Comprehensive Evaluation of the Introduction of Integrated Biomass Energy Utilization System and Optimal Environmental Policies with Simulation Modeling Approach: A Case Study of Jilin Province, China

（中国吉林省における統合バイオマス利用システムと最適環境政策の導入のモデルシミュレーションによる総合評価）

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Abstract

Increasing demand for energy consumption and rising concern about the effect of greenhouse gas (GHG) emissions on climate change are compelling countries all over the world to deploy more effective and sounder energy utilization policies. Recognized as an essential component of efforts to reduce GHG emissions, bioenergy has been a hot issue all around the world. Biomass systems operating at a steady state are considered as being inherently carbon neutral, since carbon fixation during plant growth largely offsets the carbon emissions generated during biomass combustion. The substitution of conventional fossil energy with bioresources through bioenergy technologies results both in a net reduction in GHG emission and the prospect of regional energy consumption structure adjustment. Furthermore, development of bioresource-related industries is promising to be moved forward by providing raw materials for bioenergy production.

Jilin Province, located in the northeast of China, is an important industrial and commodity grain base of China. Accelerating industrialization, low primary energy reserves and unreasonable energy utilization patterns have resulted in traditional dependence on imported energy and an energy consumption structure dominated by fossil

energy. Low energy self-sufficiency rate (57.7% in 2010) and unreasonable energy consumption structure (dominated by coal, 77.6% in 2010) are urgent problems which need to be addressed by Jilin Province. In the 12th 5-year energy development plan of Jilin Province, targets of increasing the consumption ratio of bioenergy from 0.5% to 3.7% and reducing 17% of GHG emission intensity (GHG emission per unit Gross Regional Product) by 2015 compared with the 2010 level were proposed. As a traditional agroforestry area, the extensive arable land with high yield of grain and scaled breeding and agroforestry industries are providing abundant bioresources for bioenergy utilization in Jilin Province.

In order to facilitate regional bioresource utilization for energy production through bioenergy technologies, a dynamic input-output model is developed to estimate and assess the energy, economic and environmental performances of industrialization of five bioenergy technologies within a 15-year time horizon. Electricity and solid, gaseous and liquid biofuels are energy products of bioenergy technologies. Bioenergy technologies are complemented into regional input-output table and combined with socioeconomic activities aided by their bottom-up economic and energy parameters. The simulation results for the study area indicate that the agricultural residues available for bioenergy technologies could amount to 55.16 million t, facilitating to 8.38 million t coal-equivalent bioenergy production by 2025. A 3.1% net reduction in accumulative greenhouse gas emission compared with the “business as usual” case could be achieved owing to substitution of fossil energy with electricity and biofuels produced by bioenergy technologies. From energy production, economic benefits and greenhouse gas mitigation three aspects integratedly, direct-combustion power generation and briquette fuel are more advantageous in the study area.

Then this paper outlines a complete integrated bioenergy utilization system incorporating bioresource procurement, feedstock supply, conversion technologies and energy consumption to industrialize the development and utilization of bioenergy. An input-output optimization simulation model is developed to introduce bioenergy industries into the regional socioeconomy and energy production and consumption

system and dynamically explore the economic, energy and environmental benefits. 16 terms of simulation from 2010 to 2025 are performed in scenarios preset based on bioenergy industries, carbon tax-subsidization policy and distinct levels of greenhouse gas emission constraints. An empirical study for Jilin Province is conducted to validate and apply the model. In the optimal scenario, both industrial development and energy supply and demand are optimized contributing to a 8.41% average gross regional product growth rate and a 39.9% reduction in accumulative greenhouse gas emission compared with the base scenario. By 2025 the consumption ratio of bioenergy in total primary energy could be increased from 0.5% to 8.2%. Energy self-sufficiency rate could be increased from 57.7% to 77.9%. A dynamic carbon tax rate and the extent to which bioenergy industrial development could be promoted are also elaborated. Regional economic development and greenhouse gas mitigation can be potentially promoted simultaneously by bioenergy utilization and a proper greenhouse gas emission constraint.

The methodology presented is capable of introducing new industries or policies related to energy planning and understanding the role of bioenergy development in GHG mitigation efforts and other energy-related planning settings. It allows to explore the optimal level for relationships among all socioeconomic activities and facilitate to simultaneous pursuit of economic development, energy utilization and environmental preservation.