Comprehensive Evaluation of Socio-Economic and Environmental Policies for Mitigating Water Pollution and Scarcity in Source Region of Liao River

（遼河源流域における水質汚濁物質および水不足解消のための社会経済および環境政策の総合評価）

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要　約

1. Introduction

Pressures over water environment have escalated due to water resource overexploitation and water pollution, which have become the global water environmental problems and brought negative impacts to human health and sustainable socio-economic development. Source Region of Liao River (SRLR) faces water scarcity due to the multi-stresses of decreasing water availability, increasing water demand driven by rapid economic development, accelerated urbanization and population growth. The exploration rate of surface water resources exceeds 80%, much larger than the international exploration cordon of river water resources (40%), and the groundwater has been overexploited for irrigation and manufacturing industry.

SRLR also has been suffering heavy water pollution continuously. The water quality of the whole basin is seriously deteriorating not meeting the requirements of surface water function zoning and water pollution is mainly characterized by organic pollution. Industrial sectors discharge the most total nitrogen (TN), total phosphorus (TP) and chemical oxygen demand (COD) in 2010 compared with that discharged from household and land use. Few wastewater treatment measures and management instruments have been put into practice in 2010. Only 67.4% of COD generated by urban household and 12.1% by manufacturing have been treated by municipal sewage treatment plants. In this sense, there is a space for further proper treatment of wastewater. The severe status in terms of water pollution and scarcity makes it significant to exploit eligible water environment management instruments for the prevention of water environmental degradation and promotion of socio-economic development.

Some instruments proposed separately against water pollution are insufficient without taking water environment and socio-economic development into consideration as a whole. Sustainable water environment management needs the combination of engineering and socio-economic instruments under the uniform objective framework. Thus the solution for both water pollution control and balance of supply and demand of water resources necessitates full consideration of the socioeconomic and environmental settings.

What kinds of strategies and instruments are appropriate to put into practice in SRLR? How policy system, water environmental system and socio-economic system could influence each other? How to obtain an optimal solution to accomplish total control of water pollutants discharge and balance of water supply and demand, with the minimum negative influence on socio-economic development? Implementation of any watershed management activities cause "costs" in any sense. Thus, who shall pay for the cost and how much the cost is for the society to improve the water environment is important for all the stakeholders including government. How the government should provide subsidy for adoption of new technologies or policies? The complexity of relationships between environment and socio-economy calls for solutions related to above questions.

In the face of challenges of water pollution and water resources crisis in SRLR, the main objective of the study is to explore a simulation model based on input-output (IO) approach to mitigate water pollution and water scarcity through embedding environmental economic policies and applicable technologies into complex environ-economic system to obtain an optimal set of policies and technologies which promotes maximization of regional economy under constraints of water pollutant discharge and water availability.

Specifically, this study is designed to:

1) Explore an optimization simulation model based on extended IO model (2011~2020, 2010 as base year), including socio-economic, water environmental, water resources, energy and greenhouse gases (GHG) systems.
2) Identify an optimal set of technologies and policies most effective and realize total control of water pollutant discharge, balance of water supply and water demand with the least economic sacrifice through the simulation work.
3) Specify the extent of mitigation of water pollution and water scarcity via applied policies and technologies promoted by the subsidies provided by government, and explain the mechanism of policy application and subsidization distribution.
4) Manifest the best trade-off between regional socio-economic development, water environmental conservation and water resources utilization as well as effectiveness of policies and technologies adopted.

2. Methodology

This study develops and illustrates an integrated dynamic optimization simulation model based on input-output approach to mitigate water pollution and water scarcity through embedding environmental economic policies and applicable technologies into complex environ-economic system. This model is used to obtain an optimal set of policies and technologies that promotes maximization of regional economy under constraints of water pollutant discharge (WPD) and water availability. The model consists of social-economic sub-model, water pollution control sub-model, water supply and demand sub-model, energy sub-model and GHG emission sub-model. The optimization will be solved via application of LINGO programming, a non-linear optimization software package released by LINDO Systems Incorporated.

The model framework contains three major economic entities (usual industries, energy industries and final demand sectors) and the proposed polices and technologies, which are integrated into a holistic energy-environmental-socioeconomic system through the embedded material flow, value flow and energy flow. Five subsystems within the whole system were determined. The socio-economic subsystem is elaborated as the production activities of industrial sectors, private and government consumption, gross capital formation and net exports. Subsidies for promotion of policy application are sourced from government savings. Reclaimed water production and multistep water price system are introduced into the water resource subsystem which depicts the balance of the water demand and supply. The water pollution control subsystem is utilized to calculate the amount of water pollutants generated from the production and consumption activities and that are discharged into water bodies after introducing pollution abatement technologies. The energy subsystem additionally involves the production of renewable energy. The GHG emission subsystem clarifies the variation in GHG emissions resulting from the constraints of water pollutant discharge and water availability.

Scenario simulation is used to compare the impacts of part and the whole policies proposed on economy and water pollution situation initially. Then it is used to analyze the impacts on the economy and water environment within a single constraint on water pollution or water availability and both constraints of them, as well as the corresponding policies and technologies introduced into these conditions.

