Comprehensive Evaluation of Environmental Policy for Water Pollutants and Greenhouse Gases Reduction in Jiaxing city, China

Feng XU , University of Tsukuba, Japan
Nan XIANG, University of Tsukuba, Japan
Shanshan WANG, University of Tsukuba, Japan
Yang LI, University of Tsukuba, Japan
Takeshi MIZUNOYA, University of Wako, Japan
Yabar HELMUT, University of Tsukuba, Japan
Yoshiro HIGANO University of Tsukuba, Japan

Abstract:

Recently, various environmental problems have been generated with the rapid economic development in China. The reason is that China currently over-emphasizes economic development beyond environmental issues; therefore, now it is important to enforce optimal environmental policies in order to achieve economic development as well as environmental improvement. In this study, we selected Jiaxing city as research area for the pollution problem has become more and more prominent with economic high growth, and we constructed environmental system model and social economic model to establish the scenarios. Through computer simulation, we can evaluate the efficiency of the comprehensive environmental policies from the aspects of both environmental preservation and social economic development. While the socioeconomic activities, such as production, finance and budget, are endogenous in the social-economic model, the environmental system model shows the water pollutants and the greenhouse gas reduction in the region.

Based on the environmental and socio-economic system model above, the dynamic optimization simulation is accomplished. In view of the restriction on water pollutants, greenhouse gas emissions, and economic growth, the model simulation can provide optimal policies which can achieve the best economic and environmental improvement in Jiaxing City, China.

Keyword: Environmental policy, Simulation, Social-economic model, environmental model

1. Introduction

With rapid economic growth, environmental problem generated from an increase of waste that emitted by mass consumption activities is being actualized in China. Especially, the low efficiency of livestock waste treatment system resulted in serious pollution. The Greenhouse Gas (GHG) like the methane and the nitrous oxide are generated from such untreated waste and global warming is promoted, and these GHG with greenhouse effect equal to tens to hundreds times of carbon dioxide. Moreover the untreated wastes make the problem of water pollutants more serious. It is anticipated that the global warming issue or the water pollution problem resulted from the untreated waste will become more and more important in the future.

Therefore we reconstructed biomass recycle system to convert the current waste treatment system, minimized the negative environmental impact, and improved a series of process like production, consumption, waste and so on. It is necessary to evaluate the policy that can actually introduce new technologies to solve the current environmental problems, the resource and energy problems. Finally the optimal policy is recommended.

Recently, many studies have been undertaken to protect the water environment and improve economic development. In Japan, Hirose and Higano [1] constructed simulation analysis to evaluate water purification policies in the catchment area of Lake kasumigaura, Japan. Mizunoya et. al [4] analyzed and assessed synthetic environmental policies to reduce environmental burdens by biomass technology Studies about comprehensive environmental evaluation in China are mainly concerned with theories and theoretical model at national level. Researches on integrated practical assessment of environmental degradation and economic development are in initial stages. Wang and Tang [6] constructed a two-level theoretical model of environment and economic development to analyze the efficiency of environmental subsidies. The State Environmental Protection Administration of China [5] estimated the pollutants from stockbreeding wastes and the benefits of methane fermentation. In most of these studies, conclusions are derived from simple data analysis and foreign experiences. There has been little research into the construction and analysis of a comprehensive simulation policy that includes the introduction of current treatment technologies to control water pollutant emissions without deteriorating the socio-economic activities level, especially in the suburb around large cities.

However, there is little research that constructs and analyzes a comprehensive simulation model based on the economic characteristics and situations of China, especially for rural suburbs of big cities. Therefore, feasible simulation should be constructed to realize the simultaneous pursuit of environmental preservation and economic development on the basis of characteristics of China.

In the study, we selected Jiaxing city as an objective region, and evaluated the effect of the advanced biomass technology with introduction of an existing environmental policy from the aspects of environmental impact, economy, and possibility of introduction of biomass technology.

