Projection of Municipal and Industrial Solid Waste Generation in Chinese Metropolises with Consumption and Regional Economic Models

Jinmei YANG

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ABSTRACT

The increasing volume of solid waste (SW), not only arising from household (Municipal SW, MSW) but also from industrial process (Industrial SW, ISW), has become a serious issue in Chinese metropolises with the economic growth, urbanization, industrialization, and increasing affluence. Growth of industry leads to the expansion of population, while the augment of demand by increasing population stimulates the industrial growth in turn, thereby increasing not only ISW generation, but also MSW generation. Therefore, in order to solve the waste problem for the construction of sustainable waste management system in a city, it is necessary to consider these two types of waste together, in which, the emphasis should be focused on waste reduction from the source. The starting point in adopting this should be a good understanding of the upstream flow of waste and accurate knowledge of the volume and composition of waste that will be generated in the future. However, due to deficient historical records and complex production process, the effective attempts at forecasting SW generation are far from enough, especially for ISW by waste category. A common approach which is based on the limited waste statistics and can be easily popularized into Chinese countries is thus urgent. This paper, therefore, attempts the construction of a systematic approach to make projections of SW generation by waste category from the following issues: (1) to develop household consumer behaviour model taking into account lifestyle of residents and project the demand of private consumption in the future; (2) to quantitatively investigate and project MSW generation fully considering the change in consumer behaviour and waste management policies; (3) to effectively evaluate the present and future industrial structure and their contributions to ISW generation among industries; (4) to carry out a scenario analysis of calculating CO_2 emissions in different waste treatment options based on the projected waste quantity and composition in 2015. The approach is applied on a city level as the basic administrative unit of SW management in China.

The entire framework comprises four modules—regional macro-economic module, MSW generation module, ISW generation module, and waste treatment module. Further, the study of consumption pattern conducted from the consumer behaviour model in MSW module is a prerequisite for industrial restructuring caused by change in consumption demand in ISW module. Moreover, the regional macro-economic module is to provide a means for economic structural analysis and economic forecasting, considering the influence of national GDP and socioeconomic indicators including world trade. It is found out that the regional model fits the historical records reasonably well and provides an acceptable reproduction.

In the MSW generation module for estimating and projecting MSW generation, firstly the per capita total household consumption expenditure is estimated by using total consumption expenditure model; then, household consumption pattern is estimated using an extension of the linear expenditure system (LES); thereafter, MSW generation by composition is quantitatively expressed in terms of the expenditure for consumption category and waste management policies by using ordinary least squares (OLS). Then, five Chinese cities with distinct economic levels are presented by applying the module to determine the waste generation features in different regions. The research findings clearly indicate that 1) the number of variables affecting consumer behaviour in Chinese cities is not one but the integrations of a series of indicators. Aside from Shanghai, *saving rate towards consumption* (***SAV***) and *natural growth rate* (***NAGR***) are currently the two common factors. However, in Shanghai, consumer behaviour is strongly influenced by ***SAV*** and *the average number of persons per household* (***ANPH***). 2) The MSW generation model quantitatively demonstrates the linear conversion process from consumption to corresponding waste generation in all cities. For example, education and consumption of food—as the form of consumption expenditure in this research—is the source of generation of food, plastic and paper waste. Further, glass and metal waste is estimated by food expenditure in all cities. 3) Total MSW generation per unit consumption is 0.198~0.225 kg/RMB with an average value of 0.213 kg/RMB. 4) All the waste management policies analyzed in the research will provide feasible experiences or valuable lessons to other Chinese cities. 5) Volume of per capita MSW generated in 2020 will be 1.24—2.18 folds compared to that in 2008 in each city if there were no effective policies implemented advancing to diminishing waste generation.

Then, for the forecasting of ISW generation of each waste category by industry, the ISW module is developed, linking three principal models—regional macro-economic model, regional input-output (IO) analysis, and ISW generation model. The approach investigates the influence of industrial restructuring on ISW generation, based on the study of consumption patterns, export composition figures and change in ISW generation coefficient. The principal priorities in the case study on Shanghai are as follows: 1) the approach provides an idea for a way to quantitatively analyze industrial restructuring by adjusting the converter that, in turn, helps assess the impact of these changes on sectoral output. 2) A sensitivity analysis describes that per yuan of increase in consumption on FOOD, CLSH, FUNI, EDUC, TRAN, HLTH and RESI induces to an average increase of 76.41, 76.16, 82.28, 106.54, 93.89, 148.30 and 292.58 g total ISW, respectively. 3) It is verified that ISW generation not only arises from economic growth but also from the onset of industrial restructuring. The unit ISW generation per gross output reduces from 0.16 to 0.14 tons/10 000 RMB as we move from 2002 to 2020. 4) It is investigated that the total volume of ISW generated in 2010, 2015 and 2020 will be 2.07, 2.83 and 4.12 times that of the 2002 levels. The total SW generation of Shanghai in 2020 will be 4.06 times of that in 2002. 5) However, if considering scenario analysis of adjusting ISW generation coefficient, the total SW generation is 1.93 times compared to 2002 and ISW is 2.18 times of MSW generation. 6) Based on our results, the industrial sectors making the biggest contribution to the production of each type of ISW can each be separately identified. Therefore, constraining specific industries or penetrating them with selective technological changes will be useful attempts on the way to meeting the objectives of overall waste reduction.

Finally, in the waste treatment module, the greenhouse gas (GHG) emissions emitting from the treatment and disposal of waste, including landfill site, waste-to-energy incineration and composting are calculated, respectively. Further, based on the projection of waste quantity and composition of Shanghai in 2015, a scenario analysis is carried out as well concerning the GHG emissions from alternative treatment options. The results confirm that composting and recycling of waste before the treatment are effective attempts at reducing GHG emissions in Shanghai. Further, scenario designed as the integrated waste treatment system makes the biggest reduction of GHG emissions, as 34% as compared to current treatment options with energy recovery.

In a word, this research develops the entire systematic approach investigating the upstream flow of waste generation from the viewpoint of economic growth, change in socioeconomic indicators and constitution of waste management policies, and makes a reasonable attempt at projecting SW generation of each type of waste category. Based on the results, it is suggested that for the waste reduction to promote sustainable society, government interventions including promoting green consumption, reducing extra consumption, et al. and waste policies such as increasing recycling and penetrating technological innovation in specific industries will be effective. Further, based on the forecasts of SW generation, the recycling and appropriate treatment of waste generating from municipal and industrial process can be examined from the long view. From the relationship between ISW and MSW generation, the development of industry will promote the growth of service industry and induce greater generation of recyclable items. While the recycling of these items before the waste treatment is essential for effectively reducing GHG emissions which contribute to global warming. In addition, the systematic model can be easily popularized into other Chinese cities even other Asian developing cities, thereby possibly promoting the sustainable waste management of China and Asian countries.

Key Words**:** Municipal solid waste, industrial solid waste, projection, consumption, regional economic model, input-output analysis, CO_2 emission

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A TABLE OF TERMINOLOGY ABBREVIATION

A table for the abbreviations of the all terminology appeared in the text, in alphabetical order

Terminology	Abbreviation
Adjusted R^2	AdR^2
Average number of persons per household	ANPH
Autoregressive integrated moving-average model	ARIMA
Consumption category	CA
Chinese Academy for Environmental Planning	CAEP
Coal-burning powder	CB
Clothing & shoes	CLSH
Consumer price index	CPI
Coal stone	CS
Disposal site	DS
Education, cultural & recreation services	EDUC
Environmental Protection Agency	EPA
Environmental Sanitation Bureau	ESB
Explanatory variable	EV
Food	FOOD
Household facilities, articles & services	FUNI
Gangue	GA
Gas coverage rate	GAS
Government consumption	GC
Greenhouse gas	GHG
Green coverage rate of built districts	GREEN
Medicine & medical services	HLTH
Hazardous waste	HW
Fixed capital formulation	I
Input coefficient	IC
International Financial Statistics	IFS
Intergovernmental Panel on Climate Change	IPCC

Industrial solid waste	ISW
Integrated waste management philosophy	IWMP
Linear expenditure system	LES
Landfill gas	LFG
Liquefied petroleum gas	LPG
Mean absolute percentage error	MAPE
Municipal Statistics Bureau	MSB
Municipal solid waste	MSW
Ordinary least squares	OLS
Others	OT
Miscellaneous commodities & services	OTHR
Private consumption	PC
Index of power dispersion	PD
Partial waste generation coefficient	PWC
Radioactive waste	RA
Residence	RESI
Root mean square error	RMSE
Related total consumer expenditure	RTCE
Saving deposits	SAV
Sanitary landfill	SAL
Sensitivity coefficient	SC
Subsistence demand expenditure	SE
Slag	SL
Smelting residue	SR
Solid waste	SW
Total household consumption expenditure	TCON
Total fertility rate	TFR
Transport & communication services	TRAN
Waste-to-energy	WTE

1 INTRODUCTION

1.1 Research background

Industrialization, urbanization, population growth and increasing affluence are driving the magnitude of China' increase in solid waste (SW) generation, which has become the stumbling block of improvement of environmental quality and city appearance[1-7]. Further, with the universal recognition and prevalence of sustainable development, environmental sustainability—defined as 'the ability of the environment to continue to function properly'—has been widely endorsed as an ideal goal for minimizing environmental degradation[8-10]. In the conduct of solid waste management, sustainable development acts as an integrated waste management philosophy (IWMP) with regard to the waste hierarchy of 'reduce, reuse and recycle'. This implies that waste reduction should be emphasized on top of the hierarchy along with the increasing ratio of reusing and recycling, thus aiming at minimizing waste[1, 11]. The starting point in adopting such an approach in the future should be a good understanding of the upstream flow of waste[12-14]. Further, to solve the problem of SW for the development of a sustainable society, accurate projection of waste generation by composition is crucial from the following perspectives: (1) determining long term consequences of the chosen waste legislation requires assessment of the current SW generation and accurate projections in the future[15]; (2) the accurate knowledge of the volume and composition of waste that will be generated in the future is also vital for the successful long-term planning and designing of solid waste management systems and optimisation of management strategies[13, 16, 17]; (3) the information is the important background for the implementation of recycling activities[18] as well.

Shift in waste hierarchy leads to the increase of data complexity, thus requiring more detailed information on waste generation and composition. However, in Chinese cities, due to the deficient financial support, the lack of reliable and consistent waste records makes it extremely difficult for the strategic projection of waste quantity as well as waste composition[1, 17]. It is thus meaningful to develop a common approach which is based on the limited waste statistics of cities and is easily popularized into other Chinese cities.

Fig. 1−1 illustrates the internal relationship between production and consumption in the development of a city. The city acquires resources from nature and produces a wide range of goods and merchandises, thereby promoting the industrialization as well as the development of service industry. The growth of industrial sectors results in the appearance of a large number of labours and expansion of population, causing the shift of distribution of population and urbanization. Further, the augment of demand caused by increasing consumption of population drives the production of more goods and industrial growth in turn[19]. The urbanization and consumption thus becomes integral elements of rapid economic growth and industrialization[20]. Meanwhile, the economic growth will improve the living standard of residents and change their propensity towards consumption on goods[21]. On the other hand, from the viewpoint of material flow, all materials that enter into the production process, either as raw materials or intermediates, end up as produced goods or residuals[22]. In addition, when goods are consumed and discarded as the waste, a part of them will be recycled and enter into the production process again. Therefore, industrial growth induces not only the increase of waste arising from industrial process, but also from household, institutional and business. A large body of literatures have demonstrated that unsustainable pattern of consumption and production is the key driving forces of SW generation[23-28]. Further, it has been investigated that rapid economic growth caused by industrialization has induced serious problems of SW in Asian developing countries[29]. In addition, a lot of research has proposed that sustainable development of city not only denotes the sustainable consumption, but also sustainable production[26]. Therefore, in order to improve the waste management system in a city, it is important to consider these two types of wastes together [26].

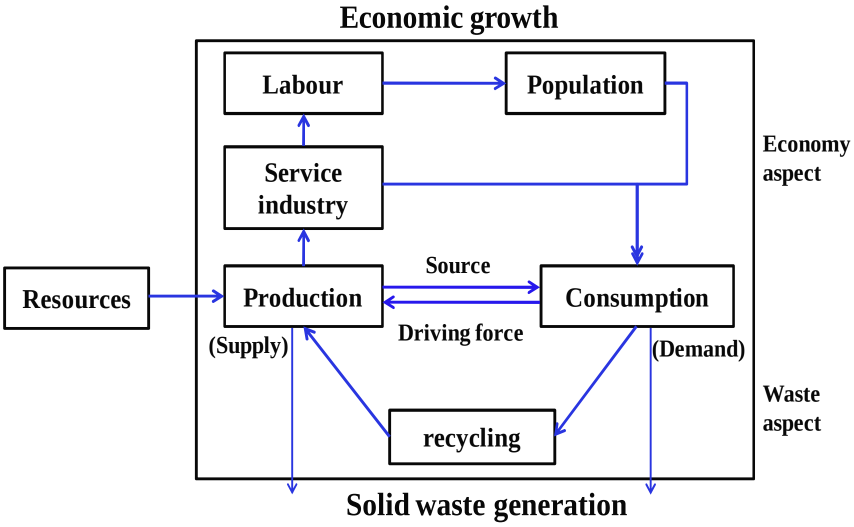

Fig. 1−1 Relationship between wastes generated from consumption and production

Two kinds of waste involved in the research are called municipal solid waste (MSW) and industrial solid waste (ISW) respectively, based on the source of SW generation in a community. The definition of waste type is different with countries and each type has its own characteristics[30]. In China, MSW is called ‘the solids discarded by the end consumers’, i.e. from residential, commercial, institutional and municipal services including street cleaning, landscaping and others[6, 31, 32] and typically collected by or on the behalf of the municipalities of local Environmental Sanitation Bureau (ESB). For example, of the MSW generation in Guangzhou, waste from household accounts for 67.5%, institutional and commercial wastes account 21.5%, the others are cleaning and sweeping waste including muddy and wood (11%)[33, 34]. The generation of each type of MSW is manifested from the consumption of a corresponding commodity[35, 36], thereby indicating that the consumption pattern accounts for the most waste generation in the total MSW. In this research, consumption pattern indicates the relative allocations of different consumption and services to specific categories within consumption categories.

On the other hand, ISW is general SW which is usually from the process of production and processing of each industrial sector and includes industrial process wastes, scrap materials, etc. [32, 37, 38]. Industrial structure is thus considered as the influential factor of generation of each type of ISW category[32]. Further, hazardous waste (HW) generated from production process is also taken into account as a part of ISW. However, construction waste and excrement are not involved in this research. Moreover, small amounts of ISW occasionally enter into MSW in Chinese cities[7].

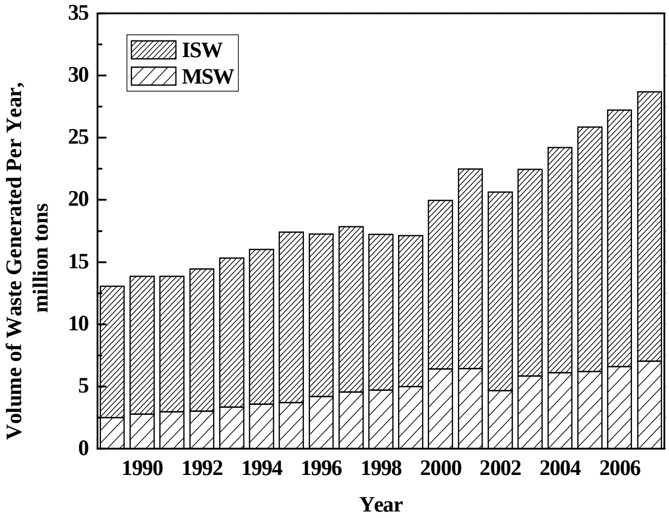

Fig. 1−2 Annual volume of solid waste generated in Shanghai

Fig. 1−2 illustrates the annual volume of SW generated in Shanghai, China including ISW and MSW. In 2007, the total volume of wastes generated was up to 28.68 million tons. Further, the average generation rate of ISW from 2000 is about 7.07% and that of MSW is about 4.77%. In addition, the volume of ISW generated per year is about 3−4 folds of MSW. In addition, Fig. 1−3 represents the source of MSW generation in whole Shanghai in 2005 (Shanghai ESB). It is easy to found out that 50% of the waste comes from residents. Further, 140100 tons of waste is recycled in whole Shanghai. On the other hand, waste generation here—defined as the amount of waste cleaned and transported in China—refers to that portion that enters into the collection and transportation system, not to what citizens deal with in their homes, such as by selling old newspapers. This amount is recognized as having a more significant effect on the design of the waste treatment system in China.

Constraining the ISW generation of highly-polluted industries has been identified as an effective way to reduce overall ISW generation levels. Under this circumstance, the identification and forecasting of the composition and volume of ISW generated by the various industrial sectors seem great significance. Further, structural changes of the economy should happen in accordance with technological innovation in the long-term, causing associated changes in the input coefficient and the relative environmental policy. However, Carter has noted in his research that such associations are ambiguous in the short- and medium-run predictions[39]. Further, there are no clear observations to conclusively indicate that IO coefficients in the short- and medium-term, that is, 10–30 years, change in accordance with technological process[40]. Further, studies in the Netherlands showed that in the short term the changes in the IO coefficients were no better than that demonstrated by the original coefficients of the base year[41]. Therefore, change in ISW generation coefficient is considered in this research to reflect the technological change, rather than change in input coefficient.

Recently, besides the consumption and production, increasing governmental measures with regard to SW have considerable changed waste generation. The implementation of ISO14001 and environmental reports helped to reduce SW generation based on the Japanese facility-level data[42]. Further, several quantitative studies have noted that charging for MSW is effective for MSW reduction, especially in Japanese cities[43, 44]. However, the different waste management policies may cause different effect on waste reduction in different regions.

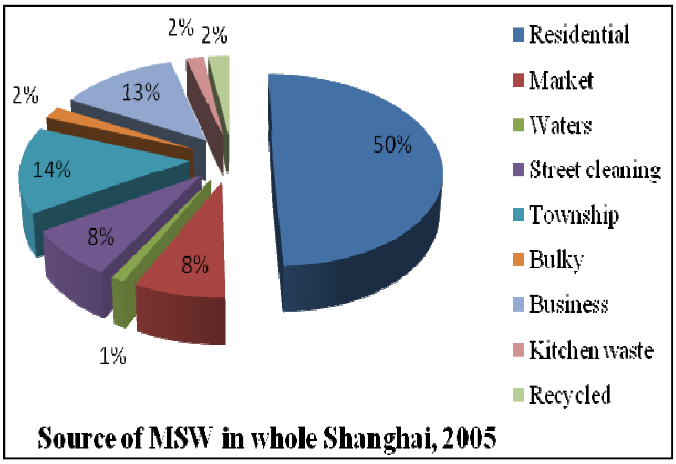

Fig. 1−3 Source of MSW in Shanghai in 2005

Further, different industrialization transformations in China has given rise to prominent regional disparity with coastal cities gradually integrating into the world markets, while inland regions lag far behind in terms of industrialization[45]. The striking imbalance of economic growth thrusts Chinese cities into different stages of economic development, urbanization as well as industrialization, thereby inducing a disparity in the waste generation situation. Recent years have witnessed increased attention being given to the analysis of relationship between waste generation and assumed prosperity indicators in terms of gross domestic product (GDP) or economic level[46-48]. It is common recognized that low waste generation rates coincide with low GDP and vice versa. Further, within one city, urban residents produce two to three folds more waste compared to their rural counterparts regardless of income levels[1]. Therefore, investigating the quantitative relationship between waste generation and economic levels is meaningful for knowing the change trend of waste generation with economic development. Unfortunately, not enough attention has been paid to conducting a quantitative analysis between characteristics of SW generation and economic levels.

In addition, although the top of waste hierarchy should be put emphasis on waste reduction from the source, the remaining waste needs to be treated efficiently to meet the standard of environmental sustainability. Solid waste management has become a series issue in China which poses striking challenge on environmental quality and sustainability[7, 49], because of its continually increasing SW volume and inadequate waste treatment facilities. Of particular concern is emissions of greenhouse gas (GHG) that contributes to global warming[50-53]. It is investigated that methane (CH_4) emission from treatment and final disposal contributes approximately 3−4% of the annual GHG emissions[54-56]. Further, of the treatment, landfill is considered as the largest source of GHG emissions, representing about 90% of total anthropogenic emissions in Canada and USA[55, 56]. However, quantity of waste generation and complexity of waste composition is growing in China[1]. GHG emissions in treatment strategies are therefore more complex. Further, waste management practices vary with regional differences, thereby inducing to the their unique characteristics[57, 58]. Besides, GHG emission fluxes are distinct in each site also due to physical factors such as the heterogeneous nature of sites, uneven height, and compaction across site and so on. Until now, the research on calculation and comparison of GHG emissions in Chinese metropolises is little.

On the other hand, a large number of research have attempted to take a broader view and compared alternative waste treatment strategies from the viewpoint of the reduction of GHG emissions[52, 59-61]. Within the analysis, recycling and source separation are widely considered having great benefits for significantly reducing GHG emissions[56, 61]. Therefore, governmental plan and cautious investments in the future should be made in alternative waste treatment options considering the GHG emissions. However, the selection of alternative treatment strategies are mostly based on the current waste generation and composition, little literature has been published on the scenario analysis on the basis of projected waste quantity and composition in the future.

1.2 Research objectives

The goal of this dissertation is not only to develop a systematic approach to accurately project the volume of SW generated corresponding to waste composition that will be generated in the future, considering the sustainable development of economy, society and waste generation; but also try to propose appropriate consideration of waste treatment in Chinese cities in view of reducing GHG emissions. Since local municipality is the administrative unit in charge of waste collection, treatment and data records, the research is thus on a city level.

The detailed research objectives are:

1. To develop a systematic approach to model the generation of two kinds of waste (MSW and ISW), taking into account the waste stream from the perspectives of economy, lifestyle of residents, production process and waste management policies. Moreover, due to the deficiency of waste records in a majority of Chinese cities, a common framework is expected for easily applying into other cities/municipalities with high applicability[18, 62]. For each type of waste category, a detailed practical framework is constructed and illustrated.

2. To assess the relationship among the expenditure on different consumption categories, governmental countermeasures and MSW generation by composition for projecting MSW generation on a basis of per capita.

3. To attempt the construction of ISW generation model in order to solve the following issues: (1) to investigate the future ISW generation caused by the change in consumption pattern; (2) to effectively evaluate the present and future industrial structures; (3) to analyse their contributions to ISW generation; and (4) to investigate the distribution of ISW generation of waste category among the sectors. Further, to assess the relationship between MSW and ISW generation in a city, particularly the influence of change in consumption pattern.

4. To estimate waste generation by composition in each city and to study and compare waste generation related to economic development and waste management policies. Broadly, integrated with the distribution of a specific geographic location, China is roughly divided into three geographical regions—the eastern, central and western regions—each of which has distinctive features with regard to SW management. Several representative metropolises from each region are selected.

5. To estimate alternative treatment strategies in view of reducing GHG emissions based on the

projection of waste generation corresponding to waste composition, and to propose appropriate suggestions.

1.3 Dissertation organization

In the pursuit of these objectives, the study will proceed from context, to the development of methodology using econometric modelling, to application of the approach into the city level, and finally results discussion. Fig. 1−4 depicts entire framework of the dissertation and the linkage among Chapters. As such, Chapter 1 introduces the research background and provides justification, and objectives of the research.

Chapter 2 firstly investigates the factors affecting consumer behaviour, consumption pattern and SW generation. Then it represents the reviews of the existing approach to forecasting waste generation in different levels and analyses the common shortcomings. Further, the researches on comparing SW generation among cities are surveyed as well. Finally, a systematic approach is proposed with its specific characteristics.

Chapter 3 thus gives an entire overview of the framework including regional macro–economic module, MSW generation module, ISW generation module and waste treatment module. Some insights are given into the linkage among the modules. Of the linkage, change in consumption pattern which is affected by consumer behaviour/propensity in MSW module is one of the most significant factors affecting industrial restructuring in ISW module, by promoting/impeding the development of corresponding industries.

Then, based on the methodology approach, several representative metropolitan cities with distinct economic levels are selected from each Chinese region to apply the MSW module in Chapter 4. The research not only to project waste generation by considering the aggregate impact of delicate change in consumption structure and waste countermeasures, but also to develop a comparative estimation among the cities with economic levels.

Chapter 5 assesses and analyzes the case study of ISW module in Shanghai until the year 2020, integrated with macro–economic module of Shanghai. The performance of the approach involves the regional input-output analysis (IO) not only for forecasting ISW generation by industrial sector but also to survey appropriate industrial restructuring by means of updating IO tables. The change in industrial structure is considered from the perspectives of change in demand caused by consumption pattern, export composition and technological change. It is carried out by the readjustment of converter and change in ISW generation coefficient.

In Chapter 6, amount of GHG emitted in treatment process and disposal site in past years is calculated in each city. Further, based on the projected waste quantity and composition in the future, a scenario analysis is carried out as well, in order to evaluate the reduction of GHG emissions in alternative waste treatment options.

Finally, Chapter 7 summarizes the main concluding remarks of the entire dissertation and gives reasonable suggestions for promoting waste management system in Chinese cities. Further, the shortage of the current approach and recommendations for the future research are represented as well.

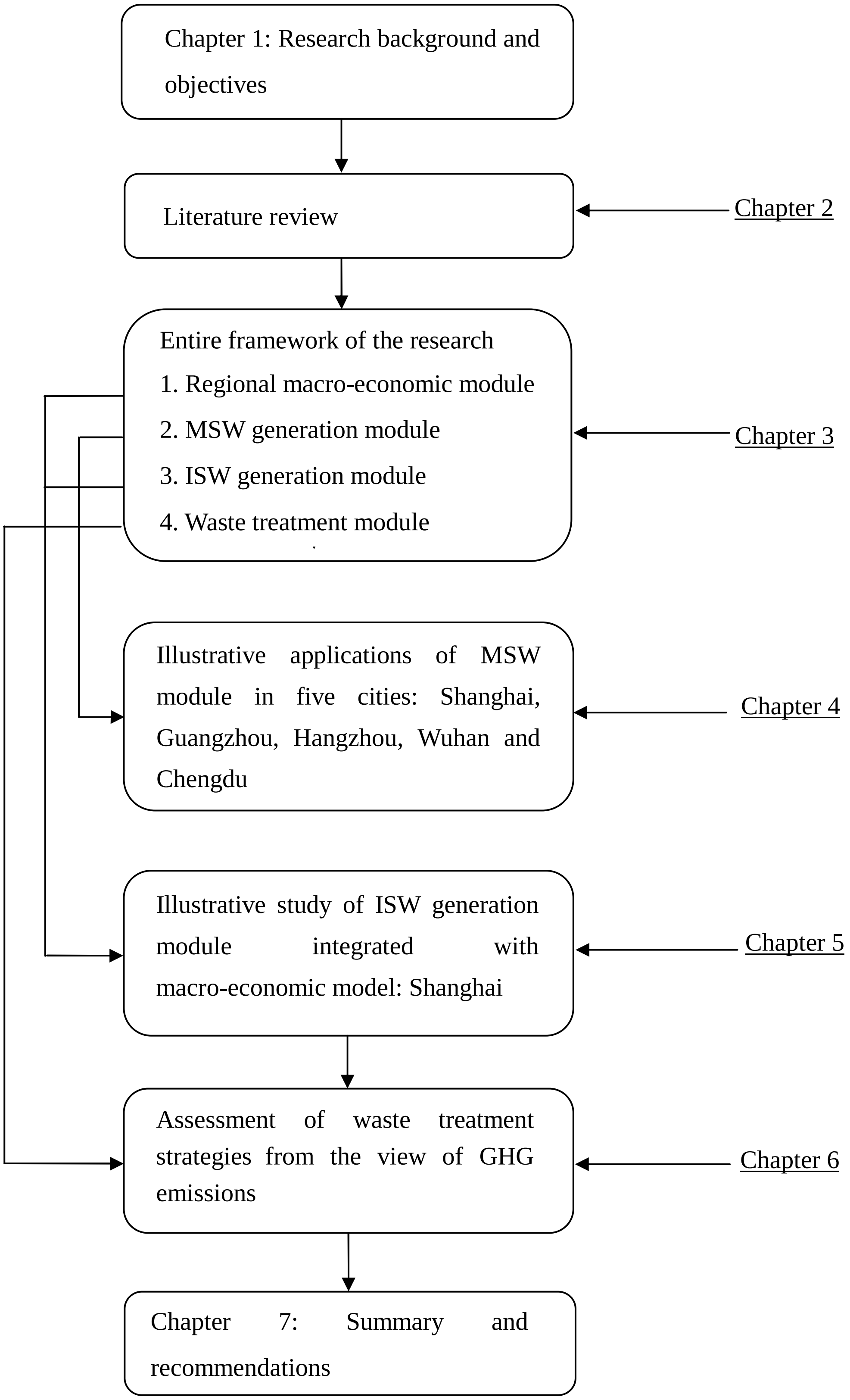

Fig. 1−4 Entire framework of the dissertation and the linkage among Chapters

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2 LITERATURE REVIEW

This chapter reviews the main factors affecting volume of solid waste generated (SW) and existing approaches to projecting SW generation. Moreover, consumer behaviour not only affects the change in consumption pattern, but also plays an important role in affecting industrial restructuring as a result of the change in demand of products. Factors affecting consumer behaviour are thus reviewed as well.

2.1 Literature review

2.1.1 Consumer behaviour

A large number of researches and theories have demonstrated that economic growth is the main factor affecting consumption expenditure in terms of GDP or income. Halada (2008)[63] investigated the relationship between consumption of certain metals and GDP using a two–steps linear regression method. Further, tangible wealth, financial wealth, household debt is found out to be the influential factors of total consumption expenditure[64]. In Ogawa's work, the ratio of debt had a greatly negative effect on consumption expenditure[65]. Moreover, significant change has also occurred in the consumer behaviour and consumption patterns during the past decades as a result of rapid economic growth. However, apart from the economy, more and more noneconomic factors have been focused to explain the change in consumer behaviour over lifetime[66]. A wide variety of studies have indicated that the lifestyle of residents, socio–economy and socio-demography constitute a latent factor in the consumption pattern[27, 67-73], and has an indirect impact on waste generation or recycling behaviour[74, 75]. For example, socio–economic indicators which include employment status, population density, urbanization, and development of health indicators, such as life expectancy, infant mortality, and household size affect consumer behaviour[70, 75, 76] and reorient consumption patterns. Correspondingly, consumption behaviour is considered to be a function of such parameters as economic growth, demographic changes, socio–cultural, socio–economic and policy measures[77]. On the other hand, it has been noted that development of sustainable consumption need to shift in both structure of consumption and production[78]. Currently, the measures on sustainable consumption to reduce energy consumption is carried out in the OECD1999–2000 program[79]. Further, the case study in the US suggests that sustainable consumption should involve fundamental change in governmental political economy[80]. Reasonable consumption should be considered associated with reasonable production[26] by making the sustainable products and less material products.

2.1.2 Existing methods of projecting SW generation

Recent years have been witnessed increased attention being given to modelling approaches in the forecasts of waste generation since 1970s. Numerous conventional methods[15, 81] mainly statistically based on socio–economic and demographic factors have been widely used for waste projection in a per-capita basis, by using single- or multi- regression models. The numerous socio-demographic and economic factors affecting waste characterization involve the following parameters as input parameters: GDP or an N-shaped relationship between ISW generation and per capita GDP[82-85]; mean living standards of the residents[16, 86], income levels of people[87]; population[88-90]; available employment statistics[91]; infant mortality[46]; life expectancy, dwelling unit size, cultural patterns, education[86], geographic location, climate and seasons[92], and other variables. Further, household size is widely used as the determinant factor of waste characteristics and it is demonstrated that waste production declines with increasing household size[47, 93, 94]. However, the waste generation and composition is unique from country to country. In the work of Hockett (1995)[95], per capita retail sales and tipping fees are significant determinants for waste generation rather than income and urbanization. A regression model is developed to estimate the generation of household waste per dweller of Mexico, linking with variables of education, income per household and number of residents in the course of Benitez[28]. The influence of global socio-economic factors on paper, metal, food and glass waste, including persons/dwelling, climate[96] and income, is analyzed using multiple linear regression in three types of countries with distinct economic levels[92]. A mathematical model is developed to project the composition and generation of hospital waste in Iran, by considering the number of beds[97]. Qu et al. showed that middle-income families (1200−2800 yuan/pers/month) generate much waste than low-income (1200 yuan/pers/month) and high-income families (>2800 yuans/pers/month) through the field study of Beijing[98]. Moreover, the impacts of recycling activities have received wider attention at different levels on waste generation by carrying out the invention analysis. Literatures concerning policies about waste recycling: no-garbage-collection program[99], waste policy in Taiwan as ‘Keep Trash Off the Ground’[100], recycling program through an *ex-post* intervention model[15]. Unfortunately, among the literatures, the effective attempts on ISW generation is surprisingly little.

Further, time series analysis or trend analysis is also widely used for projecting SW generation[101-103]. Auto Regressive and Moving Average model (ARMA) is widely used for projections of daily waste generation[101, 104, 105]. Further, Navarro-Esbri[106] developed a non-linear dynamics to solve the non-stationary problem of time series data, compared with a seasonal ARIMA. Dyson and Chang (2005)[17] presents various trends of waste generation using system dynamics modelling capable of addressing socioeconomic and environmental situations which is called Stella. In addition, in the course of Beigl[107], the relationship between MSW generation and regional development in terms of socio-economic indicators is analyzed by using historic time analysis and cross-sectional data.

Moreover, a theory of grey modelling is developed and improved for waste generation analysis with limited samples. Chen and Chang (2005)[13] applied grey fuzzy dynamic modelling into Tainan in Taiwan with uncertainty analysis. Further, several researches integrated with a GIS environment to investigate the characteristics of waste generation, considering population density, maximum building density, commercial traffic, area and so on[88, 108].

Another method to be pointed is the application of materials balance methodology. Several studies have developed a material flow analysis (MFA) to trace and stimulate plastic waste generation, considering the plastic production and consumption [109, 110]. Further, using the same theory, Hekkert et al. (2000)[111] simulated the material flow of paper and wood. A method in that economic sales data is converted to estimate waste characteristics including waste composition and generation is proposed by Gay et al.[18]. Van der Voet et al.[112] described two different modelling approaches as leaching model and the delay model on a basis of MFA, and calculated the flow of copper discarded from water heating equipment using historic data of input flows of lifetime distributions. An extended MFA system is developed as stock dynamics approach for projecting resource demand and waste generation centering at population and its lifestyle. Salhofer (2000)[113] developed a matrix-type model to estimate the quantities and types of wastes that generated by commercial/industrial sector, based on number of employees. Bruvoll and Ibenholt (1997)[22] integrated a macroeconomic model named MSG-EE to investigate the change trend of waste generation until 2010, taking into account technological progress and factor price substitution.

Previous studies have represented the complex influence on waste generation from the viewpoint of rising affluence, socioeconomic, socio-demographic factors and each of them has its own advantages and disadvantages. Just recently, attention has been shifted away from rising affluence towards consumer activities as a starting point for setting up strategies[77]. Consumption activity has been considered the driving force of waste generation as the ‘sole-end and purpose of all production’. Several studies have noted that change in consumption pattern results in change in waste composition and quantities, thereby indicating that the consumption structure accounts for the most waste generation in the total MSW[87, 114]. In the course of Daskalopoulos’s work[16], waste composition is expressed by related total consumption expenditure (RTCE) on goods and products resulting in the generation of MSW. However, the method is used as purely mechanical mathematics single-regression analysis. Further, a Local Area Resource Analysis (LARA) is integrated with a household metabolism model in order to investigate specific commodity flows and associated waste generating in specific area[115]. However, the research involved a small sample size and there was no quantitative projection of waste generation. On the other hand, Abe proposed in this work that the reduction of ISW should fully consider the determinant factors of each type of waste such as industrial structure[116].

Moreover, Rhyner (1992)[117] compared the waste generation with the influence of seasons as monthly quantities of waste from different sources. It seems that residential and commercial wastes are the most predictable.

2.1.3 Comparison among cities

There are several scales of research on waste generation based on disaggregation level as regional scale, households, settlement areas, or national levels. Further, increasing attention is being given to the analysis of the relationship between environmental pollution and economic growth[118-120]. Several studies have unveiled the positive relationship between the MSW generation rates and assumed prosperity indicators in terms of GDP[46, 47], income[92, 121] or standard of living[6, 104]. Further, it is investigated that developed countries have a relatively higher MSW generation rate than developing countries[32, 122]. Moreover, as noted in the report of world bank[1], it seems that ‘eastern cities present the similar waste generation rates’. On the other hand, low generation rate of specific waste category coincide with low income level and vice versa, such as organic and paper waste.

On the other hand, due to the lack of enough waste statistics in developing cities in China, analogy method is applied for predicting waste generation in Fushan city analogous to Guangzhou, Shenzhen, Shanghai and Beijing [123]. However, within the existing researches, not enough attention has been paid to conducting a quantitative analysis of the relationship between solid waste generation and economic level[124].

2.2 Shortcomings of the existing methods

Although a lot of attempts on forecasts of waste generation have been done, the models are far from reaching general modelling standards. Several common shortcomings are listed as follows:

1. A majority of models are not quantitative analysis or are patently over-simplistic. Using GDP or income as explanatory variable can’t explain the direct source of arisings of each type of waste and increasing complexity of the economic structure. A large number of literatures have confirmed that MSW generation arises from a series of human process which is affected by socioeconomic and demographic indicators.

2. On the other hand, compared to MSW generation, due to complex production processes and

deficient historical records, the current attempts aiming at forecasting the generation of ISW are not enough. ISW generates from industrial process which changes constantly caused by economic growth. Therefore, industrial restructuring definitely affects ISW generation. Unfortunately, the previous records on the subject have either failed to consider this.

