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Endogenous Derivation of Optimal Environmental Policies for Proper Treatment of Stockbreeding Wastes in the Upstream Region of Miyun Reservoir, Beijing

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Endogenous derivation of optimal environmental policies for proper treatment of stockbreeding wastes in the upstream region of Miyun Reservoir, Beijing

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Abstract:

Stockbreeding industries are increasing rapidly in rural areas around big cities in China, especially the rural areas around Beijing. This increase carries high risks to the environment due to emissions of large amounts of pollutants in terms of COD, T-N and T-P as well as greenhouse gases to rivers and the atmosphere. On the other hand, stockbreeding wastes are a typical biomass resource and can be used as an energy source by advanced new technologies. In this study, we selected Miyun County of Beijing and focused on analyzing the synthetic environmental management policies by computer simulation including the introduction of two new technologies to improve the environment and provide more biomass energy. The model considered both the total ecological system of the objective region and the social-economic situational changes during a ten year period from 2007 to 2016. The purpose of our research is to establish effective utilization methods for biomass resources as well as coordinate resource reutilization, environmental preservation and economic development, and finally realize sustainable development of the society.

Key words:

Environmental policy, Regional development, Biomass resource, Modeling, Simulation

1. Introduction

Miyun County is the largest rural area and the most important county of Beijing (Fig. 1). Especially the Miyun Reservoir, the only surface water resource of Beijing, provides more than 60% of the water resources for Beijing City. This important ecological value of Miyun County has a unique significance for the regional environment and dramatically influences water quality and local development of Beijing. In the catchment areas of Miyun Reservoir, stockbreeding wastes are generated and heavily contribute to environmental pollution, especially pig farming has become a source of the most serious pollutants to Miyun Reservoir. On the other hand, stockbreeding wastes are a type of carbon neutral biomass resource that can be utilized to produce biomass energy through new technologies. Therefore, we should consider the comprehensive utilization of livestock feces and urine as a biomass resource, when we formulate policies to reduce water pollutants emitted from the stockbreeding industry. Furthermore, in this paper we also consider reduction of greenhouse gases as a holistic ecological system based on materials balance.

Figure 1. Location of Miyun Reservoir

Theoretically, the integrated modeling approach from the points of studies that support developing modeling in this study summarized as follows: Integrated approach was used in modeling since the late 1960s, which input-output models extended linking to environmental or natural resource area. Most of them have been concerned with the effects of pollution from one or more industrial sectors on the output of other sectors such as Ayres and Kneese [1], Leontief [9], Forsund [2], Lee [8] and Perrings [13].

In corporation of linkage between environmental change and socio-economic development can not be attained by observational studies alone. Modeling of key environmental and socio-economic processes is an essential tool, required to strengthen management institutions and practice. The framework is itself based on a conceptual model, which sets the links between ecosystem processes, functions, and outputs of goods and services with dynamic simulations of processes in the system, which can be used to explore the consequences of environmental damage, and produce forecasts of future changes [16].

An integrated modeling, several aspects are significant to be concerned such as: how environmental policy will affect macro variables for examples; the level of output in an economy or GDP. Secondly, how impacts are distributed across different sectors of the economy and how changes in policy, for example, impact on the long-term growth rate of the economy [12].

Mathematically, the way of estimations methods and the description of the variables in equations are used based on the studies carried out in the Lake Kasumigaura by Higano and Sawada [4], Higano and Yoneta [5] and Hirose and Higano [7]. Subsequently, Mizunoya et al. [11] extended and assessed synthetic environmental policies to reduce environmental burdens by biomass technology. These studies address the lake pollution issues considering socio-economic activities related to reduction of pollution with introducing integrated dynamic linear or non-linear modeling approach.

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. Spofford [14] has made an attempt to estimate the impact of current environmental management policies on economic development in China. Wang and Tang [18] 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 [15] 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 is tailored to suit China's economy and social state and includes the introduction of advanced new technologies to control water pollutant and green house gases emissions without deteriorating the socio-economic activities level, especially in the suburb around large 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 this study, we focused on analyzing a synthetic environmental management policy by computer simulation including the introduction of two new technologies to improve the environment and provide more biomass energy. We considered both the ecological system in the objective area and the socio-economic situational changes during a ten year period. To achieve our research purposes, one objective function (minimize total nitrogen (T-N) over ten years), the water pollutants flow balance model, the air pollutants flow balance model, the energy balance model and the socio-economic model were specified to express all key factors and parameters reflecting the environmental situations and affects of human activities. The computer simulation models were used to analyze the synthetic policies with introduction of two new technologies in the objective region. The dynamic simulation running period was from 2007 to 2016 (total ten years).

We formulate the comprehensive system as a linear optimization model which we solve a mathematical optimization software package, LINGO. This enables us to simultaneously simulate the environmental system and the socio-economic system by creating as much linearity as possible in the functions that is close to the reality. Detailed discussions of linear programming theory may be found in books by Hadley [3], Hillier [6] and Wagner [17].

2. Simulation Model

2.1 Classification of sub-basins of the main rivers and pollutant sources

The Chao and Bai rivers are the main rivers flowing into Miyun Reservoir. The two rivers flow through 9 towns of Miyun County. These rivers are structured into the model and other small rivers in the sub-basins flow into one of the two major rivers

(Table 1).

Table 1: Classification of the target area

Region	Rivers		Towns		Region	Rivers		Towns	
	No.	Name	No.	Name		No.	Name	No.	Name
1	1	Bai River	1	Shi Cheng	2	2	Chao River	4	Gao Ling
			2	Feng Jiayu				5	Gu Beikou
			3	Bu Laotun				6	Xin Chengzi
								7	Tai Shitun
								8	Bei Zhuang
								9	Da Chengzi

The pollutants measured in this study included three water pollutants, T-N (total nitrogen), T-P (total phosphorus) and COD (chemical oxygen demand) and three greenhouse gases, CO_2, CH_4 and N_2O. The household wastewater disposal system was divided into two categories based on the situations in the rural suburbs, land use into 5 categories of non-point generation sources and industry into 7 categories of production generation based sources on the characteristics of Miyun County (Table 2).