2. Study area and data

Jiaxing city is located at the center of Chang Jiang Delta that overflowed most in economic energies in China. It abuts on Shanghai to the east, Suzhou to the north, Hangzhou to the west and away by each 90km, 90km, and 70km. It covers a land area of 3,915 km^2 and has a population of 3.355million in 2006. Under the jurisdiction of Jiaxing City there are two districts

(Nanhu District and Xiuzhou District), three county-level cities (Pinghu City, Haining City and Tongxiang City) and two counties (Jiashan County and Haiyan County).

Since the reform and open policy in 1980, there has been a rapid expansion of social economy in Jiaxing city of China. Since 2000, the annual growth rate of GRP has reached more than 10% (Fig 2). GRP reached 134.6 billion RMB Yuan in 2006 and GRP per capita exceeded 40 thousand RMB Yuan in Jiaxing city. On the other hand, the water pollution becomes more serious with regional economic development. About 91% of surface water quality reached the V standard that the water pollution became even more serious. Table 1 shows the density of water pollutants of the main river in Jiang city. It is understood that the water pollution problem of Jiaxing City is very serious. Therefore, the government of Jiaxing city must adopt environmental polices of water pollutants reduction to improve the quality of water.

Fig.1 Location of Jiaxing City

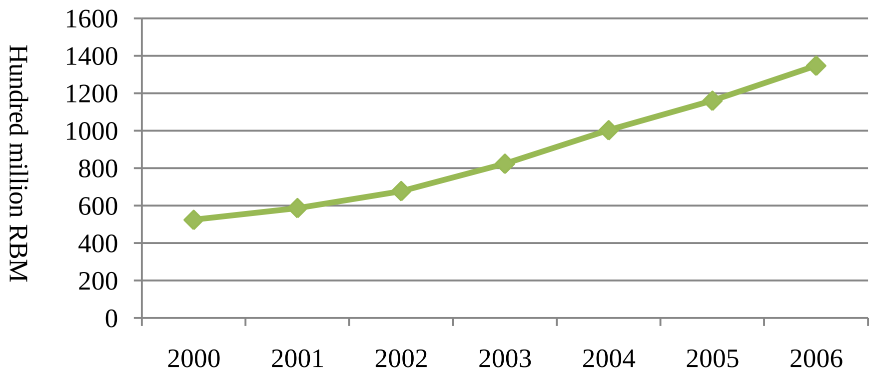

Fig.2 Changes of GRP

Table1. Density of three indicators of water pollution

NO.	Rivers' Name	Density of Water Pollution (mg/l)		
		COD	T-P	T-N
1	Shangtang	11.2	0.915	6.21
2	Hengtang	10.63	0.569	3.43
3	Pinghu	9.07	0.644	4.38
4	Changshui	7.98	0.29	2.95
5	Haiyan	8.09	0.248	1.99

3. Simulation Model

3.1 Skeleton of Simulation Model

The dynamic simulation model consisted of a water pollutants flow balance model, GHG Emission model, and socio-economic model. The water pollutants flow balance model describes how the pollutants flow into the rivers. The socio-economic model represents the social and economic activities in the region and the relation between the activities and emission of pollutants (Fig. 3)

