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Comprehensive Evaluation of Environmental Policy for Water Pollutants Reduction in Jiaying City, China

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Comprehensive Evaluation of Environmental Policy for Water Pollutants Reduction in Jiaxing City, China

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Abstract

Recently, various environmental problems have been brought with the rapid economic development in China. 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 its high water pollution problem combined with speedy economic growth, and we constructed integrated dynamic environmental-social economic system model to establish the optimization simulation. Through scenarios analysis, we can evaluate the efficiency of the environmental policies from the aspects of both environmental preservation and social economic development. This research will provide prediction on social-economic activities, such as production, finance and budget, endogenously in the social economic model, the water pollutants discharged from social economic activities in environmental system model in the region. The simulation results show a great improvement of the trade-off between environment improvement and economic development in Jianxing city, China.

Keywords: Environmental policy, Optimization simulation, Social-economic model, Environmental model, Dynamic programming

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 condition

Jiaxing city is located at the center of Yangtze River Delta in which economic development is significant in China. It is surrounded by large cities of China, Shanghai to the east, Suzhou to the north, Hangzhou to the west and with the distance distinctly of 90km, 90km, and 70km(Fig 1). It covers a land area of 3,915 km² 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).



Fig.1 Location of Jiaxing City

2.1 Economic development situation

Figure 2 show that Jiaxing's GRP (Gross regional Product) keeps a steady increasing trend, while the increase rate is above 10% per year. However the water pollution becomes much more serious along with regional economic development. About 91% of

surface water quality is beneath the V standard which is the worst level in China. Water pollution problems became constraints on the target area's further regional development. Therefore, the government of Jiaxing city should adopt environmental policies which can reduce water pollutants generation and increase water pollutants treatment to improve the water quality.

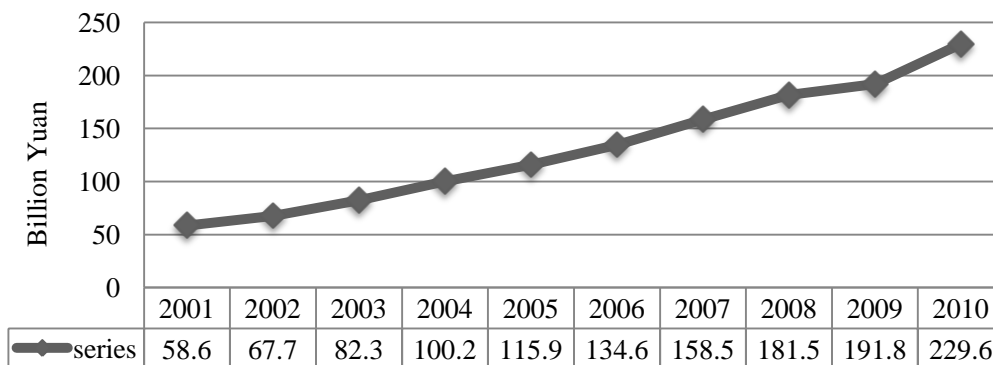


Fig.2 GRP amount increasing trend from 2001 to 2010 in Jiaxing city, China

2.2 Water quality situation

Table 1 shows the water quality change trend. Although the water quality got certain improvement by implementing water purification policies, it still confronted with serious water problems which need further treatments recently. Also, 80% of surface water quality is worse than V classification in 2010. Worse water quality will further bring negative influence for human existence and social sustainable development if the problems are not improved. Therefore, comprehensive evaluation of water purification policies is needed.

Table.1 Surface water quality classification from 2006 to 2010

year / classification	III (%)	IV (%)	V (%)	Inferior V (%)
2006	1.6	9.8	21.3	67.2
2007	1.6	4.9	27.8	65.7
2008	3.2	6.4	29.0	61.4
2009	1.6	23.5	34.4	40.5
2010	6.2	12.5	42.2	39.1

2.3 Water pollution source analysis

The pig farming industry of Jiaying is very active and there are 7.4million pigs in 2006. Stockbreeding wastes in the catchment areas contribute heavily a lot to water pollutant generation; especially pig farming has become the source of the most serious pollution in the catchment areas (Table 2).

Table2. 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

3. Simulation model constructions

3.1 Model framework

In the research, we constructed a comprehensive evaluation model to analyze the policy impacts on environmental and social-economic development, it contains 2 sub-models: social economic model and water pollutants flow balance model. The objective function is maximization of GRP. The social economic model represents the social economic activities which include population fluctuation, production of goods and services, and local finance and budget etc. in the catchment area. Water pollutants flow balance model describes the pollutants generation flow from social economic activities (Fig.3). Integrated policies we proposed in this research are aiming to realize environmental improvement and economic development (Table.3). Also, these policies and technologies variables are changed into coefficients in simulation model which can demonstrate the policy feasibility and its impacts on environmental and economic development.

