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System dynamics model and input–output model in regional ecological economy analysis and international research prospects

Fujia Li[1], Ruofan Zhao[1, 2], Hao Cheng [1,*], Aohan Lei[1, 2]

[1] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China

***CORRESPONDING AUTHOR**
Hao Cheng
chenghao@igsnrr.ac.cn

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ABSTRACT

Regional ecological-economic research focuses on balancing ecological protection, economic growth, and resource utilization to achieve sustainable development. Under global climate change and environmental pressures, its significance is increasingly recognized. The System Dynamics (SD) model and the Multi-Regional Input–Output (MRIO) model serve as key quantitative tools in this research field. SD captures dynamic feedbacks and time-lag effects in complex systems, supporting long-term policy analysis. MRIO traces resource flows and environmental impacts across regions, enabling the assessment of economic–environmental linkages. Based on various scientific research projects undertaken by the research team, we have long utilized SD and MRIO models to conduct ecological-economic studies across diverse thematic areas and spatial scales. This paper systematically reviews the empirical research conducted by the authors' team using the System Dynamics (SD) model and the Multi-Regional Input–Output (MRIO) model across various industrial sectors and spatial scales. It further explores the integration pathways of the two approaches, aiming to enrich the theoretical framework and methodological system in the field of regional ecological-economic research. Looking ahead, the research team will promote the application of SD and MRIO models in cross-border cooperation studies among China, Mongolia, and Russia, providing strong technical support for sustainable development in transboundary regions. This study holds significant theoretical importance and practical value.

KEYWORDS

System dynamics model, Multi-regional input–output model, Regional ecological economy, International cooperation research

1. INTRODUCTION

A regional ecological economy is a complex system encompassing multiple interacting components, including the economy, society, resources, and the environment [1]. Its core objective is to coordinate ecological protection, economic development, and resource utilization to achieve sustainable regional development.

The System Dynamics (SD) approach offers a powerful tool for revealing the long-term impacts of policy choices, behavioral changes, and resource shifts on regional economic, environmental, and social systems. By capturing feedback loops and time delays, SD helps researchers understand the complex causal mechanisms underlying regional development and provides scientific support for policy formulation. With its strengths in quantification and controllability, the SD model is well-suited for exploring the feasibility and sustainability of various development pathways under different scenarios. It has demonstrated significant advantages in analyzing regional sustainability, circular resource utilization, and industrial transformation—particularly in contexts involving long-term planning, multiple objectives, and complex interdependencies [2].

The input–output (IO) method, as a globally recognized analytical framework, supports the sustainable and coordinated development of regional ecological, economic, and social systems. Multi-Regional Input–Output (MRIO) analysis, which integrates national accounts with trade statistics, maps the complex network of production and consumption activities across the global economy. As environmental concerns have gained increasing attention, the MRIO model has been widely applied in assessing both economic performance and environmental impacts. It serves as a robust tool for analyzing economic linkages, resource consumption, and environmental pressures across different spatial scales, industrial sectors, and stages of the supply chain [3].

With their respective strengths in dynamic simulation and structural analysis, SD and MRIO have emerged as key analytical tools for supporting regional ecological-economic research and sustainable policy development. This study aims to analyze the mechanisms of interaction within regional ecological-economic systems, evaluate their integrated ecological and economic effects, and propose targeted optimization and regulation strategies to promote sustainable regional development. Drawing on a deep understanding of various sectors, spatial scales, and regional contexts, the authors and their team have independently developed and applied SD and MRIO models in a wide range of ecological-economic studies. These applications focus on exploring feasible and sustainable development pathways under different scenarios and verifying the effectiveness and applicability of policy strategies through empirical analysis.

2. RESEARCH METHODS

2.1 Study Area

Based on various scientific research projects undertaken by the research team, we have previously conducted extensive empirical studies using SD and MRIO models across different types of ecological-economic regions and spatial scales. The SD model has been applied to typical ecologically and economically fragile areas, such as resource-based highland regions and arid impoverished zones, to explore sustainable development pathways. The MRIO model has been utilized at international, regional, provincial, and urban levels to analyze economic linkages, resource flows, and environmental impacts.