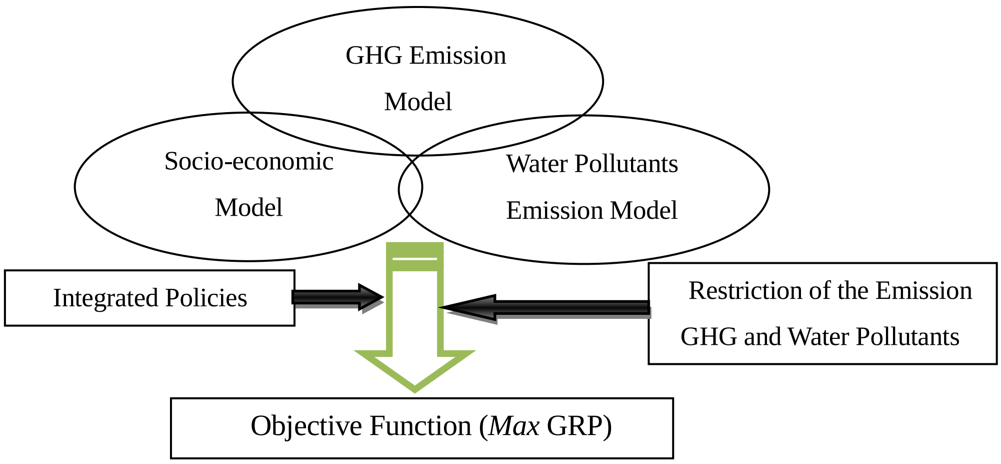

Fig.3 Construction of Sub-model

2.2 Framework of Simulation Model

The pollutants measured in this study include COD (chemical oxygen demand), T-N (total nitrogen), T-P (total phosphorus), and CO_2, CH_4, N_2O (Table 2). Table 5 shows net load of water pollutants by different sources. Stockbreeding wastes in the catchment areas contribute heavily to water pollutants, especially pig farming has become the source of the most serious pollution in the catchment areas. Table 6 shows the environmental policy being executed in Jiaxing City. Table 7 represents the integrated policies used in the simulation model to reduce water pollutants and conserve water resource for the target area.

Table2. Classification of Water Pollutants and GHG

Index	Water pollutants	Index	GHG
1	T-N	1	CO_2
2	T-P	2	CH_4
3	COD	3	N_2O

Table3. Classification of Land Use

Index	Land Use
1	Upland Field
2	Paddy Field
3	forest
4	City Area
5	Other Land Use

Table4. Classification of Industries

Index	Industry
1	Upland Cropping
2	Rice Cropping
3	Manufacturing Industry
4	Fisheries
5	Pig Farming
6	Other Stockbreeding Industry
7	Other Industries

Table5. Net load of water pollutants by different sources (2006)

(t/year)

Index		T-N	T-P	COD
Manufacturing Industry		7,802	897	17,925
Household		9,066	824	17,953
Pig Faming		10,514	2,628	26,286
Other Stockbreeding Industries		370	97	4,020
Non-point	Upland Cropping	532	158	265
	Rice Cropping	1,292	31	5,698
Fisheries		1,525	497	10,170
Other Industries		3,859	294	6,153
Total amount		34,960	5,426	88,480

Source: Yearbook of Jiaxing County, 2007 [2]

Table6. Present policies for the catchment area

Source of water pollutants		Name of policy	Measurements
Household		Sewage system	I. Subsidization for the municipality to install more sewage system and sewage plant
Non-point		Agriculture that preserves the environment and fallow field	II. Subsidization for the conversion of Upland field and rice field into fallow field III. Subsidization for famer who uses less-elution type of fertilizer
Stockbreeding industry	Pig farming	Reduction of the capital employed	IV. Subsidization for pig farming to reduce capital stock so as to adjust production
	Other stockbreeding industry	Reduction of the capital employed	V. Subsidization for other stockbreeding industry to reduce capital stock so as to adjust production
Production		Reduction of the capital employed	VI. Subsidization for industries to reduce working capital and thus adjust production

Table7. Integrated policies for the catchment area

Source of water pollutants		Name of policy	Measurements
Household		Sewage system	I. Subsidization for the municipality to install more sewage system and sewage plant
Non-point		Agriculture that preserves the environment and fallow field	II. Subsidization for the conversion of Upland field and rice field into fallow field III. Subsidization for famer who uses less-elution type of fertilizer
Stockbreeding industry	Pig farming	Reduction of the capital employed and adoption of original biomass plant technology	IV. Subsidization for pig farming to reduce capital stock so as to adjust production V. Adoption of original biomass plant technology
	Other stockbreeding industry	Reduction of the capital employed	VI. Subsidization for other stockbreeding industry to reduce capital stock so as to adjust production
Production		Reduction of the capital employed	VII. Subsidization for industries to reduce working capital and thus adjust production

4. Model structure

4.1 Objective function

The objective function was constructed to maximize the total Gross regional Product (GRP) over the target term (t=10) in order to determine an optimal policy.

$$MAX \sum_{t=1}^{T} \left(\frac{1}{1+\rho}\right)^{t-1} GRP(t) \qquad (1)$$

in which, en: endogenous, ex: exogenous,

ρ : social discount rate (=0.05)

4.2 The material flow balance model

Total pollution of the net load of water pollutants is defined by socio-economic activities of each municipality. Moreover, the water pollutant emitted by socio-economic activities composed of pollutants from households, non-point sources and production activities.