3. A fairly large body of literature exists on the prediction of total waste generation. However, within that literature, there is a surprising lack of information on the forecasts of each type of waste, not only for MSW but also for ISW.

4. Lots of socioeconomic indicators are manifested to having significant influence on waste generation. However, the mutual relationship between the indicators is not fully investigated. Besides, there is little literature considering the influence of waste policies on waste generation.

5. Proposed model must be statistically refined. However, from the statistical viewpoint, a majority of the models don't show the good statistical testing or applicability.

6. Little research has been done on developing countries, especially in Chinese cities. Further, the waste generation compared to distinct consumption level is still on the stage of qualitative analysis.

2.3 Proposed approach

Consequently, in this thesis, a systematic approach is proposed with its specific characteristics:

1. The generation of MSW and ISW is considered together for the planning of sustainable waste management system on a city level, coupling the effects of rising affluence, lifestyle of residents as well as industrial restructuring. Since the unsustainable development of rising consumption and production process is the driving forces of increasing generation of MSW and ISW, change in consumption pattern and industrial structure affected by technological change is taken into account. Therefore, a sustainable approach capable of projecting MSW and ISW from the viewpoint of the waste stream is proposed.

2. Further, the change in consumer spending pattern on each consumption category significantly affects the waste composition. Therefore, prior to the projection of waste generation, the estimation and prediction of the consumption pattern becomes necessary and important. Meanwhile, a wide variety of studies have also indicated that the lifestyle of residents and the socio-economy constitutes a latent factor in the consumption structure. The model representing the change of consumption pattern is included as well.

3. Moreover, constraining the ISW generation of highly-polluted industries has been identified as an effective way to reduce overall ISW generation levels. Under this circumstance, the identification and forecasting of the composition and volume of ISW generated by the various industrial sectors

assume great significance. Thus, in order to analyze the mutual relationship among industrial sectors, the regional input-output analysis (IO) is introduced, not only for forecasting ISW generation by industry but also for surveying appropriate industrial restructuring by means of updating IO tables.

4. Selection of appropriate waste treatment strategies in the future is affected by many factors, while the GHG emissions will be indispensable due to the increasing seriousness of global warming. It seems as a reasonable attempt that a scenario analysis of GHG emissions in different integrations of waste treatment options is carried out based on future forecasts of waste generation and the corresponding composition.

2.4 Concluding comments

The well understanding of waste stream flow is the basic background for projecting waste generation accurately. Numerous studies stress that unsustainable pattern of consumption and production is the driving force of waste generation. However, within the literatures, there is a surprising lack of information on projecting generation of each type of MSW and ISW from corresponding consumption and industrial process. Further, consumer behaviour not only affects the change in consumption pattern, but also plays an important role in affecting industrial restructuring as the change in demand. Moreover, sustainable development of a city needs to shift in structure of consumption and production. In this process, lifestyle of residents and technological change will play important roles. Substantial change in waste composition generated from consumption and production will be accompanied by.

Therefore, in the doctoral thesis, a sustainable approach fully considering the economic growth, social development and SW generation is proposed for projecting SW generation by waste category and applied into Chinese metropolises. The influence of consumption on both MSW and ISW generation will be investigated. Moreover, the evaluation of different waste treatment strategies is presented as well in terms of the reduction of GHG emissions on the basis of forecasts of waste generation.

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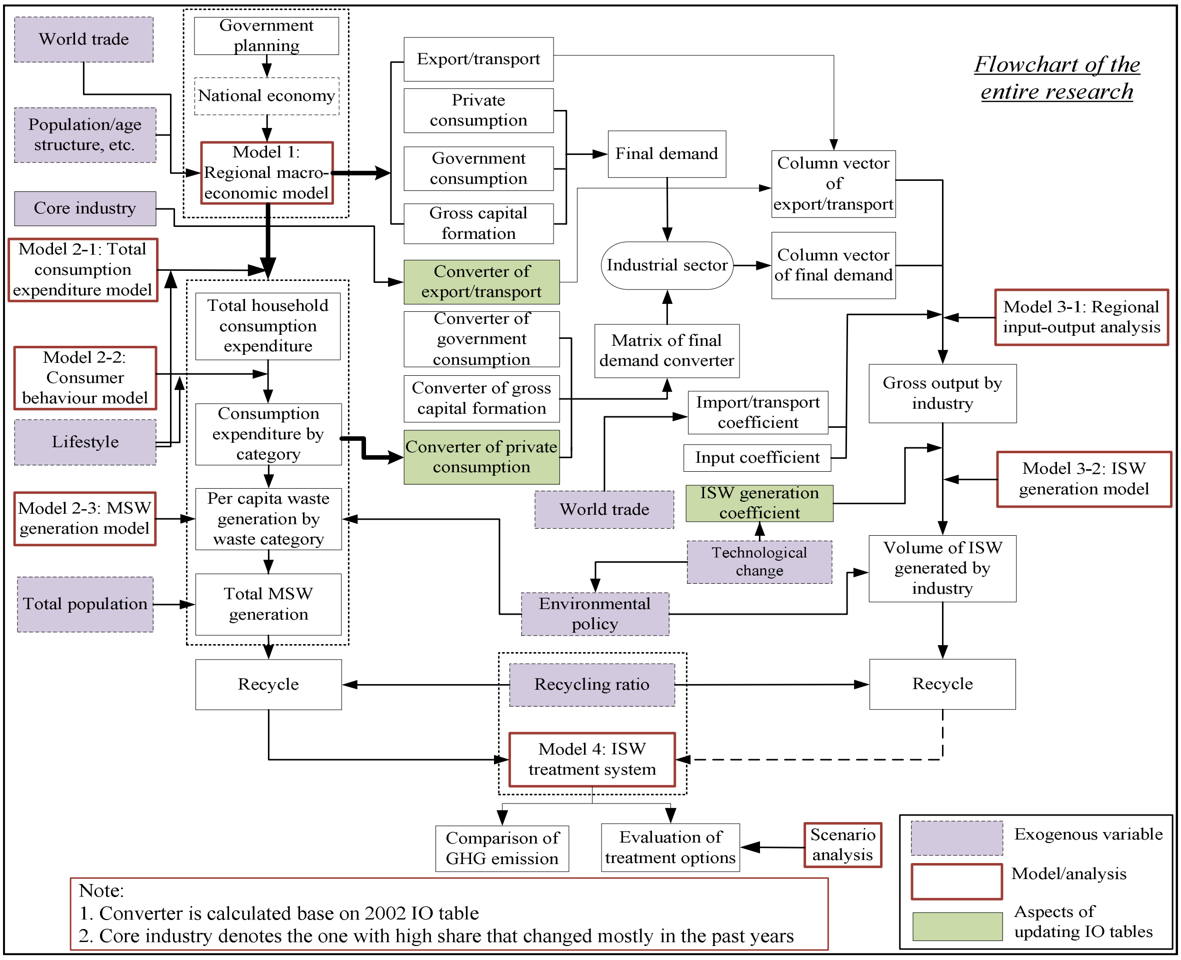
3 METHODOLOGICAL APPROACH

Based on the introduction in Chapter 2, the general methodology developed to depict an entire image of waste stream flow is represented in this chapter, fully considering economic growth, change in consumption pattern, waste management policies and industrial restructuring. The work will involve both the MSW and ISW.

3.1 General framework



Note:
1. Converter is calculated base on 2002 IO table
2. Core industry denotes the one with high share that changed mostly in the past years

Fig. 3–1 Proposed pragmatic framework of entire research

The entire schematic framework is illustrated as Fig. 3–1, comprising four integrated modules —the macro-economic module, MSW generation module, ISW generation module and waste treatment module. The purple shaded areas denote each exogenous variable in developing the approach and green areas indicate the aspects of updating IO tables. Further, each module consists of several principal models or analysis. The linkages among the modules are as follows: (1) regional GDP which is estimated in macro-economic module is a significant influential factor of per capita total household consumption expenditure (**PTCON**) in MSW module; (2) GDP and each item of final demand are also the driving factors of industrial restructuring in ISW module; (3) Change in consumption pattern which is estimated and projected by model 2–2 in the MSW module fundamentally impacts the industrial restructuring caused by demand change in the future as shown in the ISW module. The projection horizon of SW generation is until 2020 on a city level and the selection of alternative waste treatment options is based on the projection in 2015.

3.2 Regional macro-economic module

Macro-economic modules are usually applicable to national sizes and relatively lengthy time frames, several studies have presented models based on quarterly or annual observations[125-129]. According to the existing literatures on the subject, there have being many research on the macroeconomic model of China[125, 130]. In this research, the predictions of Chinese GDP figures refer to the results estimated by the Chinese Academy for Environmental Planning (CAEP) under different conditions of economic development[131]. Further, the influence of the national economy on city is gauged by the relevance of the national GDP and government consumption (GC) in the individual behavioural equations. In this research, economic structural analysis and economic forecasting on a regional level is conducted and Shanghai is selected as a case study.

Therefore, the present study is an attempt to supplement the findings of these earlier studies on the way to developing a macro-economic model for Shanghai, in accordance with Shanghai's social and economic reality, as well as national economic growth. In the model, the forecasting target variables are the Shanghai economy (GDP) and its composition: private consumption (PC), GC, fixed capital formulation (I), export (EX), transport within China (TR) and export (EXC). The most important prerequisite for the performance of the model is the clarification of the leading factors (exogenous variables) that are and will continue to be important for economic structural changes. Then, the parameters of the equations are determined by using the econometric analysis of historical records. Eight definition equations have been incorporated into the model to form a simultaneous equation system. The model is solved by using TSP 5.0[132]. Moreover, conventional statistics such as adjusted R^2 (AdR^2), *t*-statistics, *F*-statistic and the Durbin-Watson statistic (DW) which are used to detect the presence of autocorrelation in the residuals[133] validate the specification of each behavioural equation[133]. In addition, the interpolation test, including the partial test and the final test, is also taken into consideration for checking whether the model is good enough for projection or not. Partial test is a test that substitutes the actual value of explanatory variables in each equation for calculating the value of explained variable, and then compares the calculated and observed values. Further, final test is a test that substitutes the calculated values of all explanatory variables and then calculates the explained values, by the exclusion of the initial values of the explanatory variables and predetermined endogenous variables[134]. The test result of the economic indicator *i* is expressed by the mean absolute percentage error (also known as MAPE). MAPE is ‘a measure of accuracy in a fitted time series value—specifically trending—expressed as a percentage’[133], as shown in Eq. (3–1).

$$MAPE\ (i,\%) = \frac{1}{N}\sum_{t=T_0}^{T_0+N-1}\left|\frac{E_{i,t}-O_{i,t}}{O_{i,t}}\right|\times 100\,\%, \qquad (3\text{–}1)$$

in which, N denotes length in years; O_t, the observed value of *i* in year *t*; E_t, the estimated value of *i* in year *t*.

3.3 MSW generation module

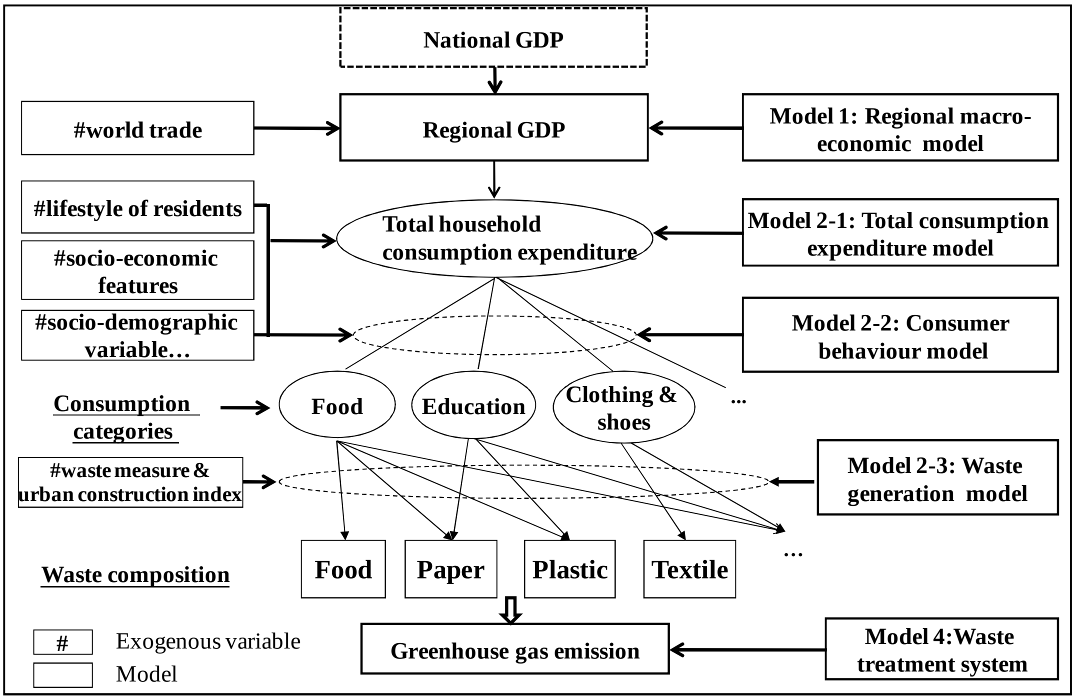


Fig. 3−2 Schematic diagram of MSW generation flow

The MSW generation module (Module 2) comprises three models, apart from regional macro-economic model, as depicted in Fig. 3–2. Prior to the analysis of the change in consumption pattern, Model 2−1 is developed for the estimation and projection of the **PTCON** by using GDP which is estimated from a regional macro-economic model; then, a consumer's behaviour model (Model 2–2) is conducted to estimate the distribution of PTCON among the commodity categories by using an extension of the linear expenditure system (LES)[135], with lifestyle factors and socio-economic indicators attributed as exogenous variables; thereafter, Model 2–3 attempts to evaluate waste generation by taking into consideration consumption and waste policies, using ordinary least squares (OLS)[133]. Model performance was assessed using TSP 5.0 software package[132].

3.3.1 Total consumption expenditure model

Per capita total consumption expenditure (**PTCON**) is affected by many factors, such as income, price as mentioned in Chapter 2. Further, a lot of consumption theory has appeared to explain the consumption characteristics of residents. Of the theories, the most important and famous ones are *absolute income hypothesis* (AIH), *permanent income hypothesis* (PIH), *life-cycle hypothesis* (LCH), and *rational expectation-Life Cycle Hypothesis* (RELCH). In the model, dispensable income is considered as the driving force of PTCON.

However, average propensity to consumer (APC) which is defined as *APC = consumption/income* has reduced over last two decades in Chinese mega-cities. It is demonstrated that the difference between real disposal income and consumption expenditure which are revised by consumer price index (CPI) is reducing with the year. Therefore, apart from income and increasing affluent, other imponderable factors which can't be ignored affect consumption expenditure as well. A number of literatures have indicated that socioeconomic indicators, household characteristics have significant influence. Therefore, **PTCON** in a given year *t* **(*$PTCON_t$*)** is expressed by the following model, considering simultaneously GDP and other factors, as shown in Eq. (3−2). Traditional statistical testing is carried out by AdR^2, *t*-statistics, *F*-statistic and the DW statistics.

$$PTCON_t = a_1 + a_2 \times PGDP_t + \sum_{k=1}^{H} b_{1k}\gamma_{k,t} \tag{3–2}$$

in which, ***$PGDP_t$***: per capita GDP in year *t*; $\gamma_{k,t}$ (k = 1,2,…,N): an exogenous variable in year *t*; a_1: constant; a_2: parameter corresponding to ***PGDP***; b_{1k}: each parameter corresponding to γ_k.

3.3.2 Consumer behaviour model

In the analysis of the consumption pattern, LES and the extended LES (ELES) are two effective and widely applied methods with the same model rationale and similar functions[136-139]. However, due to the limitation of data availability in China, LES is adopted in this research.

The LES model, first developed by Stone (1954)[136], describes the consumers' consumption preferences among different commodities. The starting point for the LES is to maximize the utility function subject to budget equation that is $\sum P_i X_i - C = 0$ (C denotes total budget). In order to solve the maximization problem, the LES is developed and the detailed information can be found in Phillips (1983)[140]. The basic rationale of this model is to classify the household consumption expenditure of each commodity category into 'subsistence' demand expenditure (sustenance) and supernumerary expenditure on various accessional extravagances. Here, 'subsistence' of consumption is defined as a standard of living that allows for the satisfaction of the minimum including physical and mental. Then, an extension of the LES model causes the former expenditure to explicitly depend on a series of lifestyle indicators and socio-economic indicators (exogenous variables, γ_k) for a time-series analysis. A more detailed description can be found in the course of Merz (1983)[135]. The final model equation is expressed as follows:

$$C_i = (b_i + \sum_{k=1}^{H} b_{ik}\gamma_k) + \alpha_i [C - \sum_{j=1}^{N} (b_j + \sum_{k=1}^{H} b_{jk}\gamma_k)], \tag{3–3}$$

with $0 < \alpha_i < 1, \sum_{i=1}^{N} \alpha_i = 1$,

where the subscript *i, j* (*i, j = 1,…,N*) is a commodity category index, such as food, clothing, etc.

C: PTCON in year *t*, (RMB, in base year prices)

C_i: per capita annual consumption expenditure of the *i*-th consumption category, (RMB, in base year prices)

b_i: constant of per capita annual 'subsistence' demand expenditure regarded as a function of γ_k

γ_k (k = 1, 2,…,H): an exogenous variable of commodity category *i*

α_i: Marginal propensity to consume in commodity category *i*, (%)

All consumption expenditure is adjusted to the base year through the corresponding CPI. Accordingly, the consumer behaviour model based on the distribution of different expenditure in various categories easily converts to differences in the occupational characteristics of exogenous variables, including the lifestyle of the residents. Furthermore, Eq. (3–3) is solved using the nonlinear three-stage least square method (3SLS)[132]. In the performance of selecting appropriate explanatory variables among all the ones, the backward stepwise regression method is cited.

3.3.3 MSW generation model

The MSW generation model is developed using OLS, and is shown in Eq. (3–4). In the equation, $W_{k,t}$ is the quantity of the *k*-th waste composition in year *t* (in kgs) such as food waste, paper waste, etc., computed by multiplying $W_{twaste,t}$ by the proportion of each type of waste in the total MSW. Here,

$W_{twaste,t}$ is the per capita annual amount of MSW generated in year t (in kgs). As mass-data of consumption category are rarely available, money-data of consumption category is cited. Meanwhile, in order to evaluate the influence of waste countermeasures, a dummy variable (DUM) is introduced; it is referred to as the ‘0/1’ variable, ‘a numerical variable used to represent subgroups of a sample in regression analysis’[133]. When the variable is ‘1’ for a certain year, it implies that some kind of waste legislation existed from that year onwards; on the other hand, the variable is set to ‘0’ prior to that year, it signifies no policy impact. In addition, in some cases, an index of urban construction is introduced in order to indirectly reflect the change in the proportion of ash waste in China. Consequently, integrated with the predicted consumption expenditure by category, computed using the LES model and the continued influence of waste management policies as well as urban construction indices, a forecasted amount for each type of waste could be obtained in the future.

$$W_{k,t} = b_k + \sum_{i=1}^{N} \beta_{ik} C_{i,t} + \sum_{m=1}^{M} \delta_{mk} DUM_{m,t} + \sum_{l=1}^{L} \lambda_{lk} S_{l,t} \quad , \tag{3–4}$$

b_k: a constant of the waste generation of composition k

$C_{i,t}$: per capita annual consumption expenditure of the i-th commodity category in year t, (RMB, in base year prices)

β_{ik}: parameter corresponding to $C_{i,t}$

$DUM_{m,t}$: m-th dummy variable (0/1 variable) in year t

δ_{mk}: parameter corresponding to $DUM_{m,t}$

$S_{l,t}$: l-th index of urban construction in year t, such as gas coverage rate (GAS, %), green coverage rate (GREEN, %), etc.

λ_{lk}: parameter corresponding to $S_{l,t}$

Furthermore, from the viewpoint of linear consistency in the waste model, the total partial waste generation coefficient (TPWC) is defined as coefficient of total waste generation to the PTCON, as Eq. (3–5), in kg/RMB. In addition, the coefficient of waste generation by composition k to the corresponding consumption expenditure C_i is defined as $PWC_{k/i}$, in kg/RMB. This value provides a possibility of comparing and analyzing the distinct waste generation trend among cities. Moreover, the marginal effect of DUM on waste generation is identified as the influential coefficient of policy intervention (MWC_{dum}).

$$TPWC_{TCON} = \frac{\partial W_{total}}{\partial TCON}, \quad PWC_{k/i} = \frac{\partial W_k}{\partial C_i}, \quad MWC_{k/dum} = \frac{\partial W_k}{\partial DUM} \tag{3–5}$$

3.3.4 Validation of the MSW module

The performance of the integrated MSW module is evaluated in terms of two aspects: (1) Initially, to make the interpretation of the results straightforward with regard to economic applicability, thereby indicating that both the sizes and signs of all the estimated parameters are meaningful, for example, the exogenous variables γ_k, coefficients estimated in the MSW generation model and (2) secondly, to validate the statistical test for the sake of model reliability. In this paper, the significance and validity of the LES model is tested using *t*-statistics, *F*-statistics, the AdR^2, and MAPE (3–1). However, because the MAPE value is considerably affected by the original values of the sample, the root mean square error (RMSE) is occasionally cited in order to eliminate the influence of original values, as represented in Eq. (3–6).

$$RMSE = \sqrt{\frac{\sum_{t=T_o}^{T_0+N-1}(E_{i,t}-O_{i,t})^2}{N}} \times 100\% \quad , \tag{3–6}$$

where N denotes length in years; O_t, the observed value of *i* in year *t*; E_t, the estimated value of *i* in year *t*.

Further, collinearity of parameters induces to the ill-conditioned models with multiple regression models. Prior to the modelling performance, the correlation coefficient (R_{ij}) between two independent variables is thus calculated and analyzed. Then, a test termed variance inflation factor (VIF) is carried out for specification of collinearity of parameters when the R_{ij} is above 0.5 and the expression equation is represented as Eq. (3–7). The value can be reported by some computer packages (SPSS), for each coefficient in a regression as a diagnostic statistic.

$$VIF_i = (1 - R_i^2)^{-1} \tag{3–7}$$

Where, R_i^2 denotes the R^2 in the regression of *i*-th variable on all the other variables.

Moreover, the identification of equations is checked as well. The necessary but not sufficient condition for identification of Equation *j* is $K_j^* \geq M_j$ and there is no question of identification with respect to identities, as shown in following table (Table 3−1) [133].

In addition, the heteroscedasticity, a basic prerequisite for OLS estimations, is proved by using the residual graph. The figure of residual sum of squares ($(\varepsilon_i^2 = (\hat{y}_i - y_i)^2)$ against estimated value of y_i ($\hat{y}_i$) is plotted for checking heteroscedasticity.

Table 3−1 Components of Equation j

	Endogenous variable	Exogenous variable
Included	$Y_j = M_j$ variables	$X_j = K_j$ variables
Excluded	$Y_j^* = M_j^*$ variables	$X_j^* = K_j^*$ variables
The number of equations is $M_j + M_j^* + 1 = M$		
The number of exogenous variables is $K_j + K_j^* = K$		

3.3.5 Back-casting estimation and future projection

Extrapolating the models out beyond the period which they were estimated, we can use the known information about the past and the present/future to make back-casting estimation and forecasts. Two types of forecasts are found to be useful viz *point forecasts* and *interval forecasts*. *Point forecasts* project ‘a single number in each forecast period’, while *interval forecasts* represent ‘in each forecast period an interval in which we hope the actual realized value will lie’. Further, three types of forecasting in terms of back-casting, *ex-post* and *ex-ante* forecasts are distinguished based on the time, depicted in Fig. 3−3, as adopted from Pindyck and Rubinfeld (1984)[141]. Back-casting estimations are carried out in order to understand the dependent variables in the past with the known exogenous variables. On the other hand, *ex-post* forecasts are used for further testing of the model based on observations on both endogenous variables and the exogenous variables are known with certainty. *Ex-ante* forecasts is the future projection based on the developed model with known or unknown exogenous variables.

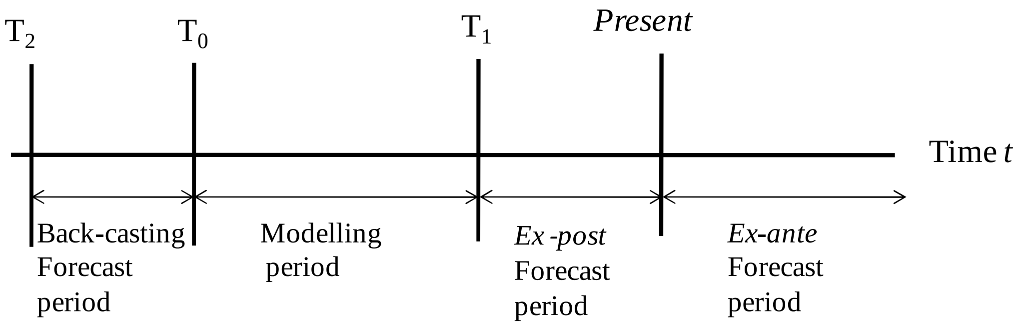


Fig. 3−3 Types of forecasting

In the MSW generation model, two types of forecasts are taken into account for exploring the change trend of waste generation in Chinese metropolises. Chinese city has longer historical records of consumption expenditure than waste data. Back-casting forecasts are thus calculated based on the existing consumption and waste management policies. On the other hand, based on the assumed exogenous variables in the module in the future, the volume of MSW generated until 2020 can be projected, so called *ex-ante* forecasts. However, due to the short waste series, the *ex-post* forecasts are not carried out in the research.

3.4 ISW generation module

Constraining the ISW generation of highly-polluted industries has been identified as an effective way to reduce overall ISW generation levels. Under this circumstance, the identification and forecasting of the volume of each type of ISW generated by the various industrial sectors assume great significance. The ISW module is the third module of the entire systematic framework, illustrated as Fig. 3–1, linking the three principal models—regional macro-economic model, the regional IO analysis and ISW generation model. The green shaded area denotes the aspects of industrial restructuring that are in accordance with the updated IO tables, introduced in section 3.4.3.

3.4.1 Regional input-output analysis

IO analysis is considered as an important branch of economics today, articulating the inter-linkages between sectors. At least 40 national economies have prepared the IO tables and the number of regional tables is growing rapidly. Recent years have seen increased attention being given to small-area IO studies[142-145], in particular, in the United States[146]. Here, regional IO analysis is applied into Shanghai, China for exploring the change in industrial restructuring in the future and the effect on ISW generation by industrial sector. A demand-driven system developed by Leontief is formulated in the regional IO analysis as Eq. (3–8).

$$AX_{pds}+FD_{pds}+E_{pds}-M_{pds}=X_{pds} \tag{3–8}$$

where X_{pds}: column vector of gross output with subscript *pds* denoting the production sector

A: Input coefficient, also called technical coefficient, IC

FD_{pds}: column vector of final demands, consisting of PC, GC and I

E_{pds}: column vector of export and transport to other Chinese regions from Shanghai

M_{pds}: column vector of import and transport into Shanghai from other Chinese regions

Further, Sapir (1976)[147] has pointed out the necessity of making imports an explicit component of the IO table in order to investigate their effects. Thus, a matrix of import coefficient $\hat{M}$ with diagonal element defined as $m_i = M_i \big/ (\sum_j x_{ij} + FD_i)$ (the subscript $i, j \in$ dimension of *pds*) is introduced. Here, the import coefficient denotes the coefficient of import & transport from other Chinese regions into Shanghai. Therefore, the transformation from the standard IO analysis can be written as the following equation, in which ‘I’ denotes an identity matrix, adopted from Miyazawa (1975)[148].

$$X_{pds} = [(I-(I-\widehat{M})A]^{-1} \times [(I-\widehat{M})FD_{pds} + E_{pds}] \tag{3–9}$$

Further, in the process of calculation of the vector of final demand FD_{pds}, the concept of the converter (CV) is introduced, as shown in Fig. 3–1. CV is defined as the output share of each industrial sector in the total output in the respective final demand item ($\sum_{pds} CV_{pds,fds} = 1$). The subscript *fds* represents each individual item of final demand. In an open, developing economy, changes in FD_{pds} usually reflect changes in consumption patterns and the composition of trade. By expressing FD_{pds} using the converter, it provides economists with the opportunity to analyze quantitatively the effects of various industrial restructuring manoeuvres on each item by adjusting the converter; the converter also assists in the assessment of the impact of these changes on sectoral output. Unfortunately, until now, surprisingly little research has been done on updating IO tables while considering changes in consumption patterns[149]. With the help of the converter, the predicted value of each final demand item is distributed among the various industrial sectors. Finally, the summation of each adjusted item forms a new column vector of the predicted FD_{pds}.

3.4.2 ISW generation model

In the ISW generation model, the volume of the overall ISW generated by sector (Y_{pds}) is estimated through the following equation:

$$Y_{pds} = \hat{D}_{pds} \times X_{pds} = \hat{D}_{pds} \times \{[I-(I-\hat{M})A]^{-1} \times [(I-\hat{M})FD_{pds} + E_{pdS}]\}, \tag{3–10}$$

where diagonal element D_i of diagonal matrix $\hat{D}_{pds}$ is defined as the total waste generation coefficient of each sector per unit gross output, measured in tons/10 000 RMB. Because Shanghai has no detailed waste statistics by industry as is available in the case of China as a whole, the coefficient on the national level in 2002 is used in place. Similarly, the waste generation coefficient of each waste category is determined by using the same method on a national level. Further, prior to proceeding with calculation, the dimensions of the waste table are adjusted to the same size as that of the IO table, based on the national economic industry classification (GB/T4754-2002). Further, the waste generation coefficient of each sector is assumed to be fixed in 2002 (business as usual, BAU), not considering the influence of environmental policies that will be affected by technological innovation.

The result is considered as the reference path which shows what is likely happen if no additional political, technical or other measures that can affect ISW generation are taken.

3.4.3 Updating the IO table

An analysis of industrial restructuring in the future through the updating of the IO table is carried out here. Generally, economic growth and industrialization will cause substantial changes in three aspects of a society: the household consumption pattern, the export structure and technical innovation[87]. Shift in consumption pattern leads to adjustment of corresponding industries. Further, economic growth will further encourage the export structure to shift away from the primary and related commodities to capital- and technology-intensive products. New export policies published by Ministry of Finance People’s Republic of China will also positively affect the export composition (http://www.mof.gov.cn/mof/). Moreover, historical evidence shows that technical change is the fundamental driving force for long-term change in human society and it will fundamentally affect the production process, cost of product and consequential environmental effect[40, 150]. Based on the change in ISW generation coefficient of industry of chemicals during the past years, the radical change has happened in developing country—China. Further, change in China’s energy policy causes the shift in inter-linkage among sectors[151, 152]. Accordingly, change in private consumption and export composition is carried out by adjusting converter vectors and technical change is taken into account by change in ISW generation coefficient.

3.4.3.1 Change in private consumption

Private consumption (PC) is one of the most important factors contributing to the total GDP, and accounted for 36.55% in 2007[153]. For the change in PC, the analysis starts with the investigation of changes in consumer behaviour. Further, since a vast and decisive majority of people live in urban areas, according the recent census figures (94.77% of PC), the study of the changes in the consumption patterns is based on urban residents only. Changes in consumption patterns are analyzed in terms of adjustments to the converter; this is illustrated in Fig. 3−4.

Firstly, PTCON is predicted by using total consumption expenditure model. Secondly, by applying MSW generation module, consumption expenditure of each commodity category in a future year can be projected. Thirdly, quantitative changes in the consumption pattern are reflected in the corresponding sectors of the IO table by GB/T4754−2002. The detailed flow from consumption to corresponding sectors is represented in sensitivity analysis in panel 3.4.4. Moreover, for the projection, change ratio of share of consumption expenditure on each category in a prediction year can be conducted by using consumer behaviour model; the same change ratio is applied into the corresponding sectors in IO table. Then, by assuming consumption patterns of residents in rural area are fixed in the base year of 2002, the converter vector of PC in a prediction year across all the residents is recalculated, as demonstrated Fig. 3−4 (4). Finally, compiling the predicted absolute value of PC and the adjusted converter, the new vector of PC is aggregated.

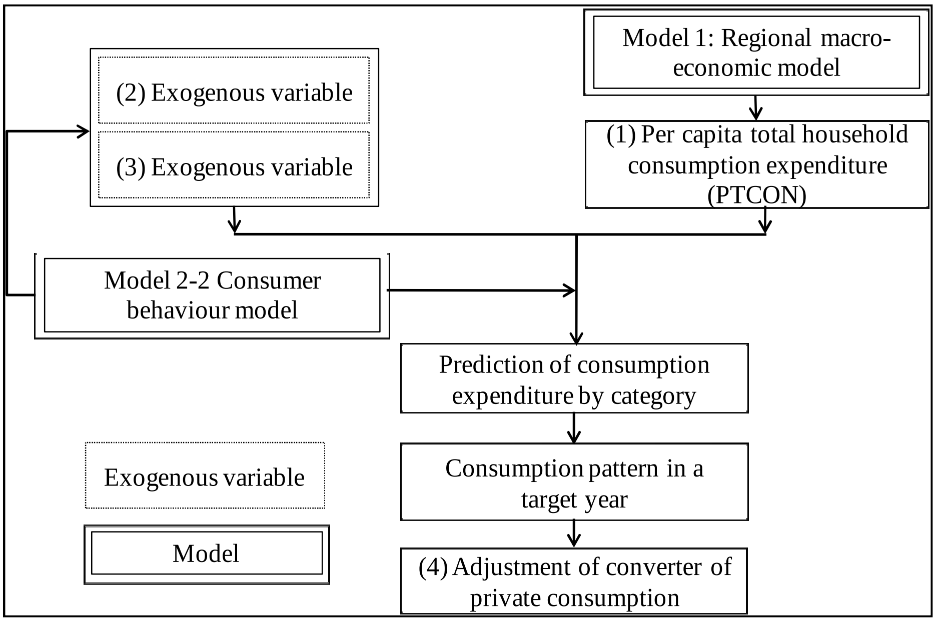


Fig. 3−4 Flow chart of adjustment of converter of PC

3.4.3.2 Change in export and transport compositions

During the past two decades, there have been considerable changes in the export shares of each industry into total export, so called the change in export structure. In this research, the basic approach to projecting future export structure is as follows. Firstly, it is necessary to understand the change trend in percentage shares of export and transport to other regions by each industry in past years. It can be calculated using existing IO tables. Based on the trend of such changes, the several top sectors with relatively high shares that changed the most are selected. Secondly, in order to project export share in future years, we first set an assumption for these selected sectors and readjust the share of the others. For each prediction year, the overall share of the other sectors is readjusted in a fixed and mutual proportion within the total share, which is maintained as ‘1’. In addition to the export structure, significant change also occurs in the structure change in transport to other regions within China. The same projection research flow is cited.

3.4.3.3 Change in ISW generation coefficient

Generally, economic growth will cause substantial changes in three aspects of a society: the household consumption pattern, the export structure and technical innovation. In this study, the IO table is updated by readjusting the converter vectors, but only to compute the final demands in terms of PC and export. Further, the technical change is considered in terms of change in ISW generation coefficients of specific sectors which generate large amount of ISW, based on the historical records.

According to the probable adjustment in above three aspects, industrial structure in a target year can be conducted quantitatively. The detailed method will be realized in the application of ISW module integrating with the real values. Moreover, in order to investigate the interdependence among the industrial sectors as well as the influence of such relationships on waste generation, sensitivity coefficient (SC, E_i) and the index of the power of dispersion (PD, F_j) in 2002 are calculated, as shown in Eq. (3–13). SC is the coefficient in which the sensitivity of specific industry when new demand for the overall industry is shown. Further, PD is the coefficient in which the degree of the given influence for the demand of a certain industry on the overall industry

$$E_i = \frac{\sum_{j=1}^{n} \overline{b_{ij}}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \overline{b_{ij}}} (i = 1,2...,n) \qquad F_j = \frac{\sum_{i=1}^{n} \overline{b_{ij}}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \overline{b_{ij}}} (j = 1,2...,n) \qquad (3\text{–}13)$$

3.4.4 Sensitivity analysis

Sensitivity analysis is designed to determine how the variation (uncertainty) of the output of a model can be apportioned when changes happened in the parameters of input and the structure of the model[154]. Here, the sensitivity analysis is carried out to investigate the change in ISW generation caused by change in consumption pattern. Therefore, per yuan increase of consumption expenditure on each consumed category is assumed to calculate the volume of total ISW generated and each waste category generated.

3.5 Evaluation of GHG emissions in waste treatment strategies

Two panels constitute the waste treatment module. The first panel is to calculate the amount of GHG emitted from current waste treatment system in each city. The second panel is to try to make a scenario analysis of the integration of alternative treatment strategies in views of reducing GHG emissions based on the projections of waste generation and composition in 2015.

3.5.1 Calculation of GHG emissions in each city

In order to make comparisons of GHG emissions among the cities, the functional unit of emission factor is set as both per ton and total volume of waste. The system boundary includes treatment and final disposal, as waste-to-energy incineration (WTE), biochemical treatment and landfill, not covering the collection and transportation system. Further, CO_2 equivalent value (CO_2-eq) is calculated and used for meaningful comparison among the cities. On the basis of Fourth Assessment Report (FAR) published by IPCC, the global warming potential (GWP) is 25 for CH_4 and 298 for N_2O over 100 years (http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf).

3.5.1.1 Disposal site (DS)

Landfill is one of most common waste treatment methods in current China and accounted for 81% in 2007[155], a large amount of landfill gas (LFG) emitted in Chinese cities thus can be expected. Significant amount of methane (CH_4), biogenic carbon dioxide (CO_2) and nitrous oxide (N_2O) is emitted from landfill site. It is evaluated that about 60% CH_4 and 40% CO_2 is generated with other trace gases in DS of Taiwan[156]. However, CO_2 is of biogenic origin not included in the national totals and it is included under agriculture, forestry and other land use (AFOLU). N_2O is also assumed to be negligible as a result of tiny content.