Table 2: Classifications of household waste water disposal system, land use and industry

Index	Facility	Index	Land use	Index	Industry
1	Sewage Plant	1	Upland Cropping	1	Fisheries
2	Untreated Waste Water	2	Forest Land	2	Pig Farming
		3	Orchard Land	3	Other Stockbreeding Industries
		4	City Area	4	Forestry
		5	Other Land Area	5	Planting Industry
				6	Manufacturing Industry
				7	Other Industries

2.2 Integrated Policies

Table 3 represents the integrated policies used in the simulation model to reduce water pollutants and greenhouse gases, and the government selected integrated policies to realize efficient improvement of the regional environment. According to the results of previous research, pig farming industry has become the source of the most serious pollutants to Miyun Reservoir. More than 25% of T-N, 41% of T-P and

36% of COD come from the pig farming industry. The catchment area has introduced wet methane fermentation technology to treat serious water pollutants emitted by the stockbreeding industry, particularly pig farming. However, the efficiency of wet methane fermentation technology is not sufficient to treat the high concentrations of wastes in the water and meet the requirements of future economic development in the catchment area. Therefore, in this paper we introduced two new technologies (*New Energy Project* and *Biomass Recycle Plant*) to particularly treat serious pollutants emitted by the pig farming industry. The government also proposed and provided preferential prices for farmers to promote utilization of organic fertilizers. The annual budget that the government spends directly and indirectly for the improvements of the Miyun environment is approximately 149.3 million RMB Yuan.

Table 3: Integrated policies for the catchment area

Source of pollutants	Name of policy	Measurements
Production	Reduction of the capital employed	1. Subsidization for industries to reduce working capital so as to adjust production
Pig Farming Industry	Introduction of hybrid technologies (*Biomass Recycle Plant* and *New Energy Project*) and reduction of the capital employed	2. Subsidization for pig farming industry to introduce *Biomass Recycle Plant*
		3. Subsidization for pig farming industry to introduce *New Energy Project*
		4. Subsidization to reduce working capital so as to adjust production
Household	Sewage system and sewage plant	5. Subsidization for the municipality to install more sewage system and sewage plant
Non-point	Promotion of organic fertilizer	6. Subsidization for farmer who uses organic fertilizer

2.3 Framework of the model

This dynamic simulation model consisted of a water pollutants flow balance sub-model, an air pollutants balance sub-model, an energy balance sub-model, a socio-economic sub-model and one objective function. The integrated policy was derived to minimize T-N, which was subjected to the sub-models. The water pollutants flow balance sub-model describes how the pollutants flow into the rivers and reservoir. The air pollutants flow balance sub-model describes how the air pollutants are emitted in the objective area. The energy balance sub-model simulated how much biomass energy can be produced by the two new technologies. The socio-economic sub-model represents the social and economic activities in the region and the relationship between the activities and emission of pollutants. The framework of the simulation model is shown in Fig. 2.

2.4 New technologies and data for the simulation

A *Biomass Recycle Plant* was developed by Ibaraki Preference as a city area project for promotion of coordination between industry, academia and government, and Advancement of Regional Science and Technology: "The Lake Ksumigaura Biomass Recycling Development Project" [11].

A *New Energy Project* was developed by Hangzhou City of China to promote effective and comprehensive utilization of pig wastes, and the project was classified as a state-level pilot project. The digital data of the new technologies are shown in Table 4.

Table 4: Digital data of two hybrid technologies

	New Energy Project	Biomass Recycle Plant	Unit
Construction cost	2.81 million	6.5 million	RMB Yuan
Maintenance cost	0.22 million	0.39 million	RMB Yuan
Electricity generated	209.88 thousand	22.7 thousand	kWh/year
Target scale of pig farm	10,000	1,000	pigs

We used the data of 2006 for the objective area. The basic data were obtained from the 2006 Yearbook of Miyun County, and the digital data for the simulation were calculated based on this basic data and related statistics from the State Environmental Protection Administration of China.

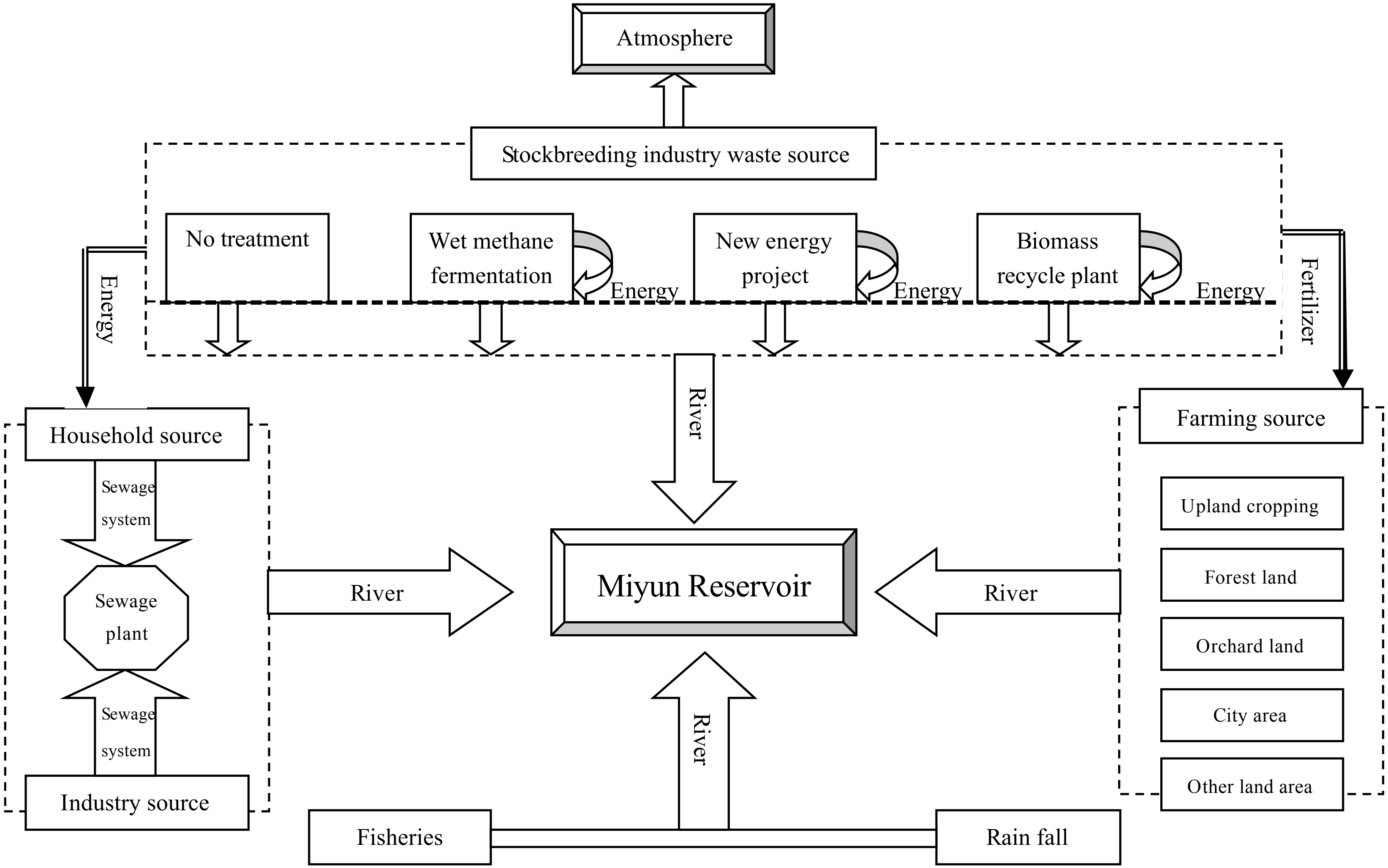

Figure 2. Framework of the model concept

3. Model structure

The dynamic simulation model consisted of more than seventy mathematical formulas so only the most important equations are included in the paper. The structure and relationship of sub-models are represented in Figure 3.