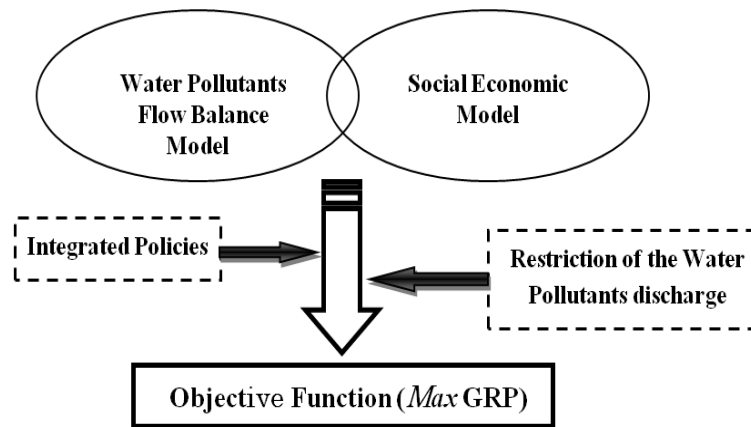


Fig.3 Construction of Sub-model

The pollutants measured in this study include COD (chemical oxygen demand), T-N (total nitrogen), T-P (total phosphorus) (Table 4). There are 7 classifications of industries in the target area. Table 6 shows the environmental policy being executed in Jiaxing City (Table 5). Table 6 represents the integrated policies used in the simulation model to reduce water pollutants and conserve water resource for the target area.

Table4. Classification of Water Pollutants and GHG

Index	Water pollutants
1	T-N
2	T-P
3	COD

Table5. 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

Table6. 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
Stockbreedin g 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 stockbreedin g 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

3.2 Objective function

The objective function was constructed to maximize the total GRP over the target term (t=10) in order to determine an optimal policy (in which, en is abbreviation for endogenous, ex is abbreviation for exogenous).

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

ρ : Social discount rate (=0.05)

3.3 The water pollutants flow balance model

Total pollution of the net load of water pollutants is defined by social economic activities of each region. Moreover, the water pollutants are emitted by social- economic activities, such as point pollution from households and production activities, non-point sources.

(1) Water pollutant load of the catchment area

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

$Q_j^{Hp}(t)$: 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)

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

(2) Pollutants from household wastewater in each municipality

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

(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

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

(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} : Coefficient 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

$$Q_j^{lp}(t) = \sum_{m=1}^7 Q_j^{lpm}(t) = p^{pm} \cdot X_j^m(t) \quad (5)$$

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

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

p^{pm} : Coefficient 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)

$$Q_j^{lp^5}(t) = P^{p^5} \cdot X_j^5(t) \quad (6)$$

$$Q_j^{lp^5}(t) = P^{p^5BP} \cdot TS_j^{BP}(t) + P^{p^5N} \cdot TSD_j^{5S}(t) \quad (7)$$

$Q_j^{lp^5}(t)$: Water pollutant p emitted by pig farming industry in municipality j at time t (en)

P^{p^5BP} : 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^{p^5N} : 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)

3.4 Policies for household wastewater generation

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

(1) Population increase in each municipality

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

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

$Z_j(t)$: 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 summed up population that uses the different sewage systems is equal to the total population of catchment area.

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

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

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

$$\Delta Z_j^k(t) \leq \Gamma_j^k \cdot i_j^k(t) \quad (11)$$

$i_j^k(t)$: 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)

3.5 Treatment policies for non-point sources

(1) Land use

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

\bar{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

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

$L_j^{lL}(t)$: 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)

3.6 Treatment measures for production activities

(1) Production function and curtailment

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

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)

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

$K_j^m(t)$: 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)

3.7 Flow balance in the commodity market

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

$X(t) = \sum_j X_j(t)$: 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)

3.8 Constraints on each pollutant

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

$$Q^p(t) \leq Q^{p*}(t) \quad (17)$$

3.9 Gross regional product

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

$$GRP(t) = \nu X(t) \quad (18)$$

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

4. Simulation Results

4.1 Case setting

We adopted COD (chemical oxygen demand), T-N (total nitrogen) and T-P (total phosphorus) as water pollutants control index in the simulation. In these 3 cases, water pollutants reduction rate are 15% in 2015 compared with that in 2006.