(1) Water pollutant load of the catchment area

$$Q^{p}(t) = Q_j^{Hp}(t) + Q_j^{Lp}(t) + Q_j^{Ip}(t) \qquad (2)$$

$Q_j^{Hp}(t)$: water pollutant p emitted by households in municipality j at time t (en)

$Q_j^{Lp}(t)$: water pollutant p emitted by non-point sources in municipality j at time t (en)

$Q_j^{Ip}(t)$: water pollutant p emitted by production activities in municipality j at time t (en)

(2) Pollutants from household wastewater in each municipality

$$Q_j^{Hp}(t) = \sum_{k=1}^{2} E_j^{pk} Z_j^{k}(t) \qquad (3)$$

(k:1=sewage plant; k:2=untreated waste water)

E_j^{pk} : the pollution emission coefficient of sewage plant k in municipality j (ex)

$Z_j^{k}(t)$: the population that use sewage plant k in municipality j at time t (en)

(3) Load of water pollutants from non-point sources in each municipality

$$Q_j^{L}(t) = \sum_{l=1}^{5} Q_j^{Lpl}(t) = G^{pl} \cdot L_j^{l}(t) \qquad (4)$$

(l:1=paddy field; l:2=rice field; l:3=forest; l:4=city area; l:5=other land use)

$Q_j^{Lpl}(t)$: pollutants p emitted by land use l in municipality j at time t (en)

G^{pl}: coeffient of water pollutant p emitted through land use l (ex)

$L_j^l(t)$: area of land use l in municipality j at time t (en)

(4) Load of water pollutants from production activities in each municipality

$$Q_j^{Ip}(t) = \sum_{m=1}^{7} Q_j^{Ipm}(t) = p^{pm} \cdot X_j^m(t) \qquad (5)$$

(m:1=upland cropping; m:2=rice cropping; m:3=manufacturing industry; m:4=fisheries; m:5=pig faming; m:6=other stockbreeding industries; m:7=other industries)

$Q_j^{Ipm}(t)$: pollutants p emitted by production of industry m in municipality j at time t (en)

p^{pm}: coeffient of water pollutant p emitted by industry m (ex)

$X_j^m(t)$: amount of production of industry m in the area of municipality j (en)

$$Q^{Ip5}(t) = P^{p5} \cdot X_j^5(t) \qquad (6)$$

$$Q_j^{Ip5}(t) = P^{P5BP} \cdot TS_j^{BP}(t) + P^{P5N} \cdot TSD_j^{5S}(t) \qquad (7)$$

$Q_j^{IP5}(t)$: water pollutant p emitted by pig farming industry in municipality j at time t (en)

P^{P5BP}: coefficient of water pollutant p emitted in pig feces and urine treated by biomass plant (ex)

$TS_j^{BP}(t)$: number of pig for which feces and urine were treated by biomass plant in municipality j at time t (en)

P^{P5N}: coefficient of water pollutant p emitted in pig feces and urine without any treatment (ex)

$TSD_j^{5S}(t)$: number of pig for which feces and urine were not treated in municipality j at time t (en)

4.3 Policies for household wastewater generation

According to the characteristics and situations of the catchment area, the treatment of household wastewater mainly depends on the sewage systems. These measures are implemented by the municipality.

(1) Population increase in each municipality

$$Z_j(t+1) = Z_j(t) + \Delta Z_j(t) \qquad (8)$$

$$\Delta Z_j(t) = \eta_j \cdot Z_j(t) \qquad (9)$$

$Z_j(t)$: population in municipality j at time t (en)

η_j: coefficient of population growth in municipality j (ex)

$\Delta Z_j(t)$: population increase in municipality j at time t (en)

(2) Population that uses the sewage systems

The population that uses the sewage systems is equal to the total population of catchment area.

$$Z_j(t) = \sum_k Z_j^k(t) \qquad (10)$$

$Z_i^k(t)$: population that uses the sewage systems in municipality j at time t (en)

