variable that does not belong to the variables extracted from the policy, the remaining seven variables can be distinguished exactly according to these three categories. At the same time, the process by which the policy achieves its objective is apparent, i.e., by controlling for these three categories of variables that only affect other variables, through the transmission of intermediate variables, thus exerting a control effect on the dependent variable.

While analyzing the policy statements and looking for policy variables, the process of policy creation and evolution is also investigated in the thesis. The general structure of the policy is linked to the responsibilities and work requirements of the stakeholders within the policy according to three aspects: master plan, management hierarchy, and legal penalties. These structural diagrams will work in conjunction with the policy model to help policymakers enhance their comprehension of policy content further.

The quantification of policy models is of significant importance, as it can have the effect of testing policy changes and can help policymakers make predictions. However, as stated in the limitations section, the current quantitative work cannot achieve predictive and policy testing effects and can only complete the rationality test for the main structure of the qualitative model.

5.4 Future Work

Addressing the limitations of the policy model will be the focus of future work. On one hand, it aims to further explore the variables and refine the relationship between them; on the other hand, it seeks to achieve a fully quantitative study of the model. Soft data collection is one of the difficulties in model quantification. Since the policy model contains a large amount of soft data such as citizen behavior related variables. The process of quantifying such data has been conducted by the author for over a year. Due to the quality and quantity of data, such data cannot be used for scientific research at this time, and further adjustments to the data collection scheme and content are needed. The Figure 55-58 shows the author's collection of the contents of some of the garbage bins in downtown Montreal, where he lives, including information on the location, type and contents of the bins. In addition, the author collected information on the contents of garbage cans on the first floor of the main building of his university for six months. Information was also collected on the separation of garbage in densely populated residential buildings in the city center according to the year of construction and number of floors of the residential buildings, which will not be discussed in detail here.