Also, the water pollutants were assumed to be descending year by year under current level. Specifically, in order to demonstrate the contribution of the biomass plant technology, we set case N15 as usual case without biomass plant technology introduction and case BP15 with technology introduction. The reduction rate in the capital employed of each industry in Case 15N-0 cannot be larger than 10%; while it in Case 15N-1 without limitation. The capital employed of each industry in Case 15BP is assumed to be increasing year by year (Table7).

Table7. Case setting in simulation model

Cases	Water pollutants reduction rate in 2015 with 2006	Reduction rate in capital employed of each industry in 2015 with 2006	Technology introduction
15N-0	15%	$\leq 10\%$	Without
15N-1	15%	No limitation	Without
15BP	15%	$\leq 0\%$	With

4.2 The analysis of simulation results

Through simulation, we obtained the feasible solution in Case 15N-1 and Case 15BP. There is no feasible solution in Case 15N-0 according to simulation results. It proved that it is impossible to achieve the dual targets of economic development and environment conservation when we don't treat the pig farming waste properly.

4.2.1 Objective function

The simulation results show that Case 15BP obtained the maximized GRP from 2006 to 2015, which demonstrate that biomass plants have positive impacts on economic development. However, GRP increase rate in Case 15BP is below 2% from 2011, the water pollutants generation constraints will limit the economic development while current technology may be not effective to support the sustainable development in the long run. High speedy technology update calls for new developed technology introduction, which is also proved in simulation. Simulation results suggest to Jiaying city to develop or introduce new water purification technology in depth, not only in

WWTPs, but also in manufactures themselves. Furthermore, it is classified that the current environment policies are not adequate to improve the trade-off between water environment and economic development.

In Case15N-1, GRP is started to decline since 2013, and the GRP is only accounts for 79% of Case 15BP in 2015. Also, there is a 234,281 million Yuan’s gap between these 2 cases objective functions (total GRP from 2006 to 2015).

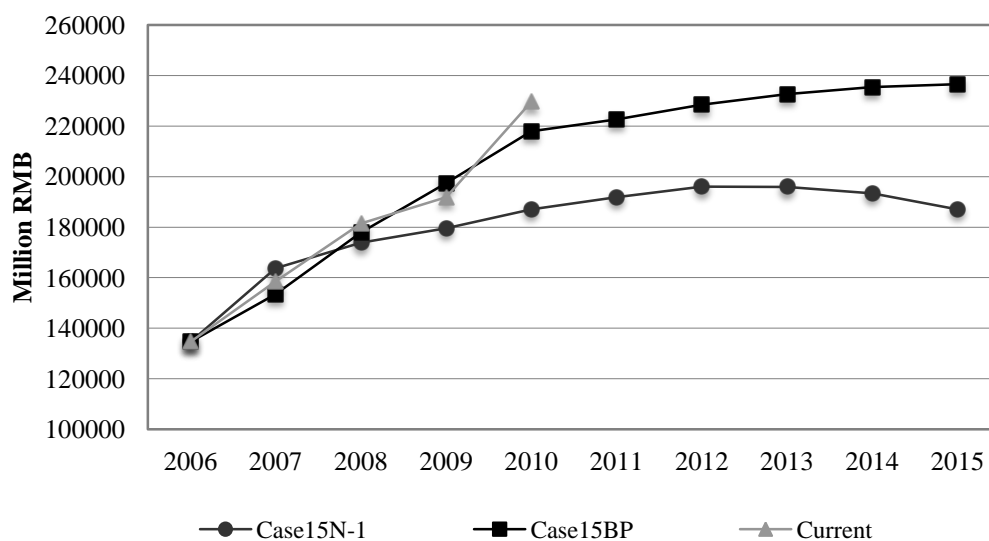


Fig. 4 Comparison of GRP changes in Case 15N-1, Case 15BP and Current situation in Jiaxing city from 2006 to 2015

Appreciate environmental policies is necessary for the target area to realize economic development as while as environmental conservation. On contrary, unreasonable environment policies’ implementation will further intense environment pollution and constraint economic development.

4.2.2 Industry development trends analysis

Figure 5 shows agriculture production’s development trends between Case 15N-1 and Case 15BP, including rice, upland, fishery, pig farming and other stockbreeding industry. Figure 3 is the manufacture and sevice industry’s development in these 2 cases. Compared Figure 2 with Figure 3, we can see that pig farming, fishery and cropping industries are seriously affected when we limit the water pollutants generation. The production of pig farming industry is almost 0 from 2010 in Case 15N-1.