3. Proposed policies

Data analysis, analytical approaches (like footprint and linkage) are used, considering governmental regulations, to formulate some decision rules for proposing policies for mitigating water pollution and scarcity. The following environmental policies and corresponding technologies will be introduced: for water pollution control, Improvement of sewage and wastewater treatment rate, Resource-oriented policy for livestock breeding industry, Promotion of forestation and grassland restoration, Promotion of new fertilizer utilization; for water supply and demand, Promotion of reclaimed water production and utilization, Implementation of multistep water price system. In order to select appropriate technologies, additional factors, such as applicability, advancement and the popularization potential of technologies are also considered.

4. Main results and conclusion

An integrated optimization simulation model has been developed to mitigate water pollution and water scarcity simultaneously through embedding environmental economic policies and applicable technologies into a complex environ-economic system to obtain an optimal set of policies and technologies that promotes the maximization of the regional economy.

The contrasts of four scenarios indicate that the formed optimal policy combination with industrial restructuring collectively achieves the targets of the WPD constraints and the water availability constraint. S54 is selected as the optimal scenario due to the relatively higher average Gross Regional Product (GRP) growth rate (9.55%), achieving the targets of water pollution control (30% COD reduction, 30% TN reduction and 25% TP reduction by 2020 compared with 2010) and water supply and demand balance. In the optimal scenario, the trends in economic development, pollutant discharge and water consumption for each sector within the simulation time horizon (2011-2020) are depicted dynamically. The production of breeding industries with relatively higher WPD coefficients decreases obviously in the simulation time horizon. Manufacturing, construction, transportation and service industries are in the opposite situation. Pollutants discharged from breeding industries and households reduce drastically in S54. Due to the rapid development of manufacturing, the WPD increases once. Water demand of construction, mining, electricity production and service industries increases more than once. Water demand of fishery, planting and breeding industries deceases continuously due to the decrease in sectoral production in the optimal scenario.

In the optimal scenario, the discharge amount of TN, TP and COD reduces 30.01%, 29.62% and 31.17% by 2020 compared with 2010, respectively. The total WPD reduction amount in the simulation time horizon 2011-2020 in S54 is facilitated jointly by sectoral production change and the optimal set of policies. The optimal set of policies contributes 92.19% and 78.03% reduction of TN and TP respectively among the total reduction amount, the rest is contributed by industrial production changes including production increase and decrease. Sectoral production changes induce a 26.28 thousand ton increase in COD discharge; the policies contribute a 85.17 thousand ton reduction in COD discharge; finally, a 58.83 thousand ton reduction in COD discharge is achieved. For water supply, reclaimed water production is introduced to mitigate the scarcity of water resources and the amount of reclaimed water supply is 80.26 million m^3, accounting for 5.56% in the total water supply in 2020 in S54. For water demand, a multistep water price system specifying a three-order water price system is introduced for urban households. The multistep water price system contributes to a decrease of 10.04 million m^3 in urban water demand compared with when no policy is introduced in 2020.

The extent of the mitigation of water pollution and water scarcity contributed by the proposed policies or technologies and the subsidies granted to promote policy or technology implementation are specified, from which the mechanisms of the policy application and the subsidization allocation are systematically clarified. Among the WPD amount reduced by the optimal set of policies in S54, biogas power generation technology (for cattle breeding industries) removes the most TN (30.00%) and TP (28.74%) with the most subsidies. Promotion of organic-inorganic compound fertilizer utilization is the second main contributor for the reduction of TN and TP accounting for 19.55% and 14.16% respectively. Wastewater treatment technologies remove the most COD discharged from manufacturing industry compared with other policies or technologies accounting for 34.38% followed by biogas power generation technology.

The simulation model predicts the biomass energy production and GHG emission. The share of electricity production by biomass energy plants increases gradually up to 1.11% by 2020 in S54. The average GHG emission growth rate in S54 is 8.95% which is smaller than the average GRP growth rate (9.55%). GHG emission intensity decrease from 331.61t CO_2-e/million CNY in 2011 to 315.81 t CO_2-e/million CNY in 2020 in the optimal scenario. Regional analysis has been conducted to detect the economic development, water pollutant discharge intensity, and water consumption intensity in each sub-region as well as the subsidy distribution.

The formed optimal set of policies and technologies is affected by water pollutants joint-removal efficiency, limitation of technology application potential, subsidy source and allocation mechanism, and specific constraints like ecological conservation, promotion of new and renewable energy, sewage rate. The optimal set of policies and technologies not only contributes to mitigating water pollution and scarcity, but also has an effect on the extent of industrial restructuring. The industrial restructuring is conducted in the form of production decrease in some sectors following an order determined by the WPD coefficients, freshwater consumption (FC) coefficient and value added rate of each industry jointly with industries having higher WPD coefficients, FC coefficients and lower value added rates as priority. Thus, the efficiency of the optimal set of policies and technologies is significant for the integrated system. Some parameters of technologies (the discharge coefficients, the coefficients of induced production by investment and the depreciation rate of technologies) and the proportion of subsidies from provincial and central government, that affect the efficiency of the optimal set of policies should be well calculated and organized when performing the economic and environmental policies.

The model is robust in the case that once the parameters and necessary data have been input, the model will obtain an optimal solution as a result of the comprehensive and overall evaluation of all of the possible policies and technologies, which can contribute to better informed policy-making and development of specific plans. This model has applicability for other regions in terms of giving an optimal solution via comprehensive assessment of all of the proposed sustainability-related policies with sufficient data accessibility to achieve regional sustainable development.

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