Further, in the IPCC guideline for calculating LFG emissions, a long time frame is necessary for getting the accurate result. However, for a majority of the Chinese cities, the waste records are far enough. Therefore, the waste quantity and composition beyond the waste period is projected by using back-casting and *ex-ante* forecasts in the MSW module. Then, the Microsoft Excel spread sheet-based model named IPCC_Waste_Model that consists of several input screens is used to calculate CH_4 emission based on the First Order Decay (FOD) methods, as represented in Eq. (3–14)[157]. The recovered LFG is also considered in the model.

$$CH_4 emissions = [\sum_x CH_4 generated_{x,t} - R_t] \times (1 - OX_t) \tag{3–14}$$

In which, X: waste category

t: inventory year

CH_4 generated $_{x,t}$: the amount of CH_4 generated by waste category x in the year t

R_t: recovered CH_4 in year t, Gg

OX_t: oxidation factor in year t, (%)

3.5.1.2 Waste-to-energy incineration

Although incineration is not a key technology in current China, more and more emphasis is being given for reducing waste volume and producing energy. Related gases emitted from combustion and open burning include CO_2, CH_4 and N_2O and CO_2 is the most important gas. The calculation equation is represented as Eqs. (3–15)−(3–17).

(1) CO_2

$$CO_2 emission\ (t, Gg / yr) = MSW \times \sum_j (WF_k \times dm_k \times CF_k \times FCF_k \times OF_k) \times 44/12 \qquad (3–15)$$

in which, MSW: total amount of MSW incinerated in year *t*, wet, (Gg/yr);

WF_j : fraction of *k*-th waste composition in year *t*, (%)

dm_j : dry matter content in the *k*-th waste composition of the MSW incinerated or open-burned, (%)

CF_j : fraction of carbon in the dry matter (i.e., carbon content) of component *k*, (%)

FCF_j: fraction of fossil carbon in the total carbon of component *k*, (%)

Water content and fraction of total carbon of each type of waste category refer to the actual value which were investigated in Hangzhou and are tabulated in Table 3−2. Further, the fraction of fossil carbon is provided by 2006 IPCC guideline, as shown in the table as well.

Table 3−2 Water content, total carbon and fossil carbon by waste category, %

Waste category	Water content	Total carbon in the dry matter	Fossil carbon
Food	72	48	0
Plastic	6	60	100
Paper	30	44	1
Textile	30	55	20
Wood	45	49	0
Glass	2	0	0
Ash	2	4.7	100
Metal	30	0	0

(2) CH_4

$$CH_4 emissions\ (t, Gg / yr) = \sum_k IW_k \times EFC_k \times 10^{-6} \qquad (3–16)$$

Where IW_i denotes total amount of MSW incinerated or open-burned, Gg/yr and EFC_i represents aggregate CH_4 emission factor, kg CH_4/Gg of waste. It is suggested that 30 kg of CH_4 is generated per TJ on a Net Calorific Basis as the default value based on IPCC guideline.

(3) N_2O

$$N_2O emissions\ (t, Gg / yr) = \sum_k IW_k \times EFN_k \times 10^{-6} \qquad (3–17)$$

Where EFN_i represents aggregate N_2O emission factor, kg N_2O /Gg of waste and the default value is 4 kg per TJ on a Net Calorific Basis.

3.5.1.3 Composting

Biological treatment of solid waste is common for treating kitchen waste not only in developing countries, but also in developed countries and it comprises composting, anaerobic digestion (AD) and mechanical-biological (MB) treatment. The main gases considered in this process are CH_4 and N_2O[157]. The calculation equations are the same with those in combustion process. However, of the amount of harmless treatment in Chinese cities, merely 2.65% of waste is treated by composting[155]. Further, among the selected cities, just 8.5% MSW in Shanghai is treated by composting in 2007, not a key treatment option; the default values of emissions factors are thus cited. The default values for CH_4 and N_2O emissions in composting process is 4g CH_4/kg waste-treated and 0.3g N_2O/kg waste-treated on a wet weight basis, respectively.

3.5.2 Scenario analysis

In order to analyze the impact of alternative treatment options on the reduction of GHG emissions for proposing appropriate selections, a scenario analysis on a basis of waste generation in 2015 is carried out. Integrated with the MSW modules, forecasts of waste quantity and composition of Shanghai until 2015 which is calculated in Chapter 4 are conducted as input files of scenario analysis. Further, based on Shanghai Eleventh-fifth Environmental Plan, there is no simple disposal expected in Shanghai until 2015 and the ratio of harmless waste treatment will achieve 100%. The scope of treatment system is within the above mentioned options and scenarios are assumed as the followings:

Baseline scenarios: there are two baseline scenarios in the research. Treatment options in 2015 are assumed as the same with that in 2007 and the ratio of simple disposal is merged into sanitary landfill with energy recovery system, as noted T_{01}. Further, the scenario without energy recovery is set as T_{00}.

T_1: T_1 is set up for comparing GHG emissions in WTE and SL both equipping with electricity-producing system. Except the fraction which is composted, all other MSW is sent for combustion with producing energy instead of landfill, and 20% residues are assumed to be generated and sent to DS.

T_2: It is designed for understanding the reduction effect of composting on GHG emissions. 50% of food waste is assumed to be composted. The remaining waste is treated in combustion plant for producing electricity. The residues are sent to DS.

T_3: T_3 is designed to explore the reduction effect of recycling prior to the waste treatment. Based on the governmental plan in Shanghai (Shanghai Solid Waste Disposal and Development Plan, 2004), the recovery ratio will be 25% in 2010 and the value is assumed to be 40% in 2015. The remaining part is treated with the same as T_{01}.

T_4: Integrated waste treatment is set as T_4 with 25% of recyclable items being recycled and 50% of food waste being treated by composting, the remaining part is sent to WTE incineration plant and the residues are sent to DS.

3.6 Concluding comments

In order to analyse the mutual relationship among economic growth, social development and waste generation, a comprehensive systematic approach is developed based on the waste stream flow. The approach comprises the macro-economic module, MSW generation module, ISW generation module and waste treatment module, which not only has the ability to project the quantity of SW generated and the corresponding composition, but also simultaneously explores the relationship between MSW and ISW generation by change in consumption pattern. World trade, change in the lifestyle of residents and the socio-economy, as well as influence of waste management policies are quantitatively introduced in the approach. An entire picture of SW generation flow in a city can be imaged. Further, one of the important applications of the approach which is the scenario analysis based on the projections of waste generation is meaningful for promoting the appropriate consideration to waste treatment system.

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4 ILLUSTRATIVE APPLICATIONS OF MSW MODULE

Chapter 3 has developed the entire approach for the forecasts of the volume of SW generated in a future year, in which MSW module comprising total consumption expenditure model, LES model and MSW generation model is represented for projecting MSW generation by waste category. The MSW module not only quantitatively explores the dynamic relationship among the expenditure of different consumption categories, governmental countermeasures and MSW generation by composition, but also simultaneously analyses the change in consumer behaviour caused by the lifestyle of residents and the socio-economy. In this chapter, several metropolitan cities in China are selected for practical scrutinizes of the module, not only for projecting waste generation by composition in each city by the year of 2020, but also for determining the waste generation features in different regions with distinct economic levels and waste management policies.

4.1 Background of study areas

4.1.1 Geographical and economic features

As mentioned in Chapter 1, China is roughly divided into three geographical regions—the eastern, central and western regions. Several cities analyzed in this dissertation are as follows: from the eastern region, coastal cities as Shanghai, Guangzhou and Hangzhou; from the central region, Wuhan; and from the western region, Chengdu. Shanghai has experienced a rapid economic take-off over the past two decades. Guangzhou city, the capital of the Guangdong province, is located in Southeast China and is one of the most developed cities in mainland China. Another eastern city is Hangzhou, the provincial capital of the Zhejiang province, a traditional tourist city situated near Shanghai. Wuhan, the city in the central region, is the capital of the Hubei province. Moreover, with the process of economic transformation over past 20 years in Chengdu, the capital of the Sichuan province, the status of the city in the Southwest region has improved markedly. A sketch map of China marking the relative location of each city is depicted in Fig. 4−1.

In addition, prior to further discussion, it would be helpful to briefly investigate the geographical and economic features of each city, which are listed in Table 4−1. All the data is obtained from respective Statistical Yearbooks of each city[153, 158-161] and the population denotes year-end registration population. The disparity in economic levels, expressed in terms of per capita GDP (PGDP) is rather evident. The level of economic development in eastern cities is higher than that in the central city Wuhan, with Chengdu being the lowest in this respect. However, per capita disposal income in Wuhan and Chengdu is at the same level. In addition, the Gini coefficient of each city, defined as average MSW generation corresponding to GDP in whole nation, is calculated as $(MSW_{city} / TMSW_{China}) / (GDP_{city} / TGDP_{China})$. In which, MSW_{city} and GDP_{city} represent the volume of MSW generated and total GDP in each city, while TMSW and TGDP stand for volume of MSW generated and GDP in whole China. The relative information is listed in Table 4−1 as well. Through calculation, Wuhan has the most serious waste problem among the selected cities with Gini coefficient being greater than ‘1’.

Fig. 4−1 A sketch map of China marking the relative location of each city

Table 4−1 Geographical and economic indicators for each city in 2007

	Shanghai	Guangzhou	Hangzhou	Wuhan	Chengdu
Population (million persons)	13.79	7.73	6.72	8.28	11.12
Areas (km^2)	6 340	7 434	16 596	8 494	12 390
Per capita GDP[1] (RMB)	66 367	71 808	61 258	35 500	29 888
Per capita disposal income[2] (RMB)	23 623	22 469.2	21 689	14 358	14 849
MSW generation (million tons)[3]	6.907	3.4	1.619	2.153	1.815
GDP (billion RMB)[4]	1 218.89	710.92	410.02	314.19	332.44
Gini coefficient	0.93	0.65	0.78	1.12	0.90

Note: [1]calculated by permanent population; [2]denotes urban households; [3]from 2008 China Urban Construction Statistics Yearbook and denotes the volume in whole city; [4]from 2008 China Statistical Yearbook

4.1.2 Change in lifestyle of residents in each city

Socio-economic indicators, demographic factors and household characteristics as the form of explanatory variables in the LES models have undergone the significant change during the last decades, with the increasing affluence and urbanization. Table 4−2 enumerates the percentage change of all available variables in Shanghai as an example (1980−2006) and Table 4−3 calculates the correlation coefficient (R_{ij}) of each other. Further, Fig. 4−2 depicts the normalized value of each explanatory variable. PTCON is per capita total consumption expenditure. It is found out that most of the variables have strong correlativity and are highly related to PTCON. Among the correlation coefficients, the values of ***SAV*** towards other variables, especially for ***ANPH*** are relatively smaller than others. The VIF values among the variables are calculated as well to further investigate the multicollinearity problem as the R_{ij} values are still larger than 0.5, shown in subsequent section.

Table 4−2 Abbreviations of indicators respecting socio-economic change

Abbreviation	Socio-economic indicators	Unit	Percentage change, %
ENG	Engel coefficient	%	−36.43
ANPH	Average number of persons per household	Person	−25.62
Life	Life expectancy	Year	10.42
Pn	Percentage of non-agriculture population in total	%	39.97
Pe	Percentage of employment per household	%	−10.81
totPs	Persons supported by each employee	Person	11.83
SAV	Saving rate towards consumption expenditure	%	11.87
NAGR	Natural growth rate	‰	−120.33
UNEM	Registered urban unemployment rate	%	37.5

Table 4−3 Correlation coefficient of any two variables

R_{ij}	*ENG*	*ANPH*	*Life*	*Pn*	*Pe*	*Ps*	*SAV*	*NAGR*	*UNE*	*PTCON*
ENG	1.000									
ANPH	0.629	1.000								
Life	−0.934	−0.806	1.000							
Pn	−0.926	−0.795	0.968	1.000						
Pe	0.751	0.753	−0.830	−0.829	1.000					
Ps	−0.758	−0.742	0.831	0.831	−0.999	1.000				
SAV	−0.589	−0.519	0.566	0.564	−0.608	0.606	1.000			
NAGR	0.643	0.908	−0.802	−0.779	0.866	−0.859	−0.566	1.000		
UNEM	−0.851	−0.722	0.895	0.860	−0.889	0.886	0.719	−0.824	1.000	
PTCON	−0.962	−0.756	0.971	0.992	−0.817	0.820	0.596	−0.747	0.871	1.000

Data source: Shanghai Statistical Yearbooks, 1981−2007

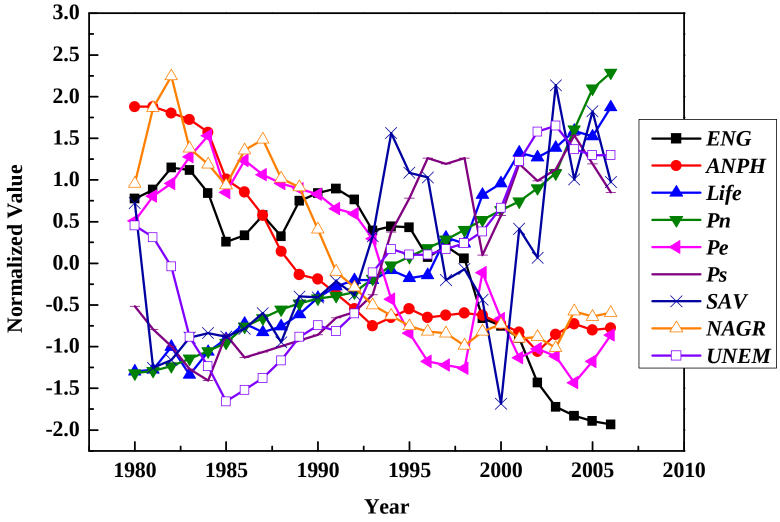


Fig. 4−2 Normalization of explanatory variables in Shanghai, 1980−2006

4.1.3 Change in consumption pattern in each city

Economic database including consumption expenditure information and corresponding explanatory variables, which represents urban area residents, is obtained from respective Statistical Yearbooks of each city. There are eight categories of consumption commodities (Table 4−4) in terms of household consumption expenditure in the model (in RMB): food (FOOD), clothing & shoes (CLSH), household facilities, articles & services (FUNI), medicine & medical services (HLTH), education, cultural & recreation services (EDUC), transport & communication services (TRAN), residence (RESI) and miscellaneous commodities & services (OTHR). Before constructing the model, the consumption expenditure by category is converted into fixed prices through respective total CPI of each city, in 1978 prices, and is regarded as an explained variable in the model.

Table 4−4 The abbreviations for the types of consumption categories

Consumption category	Abbreviation	Consumption category	Abbreviation
Food	FOOD	Clothing & shoes	CLSH
Household facilities, articles & services	FUNI	Medicine & medical services	HLTH
Education, cultural & recreation services	EDUC	Transport & communication services	TRAN
Residence	RESI	Miscellaneous commodities & services	OTHR

Fig. 4−3 depicts (a) the percentage share of consumption expenditure by category in the total consumption expenditure in each city in 2006 and (b) the change in share from 1989 to 2006. Chinese cities have similar consumption pattern with the highest share in food consumption in each city, over 35%. Further, it is obvious that all cities have the similar change trends. Expenditure on HLTH, TRAN, EDUC and RESI has experienced a marked increase during the same time period, along with a varying degree of decline in FOOD, CLSH and FUNI. On the other hand, the share of consumption expenditure in OTHR has remained almost unchanged with a slight increase of −1.63% to 1.33% among the selected cities. Moreover, FOOD and TRAN are the two main variables that change mostly in all consumption categories. Over the sample period, the share of consumption expenditure in FOOD gradually declined by 20.24%, 23.38%, 21.74%, 20.07% and 21.03% in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively. In contrast, the share in TRAN increased by 13.16%, 14.42%, 18.45%, 9.99% and 16.58% respectively, with the same city order. This change in each city thus advances to a more diversified and reasonable consumption structure placing emphasis on the product or service that delivers without material transfer[26, 162]. Possible reasons for these changes are (1) the upgrading of the consumption pattern caused by an improvement in living standards and (2) the implementation of a set of national interventions in housing, medical, pension and education. In addition, since the expenditures in EDUC and HLTH fall under ‘productive consumption’[163, 164], inevitable and increasing expenditure in these items within the relatively unchanged total consumption expenditure results in a subsequent decrease in the share of expenditure in other traditional consumption items.

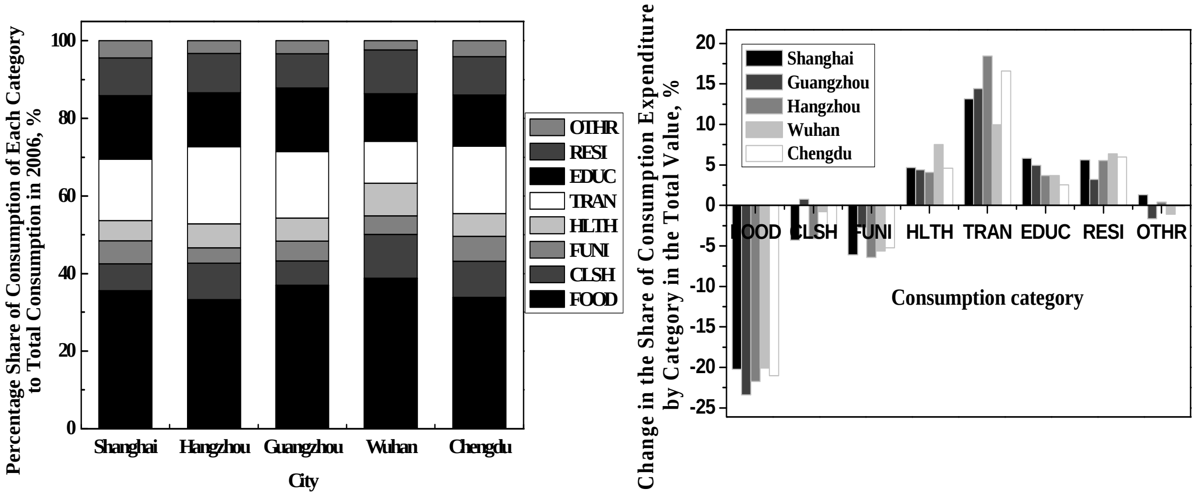


Fig. 4−3 Percentage share of consumption expenditure by category in the total consumption expenditure (a) in 2006 and (b) change from 1989 to 2006, %

4.1.4 Current situation of MSW generation in each city

4.1.4.1 Total MSW generation rates

Waste information is obtained from the local Environmental Sanitation Bureau (ESB) of each city that is leaded by Environmental Protection Agency (EPA) that also deals with the urban area. Table 4−5 tabulates the volume of MSW generated in each city from the year of 2000 (million tons) and increase rate of MSW generation in terms of geometric mean value. It is confirmed that each city has experienced a sharp increase from 2000 with the development of economy. The average change rate of total MSW generation is 4.77%, 5.76%, 5.81%, 7.65% and 5.49% in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively.

Table 4−5 Volume of MSW generated in each city (million tons) and increase rate (%)

	Shanghai	Guangzhou	Hangzhou	Wuhan	Chengdu
2000	3.67	1.86	0.86	1.68	0.89
2001	3.72	2.03	0.99	1.70	0.91
2002	4.13	2.13	1.00	1.76	0.97
2003	4.31	2.30	1.10	2.26	1.04
2004	4.82	2.37	1.19	2.91	1.10
2005	4.99	—	—	2.91	1.18
Average increase rate (%)	4.77	5.76	5.81	7.65	5.49

Note: "—" denotes that waste information is not available.

There are further notes regarding the waste generation in each city, as follows.

(1) Chinese cities are experiencing an accelerated process of urbanization with the expanding of urban area. From 2001, several rural areas were gradually amalgamated into urban areas in Hangzhou, Guangzhou and Chengdu. However, in order to keep compatibility, the waste generation regarding old central urban area is considered. Calculated per capita waste generation in the models are therefore greater than the actual values in the urban area. On the other hand, population signifies corresponding residents of old central urban area for consistency.

(2) The volume of MSW generated was measured by tonnage in the past rather than actual measurement and usually, the waste statistics provided by the local authorities is considered having been revised. However, there is no evidence to prove that the data in Chengdu has been adjusted. The data before 1996 is thus adjusted by multiplying 0.75 by the author fully considering the change trend

of waste records.

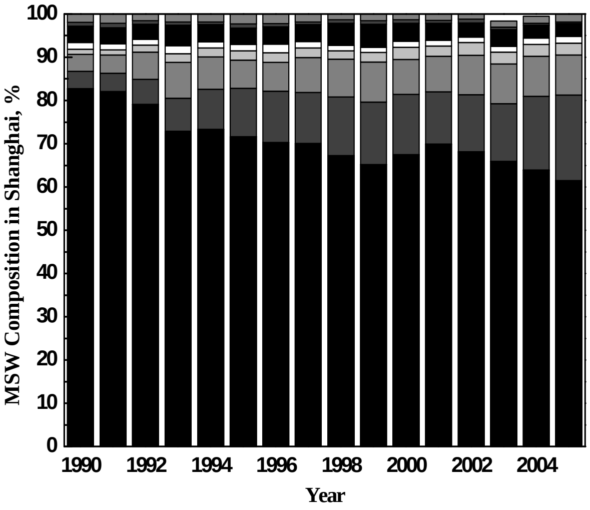
4.1.4.2 Waste composition in each city

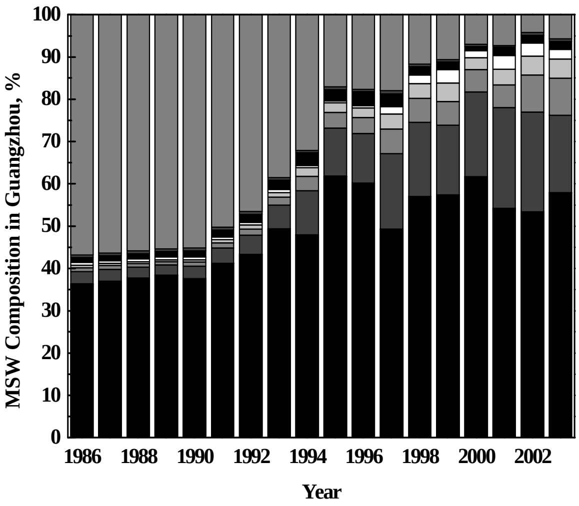
The composition and properties of the MSW is determined in accordance with the ‘classification of urban refuse generation source and refuse removal’ (CJ/T 3033-1996) and ‘classification and evaluation standard of MSW’ (CJJ/T 102-2004) in China. Fig. 4−4 describes the change in MSW composition in the central urban area of each city with the same order of waste category. Further, there are some notes concerning waste composition.

(1) Total waste composition is not 100% in several years of some cities, the differences are adjusted into ash waste as ‘inert waste’.

(2) The bulky waste is not usually included in the MSW statistics. Wood waste is mainly acquired from street sweeping with a slight fraction of 1.37%~3.99% in 2003 among the selected cities. Further, ash waste includes ash, tile, and brick waste and is mainly derived from coal burning and street sweeping in China, hereby having a disproportionately large negative impact on MSW. It reduces compost quality by introducing heavy metals and affects incinerator’s efficiency.

(3) Because the data concerning waste composition of Shanghai in 2004 was missing, the calculated value by the author based on the change trend of existing waste information is replaced. Further, as the detailed information on waste categories of plastic, paper and textile is not available in Guangzhou before the year of 1999, the specific components are assumed based on the existing respective fractions from 1999 to 2003.





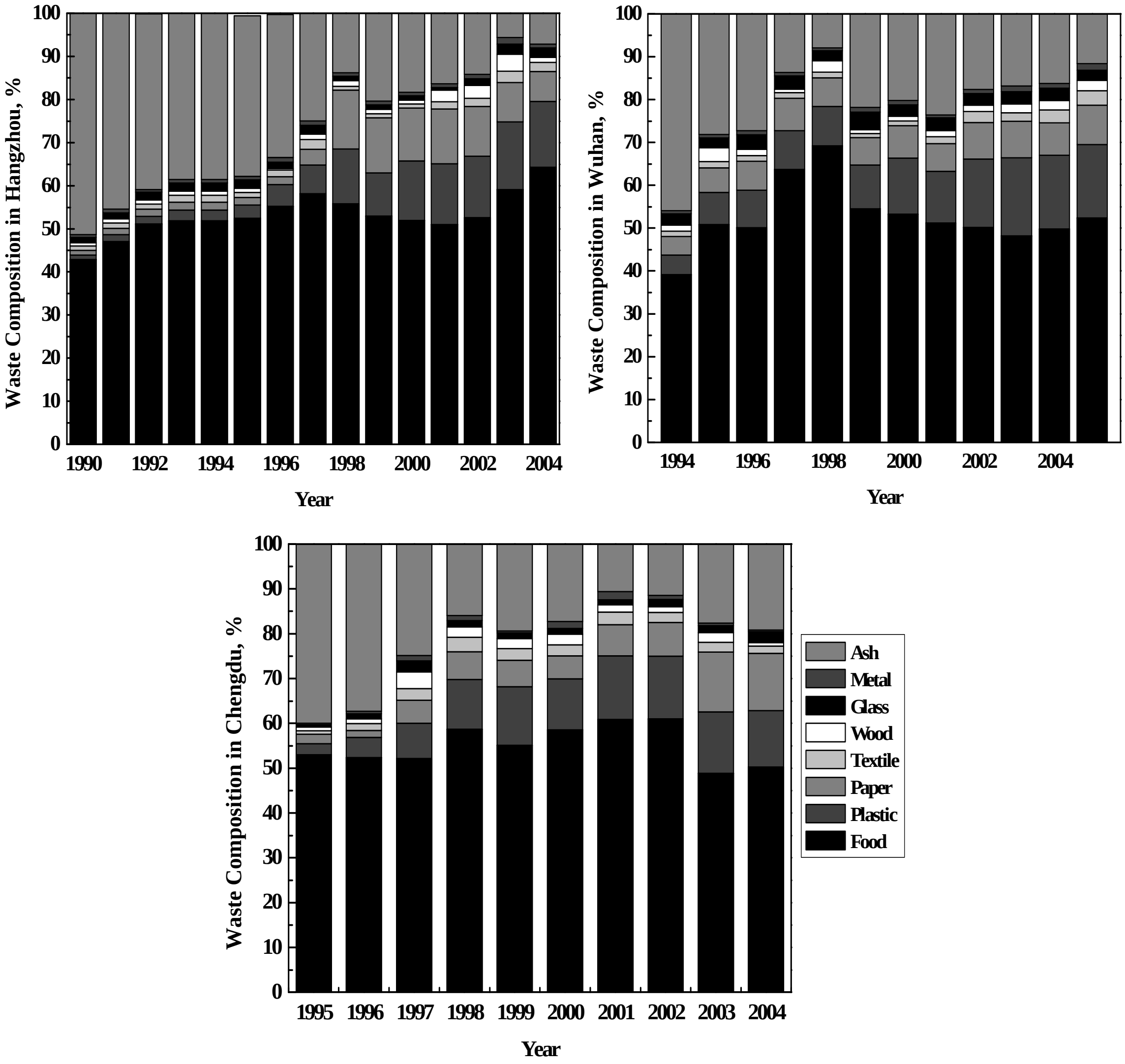


Fig. 4−4 MSW component in each city, % (a) Shanghai, 1990−2005; (b) Guangzhou, 1986−2003; (c) Hangzhou, 1990−2004; (d) Wuhan, 1994−2005; (e) Chengdu, 1995−2004

From the figure, it is believed that waste composition in each city has undergone a significant change during last decade. It is obvious to be found out that the fraction of ash waste is gradually decreasing in each city as a result of increased gas utilization ratio (GAS), from 57.26% in 1986 to 5.65% in 2003 in Guangzhou as an example[165]. Conversely, the fractions of potential recycle items such as paper, metal and plastic waste (CJJ/T 102-2004) are increasing and larger in eastern cities than those in central and western cities. The ratios in Shanghai have been increasing to 30% recently; nevertheless, these were still lower than in developed countries or districts[7, 25, 166, 167]. Moreover, food waste basically increases as an indication of growing affluence of the society[168]. However, implementing the measurement of the extent of ‘encouraging the access of clean vegetables with removed leaf scraps in the market' resulted in a decreasing proportion of food waste in Shanghai, from 82.72% in 1990 to 61.52% in 2005. On the other hand, for food waste, no apparent change trend happened in other cities. In addition, it may be inferred that the total proportion of food, plastic and paper waste in the total MSW has gradually been increasing, hereby dominating the fluctuation of the total amount of MSW. The value has accounted for 90% in Shanghai and over 80% in other cities in recent years. In contrast, the ratios of metal, glass and wood are relatively lower than others with inconspicuous change.

Further, the MSW composition of each city in 2003 is tabulated in Table 4−6. One apparent difference among the cities is the ratios of food and ash waste[169]. It is recognized that as a result of the higher GAS, cities in the eastern region have a higher proportion of organic compounds and lower proportion of ash waste than central and western cities. Further, a clusterdata analysis in terms of Euclidean distance between ratios of the eight waste components is carried out to group the cities into different clusters, as shown in Fig. 4−5[170]. No. denotes each city. From the figure, a specific description can be provided with a further division into three stages. Shanghai (No. 1) is in the first stage with the percentage of organic matter being approximately 70%, with only 1.40% of ash waste. Then, Wuhan and Chengdu (No. 4 and No. 5) are in the third stage, with the proportion of organic waste being less than 50% and ash waste being almost 20%. Guangzhou and Hangzhou (No. 2 and No. 3)—both eastern cities that are not as developed as Shanghai—are in the second stage, with proportions of organic waste and ash waste between the first and third stages.

Table 4−6 MSW composition in 2003, %

	Shanghai	Guangzhou	Hangzhou	Wuhan	Chengdu
Food	65.9	57.89	59.15	48.16	48.87
Plastic	14.33	18.26	15.66	18.26	13.72
Paper	9.23	8.78	9.14	8.48	13.3
Textile	2.7	4.56	2.59	2.08	2.16
Wood	1.37	2.25	3.99	2.01	2.21
Glass	3.82	1.89	2.35	2.8	1.55
Metal	0.71	0.64	1.51	1.34	0.53
Ash	1.4	5.65	5.63	16.87	17.66
No.	1	2	3	4	5

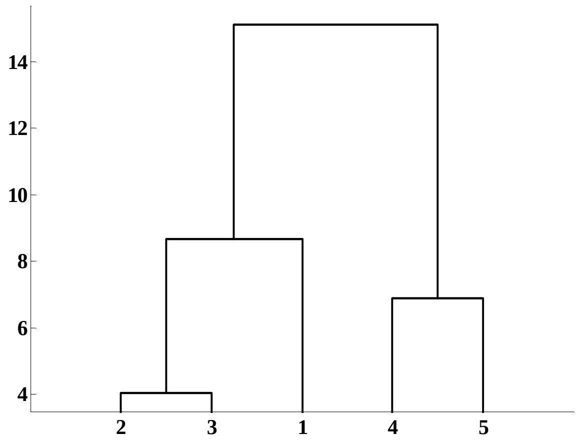


Fig. 4−5 Hierarchical cluster tree from the database

4.2 Results of total consumption expenditure model

Per capita total consumption expenditure in year *t* ($\boldsymbol{PTCON_t}$) is estimated by PGDP in year *t* ($\boldsymbol{PGDP_t}$) and $\boldsymbol{PE_t}$ in each city by the following equations with different time horizons. In which, ***PE*** denotes percentage of employment per household and is defined as average number of employees per household/average number of persons per household. Figures in parentheses are *t-ratios* for estimated coefficients and the ‘*’ and ‘**’ denote that parameter estimate is significant at the 1% and 5% levels, respectively. Moreover, the observed and estimated data series in each city are depicted in Fig. 4–6. Two assumptions in the models are: 1) The data series of $\boldsymbol{PGDP_t}$ in each city is obtained from respective Statistical Yearbooks and adjusted by PGDP deflator of each city (1978 = 100). However, because there is no corresponding deflator of ***PGDP*** in Chengdu, the value regarding GDP is replaced. 2) ***PTCON*** has the same meaning with that in LES model, and is adjusted by CPI into the same base year, 1978 as well. In addition, in Shanghai, the future ***PGDP*** is conducted by regional macro-economic model of Shanghai as introduced in Chapter 3 and calculated in Chapter 5 (ISW generation module). However, the forecasts of ***PGDP*** in other cities cite the scenario analysis.

From the results, all the estimated parameters are significant at 1% level, showing a good performance of model testing. Further, ***PTCON*** increases with percentage of employment (***PE)*** in each city, thereby implicating the inversely relationship with family size.

(1) Shanghai: $\boldsymbol{PTCON_t} = 0.0936 \times \boldsymbol{PGDP_t} + 6.072 \times \boldsymbol{PE_t}$

(44.555^*) (14.443^*)

DW = 0.493; AdR^2 = 0.98; F = 1516.38; MAPE = 7.35%; (1980−2006)

(2) Guangzhou: $\boldsymbol{PTCON_t} = 0.0979 \times \boldsymbol{PGDP_t} + 7.998 \times \boldsymbol{PE_t}$

$(23.275^{*}) \qquad (13.672^{*})$

DW = 0.354; AdR^2 = 0.95; F = 450.845; MAPE = 9.78%; (1980−2006)

(3) Hangzhou: $\boldsymbol{PTCON_t} = 0.117 \times \boldsymbol{PGDP_t} + 8.301 \times \boldsymbol{PE_t}$

$(39.428^{*}) \qquad (19.574^{*})$

DW = 1.346; AdR^2 = 0.98; F = 1040.18; MAPE = 4.28%; (1988−2006)

(4) Wuhan: $\boldsymbol{PTCON_t} = 0.132 \times \boldsymbol{PGDP_t} + 8.499 \times \boldsymbol{PE_t}$

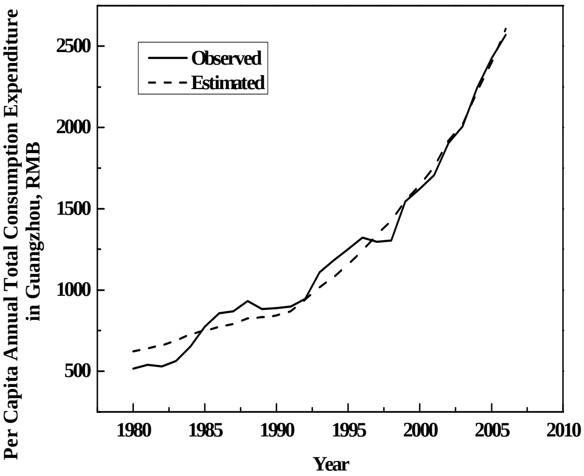
$(23.975^{*}) \qquad (15.102^{*})$

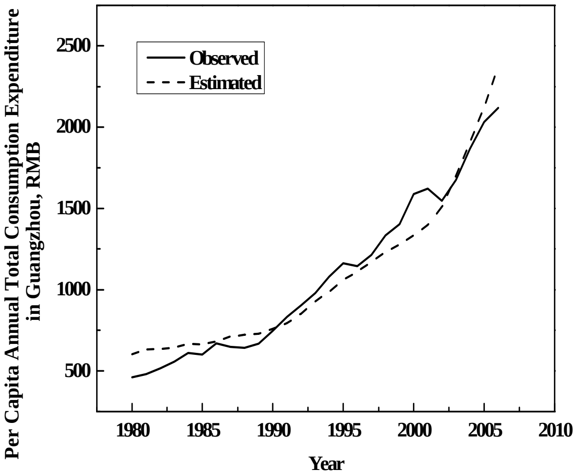
DW = 0.563; AdR^2 = 0.96; F = 398.786; MAPE = 5.04%; (1989−2006)

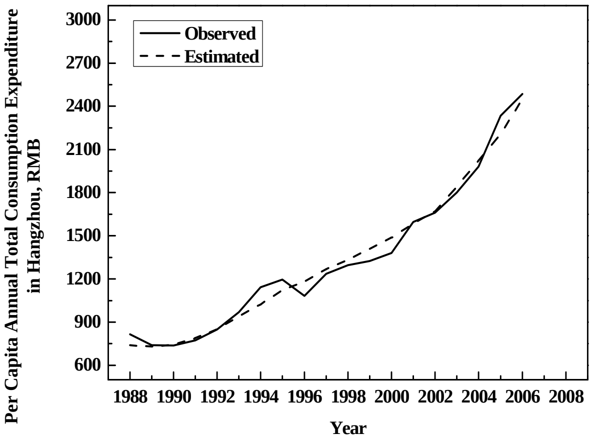
(5) Chengdu: $\boldsymbol{PTCON_t} = 0.156 \times \boldsymbol{PGDP_t} + 8.812 \times \boldsymbol{PE_t}$

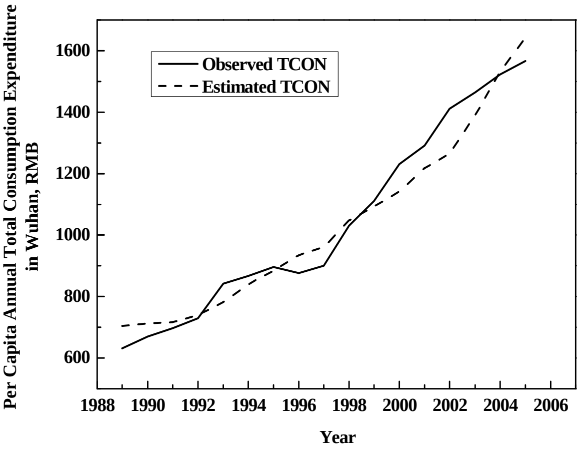
$(33.647^{*}) \qquad (24.269^{*})$

DW = 1.419; AdR^2 = 0.97; F = 797.209; MAPE = 4.28%; (1985−2006)









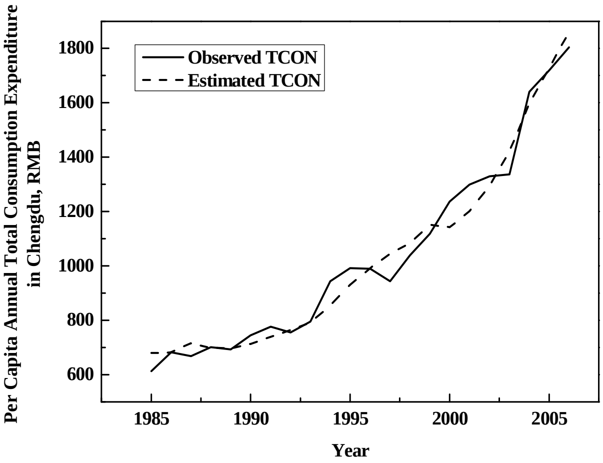


Fig. 4−6 Estimation result of ***PTCON*** in each city (a) Shanghai (b) Guangzhou (c) Hangzhou (d) Wuhan (e) Chengdu

4.3 Estimation results of LES model of each city

4.3.1 Selection of explanatory variables

The explanatory variables affecting consumer behaviour are usually the cooperative attributions of the lifestyle of residents, demographic and socio-economic indicators. The indicators of lifestyle in each city have changed rapidly over the past two decades and have undoubtedly led to significant influence on all consumption categories. The essential principle for the selection of the appropriate explanatory variables (γ_k) is as follows. Firstly, to collect all the feasible variables regarding household characteristics, socio-economic indicators and socio-demographic indicators in each city; then, to calculate the correlation coefficient (R_{ij}) between explanatory variables and VIF_{ij} when R_{ij} is above 0.5 for clarifying multi-collinearity problem [171]; finally, to attempt to find pairs with dissimilar change trends (normalized values) which fit the models well (backward testing). Different city has different optimal integration of variables which fits the model mostly from the viewpoint of good performance of model testing. However, in order to construct a common model which can be easily applied into other Chinese cites, several values which fit all models well are selected as exogenous variables in each city, as numerated in Table 4−7, in which '***SAV***' denotes *saving rate towards consumption*, %; '***NAGR***' means *natural growth rate*, ‰; '***DUM02***' is introduced as to reflect the change in measurement standards of consumption category from 2002 in Wuhan.