However, manufacture and service industry are improved for their low pollutant

discharge rate. The increase rate of manufacture and service experience a high increasing period and then slow down. The reason is rapid decline of high pollutant generation industries like pig farming industry brings wide capacity for manufacture and service industry to improve their production in the former years; and in the latter years they have to squeeze their own production to achieve water pollutants constraints. Proper environment policies are proved to be necessary again through this scenario for the industry development in Case 15N-1 is not reliable in real society.

Case 15BP with comprehensive environmental polices is more suitable for local development according to simulation results. In this case, each industry get certain development. In agriculture, the increase rate of fishery production is the largest, 36% increase in 2015 compared with 2006; the increase rate in rice and upland industry is 8% and 6%; production of pig farming industry and other stockbreeding industry remains the same as that in 2006. Moreover, manufacture and service industry experience high development trend, and the production increase 73.94% and 75.26% in 2015 when compared with 2006. Industrilization target can also be achieved in Case 15BP.

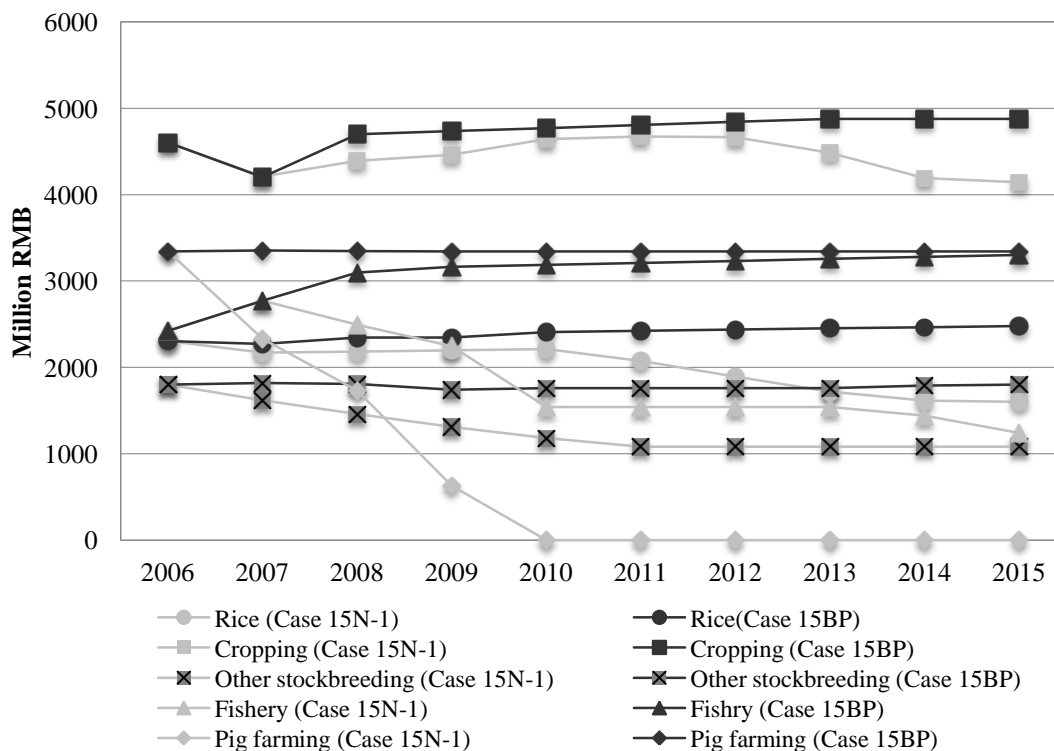
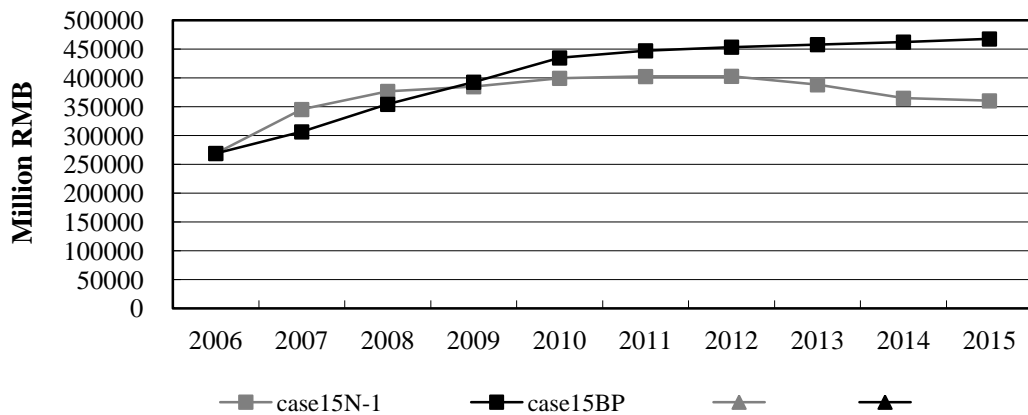