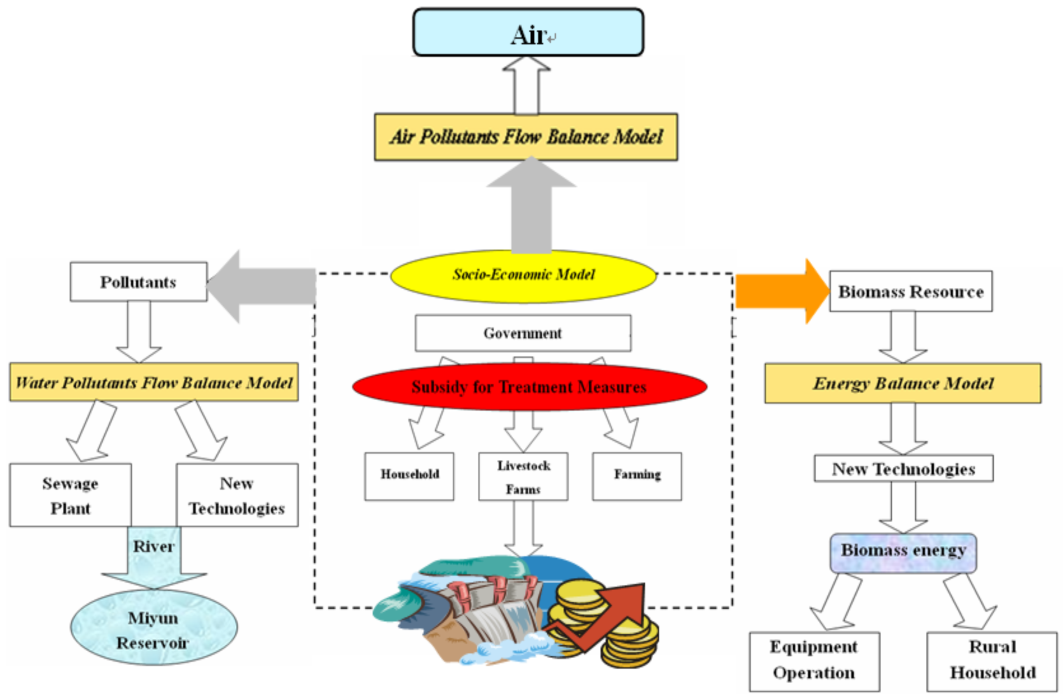

Figure 3. Structure of the simulation sub-models

3.1 Objective function

The protection and development of the water environment holds the highest priority in the upper stream area of the reservoir because Miyun Reservoir is the only surface water resource for Beijing. In addition, we investigated T-N as the most difficult degradable pollutant through different trial calculations. Therefore, an objective function was constructed to minimize the total net load of water pollutant T-N over the target term (t=10) in order to determine an optimal policy (en: endogenous; ex: exogenous).

$$Min\sum_{t=1} TP^{p}(t) \qquad p=1 \text{ (T-N)} \qquad (1)$$

3.2 Water pollutants flow balance sub-model

The net load of water pollutants in the reservoir was defined as the total water pollutants that flow through the rivers, including discharges by sewage plants, and untreated wastes from households, fisheries and rainfall in the catchment area.

(1) Water pollutant load of Miyun reservoir

$$TP^{p}(t) = \sum_{j} WP_{j}^{p}(t) + FP^{p}(t) + \sum_{m} SP_{m}^{p}(t) + RP^{p}(t) \qquad (2)$$

$TP^{p}(t)$: total net load of water pollutant p of the reservoir at time t. (en)

$WP_{j}^{p}(t)$: load of water pollutant p in region j. (en)

$FP^{p}(t)$: load of water pollutant p by fisheries. (en)

$SP_{m}^{p}(t)$: water pollutant p discharged by sewage plant m. (en)

$RP^{p}(t)$: water pollutant p from rainfall that flows into the are. (ex).

p=1 (T-N), 2 (T-P), 3 (COD)

(2) Water pollutant emitted by socio-economic activities was composed of pollutants from households, non-point sources and point sources (fisheries and sewage plant not included)

$$SEP_{j}^{p}(t) = HP_{j}^{p}(t) + NP_{j}^{p}(t) + EFP_{j}^{p}(t) \qquad (3)$$

$SEP_{j}^{p}(t)$: water pollutants emitted by socio-economic activities that flow into the reservoir through river j at time t. (en)

$HP_{j}^{p}(t)$: water pollutant p (excluding those from sewage) loaded by households in region j. (en)

$NP_{j}^{p}(t)$: water pollutant p emitted by non-point sources in region j. (en)

$EFP_{j}^{p}(t)$: water pollutant p emitted by socio-economic activities (excluding fisheries) in region j. (en)

(3) Water pollutant treated by sewage system

$$SP_{m}^{p}(t) = ES_{m}^{p} \cdot \sum_{j} P_{mj}^{SP}(t) \qquad (4)$$

ES_{m}^{hp}: pollution emission coefficient of sewage plant m in the area at time t. (ex)

$P_{mj}^{hSP}(t)$: population that uses sewage plant m of region j. (ex)

(4) Load of water pollutants from non-point sources

$$NP_j^p(t) = EL^{pl} \cdot L_j^k(t) \tag{5}$$

EL^{pl} : coefficient of water pollutant p emitted through land use l. (ex)

$L_j^k(t)$: area of land use l in region j that emitted pollutants into river. (en)

(5) Load of water pollutants from production activities

$$EFP_j^p = EFP_j^{p3\sim6}(t) + EFP_j^{p2}(t) \tag{6}$$

$$EFP_j^{p3\sim6}(t) = EI^{pm} \cdot X_j^m(t)(m \neq 1,2) \tag{7}$$

$$EFP_j^{p2}(t) = \sum_j EI^{pWF} \cdot NA_j^{WF}(t) + \sum_j EI^{pN} \cdot NA_j^N(t) + \sum_j EI^{pNP} \cdot NA_j^{NP}(t) + \sum_j EI^{pBP} \cdot NA_j^{BP}(t) \tag{8}$$