Table 4−7 Explanatory variables concerning in the LES model for each city

City	Time series	Explanatory variables			R_{ij}	VIF_{ij}
Shanghai	1980–2006	***SAV***		***ANPH***	−0.519	1.316
Guangzhou	1980–2006	***SAV***	***NAGR***		−0.800	2.674
Hangzhou	1988–2006	***SAV***	***NAGR***		0.067	—
Wuhan	1989–2006	***SAV***	***NAGR***	***DUM02***	-0.088^{*}	—
Chengdu	1985–2006	***SAV***	***NAGR***		−0.800	2.653

Note: the R_{ij} value between ***SAV*** and ***NAGR***, ***SAV*** and ***DUM02***, ***NAGR*** and ***DUM02*** is −0.088, 0.238 and −0.488, respectively, lower than 0.5, thereby no need for calculating VIF.

As shown in Table 4−7, all the explanatory variables have no apparent multicollinearity problems by the common rule of thumb that only VIF > 5 indicates a multicollinearity problem[172]. Moreover, it is verified that the number of variables affecting consumer behaviour is not one but the integrations of a series of indicators. It is interesting to find out that ***SAV*** and ***NAGR*** are currently the two common factors that significantly affect consumer behaviour in Chinese cities**.** Saving deposits is considered as one of the important factors leading to fast growth of developing economies and contribution of significant increase in family welfare. Besides, a higher saving rate in China signifies that residents have a high propensity to save money. From a long and dynamic viewpoint, reducing the current consumption for savings has financed active household investment and will increase the future consumption levels subsequently[173]. On the other hand, ***NAGR*** is another important influential indicator from the viewpoint of demographic indicators, as calculated by fertility and mortality rate. The mortality rate is considered as one important indicator of welfare and medical system of a city[174] and the fertility is usually related to population policy in China. Although fertility is believed to be notoriously difficult to project in Europe[175], in China it may be easier as a result of the '*family planning policy*' enacted by the national government.

However, in Shanghai, another variable**—**namely ***ANPH*****—**is more influential as compared to ***NAGR***, indicating that it is an advanced international metropolitan city as compared to other cities. The fact that the common variables ***SAV*** and ***NAGR*** significantly affect consumer behaviour in all cities will be very useful in projecting the household consumption pattern in other Chinese cities.

All explanatory variables are considered as prioritise parameters at the city level with high quality of data due to easy compilation, relatively good predictability and long forecasting horizon. Furthermore, it has demonstrated that ***ANPH*** and infant mortality rate included in ***NAGR*** are significant indicators in projecting the MSW generation in Europe, and performs even better than GDP[175, 176]. However, in this case, explanatory variables affect MSW generation indirectly by affecting the consumption pattern, integrated with the MSW generation model.

In addition, the explanatory variables of each selected city have changed rapidly over the past two decades and have undoubtedly led to a significant change in all consumption categories. Fig. 4−7 plots the trend of change in explanatory variables in the LES model for each city with different time frame. For a majority of the consumption categories in a city, a sudden turning point appeared around the year 1992. Firstly, this change could be interpreted as being caused by the rapid economic growth. To be more precise, it may be attributed to the crucial and decisive operation of exogenous variables, which also demonstrate unexpected turning points during the same period in each city. Moreover, the ***SAV*** is keeping changing recently; however, the ***NAGR*** in each selected city is close to achieving constancy from 1995 onwards. Accordingly, in the future, if policy-makers indulge in governmental interference in residential saving deposits, such as by changing the interest rates of deposits, the consumption pattern will be readjusted easily and will subsequently affect MSW generation.

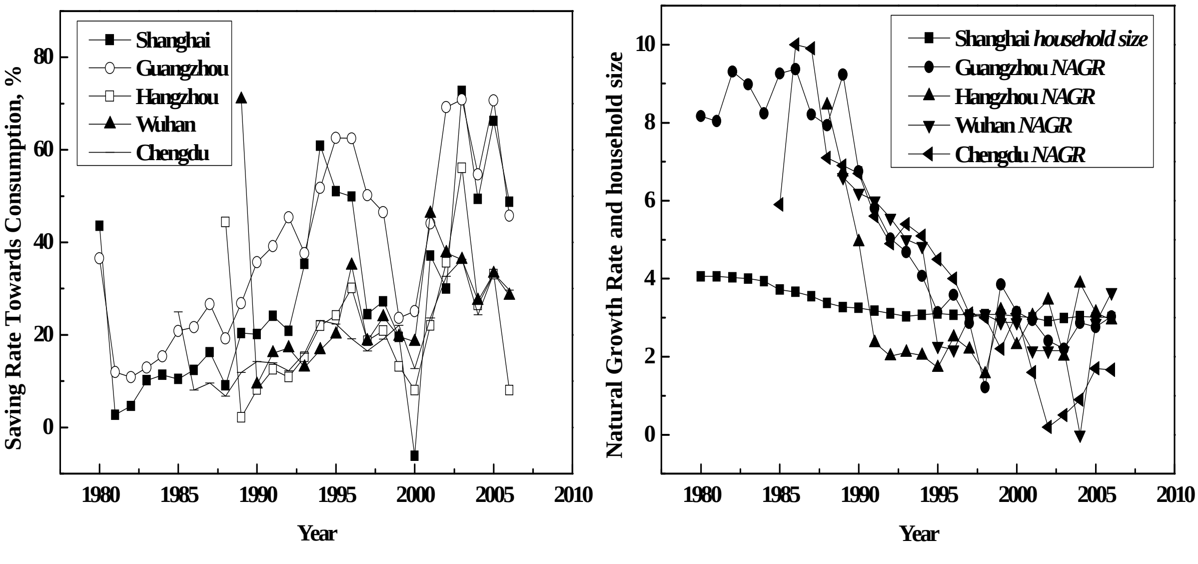


Fig. 4−7 ***SAV***, ***NAGR*** and ***ANPH*** in selected cities during different period

4.3.2 Model performances among cities

Tables 4−8 summarizes the estimated results obtained from the respective LES model for each city, and the crossed table denotes the coefficients of ‘subsistence’ demand expenditure by category on the corresponding exogenous variables. Each table for each city not only lists the estimated coefficients in the model, but also the traditional statistical testing including the R^2, MAPE (M) and

RMSE (R) values when the M-value is high. The first row presents the abbreviation of consumption category. From the table, it is evident that a majority of R^2 values are sufficiently high to be noteworthy, with 67.5% of them being greater than 0.9 and 90% being greater than 0.6. Further, most of the estimators are significant at the 5% levels, thereby denoting most of the estimators are acceptably convincing. In addition, Fig. 4−8 presents the observed and estimated data series of expenditure by consumption category in Shanghai as an example, in which the horizontal axis represents the year, and the vertical axis is the individual annual consumption expenditure (in RMB). The results for other cities are represented in Appendix No.1. In the model of each city, although considerable changes have occurred in the past decades, estimated and observed series of each category are in almost superposition, thereby demonstrating that the LES model can track consumption expenditure of each category rather well. Hence, these findings confirm that all estimators are noteworthy and validate good performances with a perspective on the projection of the future consumption pattern of each city. Moreover, the identification of the structural equations is carried out. Based on the necessary condition, $K_j^* = 0 = M_j$, the model is thus fully identified.

Table 4−8−1 Estimated results of respective LES model for each city—Shanghai (1980–2006)

	FOOD	CLSH	FUNI	HLTH	TRAN	EDUC	RESI	OTHR
Constant	1456.080 (13.356)*	148.941 (3.902)*	255.101 (6.476)*	51.427 (0.979)	50.129 (0.516)	290.618 (2.702)**	174.496 (2.360)**	102.877 (4.344)*
SAV	0.595 (0.754)	0.076 (0.575)	—	0.569 (1.396)	1.061 (1.162)	0.991 (1.118)	0.825 (1.457)	0.169 (0.880)
ANPH	−274.109 (−14.663)*	−12.305 (−1.206)	−46.685 (−4.249)*	−9.930 (−1.058)	—	−54.750 (−3.801)*	−33.517 (−2.635)**	−20.391 (−6.852)*
α value	0.207 (17.485)*	0.035 (3.966)*	0.032 (3.736)*	0.091 (13.237)*	0.225 (25.453)*	0.224 (25.286)*	0.135 (16.532)*	0.050 (18.433)*
R^2	0.98	0.55	0.74	0.93	0.98	0.98	0.96	0.97
MAPE	0.030	0.127	0.144	0.79	0.297	0.116	0.180	0.144
RMSE				12.66	16.362			

Table 4−8−2 Estimated results of respective LES model for each city—Guangzhou (1980–2006)

	FOOD	CLSH	FUNI	HLTH	TRAN	EDUC	RESI	OTHR
Constant	260.749 (2.805)	−24.083 (−0.769)	114.532 (4.267)	−115.746 (−2.166)	−425.625 (−2.674)	−286.152 (−2.227)	86.482 (1.789)	85.608 (9.891)

SAV	6.141 (3.090)	1.737 (2.822)	0.272 (0.786)	2.668 (2.658)	7.907 (2.609)	7.011 (2.838)	1.309 (1.445)	—
NAGR	—	3.241 (3.219)	−8.189 (−3.343)	7.897 (3.096)	32.701 (4.809)	21.973 (3.962)	−9.170 (−2.998)	−6.440 (−4.912)
R^2	0.98	0.95	0.81	0.96	0.95	0.98	0.95	0.81
MAPE	0.0333	0. 080	0.174	0.400	0.680	0.129	0.173	0.178
RMSE				7.277	22.42			

Table 4−8−3 Estimated results of respective LES model for each city—Hangzhou (1989–2006)

	FOOD	CLSH	FUNI	HLTH	TRAN	EDUC	RESI	OTHR
Constant	711.622 (7.041)*	195.022 (6.402)*	127.953 (9.251)*	85.116 (2.027)**	338.108 (3.056)*	235.373 (3.062)*	178.282 (3.655)*	97.791 (7.129)*
SAV	−1.742 (−1.571)	−1.143 (−2.008)$^{+}$	—	—	−5.548 (−4.018)*	−1.454 (−5.882)*	−1.074 (−2.261)**	−0.631 (−4.087)*
NAGR	8.143 (0.646)	—	−4.738 (−1.062)	11.651 (1.634)	8.478 (0.979)	17.463 (1.475)	3.504 (0.566)	−4.675 (−1.650)
R^2	0.97	0.79	0.21	0.94	0.92	0.96	0.96	0.71
MAPE	0.037	0.099	0.172	0.312	0.459	0.146	0.092	0.145
RMSE				13.847	35.984			

Table 4−8−4 Estimated results of respective LES model for each city—Wuhan (1989–2006)

	FOOD	CLSH	FUNI	HLTH	TRAN	EDUC	RESI	OTHR
Constant	448.167 (8.215)*	113.979 (5.264)*	66.768 (3.632)*	17.071 (0.465)	33.119 (0.880)	83.509 (1.677)	78.288 (0.902)	45.202 (2.536)**
SAV	—	−0.346 (−1.697)	0.390 (1.696)	0.234 (1.567)	0.278 (1.927)$^{+}$	0.446 (1.643)	0.893 (1.822)$^{+}$	—
NAGR	−16.948 (−1.280)	−3.662 (−0.764)	−4.699 (−1.122)	−7.594 (−0.847)	−10.213 (−1.107)	−13.116 (−1.078)	−22.532 (−1.060)	−5.364 (−1.202)
DUM	179.811 (10.625)*	63.314 (6.076)*	—	107.923 (12.631)*	119.288 (15.330)*	107.511 (12.487)*	77.560 (7.087)*	—
R^2	0.97	0.71	0.72	0.99	0.99	0.96	0.93	0.86
MAPE	0.024	0.118	0.102	0.117	0.147	0.098	0.170	0.087

Table 4−8−5 Estimated results of respective LES model for each city—Chengdu (1985–2006)

	FOOD	CLSH	FUNI	HLTH	TRAN	EDUC	RESI	OTHR
Constant	524.958 (5.111)*	106.218 (3.402)*	112.544 (5.555)*	63.335 (1.263)	52.932 (0.263)	139.358 (1.708)	136.930 (2.042)$^{+}$	85.114 (3.693)*
SAV	—	0.311 (0.862)	−0.498 (−0.860)	0.396 (1.290)	2.372 (1.216)	0.643 (1.072)	—	−0.990 (−2.303)*
NAGR	11.065 (0.871)	7.700** (2.129)	—	5.910 (0.960)	43.897 (1.644)	12.285 (1.275)	5.206 (0.717)	—
R^2	0.90	0.53	0.33	0.93	0.91	0.93	0.96	0.66
MAPE	0.043	0.090	0.121	0.298	1.099	0.132	0.155	0.166
RMSE				9.883	31.012			

Figures in parentheses are *t-ratios* for estimated coefficients, ‘*’, ‘**’ and ‘$^{+}$’ denote that the parameter estimate is significant at the 1%, 5% and 10% levels, respectively; ‘—’ denotes no clear impact.

Compared with the other results, several estimated parameters of consumption category with regard to the constant or/and the exogenous variables are ignored, which implies that the explanatory variables does not have significant effect. Further, except Hangzhou, a majority of positive coefficients of ***SAV*** on ‘subsistence’ expenditure in all the cities indicate that the greater the saving deposits is, the higher the individual ‘subsistence’ expenditure is. Moreover, increase in saving deposits will advance to greater increase of propensity towards expenditure on education, transportation and food in all cities as the higher coefficients than other consumption categories. It thus confirmed that education and transportation is two stimulations for people to save money. In contrast, for ***NAGR***, although a majority of the coefficients, particularly those in the LES model of Guangzhou, Hangzhou and Chengdu, are positive, those in Wuhan are negative. This indicates that the increase in population will augment ‘subsistence’ expenditure in the first three cities and will lead to the reduction of this expenditure in the last city. In most of the cities, the influence of ***NAGR*** is the biggest on EDUC consumption, due to mortality rate affected by medical policy.

The negative coefficients of ***ANPH*** in LES model of Shanghai confirm that if the family size is relatively greater, the individual annual ‘subsistence’ expenditure is lower. These findings indicate that family members share common goods in the house and this behaviour will indirectly reduce the MSW generation per capita per year[43]. The same result with the previous research that waste generation on a per capita basis is inversely related to household size[46, 93]. Moreover, with regard to the largest coefficient of ***ANPH*** to food expenditure, this variable is speculated to play a key role in the ‘subsistence’ expenditure on food, which implies that a change in the family size will lead to the greatest impact on individual ‘subsistence’ expenditure on food among all consumption categories.

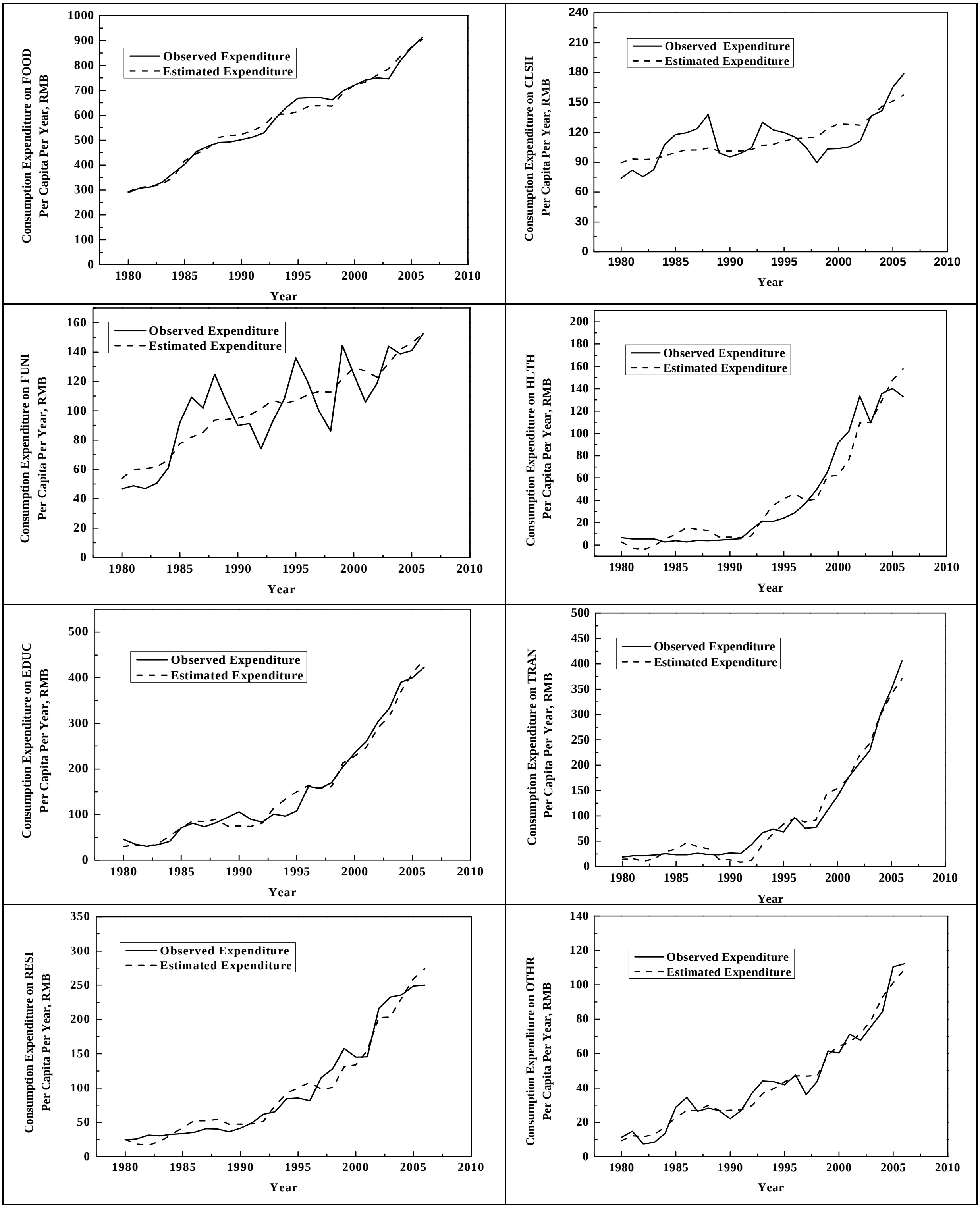


Fig. 4−8 Observed and estimated data series of each consumption category in Shanghai

4.3.3 Comparison of ‘subsistence’ expenditure and alpha value among cities

Fig. 4−9 (a) further outlines the per capita ‘subsistence’ demand expenditure by category among the cities for the year 2006. It is interesting to note that the distribution of expenditure among the categories is rather similar in each selected city; food expenditure is on the top followed by expenditure on education and transportation. Further, Hangzhou has the respective highest value of each consumption category among the cities. In addition, to a certain extent, the proportion of ‘subsistence’ expenditure in each category reflects the most basic consumption potential and induces the most basic physical components of MSW. The largest proportions—FOOD and EDUC—indicate that the waste arising from these two items is inevitable and may occupy large shares in the MSW component. This type of information is of special interest to the management in charge of MSW and can be used for projecting the trend of specific waste generation[26]. On the other hand, such information concerning ‘subsistence’ expenditure could inspire the implementation of environmental policies, such as the ‘the minimum living standard’ or ‘minimum wage’ for civil administration in a city[177].

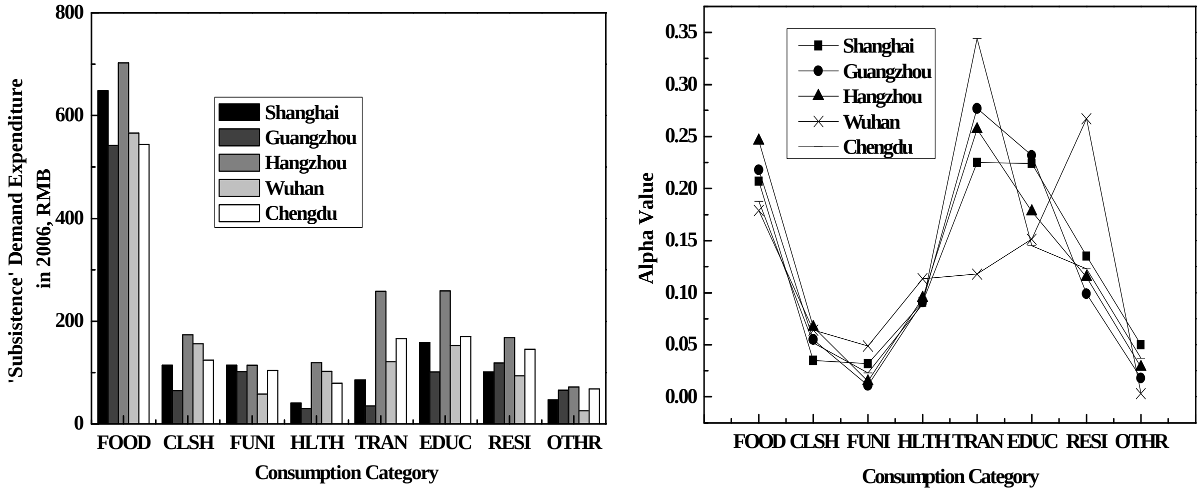


Fig. 4−9 ‘Subsistence’ demand expenditure and alpha value estimated in LES model of each city

However, it is probable that consumption propensity contributed more to the projection of MSW generation, so called alpha value—the marginal propensity to consume. Fig. 4−9 (b) depicts the alpha value estimated in LES model of each city. Due to the housing reform starting from the 1990s, the consumption propensity for residence is very high in Wuhan, thereby inducing the relatively low propensity towards other consumption categories within the total propensity being ‘1’.

Further, it is obvious that even if the individual GDP is increasing, people continue to chronically prefer spending more money on ‘edibles’[6]. This tendency may be partially explained by the boom in dining out, which has accounted for almost 30% of the total food consumption in 2007 (2008 Statistical Yearbook of each city). Further, people have high propensity towards expenditure in education and transportation in each city on account of the increasing attention on education of children and purchases of cars. Conversely, the traditional propensity is evident from the relatively similar low value of CLSH and FUNI in each city.

For a comparison among the cities, beyond the general characteristics mentioned above, eastern cities have similar propensity towards each commodity category and higher propensity towards food and education expenditure than central and western cities. Moreover, because of the greater importance of expenditure on EDUC than that on food with regard to generation of recyclable items, the future generation propensity of MSW in eastern cities will be higher than that in others. Further, as the eastern cities, Shanghai, Guangzhou and Hangzhou show the similar distribution of propensity among consumption categories. Apart from a higher propensity towards food expenditure than Taiwan, the values of other items are rather close and similar to those of Taiwan[76].

4.4 Comparison of waste generation among cities

4.4.1 Waste management policies adopted by the local government

The DUM model mentioned earlier is introduced as a reflection of waste measures. For example, ‘DUM92’ implies that a certain type of waste management policy was introduced from 1992 onwards and denoted by ‘1’; ‘0’ denotes the period prior to 1992. All relative local measures constituted in each city are enumerated in Table 4−9. It is believed that all the policies have played rather important roles in eliminating/facilitating waste generation. In Wuhan, the government amended the criteria of ‘Administration of Household Waste Management’ from 2004 onwards and relaxed the standard of waste disposal. It is believed that companies can dispose MSW to the designated areas and no longer require the approval of the relevant departments. Moreover, the government also relaxed the restrictions on participating waste transportation services. These policies induced a sharp increase in the total MSW generation from 2004 in Wuhan.

Table 4−9 Summary of waste countermeasures constituted in each city

City	Dummy variable	Explanation of waste policies
Shanghai	DUM92[1]	Encouraging the access of clean vegetables with removed leaf scraps in the

		market
	DUM00[2]	'Temporary Criterion of Management on Disposable Plastic Boxes' published in 2000 impels disposable plastic boxes separated from MSW
Hangzhou[3]	DUM98	The policy of 'Waste must be collected by plastic bags' had achieved remarkable results until 1998
	DUM02	From 2002 onwards, the measurement of waste composition was carried out in disposal sites instead of in transportation stations, thereby reducing the ratios of recyclable items, particularly the paper waste due to the appearance of scavengers at the same time
Wuhan[4]	DUM04	Relaxing the restrictions on waste disposal
Guangzhou, Chengdu		No relative waste measures have been found thus far

Note: [1]City Appearance and Environmental Sanitation Regulations (State Council Decree No. 101) and http://www.shtong.gov.cn/node2/node2245/node75681/node75692/node75729/userobject1ai92599.html (Shanghai); [2] source from <2005 Shanghai Waste Management>; [3]from the inquiry of staff in local EPA; [4]Wuhan authorities order No. 159 (http://news.sina.com.cn/c/2004-07-07/12093016294s.shtml)

4.4.2 Comparison of MSW generation by waste category

4.4.2.1 The assumptions in the model

Prior to model development, several assumptions are made in each city:

(1) The abbreviations of all the consumption categories are the same as in Table 4−4 and all expenditure is adjusted to the fixed prices by the respective CPI of each city—1978 as well. Further, the adjusted food expenditure without the food processing fees is cited in the model of Chengdu.

(2) Waste categories of food, plastic, paper, textile, glass and metal waste are estimated by respective MSW generation model (OLS) in each city and are called estimated-waste categories. On the other hand, as mentioned above, generation of wood and ash waste are affected mainly by the index of urban construction, such as GAS and GREEN, rather than consumption [165]. The generation of wood and ash waste is thus estimated by GAS and consumption in OTHR in Hangzhou. However, the quantity of these items in other cities is obtained by assuming the fractions based on the historical records, as called non-estimated waste.

(3) Certain waste categories which have small fractions have been merged for purpose of estimation. Sum of glass and metal waste is evaluated as a whole in Guangzhou and Chengdu. Moreover, in the model of Guangzhou, since there is no respective fraction of paper, plastic and textile waste before the year of 1999, the sum of these three items is thus estimated as a whole.

4.4.2.2 The development of the model

Individual annual waste generation of estimated-waste category is estimated using OLS in each city and is represented as a reasonable regression equation. A common model denoting the qualitative relationship between waste category and corresponding consumption expenditure is developed, as presented in Table 4−10. The estimation result by waste category in each city is shown in Tables 4−11. In each table, the first row stands for explanatory variables (EV), including abbreviations of consumption expenditure by commodity category and governmental countermeasures (DUM). The first column from the left indicates the each waste category (WC). Therefore, the crossed table marking with circle in Table 4−10 signifies that the causal relationship between generation of waste category and corresponding consumption expenditure or dummy variables. For example, the estimation of food waste is expressed as $W_{food\ waste,\ t} = f$ (FOOD) in each city. The cross items in the Tables 4−11 imply the partial coefficient of waste to the corresponding consumption expenditure or dummy variables ($PWC_{k/i}$ or MWC_{dum}). The *t-ratios* of all estimators in the equations are described in the parentheses. On the other hand, the statistical testing including DW, *F*-value and AdR^2 validating each equation concerning each category is also calculated and presented in the last column.

Table 4−10 Development of MSW generation model by waste category

EV / WC	FOOD	CLSH	EDUC	DUM
Food	○			
Plastic	○		○	
Paper	○		○	
Textile		○		
Glass	○			
Metal	○			

Table 4−11−1 Result of MSW generation model by waste category in Shanghai (1990–2005)

EV / WC	Constant	FOOD	EDUC	CLSH	DUM92	DUM00	Statistical testing
Food		0.386^* (10.603)			–46.339 (–1.747)		DW=0.62; F=36.348; AdR^2=0.78;
Paper		0.00890^* (3.009)	0.0962^* (10.799)				DW=0.970; F=254.716; AdR^2=0.94;

Plastic	–55.445* (–4.086)	0.0884* (3.186)	0.198* (5.266)			–13.823** (–2.606)	DW=1.212; F=152.190; AdR^2=0.97;
Textile				0.065* (10.103)			DW=0.30; F=68.353; AdR^2=0.37;
Glass		0.0185* (20.643)					DW=0.581; F=28.424; AdR^2=0.67;
Metal		0.00331* (15.575)					DW=1.633; F=11.926; AdR^2=0.46;

Table 4−11−2 Result of MSW generation model by waste category in Guangzhou (1986–2003)

EV WC	Constant	FOOD	EDUC	CLSH	Statistical testing
Food	–192.819* (–5.368)	0.738* (11.226)			DW = 1.427; F = 126.031; AdR^2 = 0.88;
Paper, Plastic & textile	–110.565* (–3.209)	0.203** (2.312)	0.609* (4.978)		DW = 1.679; F = 116.237; AdR^2 = 0.93;
Glass & metal		0.0199* (12.101)			DW = 0787; F = 31.571; AdR^2 = 0.35;

Table 4−11−3 Result of MSW generation model by waste category in Hangzhou (1990–2004)

EV WC	Constant	FOOD	CLSH	EDUC	DUM98	DUM02	Statistical testing
Food		0.427* (47.620)					DW = 0.74; F = 203.67; AdR^2 = 0.94;
Paper				0.0788* (4.109)	47.283* (10.792)	–19.141* (–4.426)	DW = 1.359; F = 178.279; AdR^2 = 0.96;
Plastic	–32.712* (–2.997)	0.0398 (1.382)		0.276* (3.045)	19.616** (2.523)	–9.534 (–1.205)	DW = 2.409; F = 132.318; AdR^2 = 0.97;
Textile			0.0545* (10.193)				DW = 0.791; F = 16.55; AdR^2 = 0.56;
Glass		0.014* (8.563)			–1.762 (–1.280)		DW = 1.121; F = 10.115; AdR^2 = 0.57;

Metal	0.00733* (15.818)	DW = 2.073; F = 21.211; AdR^2= 0.62;

Table 4−11−4 Result of MSW generation model by waste category in Wuhan (1994–2005)

EV WC	Constant	FOOD	CLSH	EDUC	DUM04	Statistical testing
Food		0.224* (16.017)			49.725** (2.845)	DW = 0.707; F = 25.523; AdR^2 = 0.69;
Paper		0.0105 (1.403)		0.0758** (2.701)	9.378* (3.397)	DW = 2.236; F = 30.441; AdR^2 = 0.84;
Plastic	–81.173* (–3.796)	0.194* (5.534)		0.0859 (1.535)	7.719 (1.378)	DW = 1.932; F = 68.972; AdR^2=0.95;
Textile			0.0260* (8.067)		7.326* (7.003)	DW=0.723; F=80.548; AdR^2 = 0.88;
Glass		0.0123* (13.410)			1.925 (1.678)	DW = 1.880; F = 14.149; AdR^2 = 0.55;
Metal		0.00406* (8.767)			2.244* (3.872)	DW = 2.130; F = 30.040; AdR^2 = 0.73;

Table 4−11−5 Result of MSW generation model by waste category in Chengdu (1995–2004)

EV WC	Constant	FOOD	CLSH	EDUC	Statistical testing
Food		0.364* (29.261)			DW=0.927; F =10.605; AdR^2=0.57;
Paper	–69.124^{+} (–1.975)	0.119 (1.554)		0.193* (3.223)	DW=2.521; F=11.708; AdR^2=0.70;
Plastic	–12.647** (–2.301)			0.283* (7.578)	DW=2.537; F=57.424; AdR^2=0.86;
Textile			0.0464* (7.238)		DW=0.537; F=24.000; AdR^2=0.75;
Glass & metal		0.0160* (9.781)			DW=1.694; F=1.045; AdR^2=0.23;

Figures in parentheses are t-ratios for regression coefficients. ‘*’, ‘**’ and ‘$^{+}$’ denote that the parameter estimate is significant at the 1%, 5% and 10% levels, respectively.

There are several aspects to be addressed:

(1) In each model, the heteroscedasticity is checked by using residuals chart and the result is added in Appendix No. 2. It is found out that ε_i^2 has no apparent change trend with the increase of $\hat{y}_i$ in each figure, thereby denoting no apparent heteroscedasticity problem in each model. Further, for the estimation of each waste category, adjusted R^2 values of most of the variables are above or near 0.6 (84.62%). Among all the parameter estimators, 70% of estimators are significant at the 1% levels and 81% are significant at the 5% levels. Further, the interpretation of the results is straightforward with regard to economic applicability. All model performance demonstrates that the MSW module is stable and feasible for future forecasting.

(2) All the models prove the quantitative conversion process of any type of consumed commodity to a corresponding waste category in each city[107]. For example, food waste is estimated by food expenditure, and paper and plastic waste are estimated by the FOOD and EDUC expenditure in all cities. Consequently, a high consumption propensity towards EDUC and FOOD estimated by the LES model would facilitate the generation of these items in the future. Further, glass and metal waste are considered from the beverage which is a part of the food consumption category. In addition, textile waste is estimated by expenditure in clothing and shoes (CLSH) in all cities.

(3) The model for plastic waste in each city includes the constant, thereby representing that apart from the influence of EDUC and FOOD expenditure, other factors affect the generation of plastic waste. Further, the equation for estimating food waste in Guangzhou includes the intercept as well. Moreover, the generation of wood and ash waste in Hangzhou is estimated by $MSW_{Hangzhou,\ wood\ \&\ ash,\ t} = 257.914^{*} + 0.932 \times \mathrm{OTHR} - 2.0975 \times \mathrm{GAS}^{**} - 41.755^{**} \times \mathrm{DUM98}$ (DW = 1.322; F=22.037; Adjusted $R^2 = 0.82$; $p^{*} < 0.01$ and $p^{**} < 0.05$).

(4) When a waste policy regarding the specific waste category is introduced in the model, the ‘DUM’ is considered to be merely related to corresponding waste category. For example, the ‘DUM92’ merely affects the food waste in Shanghai. On the other hand, when a general policy is introduced, the influence on all types of waste is considered. The constitution of ‘DUM04’ in Wuhan not only increases the generation of total MSW, but also increases the generation of each type of waste category.

4.4.2.3 Interpretation of the model results

The coefficient of each type of waste to the corresponding consumption expenditure is regarded as partial waste generation coefficient to consumption ($PWC_{k/i}$) and is applied for analysing the distinct waste generation trend among cities, as tabulated in Table 4−12. In the table, the first row indicates each city and the first column from the left stands for the *PWC* of *k/i*. For example, $PWC_{food/FOOD}$ stands for the partial coefficient of food waste to FOOD consumption expenditure, kg/RMB.

Table 4−12 Partial generation coefficient of each type of MSW (kg/RMB)

City $PWC_{k/i}$	Shanghai	Guangzhou	Hangzhou	Wuhan	Chengdu	Average value
Food/FOOD	0.386	0.738	0.427	0.224	0.364	0.350
Paper/FOOD	0.00890	0.609*	—	0.0105	0.119	0.0346
Paper/EDUC	0.0962		0.0788	0.0758	0.193	0.111
Plastic/FOOD	0.0884		0.0398	0.194	—	0.107
Plastic/EDUC	0.198		0.276	0.0859	0.283	0.211
Textile/CLSH	0.0654		0.0545	0.026	0.0464	0.0481
Glass/FOOD	0.0185	0.0199	0.014	0.0123	0.016	0.0191
Metal/FOOD	0.00331		0.00733	0.00406		

*denotes the coefficient of estimation of paper, plastic and textile waste together

Paper, plastic and textile waste is estimated together in Guangzhou, the partial generation coefficient of these items is 0.203 regarding to FOOD expenditure and is 0.609kg/RMB to EDUC expenditure, as denoted in Table 4−11−2. The main conclusions from the model can be discussed from four aspects. Firstly, the partial generation coefficients of each type of waste regarding to the same consumed category are at the same levels among the cities. A per yuan (RMB, in 1978 prices) increase in food expenditure results in an average increase of 0.386, 0.738, 0.427, 0.224 and 0.364kg food waste in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively with an average value of 0.350kg except Guangzhou. Further, the $PWC_{textile/CLSH}$ is 0.0654, 0.0545, 0.026 and 0.0464kg/RMB, respectively in Shanghai, Hangzhou, Wuhan and Chengdu and the average value is 0.0458kg/RMB. In addition, it is confirmed that the same increase in FOOD expenditure yields a greater generation of glass and metal waste in eastern cities than central in and western ones. Among the cities, the range $PWC_{glass\&metal/FOOD}$ is 0.016~0.0218kg/RMB with an average value of 0.0191kg/RMB. Moreover, it is confirmed that the same increase in EDUC expenditure yields a greater generation of recyclable items in eastern cities than central and western ones.