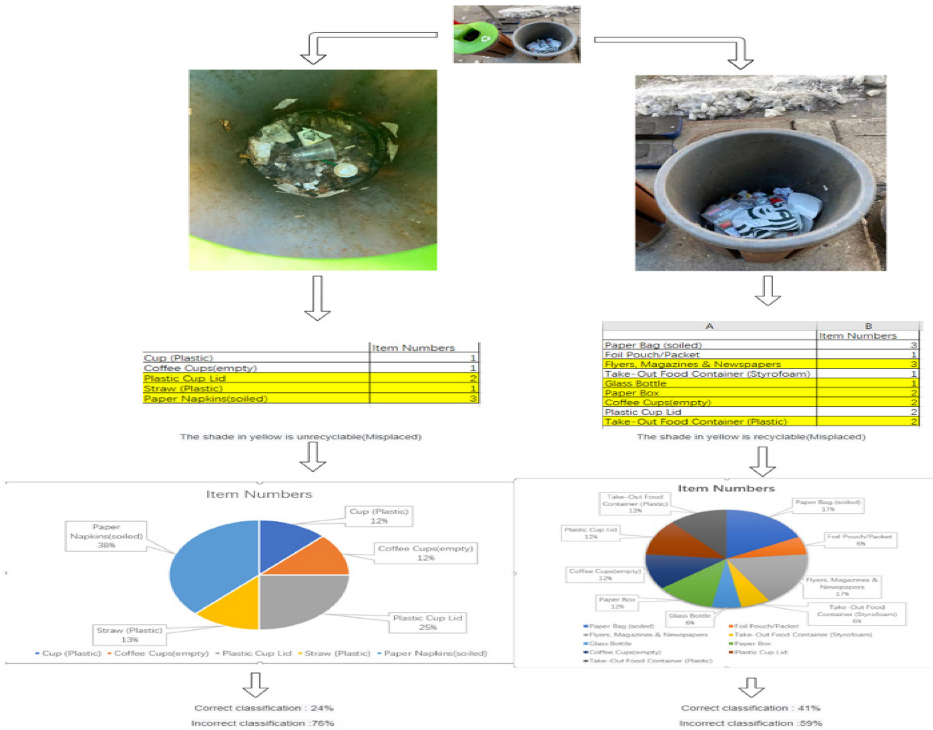

Figure 55 Montreal downtown garbage bin information collection

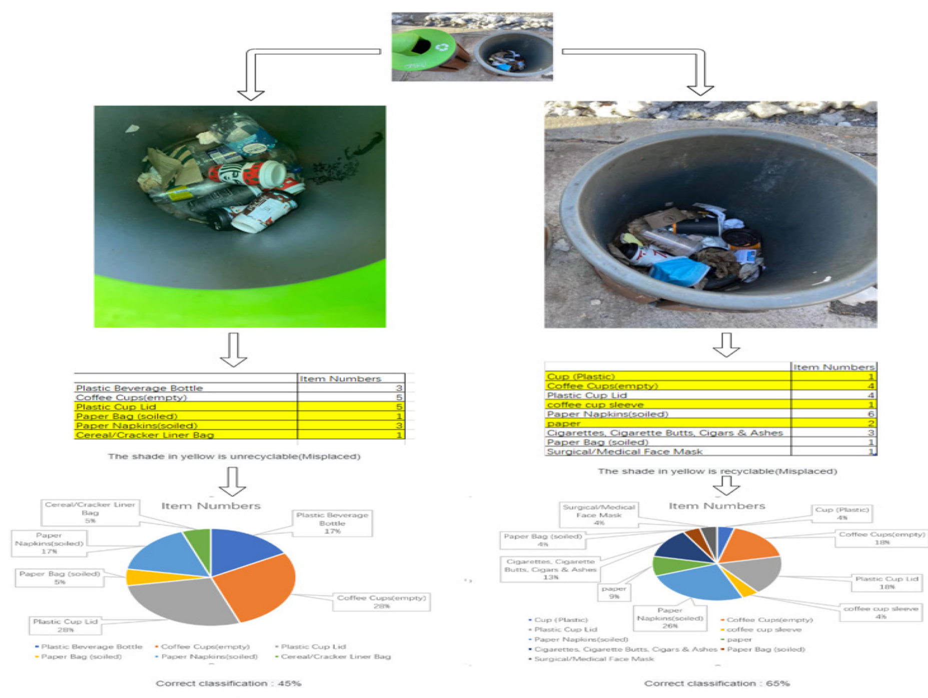

Figure 56 Montreal downtown garbage bin information collection

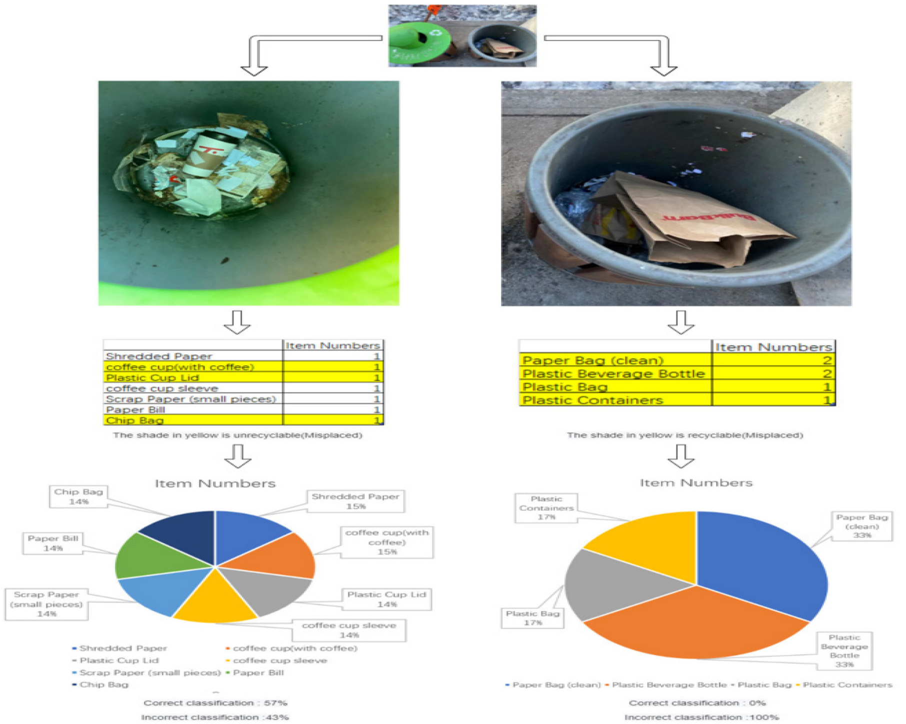

Figure 57 Montreal downtown garbage bin information collection

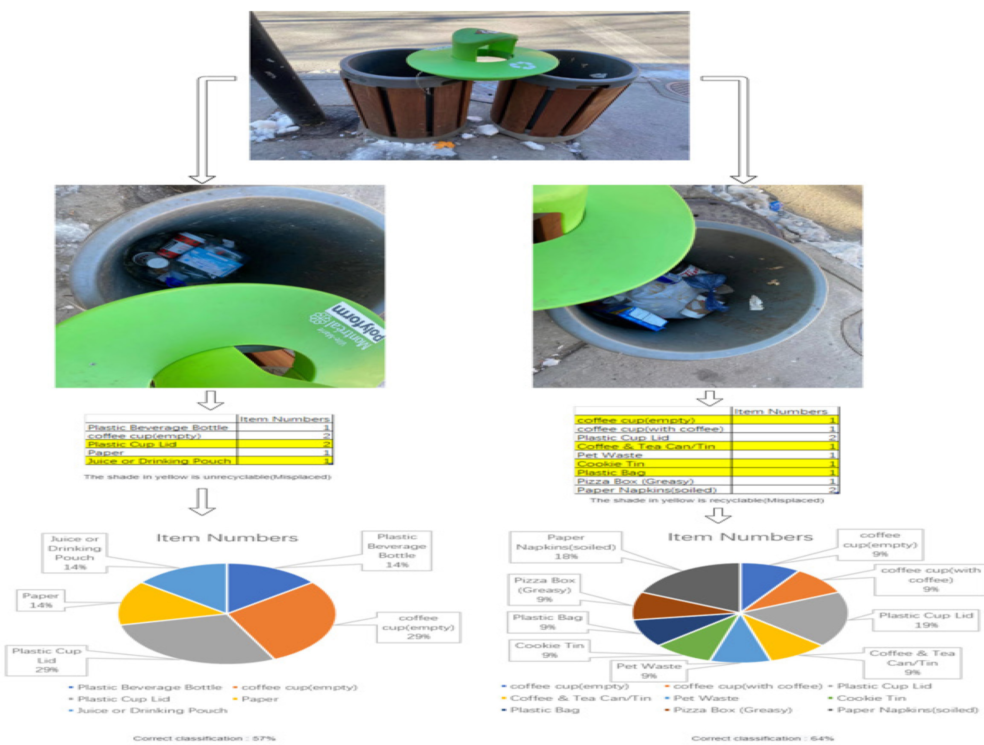

Figure 58 Montreal downtown garbage bin information collection

Appendix

Appendix 1 Template for the right type of questions [59]

#	Conditions	Question template
T1	For a concrete, proper, or abstract noun object N without any constraint	What/Who is N?
T2	For a concrete, proper, or abstract noun N with an adjective constraint A	What is A N?
T3	For an noun object A constraining an noun object N	What is A? What is/are A N?
T4	For a verb V with its subject N1 and object N2	What do you mean by V in the statement "N1 V N2"? How do/does N1 V N2? Why do/does N1 V N2? When do/does N1 V N2? Where do/does N1 V N2?
T5	For a verb object V constrained by an adverb A with its subject N1 and object N2	What do you mean by V A? Why do/does N1 V A N2? When do/does N1 V A N2? Where do/does N1 V A N2?
T6	For a verb V with an object N, but missing its subject	What/Who V N?

Appendix 2 Guideline to answer questions [59]