$EFP_j^{p3\sim6}(t)$: water pollutant p emitted by socio-economic activities (excluding pig farming and fisheries) in region j. (en)

$EFP_j^{p2}(t)$: water pollutant p emitted by pig farming industry in region j. (en)

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

$X_j^m(t)$: production of industry m in the area of region j that emitted pollutants into the rivers. (en)

EI^{pWF} : coefficient of water pollutant p emitted in pig feces and urine treated by wet methane fermentation. (ex)

$NA_j^{WF}(t)$: number of pigs for which feces and urine were treated by wet methane fermentation in region j. (en)

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

$NA_j^N(t)$: number of pigs for which feces and urine were not treated in region j. (en)

EI^{pNP}: coefficient of water pollutant p emitted by pigs whose feces and urine treated by *new energy project*. (ex)

$NA_j^{NP}(t)$: number of pigs whose feces and urine treated by *new energy project* in region j. (en)

EI^{pBP} : coefficient of water pollutant p emitted by pigs whose feces and urine treated by *biomass plant*. (ex)

$NA_j^{BP}(t)$: number of pigs whose feces and urine treated by *biomass plant* in region j. (en)

3.3 Air pollutants flow balance sub-model

$$TGG(t) = TG_1(t) + TG_4(t) \cdot GWP_4 + TG_5(t) \cdot GWP_5 \tag{9}$$

$$\begin{aligned} TG_a(t) &= EG_a^m \cdot \sum_j \{X_j^3 + X_j^4 + X_j^5 + X_j^6 + X_j^7\} \\ &+ \{EG_a^{WF} \cdot \sum_j NA_j^{WF}(t) + EG_a^N \cdot \sum_j NA_j^N(t) + EG_a^{NP} \cdot \sum_j NA_j^{NP}(t) \\ &+ EG_a^{BP} \cdot \sum_j NA_j^{BP}(t)\} + EG_a^C \cdot C(t) \end{aligned} \tag{10}$$

$TGG(t)$: total emission of greenhouse gas while considering the greenhouse effect potential of each gas (named TGG) at time t. (en)

$TG_a(t)$: total emission of greenhouse gas or air pollutant a at term t. (en)

a=1 (CO_2), 2 (CH_4), 3 (N_2O)

GWP_4: potential index of greenhouse effect of each gas when greenhouse effect by discharge of one molecule of carbon dioxide is assumed to be one. (ex)

EG_a^m : coefficient of greenhouse gas and air pollutant a emitted by industry m ($m \neq 2$). (ex)

EG_a^{WF} : coefficient of greenhouse gas and air pollutant a emitted by pig whose feces and urine treated by wet methane fermentation. (ex)

EG_a^N: coefficient of greenhouse gas and air pollutant a emitted by pigs whose feces and urine was not treated by any method. (ex)

EG_a^{NP}: coefficient of greenhouse gas and air pollutant a emitted by pigs whose feces and urine were treated by *new energy project*. (ex)

EG_a^{BP} : coefficient of greenhouse gas and air pollutant a emitted by pigs whose feces and urine were treated by *biomass plant*. (ex)

EG_a^C : coefficient of greenhouse gas and air pollutant a emitted by final demand. (ex)

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

3.4 Energy balance sub-model

(1) Energy demand

Energy demand is decided by production of industrial section and consumption of final demand section.

$$ED_j^m(t) = \theta^m \cdot X_j^m(t) \tag{11}$$

$$ED^C(t) = \theta^C \cdot C(t) \tag{12}$$

$ED_j^m(t)$: energy demand of industry m in region j at term t. (en)

θ^m: coefficient of energy demand of industry m. (ex)

$ED^C(t)$: energy demand of final demand section at time t. (ex)

θ^C: coefficient of energy demand of final demand section. (ex)

(2) Total energy demand

$$TED(t) = \sum_j \sum_m ED_j^m(t) + ED^C(t) \tag{13}$$

$TED(t)$: total energy demand at time t. (en)

(3) Amount of electric energy generated by new technologies

$$TEN_j(t) = \delta^{NP} \cdot K_j^{NP}(t) + \delta^{BP} \cdot K_j^{BP}(t) \tag{14}$$

$TEN_j(t)$: amount of electric energy generated by *new energy project* in region j at time t. (en)

δ^{NP}: coefficient of electric energy generation of *new energy project*. (ex)

$K_j^{NP}(t)$: capital of *new energy project* available in region j at time t. (en)

δ^{BP}: coefficient of electric energy generation of *biomass plant*. (ex)

K_j^{BP}: capital of *biomass plant* available in region j at time t. (en)

(4) Capital of new technologies

$$K_j^{NP}(t) \leq \chi^{NP} \cdot \frac{NA_j^{NP}(t)}{10000} \tag{15}$$

$$K_j^{BP}(t) \le \chi^{BP} \cdot \frac{NA_j^{BP}(t)}{1000} \tag{16}$$

χ^{NP} : coefficient of *new energy project* cost per pig farm. (ex)

χ^{BP} : coefficient of *biomass plant* cost per pig farm. (ex)

(5) Capital accumulation of new technologies

$$K_j^{NP}(t+1) = K_j^{NP}(t) + I_j^{NP}(t) \tag{17}$$

$$I_j^{NP}(t) = \frac{1}{\gamma^{NP}} \cdot S_j^{NP}(t) \tag{18}$$

$$K_j^{BP}(t+1) = K_j^{BP}(t) + I_j^{BP}(t) \tag{19}$$

$$I_j^{BP}(t) = \frac{1}{\gamma^{BP}} \cdot S_j^{BP}(t) \tag{20}$$

$I_j^{NP}(t)$: investment for construction of *new energy project* in region j at time t. (en)

γ^{NP} : rate of subsidization for construction of *new energy project* by the Miyun government. (ex)

$S_j^{NP}(t)$: subsidization for construction of *new energy project* by the Miyun government. (en)

$I_j^{BP}(t)$: investment for construction of *biomass plant* in region j at time t. (en)

γ^{BP} : rate of subsidization for construction of *biomass plant* by the Miyun government. (ex)

$S_j^{BP}(t)$: subsidy for construction of *biomass plant* by the Miyun government. (en)

(6) Energy balance

The demand for energy of pig farming is covered by the amount of power generated by the new technologies and the existing electric power industry.

$$TEN_j(t) + TED_j^2(t) \ge ED_j^2(t) \tag{21}$$

$TED_j^2(t)$: amount of electric energy of region j generated by electric power industry that is provide to pig farming in Miyun county at time t. (en)

$ED_j^2(t)$: energy demand of pig farming in region j at time t. (en)

3.5 Treatment policies for non-point sources

Miyun government developed the *Organic Fertilizer Promotion Policy* in 2004 and converted the majority of upland cropping areas into forest to improve the water conservation function of Miyun Reservoir. This treatment policy is subsidized by the government for the promotion of organic fertilizers.