Secondly, in the models of all cities, the partial coefficient of recyclable materials in terms of

EDUC expenditure is greater than that of food expenditure. For example, in MSW generation model of Shanghai, a per yuan increase in EDUC and FOOD leads to an average increase of 0.0962 and 0.00890kg paper waste respectively. All the coefficients can be applied into other Chinese cities with insufficient waste statistics for predicting generation of each type of waste category.

Thirdly, except Guangzhou, the increase per yuan (RMB, in 1978 prices) in education expenditure results in the increased generation of plastic rather than paper waste in all cities because, 1) most of the newspapers related to education expenditure are sold by residents in their homes in current China; 2) EDUC expenditure includes the consumption in culture and recreation articles, inducing to the great generation of plastic waste. Fig. 4−10 represents the $PWC_{plastic/EDUC}$ and $PWC_{paper/EDUC}$ in each city. Except in the model of Guangzhou, the increase of per yuan in EDUC expenditure results in a range of paper waste by 0.0758~0.193kg and plastic waste by 0.0859~0.283kg. Further, an average value of $PWC_{plastic/EDUC}$ and $PWC_{paper/EDUC}$ is 0.211 and 0.111 kg/RMB, respectively.

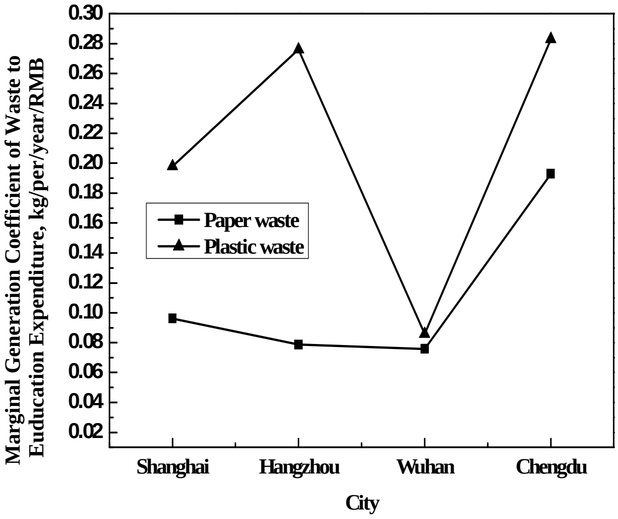


Fig. 4−10 $PWC_{plastic/EDUC}$ and $PWC_{paper/EDUC}$ in each city

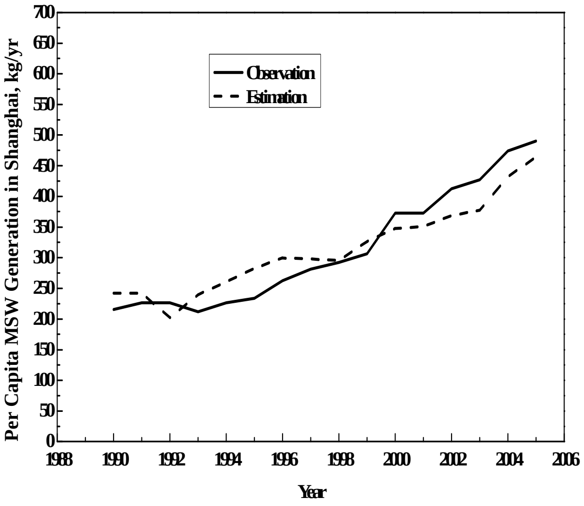
Fourthly, the different signs of DUM for Shanghai and Wuhan further manifest the distinct influence of waste policies. The waste regulation regarding food waste in Shanghai significantly eliminate the per capita food waste generation by 46.339kg per year (DUM02), whereas that in Wuhan (DUM04) enhance the waste by 49.725 kg each year. This result clearly indicates that the waste management policies on food waste in Shanghai could serve as a valuable example for other cities. Meanwhile, governmental interventions in each city have different impacts even on the same waste generation. In the case of Hangzhou, the waste measure of ‘waste must be collected by plastic bags’

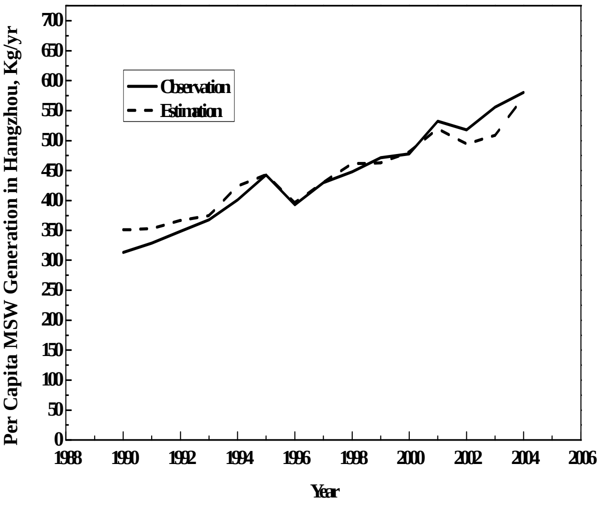
(DUM98) significantly increases per capita paper waste generation by 47.283 kg per year, and reduces the glass waste generation by avoiding cutting the plastic bags (1.762 kg). On the contrary, the appearance of a number of scavengers from 2002 onwards substantially reduces paper generation by 19.141 kg on average, as expressed by the negative coefficient of DUM02. Moreover, the constitution of waste policy in Wuhan (DUM04) causes the increase of generation of each type of waste. All waste management policies will provide a feasible experience or lesson to other cities in the future. Furthermore, as Song (2008)[178] states, the implementation of effective waste measures will definitely lower the peak of the Environmental Kuznets Curve (EKC).

Finally, combining the results estimated by the LES model, it indicates that a high consumption propensity towards education in each city will lead to a high expenditure in the future and great generation of recyclable items. Further, higher propensity in eastern cities than others will result in more generation of recyclables items.

4.4.3 Comparative results of total MSW generation

The total MSW generation in each city is calculated by sum of estimations of each estimated-waste category and actual value of non-estimated waste. Wood and Ash waste of Hangzhou is estimated in the model of Hangzhou as mentioned above. The error between the observed and estimated series of total MSW is evaluated by MAPE and the value is 9.92%, 6.78%, 3.69%, 10.57% and 6.60% in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively, denoting acceptable results. In addition, the observation and estimation of total MSW generation in each city is represented in Fig. 4−11.





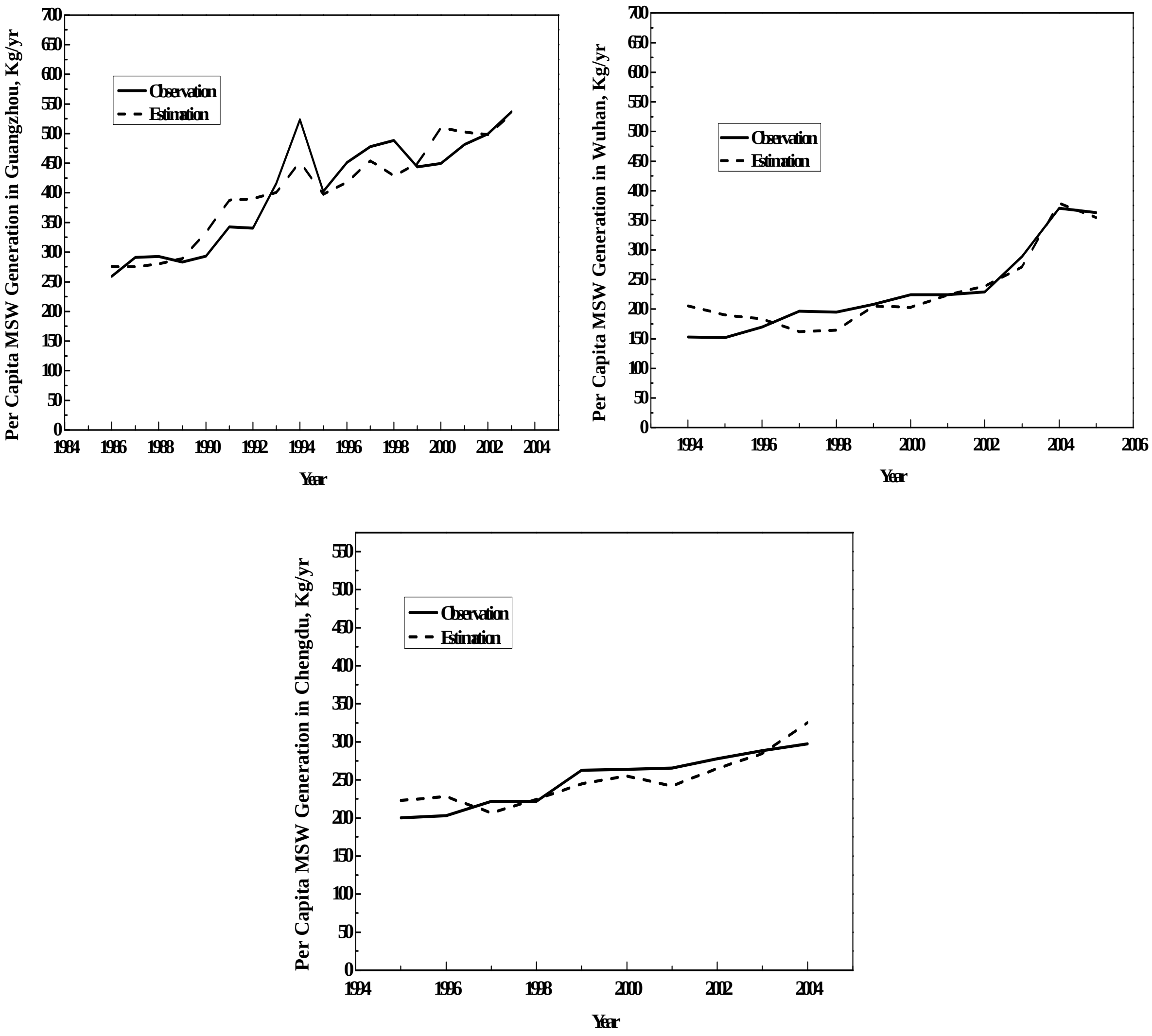


Fig. 4−11 Estimation of per capita MSW generation in each city, kg/yr

Further, in order to investigate the conversion process from consumption to total MSW generation in current Chinese cities, the relationship between individual total MSW generation and PTCON for each city is further investigated and analyzed here, as depicted in Fig.4−12. In each fitting equation, *y* stands for total MSW generation and *x* denotes PTCON.

From the figure, several points can be understood. Firstly, it seems that MSW generation increases with the economic growth in each city. This indicates that in Chinese cities, waste generation currently continues to remain in the increasing stage not only in the developing cities but also in developed ones, thereby demonstrating that economic growth is the main driving force for increasing waste generation. Secondly, the total MSW generation regarding to PTCON is considered as unit waste generation coefficient per total consumption expenditure, kg/RMB and the value is 0.211, 0.225, 0.222, 0.208 and 0.198 in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively. The values are in the same level with the average being 0.213 (0.198~0.225) kg/RMB. This is of great importance for those cities in which case there is a lack of adequate waste statistics, by providing a possibility for identifying total MSW generation once the current consumption expenditure is known. Thirdly, the coefficients in eastern cities are a little higher than in central and western cities and Hangzhou and Guangzhou have the highest values. Chung (2001) indicated that the lower income group tended to recover a greater portion of MSW for selling to waste depots[179], thereby improving the recycling rate and reducing the amount of waste simultaneously transported to a treatment facility. Consequently, due to the lower income level, waste generation in Chengdu is relatively diminished as compared with other cities. Finally, MSW generation in Wuhan and Chengdu increases totally along the trace of Shanghai. However, the intercepts in the models of Guangzhou and Hangzhou represent that apart from MSW, other wastes not from consumption may be mixed into MSW such as sludge, HW or ISW.

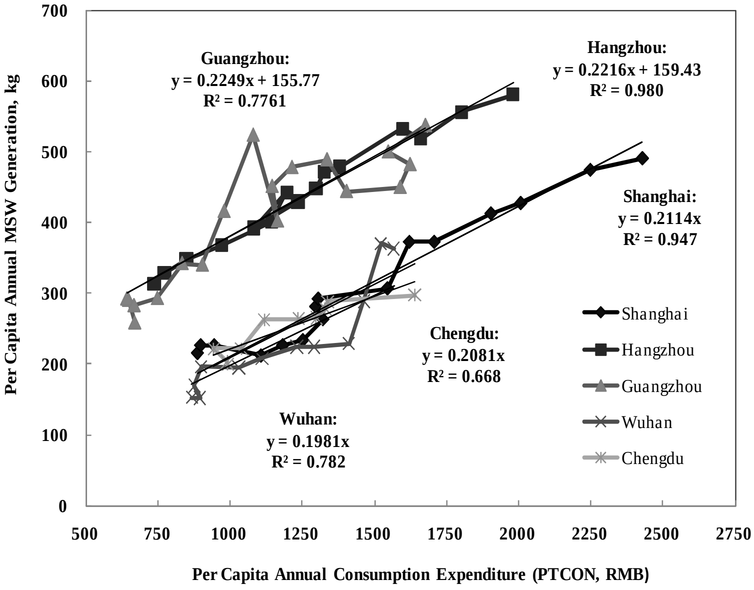


Fig. 4−12 Per capita annual MSW generation against PTCON

4.5 Back-casting and e*x-ante* forecasts of MSW generation

4.5.1 Assumption of explanatory variables

Exogenous variables in the respective total consumption expenditure model and LES model are almost the same in each city; the assumption therefore cites the same method and the forecasts are tabulated in Table 4–13. Detailed introduction pertaining to each value is represented as follows.

4.5.1.1 ***PGDP*** and ***PE*** in total consumption expenditure model

The projection of ***PGDP*** in Shanghai until 2020 is conducted by using regional macro-economic model which will be introduced in Chapter 5. On the other hand, the minimum target for Chinese economy which was proposed in the Sixteenth National Congress Report is to project the GDP of the year 2000 to quadruple by 2020 (http://xibu.tjfsu.edu.cn/elearning/lk/16en.htm). Therefore, for other cities, it is presumed that the real ***PGDP*** in 2020 is four folds of the value in 2000, based on the minimum target of economic growth. The values between the years of 2007 to 2020 are dispersed using interpolation method. Further, for ***PE*** in each city, the assumed value in 2010 and 2020 is tabulated in Table 4–13 as well, on the basis of change trend in each city.

4.5.1.2 ***SAV, NAGR*** and ***ANPH*** in LES models

Different scenarios of saving rate towards consumption (***SAV***) are assumed to increase or decrease in each city based on historical records during past decades. Further, based on the past change trend and relative city plan in Shanghai, ***ANPH*** is assumed to have a slight decrease in next decade. On the other hand, for the variable ***NAGR*** in other cities, the value until 2010 is determined on the basis of <Eleventh−Fifth Plan of each city>[180] and assumed to be fixed until 2020 for simplicity.

Table 4−13 Assumed values of exogenous variables in each city

	Shanghai		Guangzhou		Hangzhou		Wuhan		Chengdu	
	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020
SAV	20	80	20	70	10	40	40	10	50	20
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
PE	50	57	58	60	54	55	53	55	50	50
NAGR	—	—	2.8[2]	2.8	4.6	4.6	4[3]	4	4	4
ANPH	3	2.9[1]	—							

Note: [1] denotes the current fertility policy.

[2] Value in Guangzhou is calculated based on the plan of the population; that is from 9.50 million in 2005 to 10.9 million in 2010.

[3] Birth rate is planed as < 10‰ in Wuhan and the mortality rate is assumed 6‰ along with the historical records.

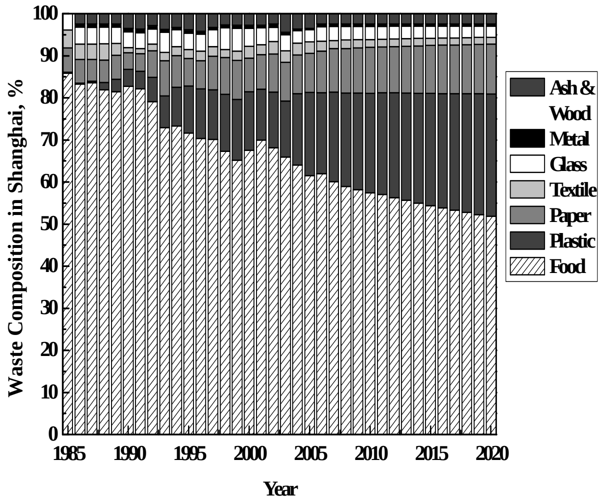
4.5.2 Projection of MSW generation in each city

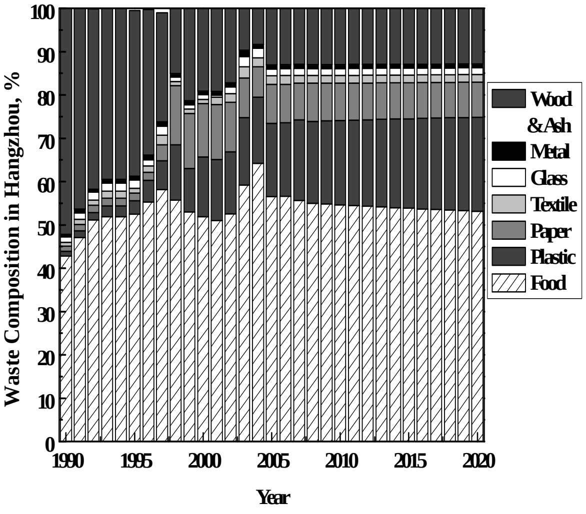
Compiling the existing consumption expenditure and exogenous variables beyond the period of model development of MSW generation model, a back-casting estimation of total MSW generation is extrapolated back to 1985. Further, based on known/assumed exogenous variables until the year of

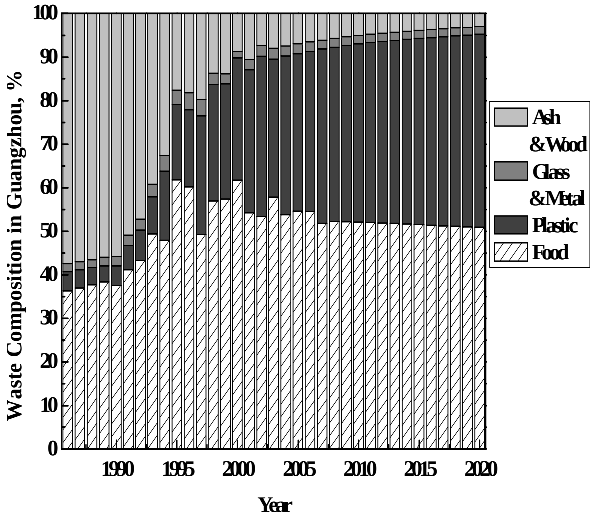
2020, MSW generation by category is projected as well (*ex-ante* forecast) by using MSW module. The fractions of wood & ash in each city are assumed based on the historical records and summarized in Table 4−14. Forecasting result of waste composition in each city is displayed in Fig. 4−13.

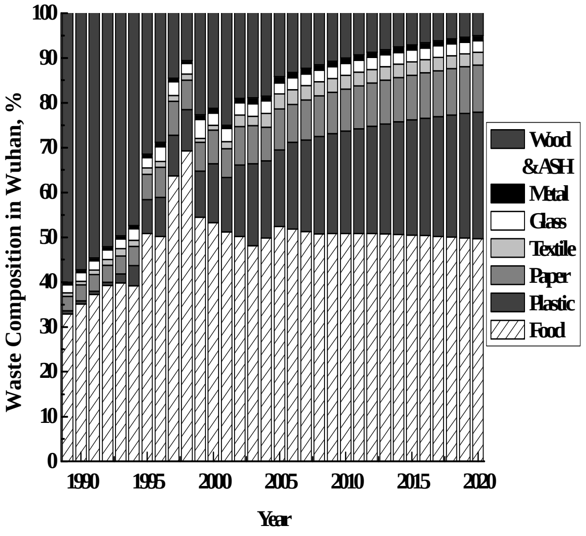
Table 4−14 Assumptions of fractions of wood & ash waste in each city, %

	Shanghai	Hangzhou	Guangzhou	Wuhan	Chengdu
Actual value	2.5 (2005)	OLS	7.98 (2003)	14.13 (2005)	18.26 (2004)
2010	2.5	OLS	5	10	15
2020	2.5	OLS	3	5	10









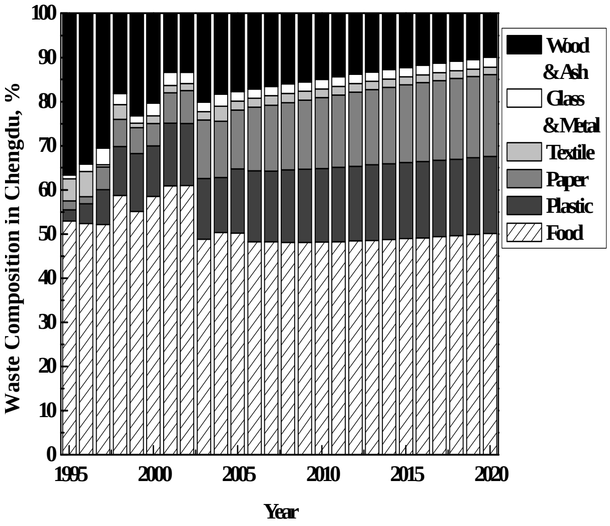


Fig. 4−13 Back-casting estimation and projection of MSW composition until 2020 (a) Shanghai (b) Hangzhou (c) Guangzhou (d) Wuhan (e) Chengdu

In the MSW generation model, the volume of per capita total MSW generated increases linearly with the PTCON, thereby demonstrating the consumption is the big driving force of MSW generation observed in current Chinese cities. It can be found out that in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, the per capita total MSW generation in 2020 will be 2.17~2.18, 1.46~1.49, 1.48~1.49, 1.24~1.25 and 1.78~1.79 times of those in 2008, thereby foreboding a serious MSW problem in Chinese big cities if there were no relative policies implemented advancing to diminishing waste generation. The MSW generation in Wuhan and Chengdu until 2020 will be the level of Shanghai around the year of 2012.

On the other hand, the fraction of each type of waste will continue experiencing a significant change during next decade. Firstly, as assumed above, the fractions of ash and wood waste will gradually decrease in all cities. Secondly, the ratios of potential recyclable items comprising plastic, paper, glass and metal will increase to over 30% and even nearly 50% until 2020 in some cities. The fraction of plastic waste in 2020 will be up to 29.05%, 21.74%, 28.26% and 17.37% in Shanghai, Hangzhou, Wuhan and Chengdu, respectively. It thus can be expected that recycling ratio will increase with rising income and consumption expenditure[181]. However, even with a marked increase in plastic and paper waste, food waste (organics) will still make up around 50% of the waste stream until 2020, thereby needing a special concern on the treatment. The values in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu will be 51.84%, 50.89%, 53.15%, 49.68% and 50.17% in 2020, respectively.

However, the modelling period of MSW generation model is no longer than 17 years in each city due to the insufficient waste information, limiting the accuracy of the model to some extent. Further, the model fails in introducing waste management policies published in recent years or in the future. For example, in Shanghai, the coverage area for implementing waste classified collection reached over 60% by 2006 in the central urban area. It is believed that these kinds of strategies will definitely play important roles in affecting MSW generation in the future.

4.5.3 General waste generation in Japan

Fig. 4−15 plots the volume of general waste generated per capita per year in Japan with (1) PTCON and (2) year (1985−2005). Quantity of waste generation includes amount of planed collection, direct collected amount, and amount of recycled items by company[182]. Consumption expenditure by consumption commodity in each year is obtained from the Ministry of Internal Affairs & Communications in Japan and is adjusted into the fixed year of 2005 (http://www.stat.go.jp/english/index.htm). It is evident that the waste generation increases with the consumption level at the beginning, but the trend is gradually slowing down recently. From the right figure, it is found out that a sudden change happened around the year of 1990.

From the viewpoint of the comparison of consumption level between Japan and Chinese cities, nominal PTCON of Japan (14 010.91 RMB) in 1985 is larger than those in Shanghai, Hangzhou, Guangzhou, Wuhan and Chengdu in 2005 (13773, 13437.6, 14468, 8234.52 and 9642 RMB). Further, the prediction of real PTCON of Shanghai in 2020 (50,262 RMB) is lower than the value of Japan in 1992 (52,318 RMB). It is thus reasonable to speculate that waste generation will still increase in the near future in the selected cities.

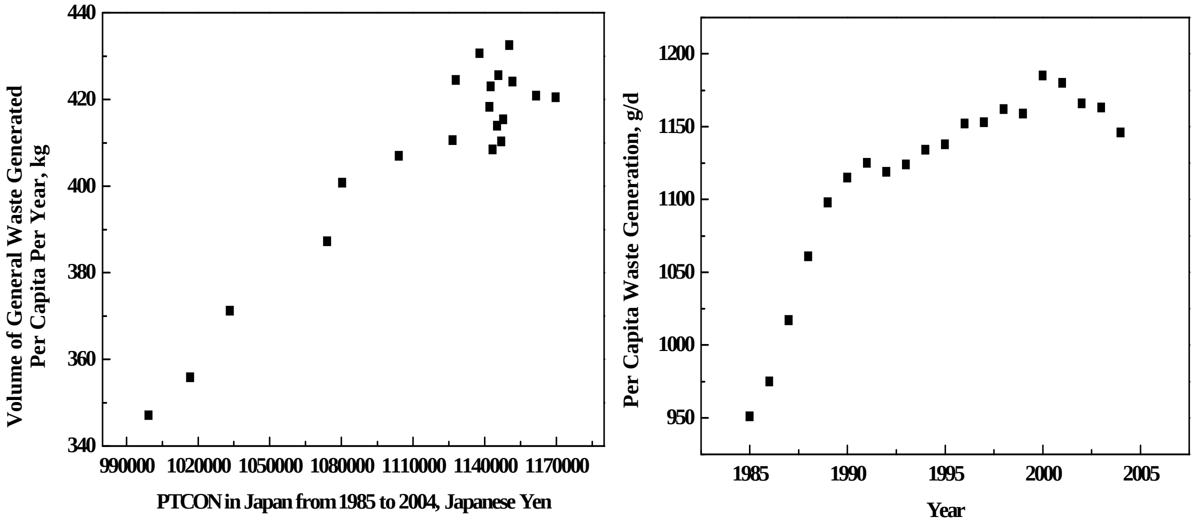


Fig. 4−14 Change in per capita volume of general waste generated in Japan with (1) PTCON (2) year

4.6 Concluding comments

In this chapter, several representative cities with different economic levels are selected from each region to be applied into the integrated MSW module for solving the following issues: (1) to make a medium-term projection of waste generation by each type of waste category; (2) to investigate the regional differences between cities regarding waste generation; (3) to examine the common feature of conversion process of any type of consumed commodity to a corresponding waste category among selected cities. Results clearly denote that integrated MSW module is validated in all selected cities and is reasonable for projecting MSW generation by composition until 2020. The main concluding comments can be discussed from the following aspects.

Firstly, in the analysis of the consumer behaviour model for each city, it is confirmed that ***SAV*** and ***NAGR*** are currently the two common factors affecting the consumer behaviour of a city, except Shanghai. Secondly, the model results provide an effective range and default value of partial generation coefficient of each type of estimated-waste category to corresponding consumption expenditure. Thirdly, the average generation coefficient of total MSW per unit consumption is 0.213 kg/RMB in selected cities, thereby providing a possibility for identifying total MSW generation of other Chinese cities once the current consumption expenditure is known. Fourthly, per capita MSW in 2020 will be 1.24~2.18 times of those in 2008 in each city. Finally, this chapter conducts a comparative analysis of the different impacts of waste measures undertaken by local governments in the cities under consideration. All the waste management policies will provide feasible experiences or valuable lessons to other Chinese cities.

In conclusion, the integrated MSW module has the ability to project the quantity of MSW generated and the corresponding composition on a city level. Further, the effective application of MSW module in selected cities will be essential and effective for model development in other Chinese cities. In addition, the projection of large volume of MSW generated should arouse the consciousness of the municipal decision makers to implement effective government interventions (implementing green consumption, building health lifestyle, et al.) for the promotion of sustainable society. Moreover, the degree of the model accuracy is partly determined by the reliability of the published information and long-term waste records in the future will definitely improve the current approach.

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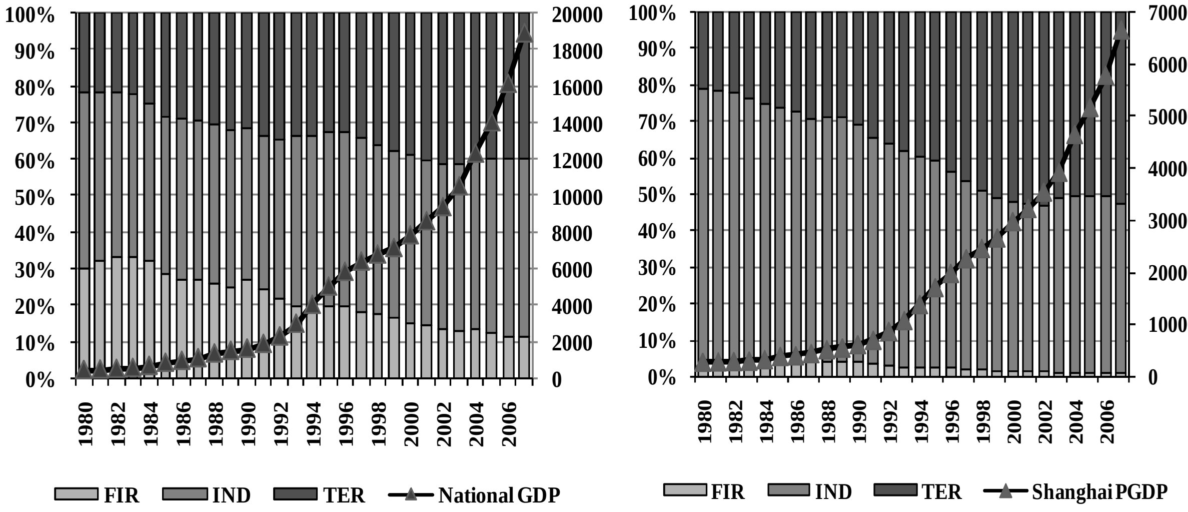
5 ILLUSTRATIVE APPLICATION OF ISW MODULE IN SHANGHAI

The industrial solid waste (ISW) generation module involving regional input-output analysis (IO) has been developed in Chapter 3 for the investigation and projection of volume of each type of ISW generated by industrial sector. Therefore, in this Chapter, Shanghai is selected as a case study for a feasible application of the module on a regional level until the year 2020.

5.1 Background information

5.1.1 Economic growth in China and Shanghai



(a) China (b) Shanghai

Fig. 5−1 National PGDP, Shanghai PGDP and their economic structure, 1980–2007

National per capita GDP (PGDP), Shanghai PGDP and change in economic structure from 1980 to 2007 are presented in Fig. 5−1. Here, economic structure is represented as the percentage share of three industries, as Primary (FIR), Secondary (IND) and Tertiary (TER) industries (agriculture, industry and service industry). Since the start of economic reforms around 1978, China has been undergoing significant transition from a planned economy to a market economy, with rapid economic growth rate nearly 10%. Fig. 5−1 (a) depicts the national PGDP and its economic structure. The percentage share of FIR has decreased from 30.2% in 1980 to 11.3% in 2007. On the other hand, the share of TER has increased from 21.6% to 40.1% during the same period. Moreover, the share of IND was 48.6% in 2007. Therefore, the Chinese economy has shifted from one that is based on agriculture to one that is increasingly dependent on both manufacturing and service industry. Meanwhile, China's economic take-off drives the economic growth in regions. The Shanghai economy has also undergone a record-high economic growth with an average growth rate of 9.56% of the real GDP and 10% of PGDP. Further, the nominal PGDP was up to 8728$ in 2007, about 3.51 folds of national average PGDP. Meanwhile, the economic structure has also experienced a significant change in the form of shift of percentage shares of three industries. In Shanghai Eighth-Fifth City Plan, the development strategy with priority of ‘tertiary, secondary and first industry’ was brought forward. Further, in 1999, by the new strategy for ‘new development of Shanghai’, the authorities proposed to simultaneously develop Secondary and Tertiary industries. The share of IND has decreased from 75.70% in 1980 to 46.59% in 2007. Conversely, the share of TER increased from 21.06% to 52.58% during the same period, thereby promoting a balance of the society that depends on manufacturing and service industries.

Moreover, from the viewpoint of expenditure, final consumption including government consumption (GC) and private consumption (PC) is one of the most important factors contributing to the total GDP of Shanghai, and accounted for 49.36% in 2007, in which PC accounted for 36.55% of GDP. Further, consumption of urban residents occupied 94.77% of total PC in 2007[183].

5.1.2 Input-output table (IO)

In the regional IO analysis, the existing IO tables of Shanghai in the years 1987, 1992, 1997 and 2002 with different industrial dimensions, are obtained from the local Municipal Statistics Bureau (MSB). The classification of sectors in IO tables in and before 1997 is based on *national economic industry classification and its code* (GB/ T4754−1994) while that in 2002 is based on *national economic industry classification* (GB/T4754−2002). The classification standard is different mainly in inner of service industry (TER); therefore, the aggregation of all service industries as one sector minimizes the error (pds24). Further, sectors of mining & washing of coal, extraction of petroleum & natural gas, metal ore mining, and metal ore mining & non-metal minerals mining are summed into one sector (pds2). Therefore, prior to the further analysis, all IO tables were aggregated into the same dimensions, comprising 24 industrial sectors (Industrial Classification and Codes of 2002 Input-Output Table), enumerated in Table 5−1. Further, the nominal gross output of each industry is illustrated in Fig. 5−2. It is evident that besides the biggest share of pds24 (33.98%), pds9, pds14, pds16 and pds23 make great contributions to the total gross output, as 8.01%, 7.67%, 6.82% and 6.89%, respectively.

All tables are valued at producers’ prices and the sectors are ‘commodity sectors’ because of the compilation standard as having at least one similar qualification (similarity in the use of products, their consumption pattern or production technique). However, in order to keep consistency with waste IO table, the terminology of industry sector is still cited.

Table 5−1 Summary of industrial sectors and codes in IO table

Code	Industrial sector	Code	Industrial sector
Pds1	Agriculture, forestry, animal husbandry & fishery	Pd13	General & special purpose machinery
Pds2	Mining (mining & washing of coal; extraction of petroleum & natural gas; metal ore mining; metal ore mining & non-metal minerals mining)	Pds14	Transport equipment
Pds3	Manufacture of food products & tobacco processing	Pd15	Electric equipment & machinery
Pds4	Textiles	Pds16	Electronic & telecommunication equipment
Pds5	Wearing apparel, leather, fur, down & related products	Pds17	Instruments, meters, cultural & office machinery
Pds6	Sawmills & furniture	Pds18	Other manufacturing products
Pds7	Paper & products, printing & record medium reproduction	Pds19	Scrap &waste
Pds8	Petroleum processing, coking & nuclear fuel processing	Pds20	Electricity, steam & hot water production & supply
Pds9	Chemicals	Pds21	Gas production & supply
Pds10	Nonmetallic mineral products	Pds22	Water production & supply
Pds11	Metals smelting & pressing	Pds23	Construction
Pds12	Metal products	Pds24	Tertiary industry

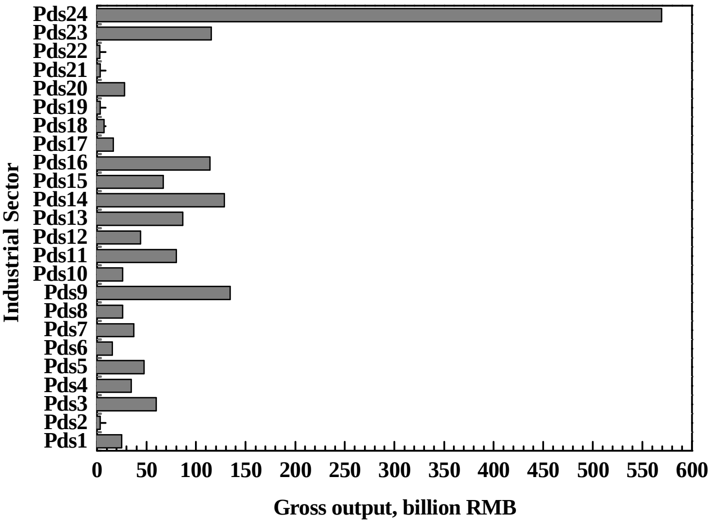


Fig. 5−2 Gross output of each industry in Shanghai in 2002

5.1.3 Current situation of ISW generation

Shanghai generates 1.23% of ISW by 1.41% of total population[184] into whole China, accounting for an average level. Fig. 5−3 represents the volume of ISW generated, treated, stocked, disposed and discharged in Shanghai from 1991 to 2006[185]. Volume of ISW generated in Shanghai increases at an average growth rate of 4% from 1989 to 2007. Further, in 2007, the ISW generation was up to 21.65 million tons with 2.1% of hazardous waste (HW) and the average ratio of ISW utilized was 94.2%. Moreover, the categories of ISW are closely related to the industrial structure of Shanghai. The principal categories of ISW are HW, smelting residue (SR), coal-burning powder (CB), slag (SL), coal stone (CS), gangue (GA), radioactive wastes (RA) and others (OT). OT waste includes industrial garbage, sludge, dust and other waste generated in industrial process. Volume of ISW generated by waste category in Shanghai from 1992 to 2006 is illustrated in Fig. 5−4. During the past years, the total ISW generation has an apparent increase trend and each waste category exhibits similar trends during the same period. In 2006, the largest component of ISW was SR, which constituted 36.84% of the total. The other major components were CB (24.53%), OT (20.70%) and SL (6.35%). These four categories made up 88.41% of the total volume of ISW[186]. Moreover, construction waste is not considered as a part of ISW generation, and there is no waste generation arising from the industry of pds19 (Scrap &waste industry).