2.2 Methods

2.2.1 SD Model

The System Dynamics (SD) model is a quantitative simulation approach used to understand the nonlinear behavior of complex systems through the construction of feedback loops, stock-flow structures, and time delays. In this study, the SD model is employed to simulate regional ecological-economic systems by capturing the dynamic interactions among ecological restoration, industrial transformation, resource consumption, and policy interventions. The modeling process involves defining key variables, establishing causal relationships, and constructing feedback structures to form a closed system. By simulating ecological-economic effects and future development trends under different scenarios, the SD model provides decision-making support for regional development.

2.2.2 MRIO Model

The Multi-Regional Input–Output (MRIO) model integrates national accounts with trade data to map production and consumption networks across regions. It has become a widely used tool for assessing economic linkages and environmental impacts under increasing sustainability concerns.

Assuming m regions and n sectors per region, the basic MRIO structure is:

$$X^s = A^{rs} X^s + Y^{rs}$$

Where X^s is the total output vector (n × 1) of region s, Ars is the technical coefficient matrix from region r to s, and Yrs is the final demand vector. When r = s, Y^{rs} represents local consumption.

This can be expressed as:

$$X^s = \left(I - A^{rs}\right)^{-1} Y^{rs} = L^{rs} Y^{rs}$$

Where I is the identity matrix and Lrs is m×m, which is called the Leontief inverse matrix, represents the output of region r in order to meet the final demand of region s1 units.

MRIO enables analysis of interregional economic flows, resource use, and environmental pressure across spatial scales, sectors, and supply chains. It is especially valuable in cross-border sustainability assessments and policy design.

3. RESULT

3.1 SD Model in Regional Ecological Economy Analysis

3.1.1 Regional sustainable development mode

Taking Gannan Tibetan Autonomous Prefecture as a case study, we designed a sustainable development model for plateau resource-based regions, including "protective development – alternative industries – ecological restoration – energy conservation and emission reduction." We used an integrated model, based on the InVEST model and the System Dynamics (SD) model, to assess and simulate the comprehensive effects and future trends of the green development model for plateau resource-based regions [4].

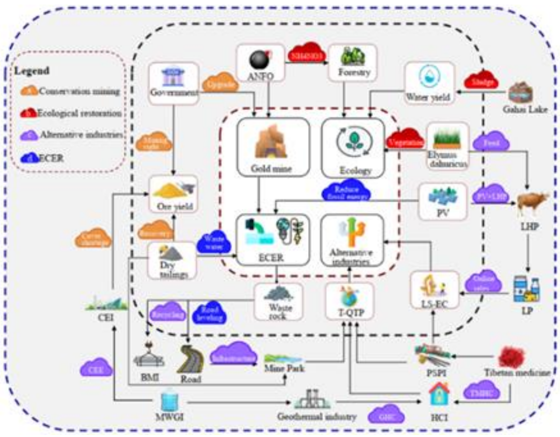

Figure 1. Sustainable Development Mode for Plateau Resource-Oriented Regions based on SD model

3.1.2 Circular economy system

Taking Anding District as a case study, we constructed a Circular Economy Effects and Policy Simulation System Dynamics (CEEPS-SD) model to evaluate the ecological-economic integrated effects of the Circular Economy System (CES) in a typical ecologically fragile and economically underdeveloped region. The study revealed that CES generates four major ecological-economic benefits: eliminating livestock and poultry manure pollution, water conservation, agricultural waste recycling, and energy conservation and emission reduction. With long-term stable operation, CES continuously enhances its ecological-economic benefits and ultimately alleviates the dual pressures of ecological fragility and economic poverty [5].