(1) Conversion of land to forest

$$L_j^k(t+1) = L_j^k(t) + \sum_{k \neq l} L_j^{lk}(t) \tag{22}$$

$L_j^{lk}(t)$: conversion of land from l to k in region j. (en)

$$L_j^k(t+1) = L_j^k(t) - \sum_{l \neq k} L_j^{kl}(t) \tag{23}$$

$L_j^{kl}(t)$: conversion of land use from k to l in region j at time t. (en) k=5, l=2

$$L_j^{52}(t) \geq \lambda^5 \cdot S_j^{5f}(t) \tag{24}$$

λ^5: reciprocal of the subsidy for conversion of one unit to forest. (ex)

$S_j^{5f}(t)$: subsidy from the government for conversion of land use. (en)

(2) Conservation of land area with organic fertilizer

$$LC_j^{OF}(t+1) = LC_j^{OF}(t) + \Delta LC_j^{OF}(t) \tag{25}$$

$\Delta LC_j^{OF}(t)$: increase in planting area that applied organic fertilizers in region j at time t. (en)

$$\Delta LC_j^{OF}(t) = ILC_j^{OF} \cdot S_j^{OF}(t) \tag{26}$$

ILC_j^{OF}: increase in planting area that applied organic fertilizers per thousand RMB Yuan in region j at time t. (ex)

$S_j^{OF}(t)$: subsidy for the utilization of organic fertilizer in region j at time t. (en)

3.6 Policies for household wastewater generation

According to the characteristics and situations of rural areas of big cities, the treatment of household wastewater mainly depends on the sewage systems and sewage plants. These measures are implemented by the local governments.

(1) Increase in the population that uses the sewage systems and plants

$$\Delta P_i^{SP}(t) \le \lambda_i^{SP} \cdot I_i^{SP}(t) \qquad (27)$$

$\Delta P_i^{SP}(t)$: increase in the population that uses the sewage plants. (en)

λ_i^{SP} : reciprocal of the necessary construction investment per person that uses the sewage plant. (ex)

$I_i^{SP}(t)$: construction investment of municipality i for sewage plant. (en)

(2) Sewage system

Investments for construction of sewage systems and plants are determined by the construction allotment of the municipality and subsidies that are provided by the local government. The construction allotment and maintenance costs are covered by local finances and special subsidizations:

$$I_i^{SP}(t) = \left(\frac{1}{1 - M_i^{SP}}\right) \cdot \xi_i^{SP} \cdot FE_i(t) \qquad (28)$$

$$MC_i^{SP}(t) = \varsigma_i^{SP} \cdot FE_i(t) \qquad (29)$$

$$I_i^{SP}(t) + MC_i^{SP}(t) \le \varpi \cdot FE_i(t) + S_i^{SP}(t) \qquad (30)$$

$FE_i(t)$: local finance by the local government. (en)

M_i^{SP} : rate of subsidy by the local government. (ex)

ξ_i^{SP} : rate of transfer for investment of household wastewater from the finance of municipality i. (ex)

MC_i^{SP} : maintenance of sewage system of municipality i at time t. (en)

ς_i^{SP} : rate of transfer for maintenance of household wastewater treatment from the finances. (ex)

ϖ : rate of transfer for treatment of household wastewater from the total finances of municipality i. (ex)

$S_i^{SP}(t)$: subsidy for household wastewater treatment granted by Miyun government. (en)

3.7 Treatment measures for production generation sources

(1) Production function and curtailment

$$X_j^m(t) \le \alpha^m \cdot \{K_j^{mP}(t) - S_j^m(t)\} \tag{31}$$

$X_j^m(t)$: total production of industry m in region j. (en)

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

$K_j^{mP}(t)$: capital available for industry m in region j. (en)

$S_j^m(t)$: subsidy for industry m granted by Miyun government. (en)

$$K_j^{mP}(t+1) = K_j^{mP}(t) + I_j^{mP}(t+1) - d^m \cdot K_j^{mP}(t) \tag{32}$$

$I_j^{mP}(t)$: investment by industry m in region j. (en)

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

3.8 Total budget of the government for the countermeasures

$$y(t) \ge \sum_i S_i^{SP}(t) + \sum_j \sum_m S_j^m(t) + \sum_j S_j^{OF}(t) + \sum_j S_j^{5f}(t) + \sum_j S_j^{NP}(t) + \sum_j S_j^{BP}(t) \tag{33}$$

$y(t)$: total budget spent by the local government for implementing the countermeasures. (ex)

3.9 Flow balance in the commodity market

Total products of each industry are decided by the balance between supply and demand.

$$\begin{aligned} X(t) \ge\ & A \cdot X(t) + C(t) + i^m(t) + B^{SP} \cdot I^{SP} + B^{NP} \cdot I^{NP}(t) + B^{BP} \cdot I^{BP}(t) \\ & + B^{mNP} \cdot \sum_j K_j^{BP}(t) + B^{mBP} \cdot \sum_j K_j^{BP}(t) + e(t) \end{aligned} \tag{34}$$

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

A : input-output coefficient matrix. (ex)

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

$i^m(t) = \sum_j I_j^{mP}(t)$: total investment at time t. (ex)

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

B^{NP} : column vector of m-th coefficient that induced production in industry m by construction of *new energy project*. (ex)

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

B^{mNP} : column vector of m-th coefficient that induced production in industry m by maintenance of *new energy project*. (ex)

B^{mBP} : column vector of m-th coefficient that induced production in industry m by maintenance of *biomass plant*. (ex)

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

3.10 Gross regional product

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

$$GRP(t) = \upsilon \cdot X(t) \tag{35}$$

GRP(t): Gross Regional Product in term t. (en)

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

3.11 Constraints on the regional economy

We set the constraints on the local economic development for each year according to the features and requirements of the Chinese economy. This also makes it sure that the optimization model of minimization of T-N has a meaningful solution.

$$GRP(t+1) \geq GRP(t) \tag{36}$$

4. Simulation results

In this study, we defined the simulation cases that reflect economic development level (GRP) as increases of n% in 2016 compared to 2006. Representative cases were selected to indicate the variations in the simulation results. Case 10 represents a GRP in 2016 with an increase of 10% compared to 2006; Case 15 an increase of 15% compared to 2006; Case 20 an increase of 20% compared to 2006.