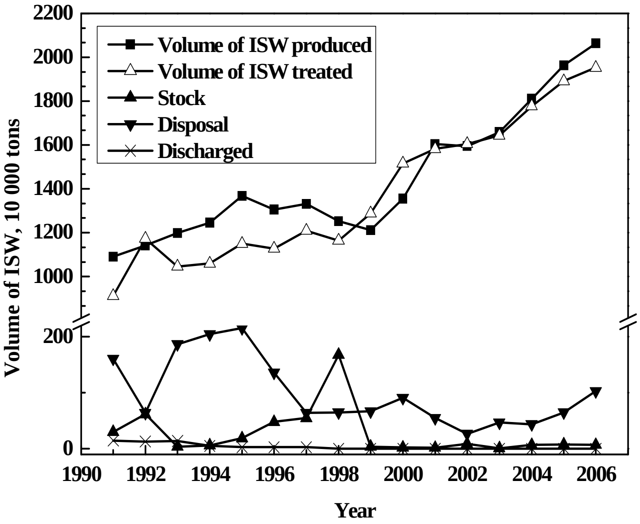


Fig. 5−3 Volume of ISW generated, treated, stocked, disposed and discharged

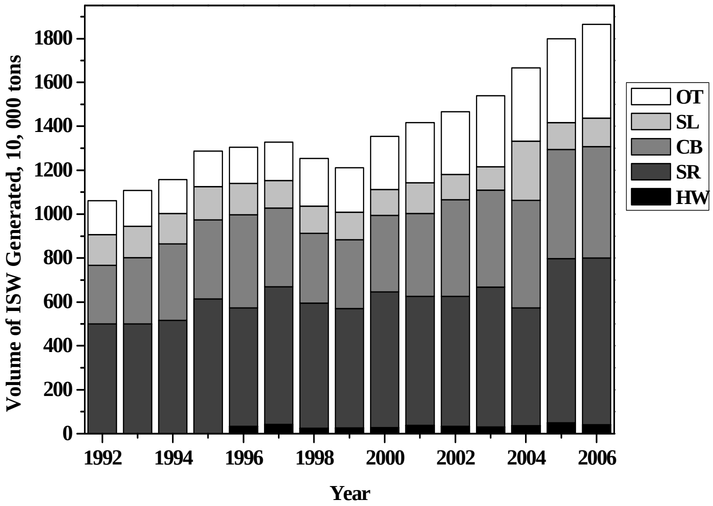


Fig. 5−4 Volume of ISW generated by each waste category in Shanghai

5.2 Macro–economic model of Shanghai

5.2.1 Characteristics of variables in the model

The main economic variables in the Shanghai macro-economic model are listed in Table 5−2, with the exogenous variables marked separately. To calibrate the model, available economic indicators, from the years 1981 to 2005, are obtained from the Shanghai MSB and the international database (International Monetary Fund 2007: International Financial Statistics, IFS[187]). The deflators of EXC and MC quote values on the national level because of the lack of information pertaining solely to Shanghai. Further, deflator of GC is calculated through the CPI and deflator of PC. Moreover, the variables denoting world trade refer to the same data as Kabeyama[130]. The exchange rate of the dollar to RMB is obtained from China Statistical Yearbook and the value in 2008 onwards is assumed fixed. Therefore, with economically meaningful equations and the given exogenous variables, the target variables, at 1990 prices, can subsequently be predicted for future years.

The economic statistics published in yearbooks are continually revised and renewed to incorporate periodic census figures on the economy. Shanghai macro-economic model cites the latest data that was published in the 2008 Shanghai Statistical Yearbook. However, the use of this version leads to certain differences in comparison between the economic indicators of the macro-economic model and IO table of 2002. Furthermore, it is usual for the data in a macro-economic model obtained from National Accounts to be conceptualized differently from that in an IO table. In an effort to address the issue of consistency, the IO analysis cites—instead of absolute values predicted from the macro-economic model—the coefficients of extension of the corresponding economic indicators, integrated with the original values in the IO table of 2002. Further, in IO analysis, the balance of GDP and its composition is adjusted by the equation of GDP = k (PC + GC + I + EX – IM + TR) based on the projected value in a target year. Then, each item readjusts based on the calculated k value.

Table 5−2 Characteristics of variables and data source for Shanghai macro-economic model

Variables	Item name	Unit	Exogenous variables
CH_GDP	Real national GDP	in 1990 price	○
CH_GC	Real national government consumption expenditure	in 1990 price	○
CH_L	Labour number in China	person	○
SH_GDP/SH_GDP_N	Real/nominal Shanghai GDP	in 1990 price	
SH_GC/SH_GC_N	Real/nominal government consumption expenditure	in 1990 price	
SH_PC/SH_PC_N	Real/nominal private consumption expenditure	in 1990 price	
SH_EXC/SH_EXC_N	Real/nominal export	in 1990 price	
SH_MC/ SH_MC_N	Real/nominal import	in 1990 price	
SH_I/ SH_I_N	Real/nominal total fixed capital formation	in 1990 price	
FIR/IND/TER	Share of three industries	%	
SH_PDG	Deflator of GDP		
SH_PGC	Deflator of government consumption		
SH_PPC	Deflator of private consumption		
SH_PI	Deflator of fixed capital formation		
SH_PEXC/ SH_PMC	Export deflator/import deflator	in 1990 price	
SH_WPI	Wholesale price index	In 1990 price	
L	Labour number	person	
SH_W	Wage of residents	RMB	
SH_POPT	The total registered population at year end	person	○
POILJ	Crude oil price	US dollars per Barrel	○
SH_EXR	Exchange rate of the dollar to RMB		○
PEW*	World industrial product export price index (average in fiscal year)	in 1990 price	○
TWM*	Real world trade (average in fiscal year)	billion dollar, 1990	○

* It is provided by 2006 econometrics • macroeconomectrics workshop (Economate database)

5.2.2 Model development and structure

Fig. 5–5 depicts the schematic figure of the model. The model roughly consists of the following five blocks: real/nominal expenditure, deflator, price, wage & labour. There are 27 behavioural equations and 8 exogenous variables. The model centres around the GDP and its composition at the 1990 prices, and includes a ratio projections of three industries (FIR, IND and TER). The influence of the national economy on Shanghai is gauged by the relevance of the national GDP and GC in the individual behavioural equations. Further, the structure and performance of the key behavioural equations are represented following the figure. In the equation for TER, DUM90 denotes the 'Eighth-Fifth City Plan' which was discussed in section 5.1.1.

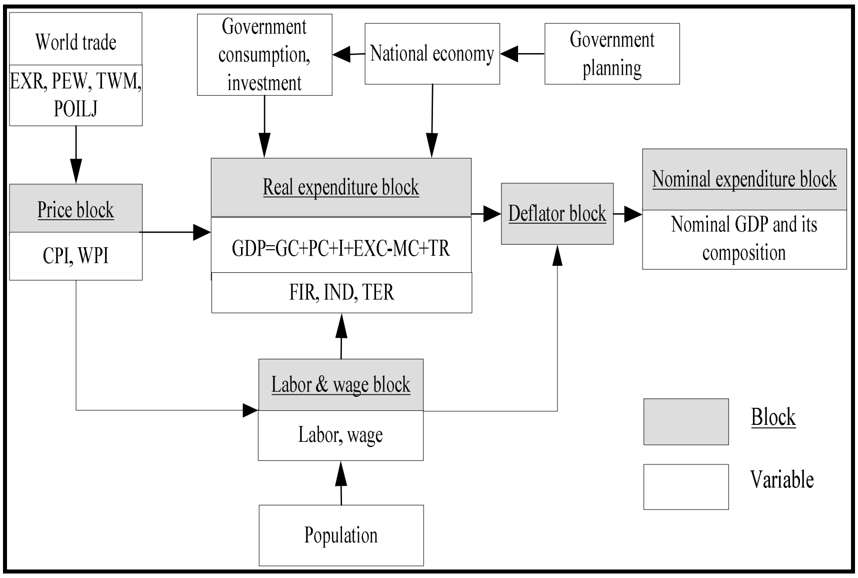


Fig. 5−5 Schematic figure of Shanghai macro-economic model

Structural equations in detailed are as follows (1981−2005) ($p^{*} < 0.01$; $p^{**} < 0.05$):

----------Real expenditure block and its composition

1. SH_GDP

$$\mathrm{LOG(SH\_GDP/SH\_L)} = 4.639 + 0.0347 \times \mathrm{LOG(SH\_I/SH\_L)} + 0.496 \times \mathrm{LOG(SH\_GDP/SH\_L)(-1)} + 0.527 \times \mathrm{LOG(CH\_GDP/CH\_L)}$$

(3.174*) (0.870) (3.636*) (3.188*)

DW = 2.085; AdR^2 = 0.996; F = 2 128.32

2. SH_GC

SH_GC = – 5.25 × 10^8 + 0.00359 × CH_GC + 1.038 × SH_GC(–1)

(–1.240) (1.437) (15.460*)

DW = 2.336; AdR^2 = 0.997; F = 3 362.98

3. SH_PC

SH_PC = 3.60 × 10^9 + 0.107 × SH_GDP + 0.6392 × SH_PC(–1)

(2.447**) (3.294*) (4.482*)

DW = 1.403; AdR^2 = 0.998; F = 5 170.79

4. SH_I

SH_I = 2.75 × 10^9 + 0.115 × SH_GDP + 0.755 × SH_I(–1)

(1.049) (2.367**) (5.489*)

DW = 0.890; AdR^2 = 0.976; F = 463.90

5. SH_EXC

SH_EXC = 3.6 × 10^6 × TWM – 6.58 × 10^{10} × SH_PEXC/(PEW × SH_EXR) + 1.111 × SH_EXC(–1)

(2.395**) (–3.370*) (16.093*)

DW = 1.897; AdR^2 = 0.987; F = 774.70

6. SH_MC

SH_MC = 0.222 × SH_GDP – 1.78 × 10^{10} × (SH_PWC/SH_WPI) + 0.952 × SH_MC(–1)

(2.710**) (–1.944) (10.443*)

DW = 1.518; AdR^2 = 0.985; F = 742.90

7. SH_TR

SH_TR = – 9.66 × 10^9 + 0.00604 × CH_GDP + 0.833 × SH_TR (–1)

(–1.091) (1.814) (6.671*)

DW = 1.011; AdR^2 = 0.951; F = 224.63

----------Nominal expenditure block

8. SH_TR_N

SH_TR_N = 9.712 × 10^9 + 1.372 × SH_MC_N – 1.360 × SH_EXC_N

(2.518**) (13.639*) (–11.529*)

DW = 0.811; AdR^2 =0.950; F = 217.894

----------Price block

9. SH_WPI

$SH\_WPI = 3.502 + 0.428 \times SH\_PMC + 0.474 \times SH\_WPI(-1)$

(0.494) (2.801*) (3.275*)

DW = 0.437; AdR^2 = 0.956; F = 250.011

10. SH_CPI

$SH\_CPI = -7.246 + 0.413 \times SH\_WPI + 0.264 \times SH\_PC + 0.49221 \times SH\_CPI(-1)$

(–3.669*) (11.910*) (4.777*) (9.029*)

DW = 1.126; AdR^2 = 0.998; F = 4952.82

----------Deflator block

11. SH_PGC

$SH\_PGC = 3.164 + 0.174 \times SH\_WPI + 0.865 \times SH\_PGC(-1)$

(0.620) (1.795) (10.005*)

DW = 1.302; AdR^2 = 0.977; F = 484.486

12. SH_PPC

$SH\_PPC = 2.651 + 0.3108 \times SH\_CPI + 0.6969 \times SH\_PPC(-1)$

(0.745) (2.837*) (6.151*)

DW = 1.317; AdR^2 = 0.992; F = 1466.01

13. SH_PI

$SH\_PI = 3.4461 + 0.2003 \times SH\_WPI + 0.8573 \times SH\_PI(-1)$

(0.705) (1.889) (10.657*)

DW = 1.225; AdR^2 = 0.985; F = 749.950

14. SH_PEXC

$SH\_PEXC = -7.300 + 0.157 \times (PEW \times SH\_EXR) + 0.405 \times SH\_PEXC(-1)$

(–1.830) (9.373*) (6.487*)

DW = 1.498; AdR^2 = 0.987; F = 875.412

15. SH_PMC

SH_PMC = 1.861 + 0.115 × (PEW × SH_EXR) + 0.115 × (POILJ × SH_EXR) + 0.343 × SH_PMC(–1)

(0.642) (9.290*) (5.369*) (5.022*)

DW = 1.604; AdR^2 = 0.989; F = 723.215

----------Labor & wage block

16. SH_W

SH_W = – 1.55 ×10^{10} + 211.443 × (SH_GDP/SH_L) + 6.26 ×10^{7} × SH_PC

(–7.682*) (9.014*) (1.653)

DW = 1.509; AdR^2 = 0.981; F = 596.488

17. SH_L

SH_L = – 243.119 + 2.75 × 10^{-5} × SH_POPT + 0.8541 × SH_L(–1)

(–1.196) (1.236) (5.328*)

DW = 2.415; AdR^2 = 0.856; F = 69.152

----------Composition of economy

18. TER

TER = 0.03925 + 0.8820 × TER(–1) + 0.02574 × DUM90

(134.985*) (–4.163*)

DW = 1.312; AdR^2 = 0.992; F = 1356.86

19. IND

IND = 0.01372 + 0.9583 × IND(–1)

(0.938) (39.536*)

DW = 1.142; AdR^2 = 0.986; F = 1563.07

----------Definition equations

20. SH_PDG = SH_GDP_N/SH_GDP × 100

21. SH_PC_N = SH_PC × SH_PPC/100

22. SH_GC_N = SH_GC × SH_PGC/100

23. SH_I_N = SH_I × SH_PI/100

24. SH_EXC_N = SH_EXC × SH_PEXC/100

25. SH_MC_N = SH_MC × SH_PMC/100

26. $SH\_GDP\_N = SH\_GC\_N + SH\_PC\_N + SH\_I\_N + SH\_EXC\_N – SH\_MC\_N + SH\_TR\_N$

27. $FIR + IND + TER = 1$

5.2.3 Model testing

Although considerable changes have occurred in the Shanghai economy over the last two decades (1981−2005), the regional model fits the historical records reasonably well and provides an acceptable reproduction, as denoted in Fig. 5−6. Further, Table 5−3 lists the results of partial test and final test for simulation analysis. Apart from ‘I’ and ‘EXC’, the partial tests of all economic indicators are within 5%, demonstrating an acceptably accurate result. Although the values of the final test are higher than those of the partial test, these values are still meaningful—showing that the overall model is good enough for estimation and future forecasting. In addition, for the identification of structural equations, the number of total endogenous variables in the model is G=19, and the number of predetermined variables in the model including exogenous variables is K=27; therefore, all the equation are considered to be over-identified.

Table 5−3 The partial test and final test for simulation analysis

Economic indicator	GDP	PC	GC	I	EXC	IND	TER	CPI
Partial test (%)	0.00	2.75	4.56	12.17	6.71	1.32	1.20	1.90
Final test (%)	4.98	4.36	4.33	18.73	15.09	2.04	2.70	8.07

5.2.4 Different scenarios of economic growth

There are several assumptions for the projections of Shanghai economy by using macro-economic model of Shanghai. Firstly, the predictions of Chinese GDP figures refer to the results estimated by the Chinese Academy for Environmental Planning (CAEP) under different conditions of economic development[131], as shown in Table 5−4. In which, Chinese GDP is projected on the basis of the assumptions of total factor productivity rate (TFP). Under the average lower economic growth rate of Chinese GDP, the predictions, project the GDP of the year 2000 to quadruple by 2020, thereby meeting the objectives of ‘building a well-off society in an all-round way’, as proposed in the Sixteenth National Congress Report (http://xibu.tjfsu.edu.cn/elearning/lk/16en.htm). On the other hand, under the higher economic growth rate, the predictions project the GDP of the year 2000 to quadruple by 2017, three years ahead of schedule.

In the macro-economic model, the specified exogenous variable for Shanghai—the total registered population at year end (POPT)—refers to the projected value in the current population policy, tabulated in the 2002 Population and Family Planning Yearbook of Shanghai. Three scenarios are considered in terms of the total fertility rate (TFR)[188]. Therefore, given all exogenous variables, predictions of major economic indicators can be achieved.

Table 5−4 Assumption of the average economic growth rate, %

Year	Low rate (%)	Benchmark rate (%)	High rate (%)
2006–2010	7.3	8	8.5
2011–2015	6.8	7.5	7.9
2016–2020	6.4	7	7.2
Growth rate of TFP (%)	2.2	2.6	3

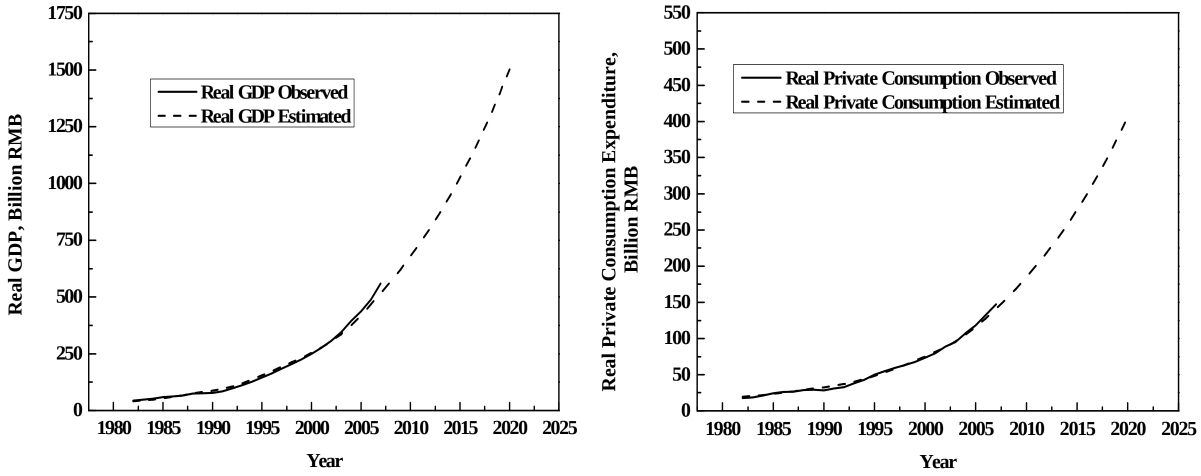


Fig. 5−6 Projection of economic indicators of GDP and PC, 1981−2020

Fig. 5−6 depicts the change trend of GDP and PC under the lower growth scenario of Chinese economy and current population policy as two projected examples. The predicted results in Shanghai signify that the average economic growth rate will be 10.41% during the period 2006–2010; then, this rate will decline to 8.41% during the next decade. However, under the benchmark rate of Chinese economy, the predicted economic growth rate will be 10.15% during the period 2006–2010; then, this rate will decline to 8.88% during the next decade. Moreover, the percentage share of three industries as FIR, IND and TER will be 4%, 41% and 55% in 2020, almost the same with that in 2005. Then, the results for projecting ISW generation is calculated under benchmark rate of national GDP growth.

5.3 Industrial restructuring by updating IO tables

5.3.1 Change in private consumption

Previous research has been utilised while applying a consumption expenditure model onto the urban areas of Shanghai in order to analyze the changes in consumer behaviour and the influences on consumption patterns in Chapter 4. Based on the consumer behaviour model, it is believed that '*saving rate towards consumption expenditure*' (***SAV***) and the '*average number of persons per household*' (***ANPH***) are two prominent explanatory variables that affect consumer behaviour in Shanghai greatly. The projections of two variables are also conducted in Chapter 4. Therefore, the consumption pattern denoting percentage share of each consumption category to total consumption from 2005 to 2020 is projected and depicted in Fig. 5−7. It is confirmed that with economic growth, the consumption structure will change considerably and advance to a more diverse framework in the coming decade. From 2002 to 2020, the share in food consumption will decline greatly—by 32.57%. Engle coefficient is almost the same with that of Japan between 1986 and 1987. In contrast, the shares of the education and transportation sectors will witness an apparent increase of 27.80% and 81.22%, respectively, as a result of the increasing emphasis on children's education and the improvements in transportation vehicles. Further, with the increasing attention being given to health in Shanghai, the expenditure that people incur on medicine and medical services will undergo great increase of 12.22%.

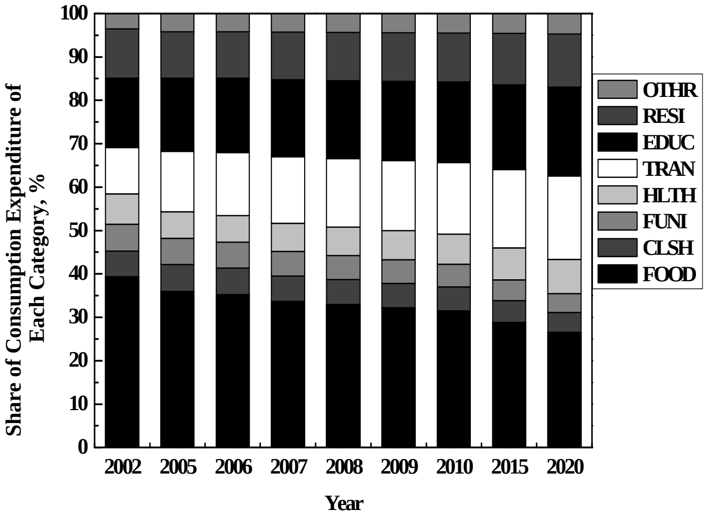


Fig. 5−7 Change in consumption pattern in a target year, %

Finally, quantitative changes in the consumption pattern are reflected in the corresponding sectors of the IO table by GB/T4754-2002. The research flow from consumption to corresponding industrial sectors is the same with that in sensitivity analysis. Further, the change ratio of share of consumption on each category is applied into corresponding sectors. Then, assuming consumption patterns of residents in rural area are fixed in the base year of 2002, the converter vector of PC in a future year across all the residents is readjusted and expressed, as demonstrated Table 5−5. Finally, compiling the predicted absolute value of PC and the adjusted converter, the new vector of PC is conducted.

Table 5−5 Change in converter of PC in a target year, %

	2002	2006	2007	2008	2009	2010	2015	2020
pds1	8.24	8.66	8.72	8.74	8.77	8.79	8.90	8.99
pds2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
pds3	17.73	16.87	16.33	16.07	15.80	15.54	14.58	13.70
pds4	1.17	1.23	1.24	1.25	1.25	1.25	1.27	1.28
pds5	4.92	5.39	5.18	5.10	5.01	4.92	4.54	4.25
pds6	1.09	1.10	1.06	1.04	1.02	1.00	0.93	0.87
pds7	2.39	2.68	2.79	2.83	2.88	2.93	3.11	3.26
pds8	0.46	0.48	0.48	0.49	0.49	0.49	0.49	0.50
pds9	3.70	3.89	3.92	3.93	3.94	3.95	4.00	4.04
pds10	0.51	0.53	0.54	0.54	0.54	0.54	0.55	0.55
pds11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pds12	0.49	0.51	0.52	0.52	0.52	0.52	0.53	0.53
pds13	0.19	0.20	0.20	0.20	0.20	0.21	0.21	0.21
pds14	2.53	1.93	2.03	2.08	2.13	2.18	2.37	2.54
pds15	2.09	2.20	2.22	2.22	2.23	2.24	2.26	2.29
pds16	3.99	3.07	3.23	3.31	3.39	3.46	3.76	4.02
pds17	0.68	0.71	0.72	0.72	0.72	0.72	0.73	0.74
pds18	1.24	1.31	1.31	1.32	1.32	1.33	1.34	1.36
pds19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pds20	2.03	1.32	1.28	1.26	1.25	1.23	1.15	1.10
pds21	0.86	0.31	0.32	0.32	0.33	0.33	0.35	0.36
pds22	0.52	0.12	0.13	0.13	0.13	0.13	0.13	0.14
pds23	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.11
pds24	44.98	47.28	47.59	47.73	47.88	48.02	48.59	49.14

5.3.2 Change in export and transport compositions

Fig. 5−8 represents the change in percentage shares of export and transport to other regions by each industry in past years. Based on the trend of such changes, the four top sectors with relatively high shares that changed the most were as pds4, pds7, pds16, pds17 (98.48%, 83.00%, 64.25% and 23.78%, respectively) in the export composition. Further, in the structure of transportation to other regions in China, two sectors named pds9 and pds24, are considered to have undergone the most change in this regard. In addition, from 2007, the government has published a series of policies to cancel or lower the tax rebate on the export, such as iron and steel, textile and other primary-product-producing sectors (Ministry of Finance People's Republic of China). New export policies will further encourage the export structure to shift away from the primary and related commodities to capital- and technology-intensive products, and greatly affect the share of the above-mentioned sectors, especially pds4.

In the current paper, the forecasting methods of arriving at the shares of above sectors are different in each case. Projections of data related to 'pds4' and 'pds7' use the average decreasing ratio calculated from historical records of 4 years; projections pertaining to 'pds17' use the method of regression analysis of OLS. Further, because of the strong upward trend of 'pds16', the export share of this sector is assumed to be steady at 40% in 2020: a reasonable prediction is achieved by using the logistic function of the historical data for this sector. The forecasts with respect to transport structures for pds9 and pds24 are projected by the method of regression analysis as well. Table 5−6 summarizes the predictive methods for above industries and Table 5−7 tabulates the predictions. Under the incumbent policies, the shares of pds4 and pds9 will decline in the next decade. Further, Fig. 5−9 illustrates the forecasts of export share of each sector to total sectors.

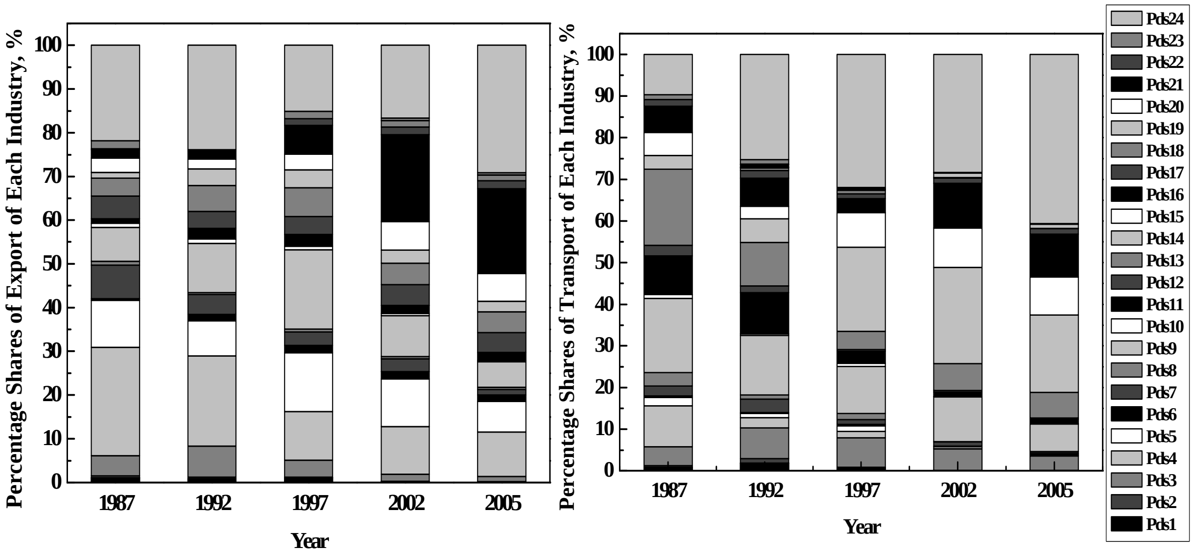


Fig. 5−8 Percentage shares of each industry of (a) export, and (b) transportation to other regions

Table 5−6 Prediction models for each industrial sector

Category	Industry code	Prediction model	
Export	Pds4	Average decrease ratio	0.9476
	Pds7	Average decrease ratio	0.9367

	Pds16	Logistic model	$f(x) = 40 \times (1 - 1/(1 + \exp(0.207x - 414.9788)))$
	Pds17	OLS method	$f(x) = -233.182 + 0.117x$; Ad$R^2 = 0.82$; F = 14.777;
Transport	Pds9	OLS method	$f(x) = -0.026x + 0.2$; Fix the value in 2010
	Pds24	Logarithm curve	$f(x) = 27.915\ln(x) - 211.86$; Ad$R^2 = 0.81$

Table 5−7 Projections of the respective shares of the sectors in terms of export and transport, %

Category	Industry code	2002	2005	2010	2015
Export	Pds4	10.855	9.236	7.058	5.393
	Pds7	2.859	2.350	1.694	1.221
	Pds16	19.950	22.579	31.398	36.454
	Pds17	1.761	2.207	2.794	3.381
Transport to other regions	Pds9	0.107	0.066	0.046	0.046
	Pds24	0.283	0.406	0.458	0.528

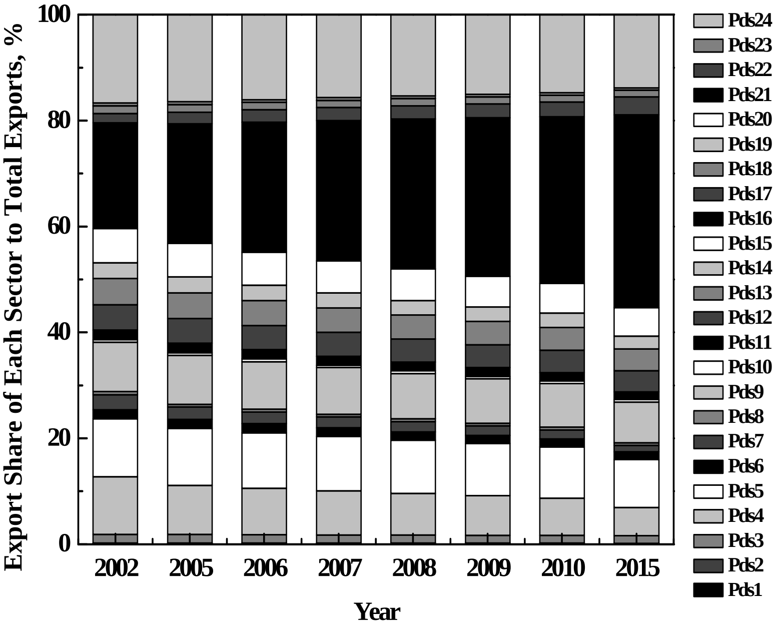


Fig. 5−9 Predicted export share of each sector to total export, %

5.4 ISW generation model

5.4.1 Sensitivity analysis

Fig. 5−10 illustrates the relationship between the index of power of dispersion (PD) and sensitivity coefficient (SC) of each sector based on 2002 IO table. Dotted lines with values of ‘1’ separate the whole area into four quadrants. The first quadrant denoting that the values of PD and SC are both above 1 comprises three industries as pds9 (chemicals), pds11 (metals smelting & pressing) and pds16 (electronic & telecommunication equipment), thereby illustrating the important influence on economic growth of Shanghai.

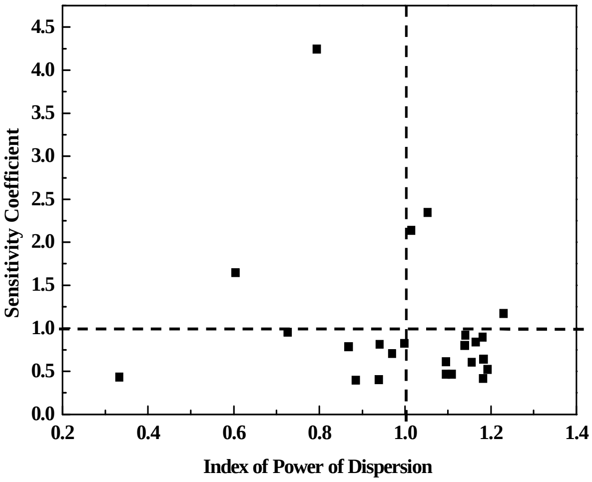


Fig. 5−10 Relationship between PD and SC

Further, sensitivity analysis is carried out to investigate the influence of change in consumption expenditure of each consumed category on ISW generation by waste category. Firstly, to determine the industries related to each type of consumption category and share of each corresponding industry based on the distribution of consumption among the sub consumption category. For example, consumption expenditure on TRAN is made up of consumption on transportation and communications and the ratio of respective expenditure was 1:1 in 2002 in Shanghai. Further, electricity, fuel and water fee constitute the consumption expenditure in RESI, with a percentage share of 52.93%, 31.45% and 15.63% in 2002, respectively[189]. Then, using IO analysis to explore the change in gross output of each industry when a per yuan increase in each consumption category happens; thereafter, integrating the ISW generation coefficient per unit gross output to analyze the change in ISW generation by category, as partial ISW generation coefficient per unit consumption. The change in gross output of each industry is illustrated in Eq. (5–1) and A_{2002} denotes the input coefficient in 2002. The results regarding partial ISW generation coefficient per unit consumption for each waste category are tabulated in Table 5−8 with RA assumed to be negligible.

$$\Delta X_{pds} = (I - A_{2002})^{-1} \times \Delta FD_{pds}, \quad \Delta Y_{pds} = \hat{D}_{pds} \times \Delta X_{pds} \tag{5–1}$$

Table 5−8 Partial ISW generation coefficient per unit consumption

Consumption category	Related industry	ISW generation by waste category per unit consumption (g)							
		Total	HW	SR	CB	SL	CS	GA	OT
FOOD	pds3	76.41	0.92	4.79	12.63	11.82	7.95	15.31	22.98
CLSH	pds5	76.16	1.36	6.76	14.51	12.05	10.11	20.15	11.22
FUNI	pds6	82.28	1.34	8.18	15.21	11.00	10.98	22.01	13.56
EDUC	pds7	106.54	1.73	9.71	20.51	20.21	11.81	24.31	18.26
TRAN	pds14 &pds16	93.89	1.32	17.20	13.97	9.47	11.70	27.35	12.87
HLTH	pds9	148.30	5.35	9.31	25.00	23.25	19.11	36.98	29.27
RESI	pds20, pds21 & pds22	292.58	1.12	5.64	108.40	34.64	46.51	78.22	18.03

Results show that increase of unit consumption on RESI will cause the greatest generation of ISW because of corresponding increase of gross output of pds2 and pds20. Further, per increase of RMB in HLTH and EDUC induces great generation of ISW as well. The range of partial generation coefficient of total ISW is 76.16~292.58 g/RMB with an average value of 125.17 kg/RMB.

5.4.2 Estimation of volume of ISW generated

Compiling the fixed waste generation coefficient of each sector on a national level for the year 2002, and the existing gross output by industry in the existing IO tables for Shanghai, the estimated volume of ISW generated can be calculated for comparison with the waste statistics. The estimated volume is about 1.5 times that published in the yearbooks in 1997 and 2002, respectively. One of the reasons for the error is that the average level of technology on a national level is lower than that for a developed city such as Shanghai: this leads to a higher ISW generation coefficient. Therefore, using the ISW generation coefficient in national level leads to an unavoidable error. Adjusting the ISW generation coefficients to approach the real values will be greatly useful for improving the estimation result. This will, however, demand further work, which is beyond the scope of this thesis.

5.4.3 Projection of volume of ISW generated

The projected volumes of total ISW generated until the year 2020 are plotted in Fig. 5−11, not considering the adjustment of input coefficient. Economic growth based on the development of industry will result in progressively greater volumes of ISW as we move from 2002 towards 2020. The projected volume of ISW generation in 2005 and 2006 is 1.88 and 2 times of respective actual value in the same year. The total ISW generation in 2010, 2015 and 2020 will be 2.07, 2.83 and 4.12 folds, respectively, that of the 2002 levels. Further, the different shift of alternative technologies among input structure and/or technological innovation affect the mutual proportion of each industrial sector. As a result of the increased learning of consumer propensities towards transportation and changes in export composition, in 2020, the gross outputs of pds16 and pds17 will be up to 8.78 and 7.83 times, respectively, of the 2002 levels. Meanwhile, the indices related to the power of dispersion of these sectors are both higher than 1 (1.230 and 1.156), denoting a big influence on the production of other sectors. The government should pay more attention to such sectors while planning its waste reduction policy. Further, although the contribution of pds24 to the total ISW generation is small (1.23% in 2020), the sector sees a significant increase in its share of the gross output: owing to increasing consumer propensities towards the areas of education, health and transportation, the gross output of pds24 in 2020 is 5.41 times that of the 2002 levels.