(3) Increase in the population that uses the sewage systems

$$\Delta Z_j^k(t) \le \Gamma_j^k \cdot i_j^k(t) \qquad (11)$$

$i_j^k(t)$: increase in the population that uses the sewage systems in municipality j at time t (en)

Γ_j^k: reciprocal of the necessary construction investment per person that uses the sewage plant (ex)

4.4 Treatment policies for non-point sources

(1) Land use

$$\overline{L} = \sum_{j=1}^{6}\sum_{l=1}^{5} L_j^l(t) \qquad (12)$$

$\overline{L}$: Gross area (ex)

$L_j^l(t)$: area of land use in municipality j at time t (en)

(2) Conversion of paddy fields and rice fields to other land

$$L_j^l(t+1) = L_j^l(t) + \sum_{L \neq l} L_j^{lL}(t) - \sum_{l \neq L} L_j^{Ll}(t) \qquad (13)$$

$L_j^{lL}(t)$: conversion of land from l to L in municipality j at time t (en)

$L_j^{Ll}(t)$: conversion of land from L to l in municipality j at time t (en)

4.5 Treatment measures for production activities

(1) Production function and curtailment

$$X_j^m(t) \leq \alpha^m \left\{K_j^m(t) - S_j^m(t)\right\} \qquad (14)$$

α^m : ratio of capital to output in industry m (ex)

$S_j^m(t)$: subvention to industry m from government in municipality at time t (en)

$$K_j^m(t+1) = K_j^m(t) + i_j^m(t) - d^m K_j^m(t) \qquad (15)$$

$K_j^m(t)$: capital available for industry m in municipality j at time t (en)

$i_j^m(t)$: investment by industry m in municipality j at time t (en)

d^m : depreciation rate of industry m (ex)

4.6 Flow balance in the commodity market

$$\begin{aligned} X(t) \geq AX(t) + C(t) + I^m(t) + B^S \cdot i^1(t) \\ + B^{BP} \cdot K^{BP}(t) + e(t) \end{aligned} \qquad (16)$$

$X(t) = \sum_j X_j(t)$: column vector of the m-th element that is the total product of industry m in the basin (en)

$I^m(t) = \sum_j I_j^m(t)$: total investment at time t (en)

$i^1(t) = \sum_j i_j^1(t)$: total investment for construction of sewage system (en)

$K^{BP}(t) = \sum_j K_j^{BP}(t)$: capital available for biomass plant at time t (en)

A : input-output coefficient matrix (ex)

$C(t)$: total consumption at time t (en)

B^S : column vector of m-th coefficient that induced production in industry m by construction of sewage system (ex)

B^{BP} : column vector of m-th coefficient that induced production in industry m by construction of biomass plant (ex)

$e(t)$: column vector of net export (en)

4.7 Gross regional product

We adopt the index of GRP to reflect the development of the local socio economy.

$$GRP(t) = vX(t) \quad (17)$$

v : row vector of m-th element that is rate of added value in m-th industry (ex)

4.8 Constraints on each pollutant

We set upper constraints on the emissions of GHG, COD, T-N and T-P in the simulation.

$$Q^p(t) \le Q^{p*}(t)$$

$$GHG(t) \le GHG^*(t)$$

in which

$GHG(t)$: the total emission of greenhouse gases emitted by industry m (ex)

5. Results of the simulation

5.1 Simulation cases

In this study, we define the simulation cases that water pollutants amount reduces 15% per year during the future 10 years from 2006, and we set case 1 that select the present policies (Table 6) and set case 2 that select the integrated policies (Table 7).

5.2 Objective function

In this simulation, we found that case 1 compared with case 2 has a difference of about 172 billion RMB (Fig.4).