4.1 Objective function and total GRP

In this study, we adopted integrated policies with the introduction of two new technologies for the simulation, and the policy effectively reduced the environmental pollutants in this simulation. A feasible solution was reached for Case 10 that both adopted and did not adopt the two new technologies, and a feasible solution was achieved for Case 20 when we adopted the two new technologies. No feasible solution could be obtained for Case 21 that both adopted and did not adopt the two new technologies.

Comparing the results of the simulations, the introduction of new technologies is effective to reduce water pollutants and green house gases, and at the same time achieve economic development. When introduction of the new technologies and GRP increased by 20% compared to 2006 (Case 20), the objective value for T-N (sum of T-N for 10 years) decreased about 3,499 tons as compared to when not adopted (Fig. 4). Introduction of two new technologies raised the rate of economic growth 10% as compared to no introduction of new technologies. Moreover, the total GRP accumulated for ten years had a difference of more than 1,819 million RMB Yuan when the two new technologies were adopted in Case 10 as compared to when not adopted (Fig. 5).

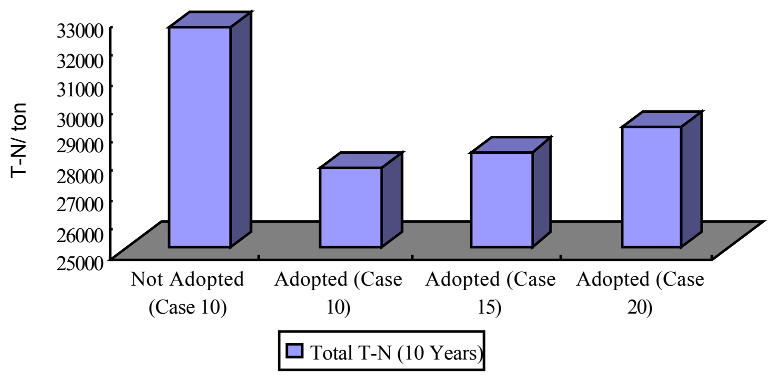

Figure 4. Objective value for T-N (sum of T-N for 10 years)

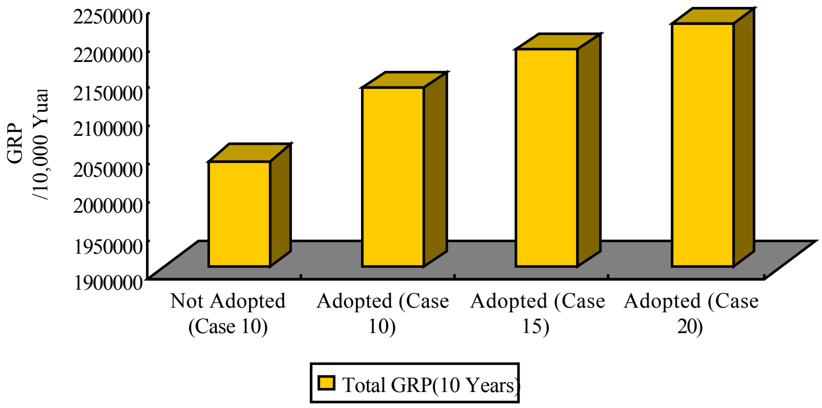

Figure 5. Accumulated total GRP (2007-2016)

The variations in total amounts of T-P and COD flowing into the Miyun Reservoir are shown in Fig. 7 and Fig. 8. In Case 10, the net load of T-N was reduced 25.3% (see Fig. 6), and the net load of T-P and COD was reduced 42.0% and 36.7%, respectively, in 2016 with adoption of the new technologies when compared with no adoption. This result verifies that it is necessary to consider the minimization of T-N as the objective function when we formulate integrated policies to improve the water environment.

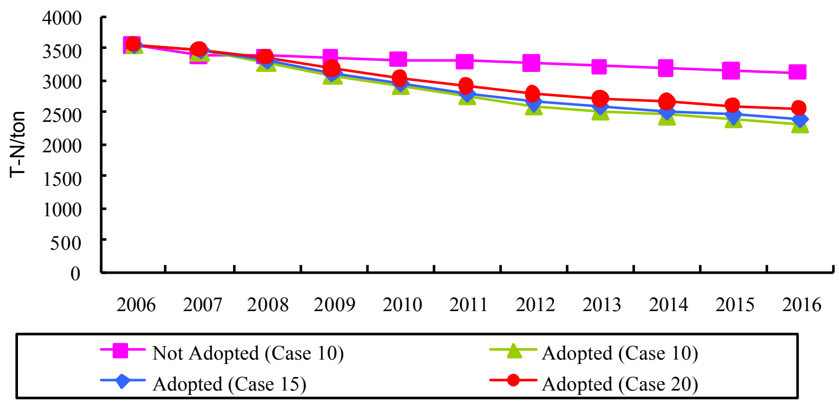

Figure 6. Changes in T-N

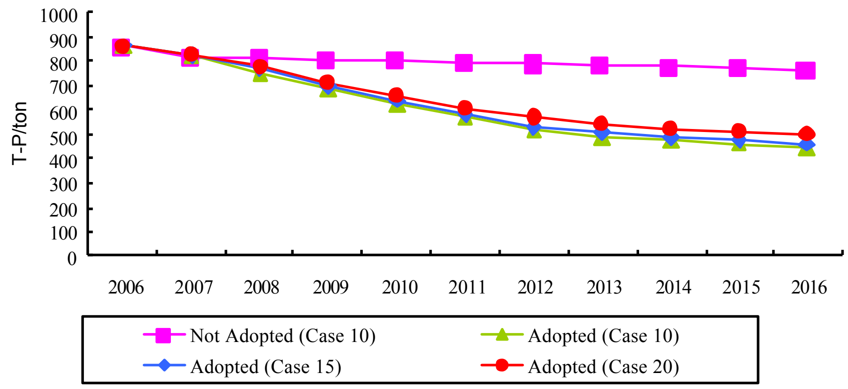

Figure 7. Changes in T-P

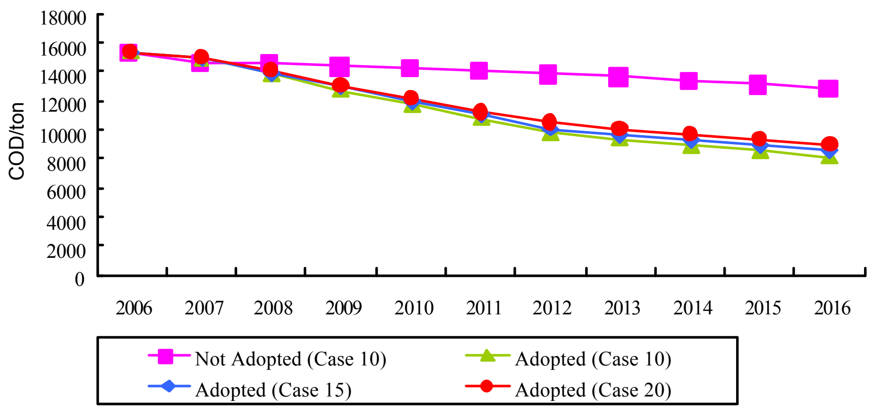

Figure 8. Changes in COD

4.2 Budget expenditures for the policy

In Fig. 9, we show the accumulation of budget allotment in the simulation. It is interesting that the measured cost for the production generation source decreased when the new technologies were adopted in Case 10-20 as compared to when not adopted (Case 10) and subsidies were drawn from the introduction of the two new technologies. This result shows that the subsidy for the introduction of two new technologies can mainly be covered by the diverted budget from the measured costs for the production generation source.