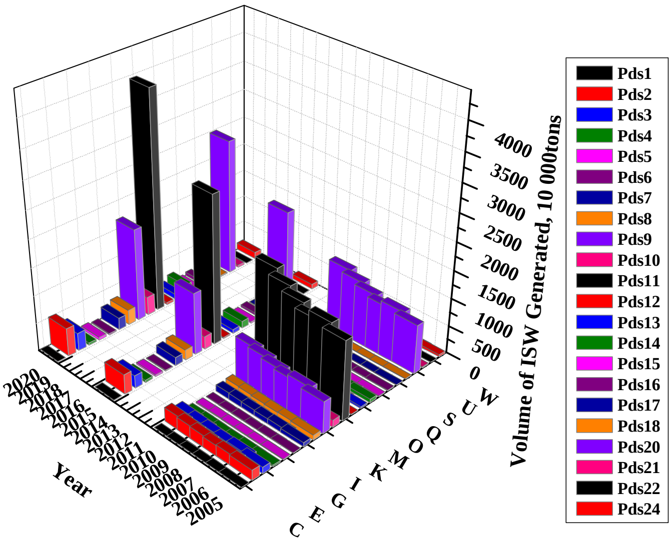


Fig. 5−11 Volume of ISW generated by each sector, 2002−2020

Fig. 5−12 describes as an example one of the predictions related to ISW generation by industry of all categories in 2020, and the comparison of such an estimated result with the corresponding 2002 figure. Among all waste categories, the volume of RA is assumed to be negligible because of a tiny share (0.01%). Further, three aspects are addressed. Firstly, the volume of each type of waste will increase over the next two decades. Among the waste categories, CS has the greatest increase ratio—3.41 times by 2020—as a result of the development of the mining industry, followed by GA, which will increase 3.24 times. Secondly, the adjustment of industrial structure in the future will lead to significant change in the respective shares of each waste category to total ISW. Percentage share of SL and OT into total ISW generation have reduced from 17.16% and 18.58% in 2002 to 16.50% and 18.13% in 2020, respectively. On the other hand, respective share of SR waste increases from 22.20% to 22.84% from 2002 to 2020. Thirdly, it is relatively simple to identify the industrial sector that generates the largest contributions to each type of ISW. For example, in 2020, the largest component of SR will be generated by pds11, at about 90% of total volumes. In addition, pds11 also generates the majority of the GA production (70%). On the other hand, the accelerated development of one of six dominant industries, the auto manufacturing industry, will further promote the development of pds11. Moreover, pds20 is one of the most important factors in CB production, moving up to 79% by 2015. Therefore, for preventing and reducing the generation of SR and GA, it will be necessary to bring about technological innovations in pds11 with immediate effect.

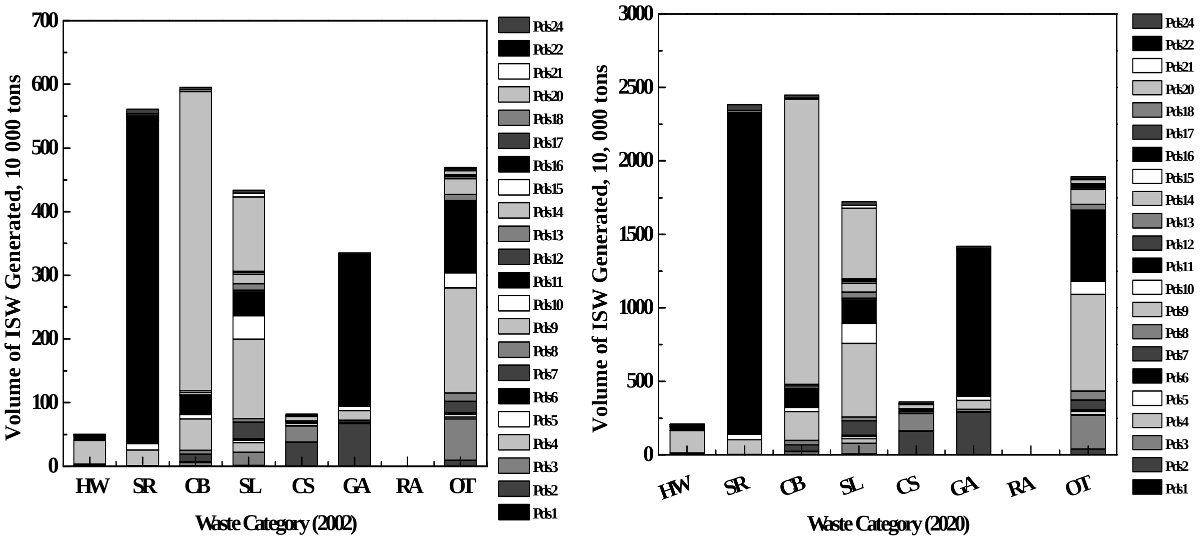


Fig. 5−12 Volume of ISW generated by industry in 2002 and projection in 2020

In order to investigate the relationship between economic growth, industrial restructuring, and ISW generation, Fig. 5−13 represents the unit ISW generation per gross output from 2002 to 2020. Gross output indicates gross value added (net output, GDP) plus intermediate consumption, as expressed in the IO table. Economic growth based on the development of industry will result in progressively less volumes of ISW as we move from 2002 towards 2020. From the figure, the unit ISW generation per gross output is gradually declining from the year 2002 to 2020, as from 0.16 in 2002 to 0.14 tons/10 000RMB in 2020. It emerges that economic growth is no longer the sole factor affecting ISW generation; the influence of industrial restructuring is becoming progressively more important.

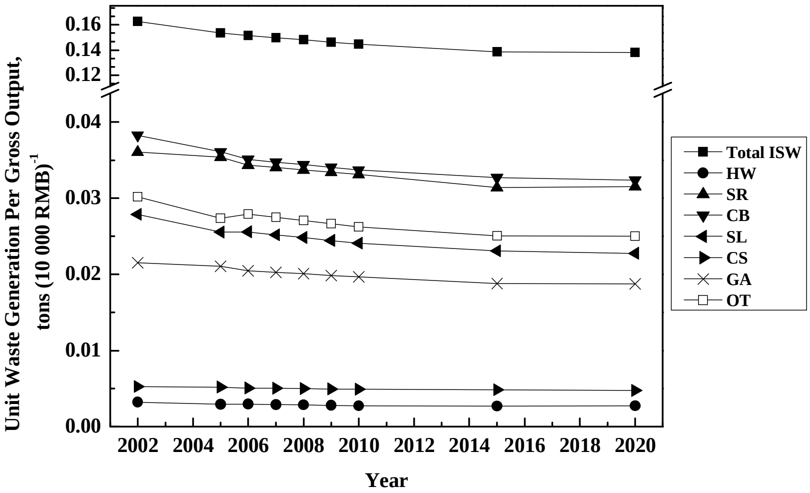


Fig. 5−13 Projected unit ISW generation per gross output, tons/10 000 RMB

5.4.4 Change in ISW generation coefficient

Table 5−9 Projections of ISW generation coefficients of three sectors

Industrial sector	1992	1995	1997	2002	Prediction method
Pds11	3.579	1.707	1.822	1.161	$y = 8.5E + 88e^{(-0.102 \times \text{year})}$; $R^2 = 0.84$
Pds20	7.957	4.155	3.338	2.145	$y = 5.1E + 109e^{(-0.126 \times \text{year})}$; $R^2 = 0.94$
Pds9	0.923	0.432	0.373	0.311	$y = 3E + 38e^{(-0.045 \times \text{year})}$; $R^2 = 0.97$

China has the statistics of ISW generation by industrial sector from 1991; however, the dimension and scope of sectors are continually revised. Further, Chinese government started to compile national IO tables from 1987 with changing dimension of sectors as well. However, for industries pds9 (chemicals), pds11 (me smelting & pressing) and pds20 (electricity, steam & hot water production & supply), three top sectors mostly generating ISW, the dimension is the same during the past years. Therefore, the ISW generation coefficients of above three sectors in 1992, 1995, 1997 and 2002 are calculated, as tabulated in Table 5−9. The prediction model for each sector is also listed in the table. Using the projected ISW generation coefficient, the total ISW generation in 2010, 2015 and 2020 will be 1.29, 1.35 and 1.58 times, that of 2002 level, reducing by 62% as compared to the projection value under benchmark. Further, the share of the three sectors will reduce for generating ISW. For example, the respective share of ISW generation of pds9, pds11 and pds20 into total ISW generation will reduce from 16.52%, 36.87% and 23.77% to 13.40%, 23.88% and 4.311% as we move from 2002 towards 2020.

5.4.5 ISW generation regarding different scenarios of economic growth

Assuming the population projection is under the current population policy, ISW generation by waste category under economic growth with low rate is projected and tabulated in Table 5−10.

Table 5−10 Projections of ISW generation under low economic growth rate, million tons

	Total ISW	HW	SR	CB	SL	CS	GA	RA	OT
2002	25.28	0.50	5.61	5.95	4.34	0.82	3.35	0.00	4.70
2005	36.92	0.71	8.50	8.67	6.14	1.25	5.06	0.00	6.59
2006	42.18	0.83	9.56	9.79	7.12	1.41	5.69	0.00	7.77
2007	40.58	0.79	9.23	9.42	6.83	1.36	5.49	0.00	7.45
2008	45.30	0.88	10.32	10.53	7.60	1.54	6.15	0.00	8.28
2009	49.86	0.96	11.39	11.62	8.33	1.70	6.78	0.00	9.08
2010	54.42	1.04	12.46	12.70	9.07	1.86	7.41	0.00	9.87
2015	71.80	1.41	16.28	16.94	11.96	2.50	9.72	0.00	12.98
2020	100.05	2.00	22.76	23.55	16.55	3.48	13.57	0.01	18.11

From the comparison among the predictions under different rates of economic growth, it is easily to found out the waste generation increases with the economic development. Under the high economic growth rate, the volume of total ISW that will be generated in 2020 is about 4.50 times of that in 2002. On the other hand, under the low economic growth rate, the total ISW volume in 2020 is about 3.96 times of that in 2002. Therefore, the ISW generation increases linearly with the development of economic growth.

5.5 Relationship between ISW and MSW generation

In 2020, total SW generation (MSW and ISW, not including construction waste) is 4.06 folds as compared to 2002 and the volume of ISW will be about 5.68 folds of MSW generation in 2020, greater than the current 3-4 folds. Further, if taking into account scenario analysis of adjusting ISW generation coefficient of pds9, pds11 and pds20, the total SW becomes 1.93 times compared to 2002 and ISW is 2.18 times of MSW. Based on the previous results, propensity of consumer towards education, transportation and medical service stimulates the development of service industry; the share of gross output of pds24 thus will be up to 5.41 times of that in 2002, greater than GDP development. Moreover, the development of service industry will induce more consumption in education, transportation service in turn with less or without waste transfer. On the other hand, the ISW generation from service industry is although increasing with the share increasing from 0.93% to 1.23% from 2002 to 2020, the absolute share is not apparent. However, the development of service industry will greatly drive the development of other sectors because of a high sensitivity coefficient (4.24), thereby resulting in a big generation of ISW in other sectors. Consequently, the development of service industry will cause much greater generation of ISW than MSW.

In addition, as estimated in Chapter 4, a per yuan (RMB, in 1978 prices) increase in per capita food expenditure results in an average increase of 386g food waste, 8.90g paper, 88.4g plastic, 18.5g glass and 3.31g metal in Shanghai, as total of 505g. Therefore, the MSW generation by total population will be 6739 tons in 2002 (in 1978 price) and 1226 tons (current price). On the other hand, a per yuan increase (current price) in food expenditure induces to increase of 0.92g HW, 4.79g SR, 12.63g CB, 11.82g SL, 7.95g CS, 15.31g GA and 22.98g OT in 2002, as total of 76.41g IS.

5.6 Concluding comments

Projecting ISW generation is difficult for researches because of complex production processes, which in turn are affected by many factors. This chapter launches a reasonable case study at projecting ISW generation of each waste category by industry in Shanghai. It is verified that ISW generation not only arises from economic growth but also, from the onset of industrial restructuring. We regard the present work as a pilot model, which needs considering change in input coefficient in the long-term caused by technological innovation and environmental policies. The principal priorities are as follows: 1) the change in consumption pattern which is estimated in Chapter 4 is introduced in the IO analysis to quantitatively reflect the change in PC among various sectors. 2) It provides an idea for a way to quantitatively analyze industrial restructuring by adjusting the converter that, in turn, helps assess the impact of these changes on sectoral output. 3) A sensitivity analysis is also carried out to investigate the change in ISW generation by increasing per unit consumption expenditure on each consumed category. Per RMB increase of consumption on FOOD results in an average generation of 1226 tons of MSW and 76.41 g ISW. 4) Total SW generation will be 5.68 times compared to the value in 2002. When considering the influence of technological change on change in ISW generation, the value will be 1.93 times, still indicating an increasing change trend.

However, it is investigated that the technological innovation will alter input coefficient in the long-frame, especially for developing countries. More effective methods such as involving the separation of old and new technological layer in each sector should be considered for the improvement of research. Moreover, it can be expected that the model application will improve when local ISW generation coefficients are supported or further research on approaching the real values is carried out. In addition, the research will be more fruitful if the influences of technological innovations on ISW generation coefficient are fully investigated.

5.7 References for Chapter 5

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6 EVALUATION OF GHG EMISSIONS IN WASTE TREATMENT STRATEGIES

Chapter 6 calculates and compares the amount of GHG emitted from different waste treatment strategies including treatment process and final disposal. Further, a scenario analysis based on the forecasts of waste generation in 2015 is carried out.

6.1 Background information

6.1.1 Climate variations in each city

Decomposition of organic component in disposal site (DS) is significantly affected by local climate. Thus, prior to calculating GHG emissions especially in landfill sites, it would be very helpful to investigate the climate conditions of each city, including mean annual temperature (MAT), average relative humidity (H), potential evapotranspiration (PET) and mean annual precipitation (MAP) (Table 6−1). Data is obtained from respective Statistical Yearbook of each city. Based on 2006 IPCC guideline[157], when MAT ≤ 20°C and MAP/PET>1, the climate is defined as wet climate in Boreal and Temperate zone (W). On the other hand, when MAT > 20°C and MAP ≥ 1000mm, it belongs to moist and wet climate in Tropical zone (M); the decomposition of organic matter in a DS is rapid in this condition[190]. There is no available information of PET values in Wuhan and Chengdu. However, the two cities locate in the same latitude zone with Hangzhou and Shanghai, thereby considered as W climate.

Table 6−1 Climatic variations in each city in 2007

	Shanghai	Hangzhou	Guangzhou	Wuhan	Chengdu
MAT	18.2	18.4	23.2	18.5	16.8
H (%)	68.8	71.3	70.8	66.8	76.7
PET (mm)	813.8	1150−1400	—	—	—
MAP (mm)	1290.4	1378.5	1370.3	1023.2	624.5
MAP/PET	>1	>1	—	—	—
Climate zone	W	W	M	W	W

Source: 2008 Statistical Yearbook of each city; '—' denotes no available information

6.1.2 Waste information and current treatment options

Chapter 4 has introduced the MSW information including waste quantity and composition. Table 6−2 tabulates the waste generation rates per capita in different years in each city. It is confirmed that each city has experienced a sharp increase during the last decade with the development of economy.

Table 6−2 MSW generation per capita per year in each city in different years (kg/per/yr)

Year	Waste generation rate per capita per year (kg/per/yr)				
	Shanghai	Guangzhou	Hangzhou	Wuhan	Chengdu
1990	0.59	0.81	0.86	—	—
1995	0.64	1.11	1.21	0.42	0.55
2004	1.30	1.08 (2003)	1.59	1.01	0.81

Note: "—" denotes no available waste information.

Adequate understanding of the characteristics of waste management is effective for the improvement of SWM system. The waste treatment strategies in Chinese cities mainly consist of waste-to-energy combustion (WTE), composting and landfill, in which landfill is the first choice in a majority of cities. Further, the open dumping or simple disposal accounts for a big share. Table 6−3 tabulates the SW treatment options of each city in 2007, in which SAL denotes sanitary landfill. Table 6−4 summarizes the waste treatment options in Shanghai from 2003 to 2007. The first formal WTE plant in Shanghai called Yuqiao plant put into operation in 2002. Another plant named Jiangqiao plant opened in 2005. Incinerators in two plants are both grate furnaces with continuous operation and electricity-generating system (Germany Steinmuller). All the waste was therefore assumed to be sent to disposal sites or open dumping before 2002 in Shanghai. One of main disposal sites—phase IV Laogang DS with 45m landfill depth was transformed and went into operation in 2005 capable of processing over 8000 t/d and producing about160 kWh electricity per ton waste[191].

Table 6−3 SW treatment options of each city in 2007, %

	Shanghai	Guangzhou	Hangzhou	Wuhan	Chengdu
SAL	54.63	71.47	82.33	54.05	92.63
Compost	8.50	0	0	0	0
WTE	15.64	10.88	17.67	0	3.42
Simple disposal	21.23	17.65	0	45.95	3.95

Note: original data is obtained from Department of Integrated Finance Ministry of Construction[192] and has been recalculated by the author.

History of waste treatment options in Guangzhou is summarized in Table 6−5[193] and it is common in Chinese cities. The WTE plant operated starting from 2005 in Guangzhou. In the new government plan, the ratio of incineration will be up to 62.5% with 29.3% of landfill and 8.2% of composting in 2010[34].

In Hangzhou, the biggest DS for disposing most of SW in urban area is Tianziling DS. The site opened in 1992 in strict accordance with stratified operation unit and the basic flow is level-compact-cover. Further, the landfill gas (LFG) recovery system was in use from October 1998 and generated energy with two 970kw power units. On the other hand, WTE plant equipping with fluidized bed with treatment capacity of (2 × 300t/d + 200t/d) started to operation around the year 2002. Further, fly ash and incineration residues account for 18−20%. In which, fly ash is usually sent to cement plant and residues are used for construction materials. Another plant was built in July 2004 with the treatment capacity being 450t/d−1050t/d, 7.5MW turbo generator and gas removing system. Therefore, before the year of 2002, all the MSW is supposed to be sent to DS or open dumping as the case in Shanghai.

In Wuhan, currently all the waste is sent to DS with a high rate of open dumping or simple disposal. On the other hand, a small amount (3.42%) of MSW is incinerated in Chengdu.

Table 6−4 Waste treatment options in Shanghai from 2003 to 2007

Shanghai	Harmless treatment plants				Percentage share (%)			
	Sum	SAL	Compost	WTE	SAL	Compost	WTE	Simple disposal
2003	12	4	2	2	3.09	3.14	5.60	88.16
2004	7	3	2	2	2.59	6.38	11.25	79.78
2005	5	2	1	2	11.21	8.07	16.46	64.25
2006	4	1	1	2	31.72	8.80	17.39	42.09
2007	4	1	1	2	54.63	8.50	15.64	20.83

Table 6−5 History of waste treatment in Guangzhou

Year	History of waste treatment
1949−1970	Most of garbage is sent to rural area for producing fertilizer
1970−1986	Open dumping
1987−1990	Laohulong DS was built with coarse equipment

1989−2003	Datianshan DS started to operate with the capacity of 2200t/d, 2 compactors, 1 excavator and 6 bulldozers. Likeng DS was also in use from the beginning of 1990s.
2002	Xingfeng DS, 6300t/d, double-layer HDPE impermeable membrane technology; LFG is in flare or generating energy
2005	Likeng waste-to-energy combustion plant, 1000t/d (planning)

6.2 Emission of GHG in waste treatment strategies

6.2.1 CH_4 emissions from DS of each city

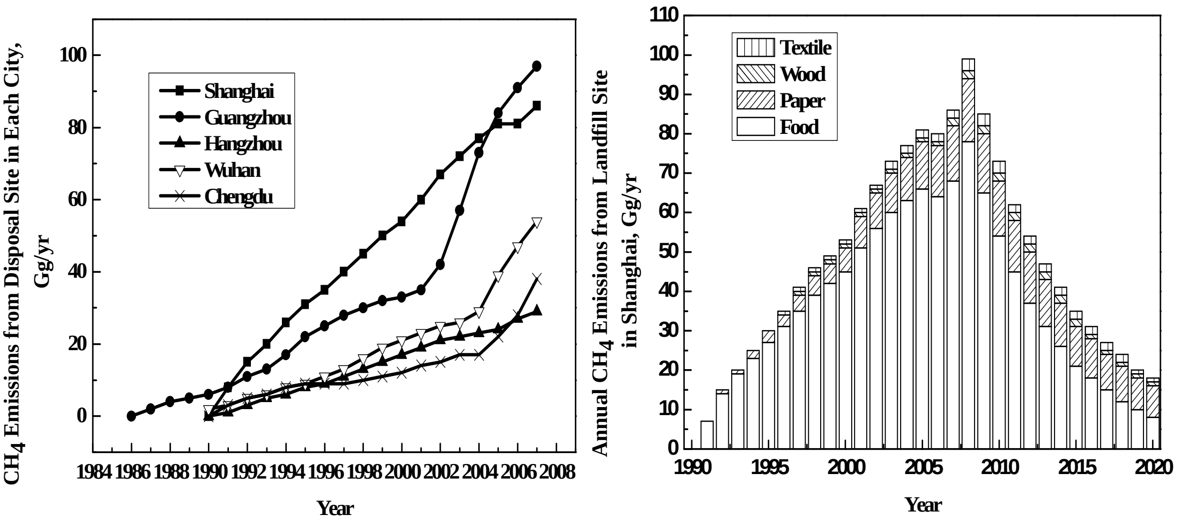

Fig. 6−1 CH_4 emissions from DS in each city and the source in Shanghai

Fig. 6−1 depicts the CH_4 emissions from DS in each city and the emission from each type of waste in Shanghai. In 2007, emissions are 2150, 2425, 725, 1350, and 950 Gg CO_2-eq/yr in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively. Guangzhou belongs to wet climate (W) which accelerates the waste decomposition rate in DS, thereby leading to a big contribution to GHG emissions. In hot, wet climates with shallow disposal sites, degradation may be fast enough to justify the use of a later starting year. Apart from Guangzhou, Shanghai emits much CH_4 than other cities because of large volume of MSW generated. Further, emissions in Hangzhou are lower than in Shanghai and Guangzhou as a result of higher rate of incineration. On the other hand, the CO_2 emission factors are 0.45, 0.54, 0.42, 0.38 and 0.42 kg CO_2-eq/ kg waste-treated in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu, respectively. It confirms that Guangzhou has the highest emission factor and eastern cities have higher CO_2 emission levels than central and western cities.

Moreover, from the source of emission from each waste category, food waste makes the biggest contribution followed by paper waste; the total GHG emissions from these two items accounted for 95% in 2007. Further, with the change in waste composition and the increasing fraction of paper waste, the amount of CH_4 emitted from food waste is decreasing with the increasing amount from paper waste. The share from food waste had reduced from 93.3% in 1992 to 78.98% in 2007 and the share from paper was up to 16.09% in 2007. Therefore, with the increasing fraction of recyclable items in MSW, recycling of recyclable items prior to waste treatment will be a good and effective consideration to reducing amount of CH_4 emitted from DS. Further, in the Fig. 6−1, even though no more waste will be sent to DS from the year of 2007, the emissions will continue a long time and total amount of CH_4 emissions will be 19 Gg/yr in 2020. The largest amount will appear in 2008.

6.2.2 Emissions from waste-to-energy incineration

The average lower heating value of MSW in Shanghai was 5488.3kJ/kg in 2005, and it is supposed to be 6812kJ/kg in 2015 based on a regression analysis of historical records (Table 6−6), with the prediction model as $\textit{heating value} = 126.177^{*} \times \textit{year} - 247434.254^{*}$ (Adjusted $R^2 = 0.971$; F=202.531; and $p^{*}<0.05$). The emission factors of CH_4 and N_2O are thus calculated and shown in Table 6−7, in which, it is assumed that the emission factors are the same in 2015 with those in 2010. Further, Table 6−8 tabulates the CO_2-eq emission by waste category in waste-to-energy combustion plants of Shanghai and Hangzhou, in which sum0 denotes the sum of CO_2 emissions from waste category; CH_4-CO_2 and N_2O-CO_2 stand for the CO_2-eq from CH_4 and N_2O emissions. Energy generation is not considered in this part for simplicity. Moreover, the starting year of incineration operation in Guangzhou was after 2004, not involved in the result. From Table 6−8, several points are addressed. Firstly, CO_2 emissions are much greater than CH_4 and N_2O emissions in combustion process. Secondly, plastic waste represents the waste type with the highest fossil carbon fraction and contributes the greatest share of CO_2 emission among the components. The share of GHG emitted from plastic waste into T-sum is up to 94.76% and 91.48% in Shanghai and Hangzhou in 2007. Thirdly, the contribution of ash waste to T-sum is decreasing with the decrease of fraction in SW, from 7.15% in 2002 to 3.47% in 2007 in Hangzhou.

Table 6−6 Lower heat value of SW in Shanghai (kJ/kg)

Year	1993	1994	1995	1996	1998	2000	2005
Lower heat value	4000	4200	4150	4500	4700	5000	5488.3

Source: Shanghai Academy of Environmental Sciences (AES)

Table 6−7 Emission factors of CH_4 and N_2O in 2005 and 2015

	Default emission factor	2005	2010	2015
CH_4	30 (kg GHG per TJ on a Net Calorific Basic)	0.163 g/kg	0.185 g/kg	0.185 g/kg
N_2O	4 (kg GHG per TJ on a Net Calorific Basic)	0.022 g/kg	0.025 g/kg	0.025 g/kg

Table 6−8 CO_2-eq emission from waste-to-energy combustion in Shanghai and Hangzhou, Gg/yr

	Year	*Plastic*	*Paper*	*Textile*	*Ash*	Sum0	CH_4-CO_2	N_2O-CO_2	T-Sum
Shanghai	2002	56.27	0.21	1.70	0.40	58.59	0.84	1.35	60.78
	2003	71.60	0.25	1.84	0.57	74.26	0.98	1.58	76.82
	2004	186.49	0.55	4.09	1.52	192.66	2.16	3.48	198.30
	2005	326.45	0.83	6.22	2.52	336.02	3.25	5.23	344.50
	2006	362.24	0.92	6.90	2.80	372.85	3.61	5.80	382.26
	2007	415.49	1.06	7.91	3.21	427.67	4.14	6.66	438.46
Hangzhou	2002	110.68	0.49	2.04	8.98	122.19	1.30	2.09	125.58
	2003	121.46	0.39	2.74	3.57	128.16	1.43	2.30	131.89
	2004	118.59	0.29	2.26	4.50	125.65	1.55	2.49	129.68
	2005	144.22	0.36	2.74	5.48	152.80	1.86	2.99	157.64
	2006	153.54	0.38	2.92	5.83	162.67	1.98	3.18	167.83
	2007	174.67	0.43	3.32	6.63	185.06	2.25	3.62	190.93

6.2.3 Emissions from composting

According to Table 6−3, only 8.5% of MSW in Shanghai was sent for composting in 2007 and the CO_2-eq from composting was 119.03Gg. Then, making a sum of emissions in each city, it is found out that the total CO_2-eq emissions in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu are 2707.49, 2425, 915.93, 1350 and 950Gg in 2007, respectively and CO_2 emission factor is 0.43, 0.54, 0.53, 0.38, and 0.42 kgCO_2-eq/kg waste-treated. It is evident that the factors in eastern cities are higher than those in central and western cities.

6.3 Scenario analysis

6.3.1 Projections of waste quantity and composition

Projections of waste quantity and composition of Shanghai until 2015 are conducted as input files of scenario analysis, tabulated in Table 6−9. Further, based on Eleventh-fifth Environmental Plan, there is no simple disposal expected in Shanghai from 2020 and the ratio of waste harmless treatment will achieve 100%.

Table 6−9 Projections of MSW quantity and composition of Shanghai until 2015

Year	Quantity (10 000 tons)	Waste composition, %						
		food	*plastic*	*paper*	*textile*	*glass*	*metal*	*ash & wood*
2011	715.93	57.00	24.20	10.88	1.83	3.04	0.54	2.5
2012	762.17	56.30	24.87	11.02	1.80	2.99	0.53	2.5
2013	811.84	55.63	25.50	11.15	1.77	2.94	0.53	2.5
2014	865.18	54.99	26.09	11.27	1.74	2.89	0.52	2.5
2015	922.49	54.39	26.66	11.38	1.71	2.85	0.51	2.5

6.3.2 Emissions of CO_2-eq in each scenario

Based on the technological evaluation of DS in Shanghai, the recovery efficiency of LFG is assumed as 40% with energy producing efficiency being 20%. Further, landfill of one ton MSW generates about 160kWh electricity[191]. Further, in waste-to-energy combustion plant, combusting one ton waste produces about 200-250kWh electricity and the latter value is cited in the scenario analysis. As in the reported in Japan[194], the CO_2 emission factor in generating electricity by using thermal power is 0.8kg-CO_2/kWh in 2005 in Shanghai. The value is supposed to be fixed in 2015. Further, in the composting process, based on the survey which was done in Okayama, Japan, the product producing rate is assumed to be 20% and the CO_2 emission rate is 0.504kg-CO_2/kg product (Environmental burden basic unit based on IO table, Architectural Institute of Japan(1990)). Moreover, emissions from recycling process are not involved because no relative information is available. The CO_2-eq emissions in different scenarios are tabulated in Table 6−10.

Table 6−10 Emissions of CO_2-eq in alternative waste treatment strategies, Gg/yr

Scenario	DS	WTE	Compost	Recovery (kWh)	CO_2-eq in recovery	Total CO_2-eq
T_{01}	5175.00	875.66	157.60	8.59E+08	−399.16	3739.09
T1		5122.93	157.60	2.24E+09	−1808.19	3472.33
T2		4075.40	504.23	1.78E+09	−1478.81	3100.82
T3	5000.00	724.67	130.42	7.10E+08	−330.22	3524.87
T4		3110.75	504.23	1.36E+09	−1087.79	2473.50

Under T_{00}, the total GHG emission factor will increase from 0.43 in 2007 to 0.63 kg CO_2-eq/kg waste-treated as a result of increasing volume of total MSW generation and fraction of paper waste. However, the emission factor will decrease to 0.38 when energy producing is considered in DS, as represented in T_{01}. Further, compared to T_{01}—the current waste treatment strategies with LFG recovery system—the GHG emissions have the varying extent in reducing GHG emissions in each scenario.

T_1 scenario as MSW being sent to waste-to-energy combustion plant will diminish the GHG emissions. However, the scenario has no apparent advantage than landfill with LFG recovery, 7% reduction compared to T_{01} by 75.86% of MSW. Further, GHG emissions will reduce by 17% in T_2 with 50% of food waste is composted. Moreover, T_3 scenario with 40% of recyclable items being sent to recycling center will reduce the GHG by 43% than T_{00}, but no apparent advantage than T_{01} with LFG recovery (by 6%). Finally, T_4 scenario designing as integrated waste management system makes the biggest reduction of GHG emissions, as 34% compared to T_{01}. The result confirms the former researches[59] that recycling and incineration are effective for GHG reduction. Meanwhile, composting also has great influence on the reduction of GHG emissions in Chinese cities. However, the GHG emissions in the recycling process are not included in the research.

On the other hand, from the viewpoint of energy production, T_1 generates the most electricity power (2.24×10^9kWh). Therefore, from the viewpoint of energy benefit, the incineration is a better selection than other waste treatment strategies.

6.4 Concluding comments

Reduction of GHG emissions from waste management which contributes to global warming has been given increasing concern. However, the characteristics of GHG emissions are distinct in each country or region. This Chapter made it own effort in calculating the GHG emissions in several Chinese megacities with distinct economic levels and carried out a scenario analysis of the integration of alternative waste treatment strategies. The scenario analysis is conducted on the basis of the forecasts of waste quantity and composition of 2015 in Shanghai. Several aspects are addressed. Firstly, CO_2 emission coefficient is higher in eastern cities than that in central and western cities. In Shanghai, the value in 2007 is about 0.43 kg-CO_2/kg-waste. Further, scenario analysis has demonstrated that composting and recycling are effective methods to reduce the CO_2-eq emission in Shanghai. T_2 and T_3 scenarios reduce the emissions by 17% and 6% as compared to T_{01}, respectively. Waste-to-energy combustion will diminish GHG emissions; however no apparent advantage is shown compared to landfill with LFG recovery system. In addition, integrated waste management systems leads to a GHG emission reduction by 34% compared to T_{01}. This result has thus the ability to provide effective reference for the local authorities to select the appropriate waste treatment method comprehensively considering environmental loads in terms of GHG emissions. However, although the back-casting estimation of waste generation and using the data from treatment plants lessens the uncertainties in calculation, the underestimation of GHG emissions in DS may be existed. Accurate plant-specific activity data is strongly desired for further research.

6.5 References for Chapter 6

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7 CONCLUSIONS AND RECOMMENDATIONS

The objective of this dissertation is to develop a common systematic approach to projecting the volume of solid waste arising from household and industrial process fully taking into account economic growth, socioeconomic factor, consumption and industrial restructuring and apply it into Chinese metropolises. Chapters from 3 to 6 represent the body of the entire framework and the main scientific results. This chapter will present a summary of major findings of this study, and recommendations for future research.

7.1 Summary of key points

Chapter 1 investigates the background of the research and proposes the research objectives. Rapid economic growth in China has brought the rapid development of urbanization and industrialization of a city as well as the inflow of a large number of population. The increasing demand by population stimulates the further development of industry in turn. Therefore, in order to improve the SW management of a city, it is necessary to consider the wastes arising from industrial process (ISW) and household (MSW) together, in which, the accurate forecasts of SW generated in the future is vital. Further, a large number of researches have demonstrated that unsustainable pattern of consumption and production is the main driving force of generation of MSW and ISW. However, due to the lack of enough financial support, the waste data is severely deficient in Chinese cities; a common approach which can be easily applied into other cities is thus strongly desired.

Then, Chapter 2 reviews the existing literatures in terms of projections of SW generation. Recent years have witnessed increased attention being given to the forecasts of solid waste generation. However, it is unfortunately to find out that a majority of methods are merely linear or nonlinear regression analysis on the basis of GDP or other economic factors and the main emphasis is focused on generation of total MSW; little research has been done on projecting ISW generation of each waste category by industrial sector. In addition, the existing literature failed to consider the influence of consumption pattern and industrial structure on SW generation. Fully inspecting the limit of the existing literatures, a sustainable systematic approach is proposed in order to project SW generation of each type of waste category, from the perspectives of economic growth, social development, environmental policy and industrial restructuring.

Afterward, Chapter 3 depicts the entire framework of methodological approach. It is made up of four integrated modules—the macro-economic module, MSW generation module, ISW generation module and waste treatment module. Firstly, the macro-economic module is to provide a means for economic structural analysis and economic forecasting on a regional level, considering the influence of national GDP and socioeconomic indicators including world trade. Secondly, MSW module, comprising four models—regional macro-economic model (projection of PTCON), total consumption expenditure model, consumer behaviour model (LES model) and MSW generation model (OLS), is developed as to assess the relationship among the lifestyle of residents & socio-economy, governmental measures and MSW generation of each type of waste category. Thirdly, the ISW generation module is developed involving the regional IO analysis for the projection of ISW generation by industrial sector and the industrial restructuring is carried out by the updating of IO table. The approach investigates the influence of industrial restructuring on ISW generation, based on the study of consumption patterns, export composition and ISW generation coefficient. Finally, in waste treatment module, amount of GHG emitted from the treatment and disposal of waste, including waste-to-energy combustion, compost and landfill is calculated, respectively. Further, based on the forecasts of waste quantity and composition of Shanghai in 2015, a scenario analysis is designed as well.

Then, Chapters 4 to 6 represent the application of the approach framework. Chapter 4 mainly focus on the applications of MSW module into five Chinese metropolises with distinct economic levels to determine the waste generation features in different regions and to create a feasible comparison among cities. Further, the back-casting and *ex-ante* projections of MSW generation in each city are carried out as well. Main achievements are:

(1) The number of variables affecting consumer behaviour in Chinese cities is not one but the integrations of a series of indicators from the viewpoint of both the lifestyle of residents and socio-demographic features. Aside from Shanghai, the two common variables—*saving rate towards consumption* (***SAV***) and *natural growth rate* (***NAGR***) are found to be greatly influential to consumer behaviour. However, in Shanghai, consumer behaviour is strongly influenced by the lifestyle of residents with ***SAV*** and *the average number of persons per household* (***ANPH***).

(2) For the analysis of ‘subsistence’ expenditure among the cities, Hangzhou has the respective highest value of each consumption category among the cities. Further, the largest proportion of ‘subsistence’ expenditure in FOOD indicates that the waste arising from this item is inevitable and may occupy large share in the MSW component.

(3) Except Wuhan, the other cities have the similar consumption propensity towards each type of commodity category. Further, eastern cities have higher propensity towards expenditure on food and education than central and western cities as a result of increase in dining out and education on

Children.

(4) The model quantitatively demonstrates the linear conversion process from consumption to corresponding waste category. For example, food waste is estimated by food expenditure, and paper and plastic waste are estimated by the FOOD and EDUC expenditure in all cities. Consequently, a high consumption propensity towards EDUC and FOOD estimated by the LES model would facilitate the generation of these items in the future. Further, glass and metal waste are considered from the beverage which is a part of the food consumption category. In addition, textile waste is estimated by expenditure in clothing and shoes (CLSH) in all cities.

(5) The results of MSW generation model provide an effective range and default value of partial generation coefficient of each type of estimated-waste category to corresponding consumption expenditure ($PWC_{k/i}$). It is demonstrated that per yuan (RMB, in 1978 prices) of increase of consumption expenditure on FOOD, CLSH and FOOD leads to an average increase of food, textile, and glass & metal waste as 0.224~0.427, 0.0260~0.0654, and 0.0160~0.0218 kg, respectively. Further, an average value of $PWC_{plastic/EDUC}$ and $PWC_{paper/EDUC}$ is 0.211 and 0.111 kg/RMB, respectively, as observed in selected cities.

(6) The unit generation coefficients of total MSW per consumption are at the same level among the selected cities and the average value is 0.213 kg/RMB, thereby providing a possibility for identifying total MSW generation of other Chinese cities once the current consumption expenditure is known.

(7) The research conducts a comparative analysis of the different impacts of waste measures undertaken by local governments in the cities. The waste regulation regarding food waste in Shanghai significantly eliminate the per capita food waste generation by 46.339kg per year (DUM02), whereas that in Wuhan (DUM04) enhance the waste by 49.725 kg each year. All the waste management policies will provide feasible experiences or valuable lessons to other Chinese cities.

(8) Per capita total MSW generation in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu in 2020 will be 2.17~2.18, 1.46~1.49, 1.48~1.49, 1.24~1.25 and 1.78~1.79 times respectively, that of the 2008 levels, thereby foreboding a serious MSW problem in Chinese big cities if there were no relative policies implemented advancing to diminish waste generation. On the other hand, fractions of potential recyclable items will be over 30% in selected cities with around 50% of food waste until 2020.