Fig.5 Agriculture development trends in Case 15N-1 and Case 15BP from 2006 to 2015



**Fig6. Manufacturing and Service industry development trends
In Case 15N-1 and Case 15BP from 2006 to 2015**

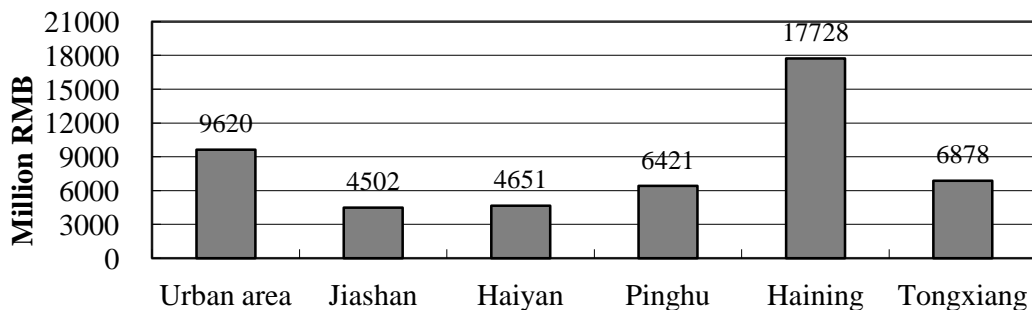
4.2.3 Feasibility of biomass plant promoting policy

(1) Investments of biomass plants

In this research, the biomass technology we adopted is developed and made in Japan. And the relative coefficients of methane fermentation device in simulation are also obtained and calculated based on the biomass plant in Japan (Table 8).

Figure 7 is the total investment for biomass technology for each region, including installation and maintenance fee. The total investment is 49,800 million Yuan in Jiaxing city for the simulation period. Table 3 further shows the total environment policy costs between Case 15N-1 and Case 15BP.

Although the total investment in Case 15BP is 34,210 million Yuan than Case 15N-1, the corresponding benefits brought by biomass plant is 232, 281 million Yuan, and the industry development is much more suitable for local area.



**Fig.7 Total investments of biomass plants in each region of Jiaxing city
from 2006 to 2015**

Table.8 Environment policies investment for Jiaxing city between Case 15N-1 and Case 15BP from 2006 to 2015

Environment policies	Case 15N-1	Case 15BP
sewage system	6800	6800
Biomass plant	0	49800
Reduction of the capital employed each industries	16080	850
Others	2280	1920
Total	25160	59370

The simulation results proved that comprehensive environment policies with biomass technology introduction are beneficial for the target area to achieve environment protection and economic development.

5. Conclusions

Effective and proper environmental policies are critical in achieving sustainable development. In order to find out whether the technology and policy choices are suitable for local development, comprehensive environmental policy evaluation is needed which considers the environment, social and economic aspects together. How to achieve the balance between economic development and environment protection is a constant topic in society, especially for developing countries in which their high speed economic development will cause environment deteriorating seriously. Comprehensive environment policy evaluation will be effective to provide optimal development plan and policy-making basis for government. While technique or project assessment is limited to the impacted factors, it is too narrow to provide a quantity and comprehensive policy proposals.

A good environmental policy evaluation method need to be realistic, systemically and integral. The innovative point of this study is utilizing environmental engineering approach to analysis economic and environment problems. In the study, the interaction between environmental and socio-economic activities is analyzed, of which indicators and variables are integrated into a dynamic mathematical model based on certain principles and assumptions. Economic development of each industry is based on input-output analysis. And this model is based on material balance, value balance and energy balance.

Another contribution is that the computer simulation is made to evaluate comprehensive environmental policies and identify the most (social) cost effective measures in order to improve the environment and finally achieve sustainable development. This simulation model can predict the real society and economic development, while provide optimization policy proposals.

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 2015 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

The simulation results provide the GRP achievement, policy subsidy, and biomass plant construction in each case. Case 15BP that the biomass plant technology was adopted as the optimization choice 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 232, 281 million RMB, when we adopt the biomass plant technology. When the technology facility is made in Japan, the total cost (include construction cost and the maintenance cost) are 49,800 million RMB respectively over 10 years. The results prove that there will be large economic benefits when we introduce the biomass technology, and the benefits will be larger if we make the facilities in China with cheaper cost. Therefore, the environment policy with biomass plant technology introduction is proved to be effective and feasibly for the study area to achieve sustainable development.

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