As shown in Fig. 9, we also found that the measured costs for household wastewater generation have only a small difference among Cases 10-20 that adopted the new technologies. Therefore, we conclude that a policy that installs more sewage plants and systems is an effective tool to reduce pollutants emitted by households and this policy is adaptive to specific situation in rural areas of China.

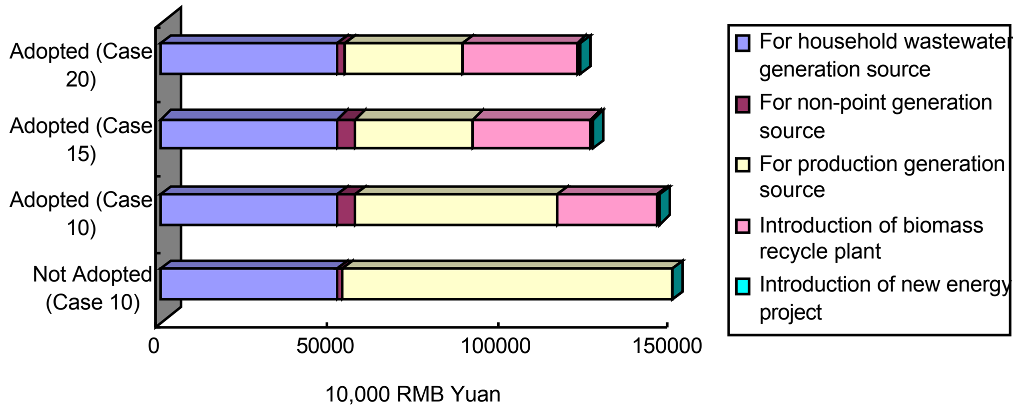

Figure 9. Accumulated total budget expenditures for each policy

4.3 Variations in production of pig farming industry

The variation in production of the pig farming industry is shown in Fig. 10. In this simulation, the policy to introduce new technologies is adopted in Case 20 in the catchment area, the amount of production of the pig farming industry increases about 448 million RMB Yuan over a total of ten years for the simulation period as compared with not adopting the technologies and the production of pig farming increased more than 33.7% as compared to 2006.

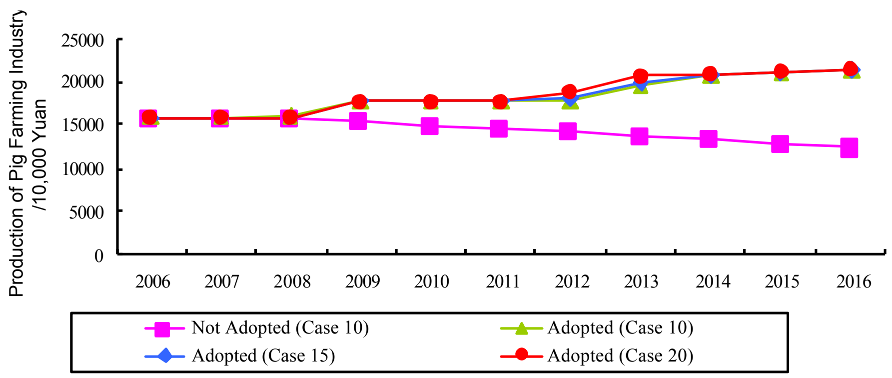

Figure 10. Changes in production of pig farming industry

4.4 Pollutants emitted from pig farming industry

Table 5 shows that the water pollutants from the pig farming industry that flow into the reservoir were obviously reduced with the introduction of the two new technologies, 6,423 tons of T-N, 2,716 tons of T-P and 42,729 tons of COD can be reduced in the total ten years (2007-2016) by introducing the new technologies.

Table 5: Reduced Emissions of water pollutants

		Water Pollutants		
		T-N	T-P	COD
Reduced in Pig Farming Industry (Derived Emission Amount in Case 20 (Without Hybrid Technologies) - Case 20 (With Hybrid Technologies) (t))	2006	0	0	0
	2007	53.1	24.1	382.7
	2008	175.7	75.9	1,195.8
	2009	308.8	131.7	2,073.1
	2010	441.8	187.5	2,950.4
	2011	574.8	243.3	3,827.8
	2012	707.8	299.1	4,705.1
	2013	840.9	355.0	5,582.5
	2014	973.9	410.8	6,459.8
	2015	1,106.9	466.6	7,337.2
	2016	1,239.9	522.4	8,214.5
Accumulated Total in 10 Years (2007～2016) (t)		6,423.6	2,716.4	42,729.0

Moreover, from the aspect of greenhouse gases, the new technologies emit much less CH_4 and N_2O than any other method of animal waste treatment. This indicates that utilization of biomass resources contributes to mitigation of the GHG even if CO_2, a generated biomass resource is not considered as carbon neutral. In this simulation, about 17 thousand tons of greenhouse gas can be reduced in the total ten years by introducing the two new technologies (see Table 6).

Table 6: Reduced emissions of greenhouse gases

		Green House Gases			
		CO_2	CH_4	N_2O	GHG
Reduced in Pig Farming Industry [Derived Emission Amount in Case 20 (Without Hybrid Technologies) - Case 20 (With Hybrid Technologies) (t)]	2006	0	0	0	0
	2007	-433	96	1	2,130
	2008	-2,632	295	2	5,277
	2009	-5,094	510	3	8,577
	2010	-7,557	725	4	11,877
	2011	-10,019	939	6	15,176
	2012	-12,481	1,154	7	18,476
	2013	-14,943	1,369	8	21,775
	2014	-17,406	1,584	10	25,075
	2015	-19,868	1,799	11	28,375
	2016	-22,330	2,014	12	31,674
Accumulated Total in 10 Years (2007～2016) (t)		-112,764	10,485	64	168,413

4.5 Amount of electric energy produced by the new technologies

The amount of electric energy produced by the two new technologies is shown in Table 7. In this simulation, we found that if a policy to introduce the new technologies is adopted in Case 20 in the catchment area, about 33 million kwh electrical energy over the total ten years can be generated by two new technologies.