#	Questions	Guideline
G1	What/Who is N? N: a concrete, proper, or abstract noun object What is A N? A: an adjective constraint	a) If (A)N is the product to be designed, then the answer should address 1) the purpose of (A)N; 2) the definition of (A)N according to the life cycle of the product and the categorization of environment components for each event in the lifecycle; b) Else, if N is an environment component of a product, then the answer should define (A)N according to the life cycle of the environment component and the categorization of the other environment components for each event in the lifecycle; c) Else, the components and attributes of N should be described.

G2	What/Who do/does V N? V: a verb	For N1 that V N, the answer should define the components and attributes of N1 in the context of V N.
G3	When do/does N1 V N2? When do/does N1 V A N2?	The answer may assume one of the following two forms: a) In/On a time, N1 V(A) N2; b) When/During/While N3 Va N4, N1 V(A) N2.
G4	Where do/does N1 V N2? Where do/does N1 V A N2?	The answer may assume one of the following two forms: a) In/Along/Through a place, N1 V(A) N2; b) N3 Va N4, where N1 V(A) N2.
G5	Why do/does N1 V N2? Why do/does N1 V A N2?	The answer should be organized as: To Va Na, N1 V (A) N2.
G6	What do you mean by V? What do you mean by V A? How do/does N1 V N2?	a)If the subject (N1) or object (N2) of V is not the product, then the answer should include all activities included in V-ing in the context of N1 and N2; b) Else, skip the question and leave for solution generation.

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