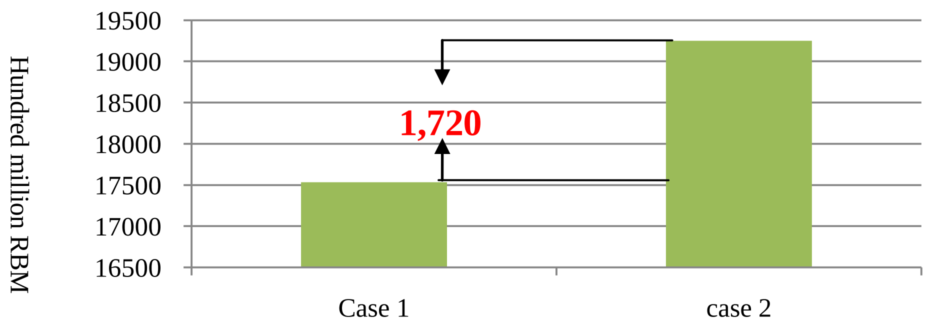

Fig.4 Comparison of objective function

5.3 Conclusion

In this study, we introduced biomass plant technology and adopted integrated policies to construct environment-social economy simulation model, and the optimal simulation was carried out to analyze the efficiency of biomass plant technology. In this simulation, we set the purpose that the emission amount of water pollutants COD, T-N, T-P realize the reduction of 15% during the period of 2007 to 2016 as compared to 2006. Therefore, we set the cases that with and without adoption of biomass plant technology to compare the possibility and feasibility of introduction of biomass plant technology for the objective area. According to the simulation results, when we did not adopt the biomass plant technology, the development of GRP was restricted in order to realize the purpose of water pollutants decease 15%; however, when the biomass plant technology was adopted in the simulation, the introduction of biomass plant technology allows simultaneous pursuit of environmental preservation and economic development.

Moreover, with the same constraints functions and purpose that realize water pollutants decrease 15%, the amount of objective function (accumulated amount of GRP over 10 years) has a difference of about 172 billion RMB, when we adopt the biomass plant technology. The treatment scale of biomass plant technology is 1,000 pigs and construction cost of the facility is 8 million RMB when the technology is made in Japan. Based on the results of simulation, when the technology facility is made in Japan, about 5,705 of biomass plant technology facilities should be construction in the study area, the total construction cost and the maintenance cost are 40.6 billion RMB and 18 billion RMB, respectively. The total cost is about 58.6 billion RMB over 10 years; on the other hand, the amount of objective function increase 172 billion RMB as compared with not adopt biomass plant technology. We should make a point that the cost of technology facility would be down when the facility is made in China. According to the technical expert, the cost of biomass plant technology facility made in China is about 20% as compared when it is made in Japan. Therefore, the amount of subsidization for biomass plant technology is about 12.6 billion RMB over 10 years. Therefore, it is absolutely of necessity and possibility to introduce biomass plant technology into the study area. Moreover, untreated stockbreeding wastes are the most serious resource of water pollution and greenhouse gases (CH_4, NO_2). The biomass plant technology contributes to the reduction of GHG. In this simulation, when we adopt biomass plant technology facility, the GHG emission (calculated by GWP) would decrease about 9,253,368 tons over 10 years.

According to this research, the following conclusions can be obtained. When we did not adopt biomass plant technology, 15% decrease in water pollutants emission can be realized at the cost of significant reduction of the production of each industry in the study area. When we adopt biomass plant technology, it allows simultaneous pursuit of environmental preservation and economic development. The cost-benefit analysis result shows there is a great feasibility and possibility to introduce biomass plant technology in the study area.

References

1. Fumiaki H., Yoshiro H. (2000), A simulation analysis to reduce pollutants from the catchment area of lake Kasumigaura. Studies in Regional science, Vol.30, No.1, 47-63.
2. Jiaxing County statistics (2007), Yearbook of Jiaxing Country statistics.
3. Jingjing Yan, Feng Xu, Chuanjin Kang, Yoshiro Higano(2010), Comprehensive Evaluation of Optimal Pollutant-minimization Policies in Rural Areas of China, Human and Environmental Symbiosis, Vol.17, pp87-98.
4. Mizunoya T., Sakurai k., Kobayashi S., Piao S.H., Higano Y. (2007), A simulation analysis of synthetic environment policy: effective utilization of biomass resources and reduction of environmental burdens in Kasumigaura basin. Studies in Regional Science, Vol.36, No.2, pp.355-374.
5. State Environmental Protection Administration (2002), The pollution and measurements for stockbreeding industry wastes in China.
6. Wang B., Tang L.J. (2003), Analysis of environmental and economic integration systems optimization. Systems Engineering-theory practice, Vol.3, pp. 14-17.