Table 7: Amount of electric energy produced by the two hybrid technologies

Year	Electrical Energy (10,000 kwh)		
	Adopted (Case 10)	Adopted (Case 15)	Adopted (Case 20)
2007	37.94	33.63	28.66
2008	99.95	97.83	90.97
2009	161.96	162.02	158.30
2010	223.97	226.22	225.64
2011	285.98	290.41	292.97
2012	347.99	354.61	360.31
2013	410.00	418.81	427.64
2014	472.01	483.00	494.97
2015	534.02	547.20	562.31
2016	596.03	611.40	629.64
Accumulated Total in 10	3,169.86	3,225.13	3,271.42

Years (2007 ~ 2016)			

According to the CO_2 emission coefficient of coal pover generation system in China, when we adopted new technologies, the emission of CO_2 can be reduced about 32.01 thousand tons as compared to general coal power generation system.

4.6 Cost-benefit analysis and regional analysis

The simulation carried out in Case 20 shows that 151 *biomass recycle plants* and 14 *new energy projects* should be installed to treat the pig wastes (see Fig. 11). The total cost is about 1.09 billion RMB Yuan over the total ten years. At the same time, the accumulated total GRP would increase about 1.82 billion RMB Yuan over the same period. This shows that there is great feasibility and possibility to introduce new technologies in the catchment area.

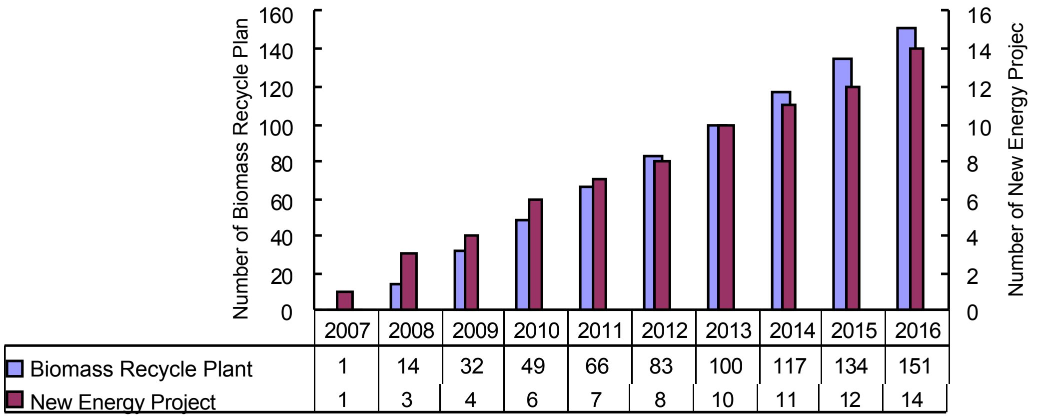

Figure 11. Number of two new technologies (Case 20)

Table 8 shows the regional allocation of new technologies for pig farming industry in 2016. We find another interesting phenomenon that the number of pigs in Region 2 is about 3 times larger than that in Region 1. But the subsidy provided for Region 1 is larger than Region 2. The subsidy provided for Region 1 mainly is occupied by Bu Laotun Town, and 6 *new energy projects* should be installed for the concentrated large-scale pig farms in Bu Laotun Town. Even in this simulation, since its per capita scale of financial affairs is the smallest one in this catchment area, installation of sewage system was not set up in time to keep up with the regional development. Therefore, the Miyun government should provide more budgets to introduce new technologies in Bu Laotun Town prior to other towns.

Table 8: Regional allocation of two new technologies for pig farming industry in 2016

Region	Town	Number of Pig	Subsidy (10 000 Yuan)	Per Capita Scale of Financial Affairs (10 000 Yuan)	Number of New Energy Project	Number of Biomass Plant
Bai River	Shi Cheng	3,445	27.36	0.378	0	0
	Feng Jiayu	12,663	100.55	1.162	2	0
	Bu Laotun	60,459	480.07	0.111	6	0
Total of Region 1		76,568	607.98	0.404	8	0
Chao River	Gao Ling	66,117	149.21	0.277	2	47
	Gu Beikou	19,345	43.66	1.218	0	14
	Xin Chengzi	22,197	50.09	0.247	1	16
	Tai Shitun	45,594	102.89	0.195	1	33
	Bei Zhuang	25,778	58.17	0.360	1	18
	Da Chengzi	32,077	72.39	0.161	1	23
Total of Region 2		211,107	476.42	0.320	6	151
Total		287,675	1,084.40	—	14	151

5. Conclusion

The basic aim of this article has been to develop a dynamic liner model, and to verify it through carrying out simulations in order to evaluate the possibility and feasibility to introduce new technologies into rural areas around big cities in China and research the arrangement of the new technologies to realize effective utilization of stockbreeding biomass resource. When we adopted the policy to introduce two new technologies, the policy was a very effective tool to reduce environmental pollutants in all simulations. The introduction of two new technologies raised the level of economic growth by 10% as compared to not adopting the new technologies policy. When the two new technologies were introduced in Case 10, the objective value (total T-N) showed a reduction of about 13% as compared to not adopting the new technologies. Moreover, we also found that if the policy to introduce the new technologies was adopted in the catchment area, production of the pig farming industry increased about 448 million RMB Yuan over the total ten year simulation period as compared with not adopting.

Concerning environmental pollutants, we found a reduction of about 19.7% (168 thousand tons) of greenhouse gases emitted by the pig farming industry in the total ten year simulation (2007-2016) when we introduced the new technologies in Case 20. In addition, we found that about 47% (6,424 tons) of T-N, 53% (2,716 tons) of T-P and 54% (42,729 tons) of COD emitted by the pig farming industry in the total ten year simulation can be reduced by introducing the new technologies. From the aspect of biomass electric energy, more than 32.7 million kwh of electric energy can be generated when we adopted the two new technologies.

From the aspects of different regions, although Chao River basin has smaller amount of pig, its large-scale pig farms are concentrated, more *new energy project* should be installed in Region 1; since the distribution of pig farms is dispersed in Bai River basin, more *biomass plant* should be installed in Region 2.

The results of this study establish the synthetic policies for the catchment area, especially the introduction of new technologies for pig farming industry are very effective and the utilization of biomass resources allows simultaneous pursuit of environmental preservation and economic development. When we introduce new technologies to utilize biomass resource, preferential policies becomes essential, the government should implement preferential policies, such as carrying out tax preference and raising subsidized rate to encourage the utilization of new technologies. This comprehensive evaluation is expected to improve the biomass resource utilization and environmental reservation and form the basis of policy decision-making for sustainable development of rural areas of big cities in China.

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