Chapter 5 represents the empirical application of ISW module linking with regional macro-economic model. The principal priorities in the case study on Shanghai are as follows:

(1) Although considerable changes have occurred in the Shanghai economy over the last two

decades (1981−2005), the regional model fits the historical records reasonably well and provides an acceptable reproduction with the acceptable statistical testing.

(2) The approach provides an idea for a way to quantitatively analyze industrial restructuring by adjusting the converter that, in turn, helps assess the impact of these changes on sectoral output. The change in consumption pattern which is estimated in Chapter 4 is introduced in the regional IO analysis to quantitatively reflect the change in private consumption among various sectors.

(3) Increase in consumption expenditure not only induces to the increasing generation of MSW, but also the great generation of ISW. Through effective sensitivity analysis, per yuan of increase (in current prices) in consumption on FOOD, CLSH, FUNI, EDUC, TRAN, HLTH and RESI induces to an average increase of 76.41, 76.16, 82.28, 106.54, 93.89, 148.30 and 292.58 g of total ISW, respectively. Partial generation coefficient of each type of waste category per unit consumption is conducted as well.

(4) The estimated volume of ISW produced is about 1.5 times that published in the yearbooks in 1997 and 2002, respectively. Moreover, the total projected volume of ISW generated in 2010, 2015 and 2020 will be 2.07, 2.83 and 4.12 times, respectively, that of the 2002 levels. Fully considering adjusting the ISW generation coefficient, the value becomes 1.29, 1.35 and 1.58.

(5) It is verified that ISW generation not only arises from economic growth but also from the onset of industrial restructuring. Due to the industrial restructuring caused by change in consumption pattern and export composition, the unit ISW generation per gross output reduces from 0.16 in 2002 to 0.14 tons/10 000 RMB in 2020.

(6) Based on our results, the industrial sectors making the biggest contribution to the production of each type of ISW can each be separately identified. For example, in 2020, the largest component of smelting residue (SR) is generated by metals smelting & pressing industry (pds11), at about 90% of total volumes. In addition, pds11 also generates the majority of the gangue (GA) production (70%). Therefore, constraining specific industries or penetrating them with selective technological changes will be useful attempts on the way to meeting the objectives of overall waste reduction. If adjusting the ISW generation coefficient based on historical records, the respective share of ISW generation of chemicals (pds9), pds11 and electricity, steam & hot water production & supply (pds20) into total ISW generation will reduce from 16.52%, 36.87% and 23.77% to 13.40%, 23.88% and 4.31% as we move from 2002 towards 2020.

(7) Further, the total SW generation of Shanghai in 2020 is about 4.06 folds compared to 2002 and the volume of ISW is about 5.68 folds of MSW generation in 2020. Further, if taking into account scenario analysis of adjusting ISW generation coefficient of pds9, pds11 and pds20, the total SW is

1.93 times compared to 2002 and ISW is 2.18 times of MSW. Development of service industry results in much generation of ISW than MSW.

(8) In addition, increase of per yuan RMB (in current price) on food consumption results in generation of 1226 tons of food, paper, plastic, glass and metal waste as well as 76.41g ISW.

Above work provides the basic information for projecting SW generation by waste category in Chinese cities. Based on the results, Chapter 6 not only calculates the GHG emissions in current waste treatment options, but also evaluates the alternative waste treatment strategies in view of the reduction of GHG emissions based on the forecasts of waste generation of Shanghai in 2015. Main remarks are as follows:

(1) Eastern cities emit much GHG than central and western cities as a result of large amount of MSW generation. It is found out that the total CO_2-eq in Shanghai, Guangzhou, Hangzhou, Wuhan and Chengdu is 2707.49, 2425, 915.93, 1350 and 950Gg, respectively and CO_2 emission factor is 0.43, 0.54, 0.53, 0.38, and 0.42kg CO_2-eq/kg-waste in 2007.

(2) Under landfill without LFG recovery system, the total CO_2-eq emission factor increases from 0.43 in 2007 to 0.63 kg CO_2-eq/kg waste-treated in 2015 due to increasing volume of waste generation and fraction of paper waste. However, the emission factor decreases to 0.38 when energy producing is considered in DS.

(3) Scenario analysis demonstrates that composting is effective method to reduce the CO_2 emission in Shanghai. Corresponding scenario—T_2 (50% of food waste is composted) reduces the emissions by 17% as compared to T_{01} with LFG recovery system, respectively. Further, recycling (T_3) and waste-to-energy combustion (T_1) will diminish GHG emissions by 6% and 7%, respectively as compared to T_{01}.

(4) The integrated waste treatment system designed as T_4 reduces 34% of CO_2 emissions as compared to current treatment strategies with LFG recovery. The emission factor reduces to 0.25 kg CO_2/kg waste in 2015.

Therefore, this dissertation contributes its effort to develop a systematic approach to projecting SW generation of each type of waste category within limited waste statistics and makes a reasonable attempt at Chinese metropolises. The influence of consumption on increasing generation of MSW and ISW by stimulating industrial restructuring is fully discussed and represented. For the waste reduction, the constitution of relative policies including ‘green consumption’, effective waste management policies and the penetration of technological innovation in specific industries is considered to be effective. Moreover, with the increasing fractions of paper and plastic waste in MSW generation, the recycling of these items before the waste treatment is essential for effectively reducing GHG emissions which contribute to global warming. In addition, the systematic approach can be easily popularized into other Chinese cities or even Asian cities with insufficient waste statistics, thereby providing a possibility for promoting the waste management in whole China and sustainability development of society.

7.2 Recommendations for future research

The dissertation attempts to contribute to the methodological development in profit in policy-making by local municipalities for accurate projection of SW generation and deal with the increasing SW problem. Based on the current results, the research will be improved when several aspects are carried out in the future:

1. Models are simplified representations of reality. When operating and interpreting its result and applying into the practices, it is important to be aware of its limitations, listed as follows.

(1) Solid waste actually arises from consumption of goods and conversion of materials in the industrial process. The weight base data of input materials is therefore accurate for projection. However, the monetary data is in replace due to the lack of relative information, thereby causing the unavoidable error.

(2) The influence of current environmental policies on waste generation is taken into account in the research; the constitution of new management policies in the future however can’t be reflected in the current approach. Further, the change in influence of policy on waste generation is not reflected.

(3) As mentioned previously, ISW module including IO analysis is a static model, working with one-year averages. The dynamics of labour coefficient, capital coefficient is thus not considered.

(4) All the industrial sectors are aggregated into 24 ones without dissecting the internal relationship of the service industry. A more disaggregated sector classification will make the results more reasonable. However, it strongly needs the data support.

(5) The research on influence of technological change in ISW generation coefficient is far from enough. The effect of environmental policy in ISW generation coefficient is not covered in current research. Further, the change in input coefficient in long-frame should be considered on the basis of investigating the current old & new technological layers and projecting the share of them.

(6) In ISW module, the ISW generation coefficient on national level is in replace rather than local coefficients. It can be expected that the module application will improve when local generation coefficients are supported or further research on approaching the real values is carried out.

2. Data inaccuracy

(1) The quality of data partially determines the exactness of the approach. Data inaccuracy as the

measurement error can never be entirely avoided, especially in developing cities. It is a common problem for any type of data in the approach. The measurement method of data keeps changing in Chinese cities because of the increasing urbanization and change in policy, thereby increasing the uncertainty of the data. Further, data which is used in the research describes fairly well the average yearly impacts of waste information, not capture for instance differences between summer and winter.

(2) A majority of Chinese cities haven’t developed the mature data measurement system or haven’t published the existing data, especially for waste composition. It severely limits the research progress and is adverse for solving waste problem in a city. A public and transparent database is essentially desired. Moreover, long-term and accurate waste records in the future will definitely improve the current approach.

(3) In waste treatment module, apart from long-frame waste statistics, accurate plant-specific activity data is strongly desired for further research.

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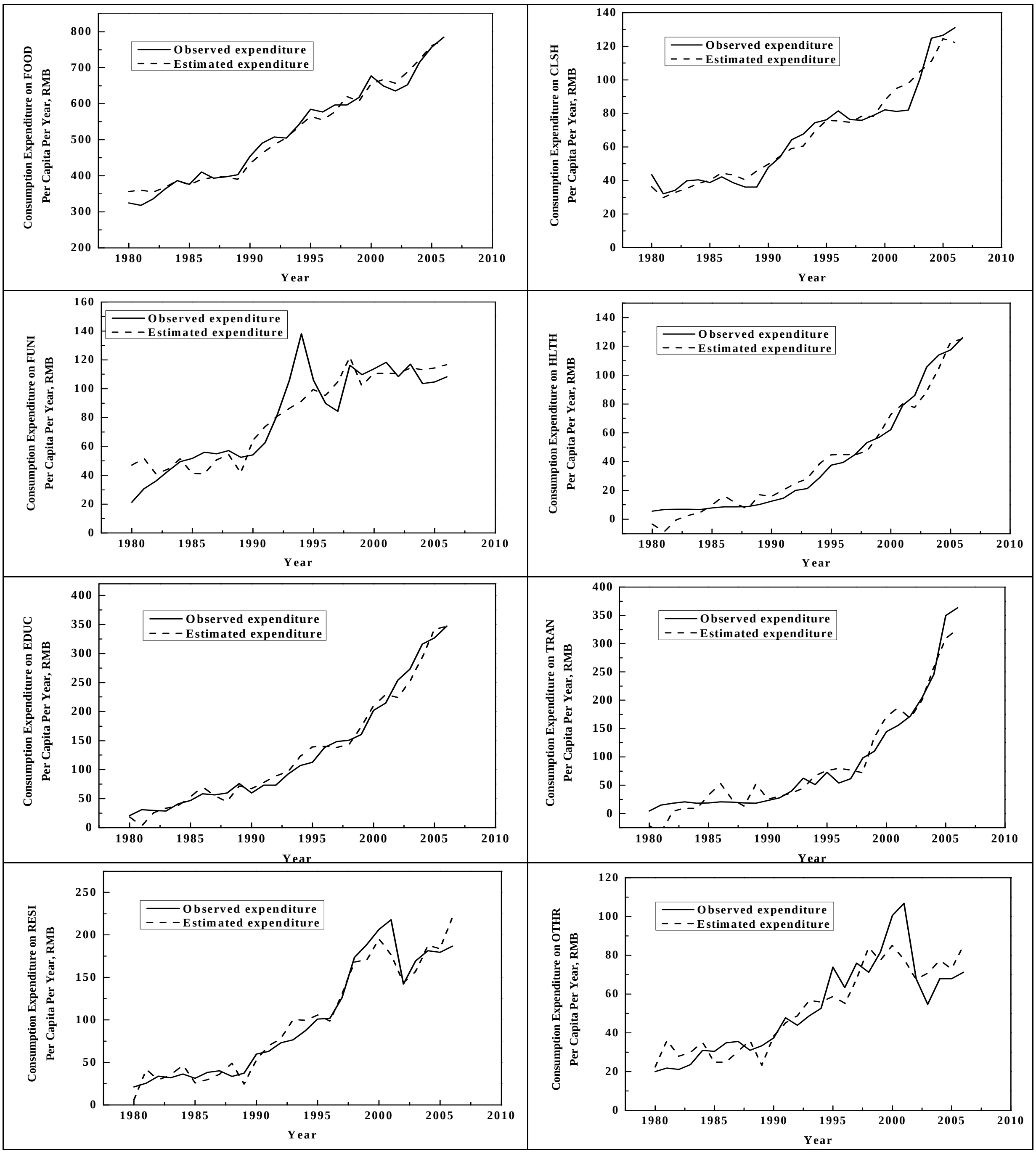
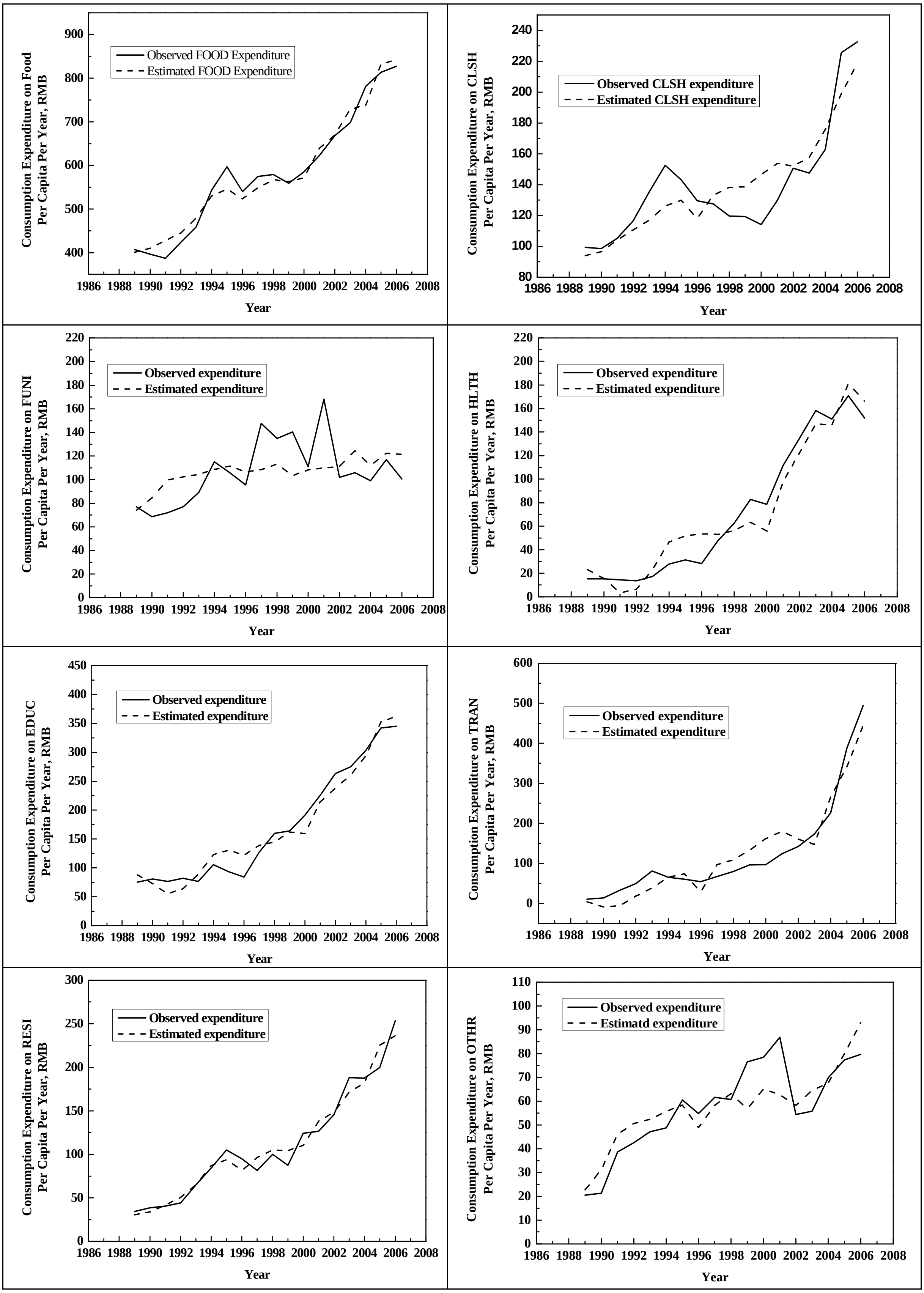
APPENDIX

Appendix No. 1

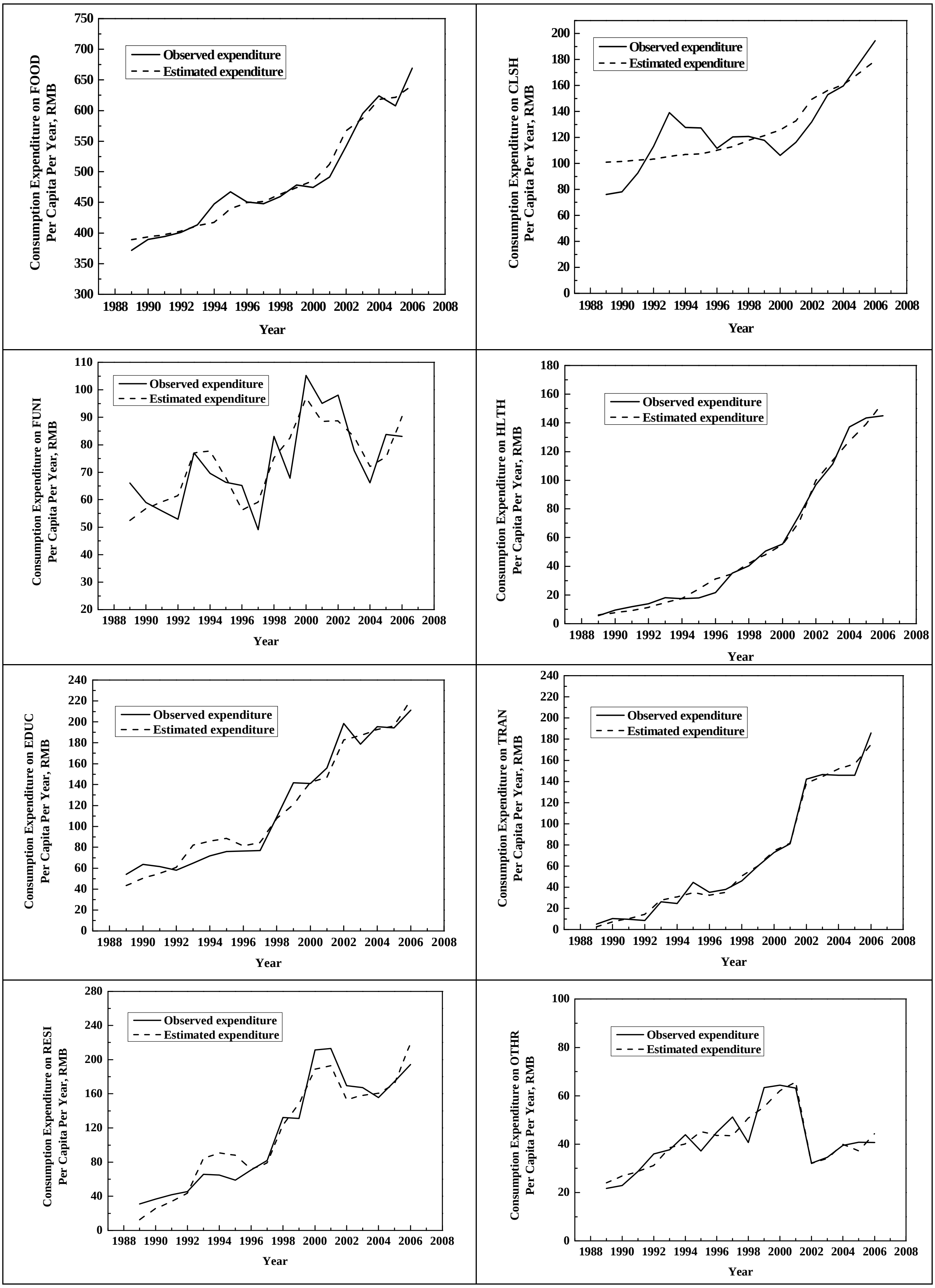
Observed and estimated data series of each consumption category in (1) Guangzhou (2) Hangzhou (3) Wuhan and (4) Chengdu



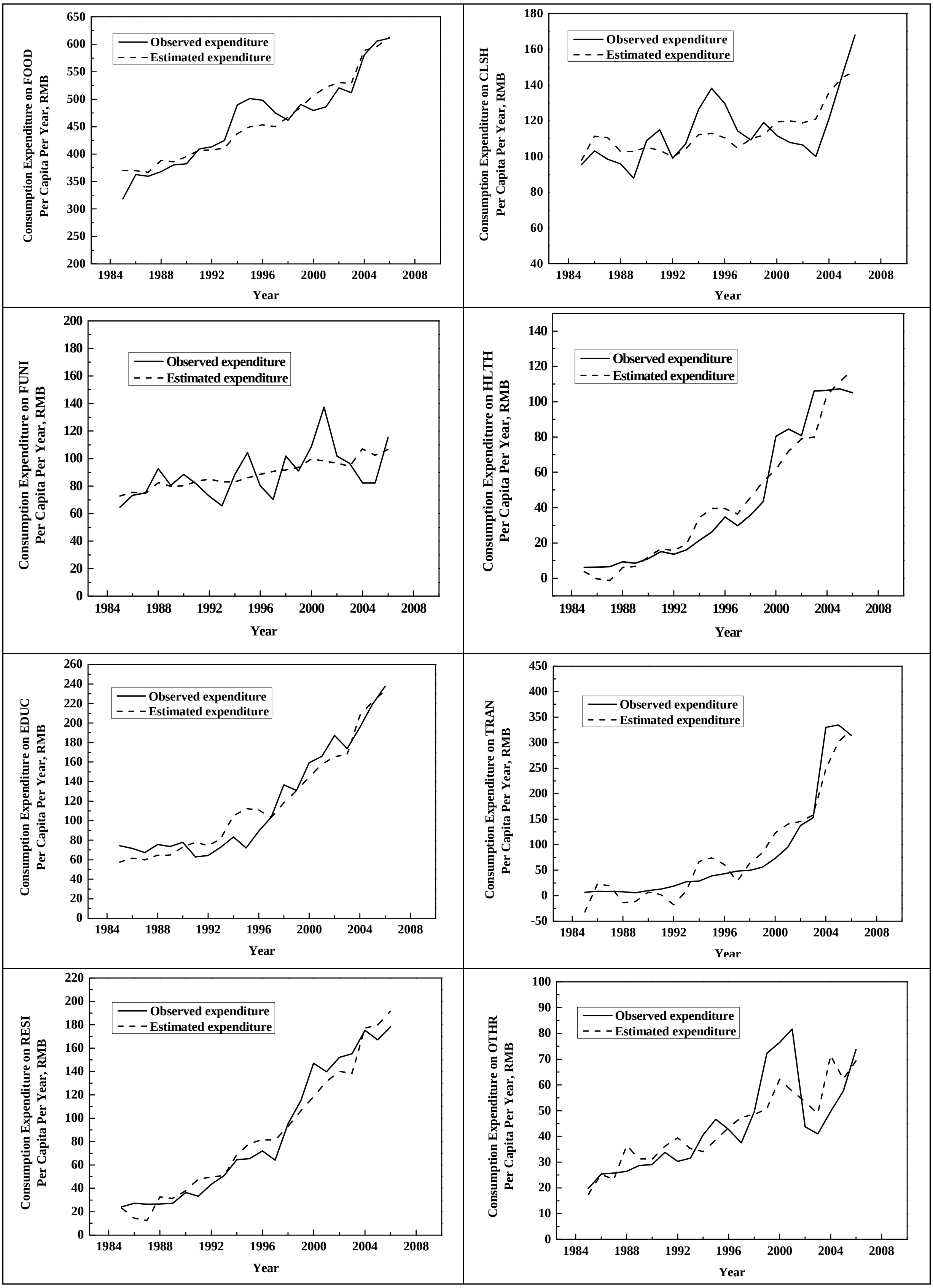
(1) Guangzhou


Consumption Expenditure on Food Per Capita Per Year, RMB
Observed FOOD Expenditure
Estimated FOOD Expenditure
400
500
600
700
800
900
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on CLSH Per Capita Per Year, RMB
Observed CLSH expenditure
Estimated CLSH expenditure
80
100
120
140
160
180
200
220
240
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on FUNI Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
0
20
40
60
80
100
120
140
160
180
200
220
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on HLTH Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
0
20
40
60
80
100
120
140
160
180
200
220
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on EDUC Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
0
50
100
150
200
250
300
350
400
450
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on TRAN Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
0
100
200
300
400
500
600
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on RESI Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
0
50
100
150
200
250
300
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year
Consumption Expenditure on OTHR Per Capita Per Year, RMB
Observed expenditure
Estimatd expenditure
0
10
20
30
40
50
60
70
80
90
100
110
1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008
Year

(2) Hangzhou


Consumption Expenditure on FOOD Per Capita Per Year, RMB
Consumption Expenditure on CLSH Per Capita Per Year, RMB
Consumption Expenditure on FUNI Per Capita Per Year, RMB
Consumption Expenditure on HLTH Per Capita Per Year, RMB
Consumption Expenditure on EDUC Per Capita Per Year, RMB
Consumption Expenditure on TRAN Per Capita Per Year, RMB
Consumption Expenditure on RESI Per Capita Per Year, RMB
Consumption Expenditure on OTHR Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
Year
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008

(3) Wuhan

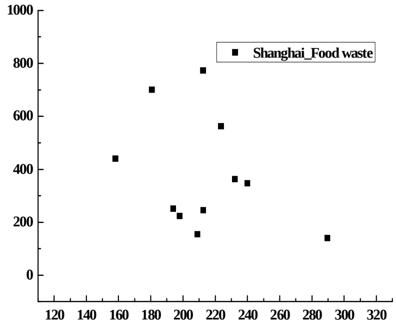

Consumption Expenditure on FOOD Per Capita Per Year, RMB
Consumption Expenditure on CLSH Per Capita Per Year, RMB
Consumption Expenditure on FUNI Per Capita Per Year, RMB
Consumption Expenditure on HLTH Per Capita Per Year, RMB
Consumption Expenditure on EDUC Per Capita Per Year, RMB
Consumption Expenditure on TRAN Per Capita Per Year, RMB
Consumption Expenditure on RESI Per Capita Per Year, RMB
Consumption Expenditure on OTHR Per Capita Per Year, RMB
Observed expenditure
Estimated expenditure
Year
1984
1988
1992
1996
2000
2004
2008

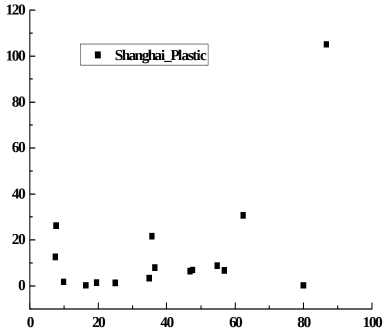
(4) Chengdu

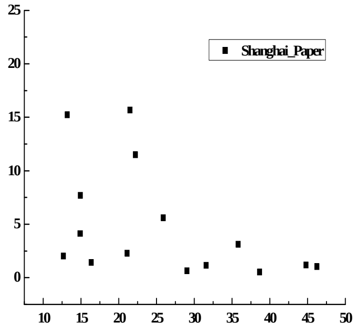
Appendix No. 2

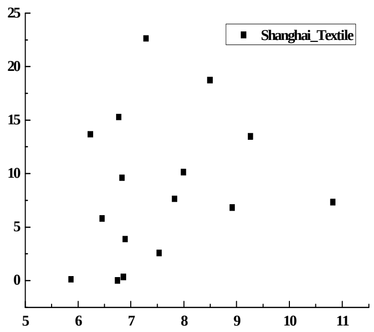
Plot of residual sum of squares against estimator of generation of waste category for checking heteroscedasticity problem in each city, as the order of Shanghai, Hangzhou, Guangzhou, Wuhan and Chengdu

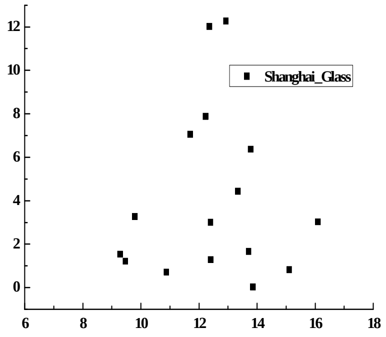
(1) Shanghai:

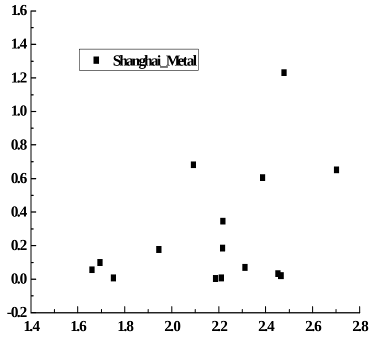




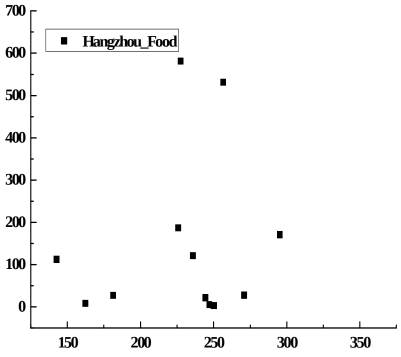


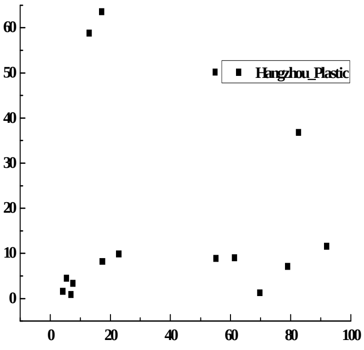


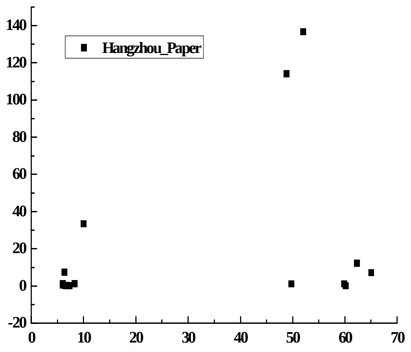


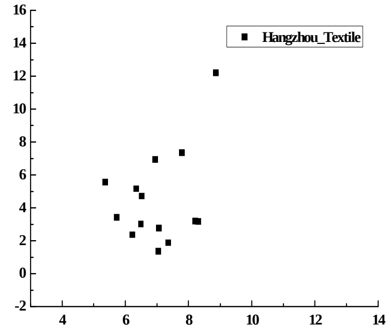


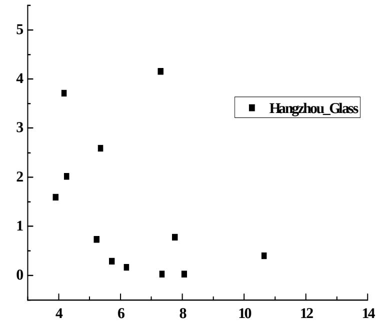
(2) Hangzhou:

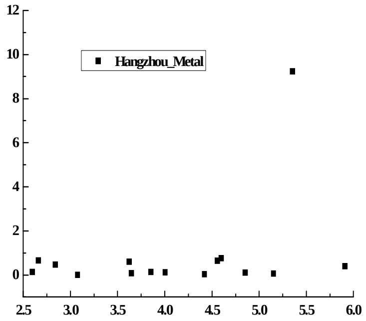


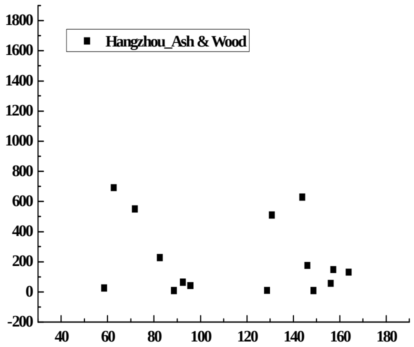




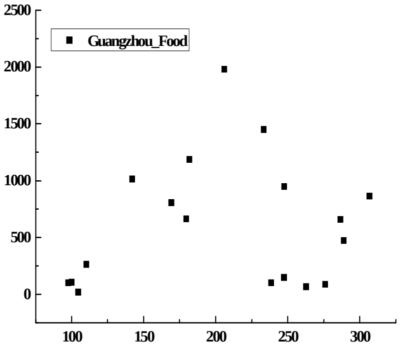


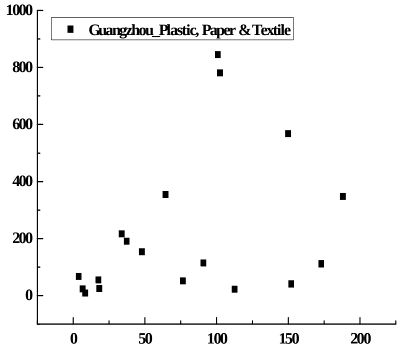


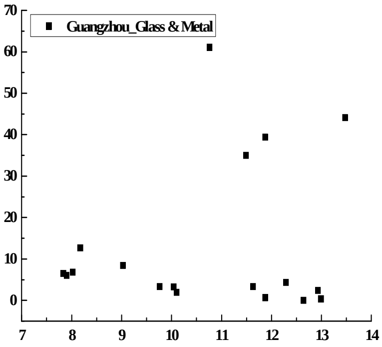




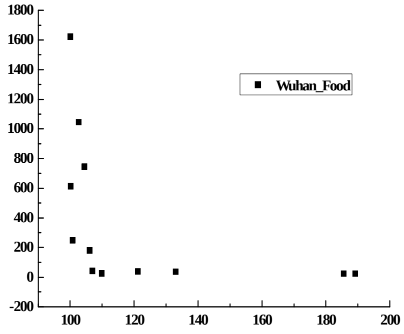
(3) Guangzhou:

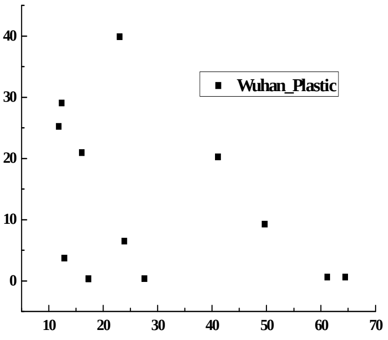


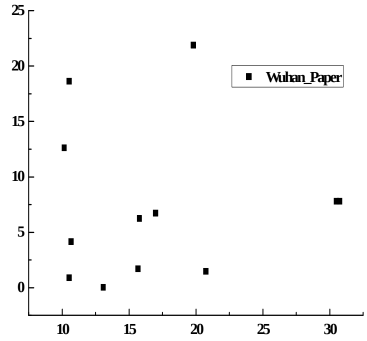


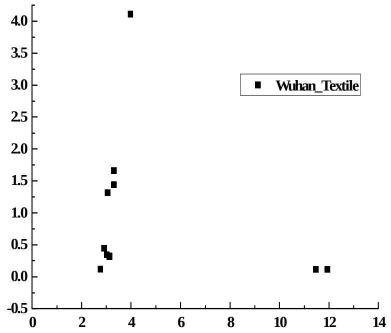


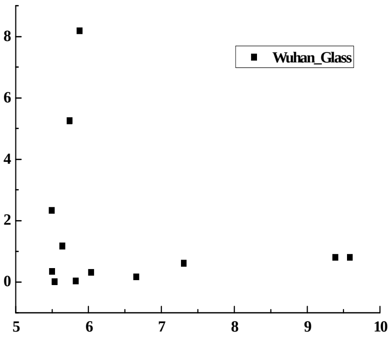
(4) Wuhan

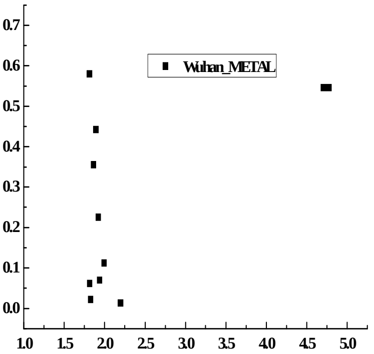




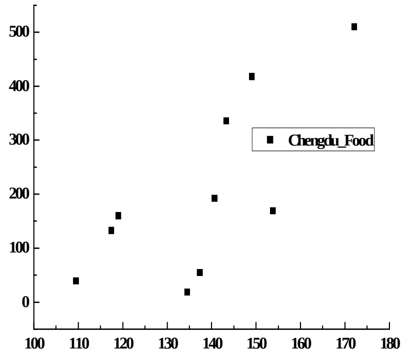


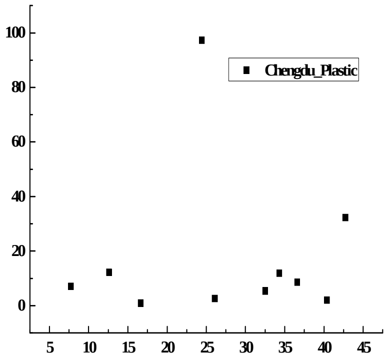

Wuhan_Textile
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
2
4
6
8
10
12
14

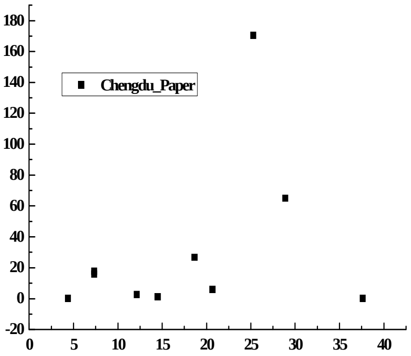

Wuhan_Glass
0
2
4
6
8
5
6
7
8
9
10

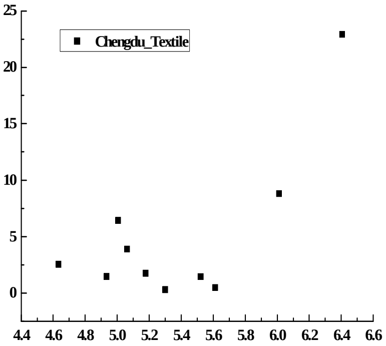

Wuhan_METAL
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

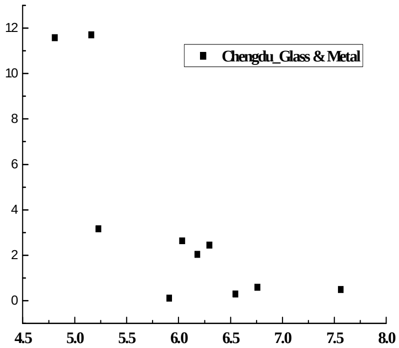
(5) Chengdu:


Chengdu_Food
0
100
200
300
400
500
100
110
120
130
140
150
160
170
180


Chengdu_Plastic
0
20
40
60
80
100
5
10
15
20
25
30
35
40
45


Chengdu_Paper
-20
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40


Chengdu_Textile
0
5
10
15
20
25
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6


Chengdu_Glass & Metal
0
2
4
6
8
10
12
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0