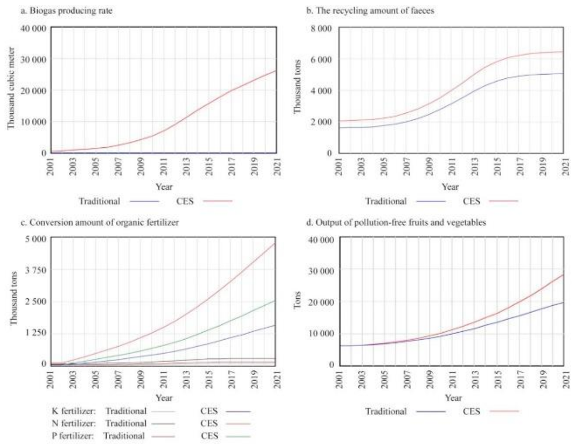

Figure 2. Ecological and Economic Benefits of the Circular Economy Scenario in Anding District based on SD Model

3.1.3 Industrial transformation

Taking Kongtong District's ecological agriculture transformation as a case study, we simulated material and energy flows within the ecological agriculture industry chain using the AEP-SD model. Based on the simulation results, we identified potential risks and negative impacts of the system, providing practical policy recommendations for the management and development of Kongtong District's ecological agriculture system [6].

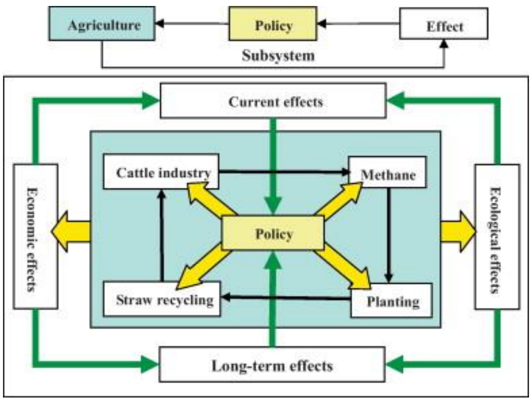

Figure 3. Ecological Agriculture transformation in Kongtong District based on SD model

3.2 MRIO Model in Regional Ecological Economy Analysis

3.2.1 National analysis

In terms of application at the national scale, we study the pulling effect of China's international fishery trade (CFIT) on other domestic industries (Fig 4). We use the full supply model to evaluate the overall pull effect of China's international fishery trade on the domestic market. It is concluded that the pull effect of China's fishery international trade on the domestic market has a significant growth rate, and the pull effect is much higher than that of the domestic trade of fishery [7].

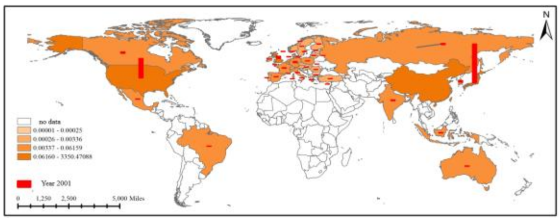

Figure 4. The pulling effect of CFIT on countries around the world in 2001

3.2.2 Regional analysis

In terms of application at the regional scale, we study the embodied carbon emission transfer between Northeast China and other provinces (Figure 5). The embodied carbon transfer effect of inter-regional trade (CEs-RT) is a key factor affecting the pattern of regional carbon emissions. Taking Northeast China as a typical case area, we conduct an in-depth study based on China's inter-provincial and inter-regional input-output tables. Comprehensively using the MRIO model, we investigate the spatiotemporal evolution process and driving mechanism of embodied carbon emission transfer between Northeast China and other provinces. We also put forward suggestions for regional industrial structure regulation and control with better emission reduction effect[8].

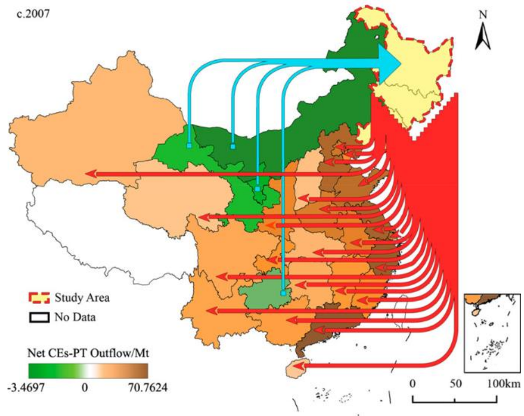

Figure 5. Spatial-temporal evolutions of net CEs-RT outflow for Northeast China in 2007

Note: The red lines and the blue lines have the same width. The arrows express the direction of the net CEs-PT transference. The amount changes of the red lines and the blue lines express the amount changes of the net CEs- PT outflow target provinces and the net CEs-PT inflow source provinces

3.2.3 Provincial analysis

In terms of application at the provincial scale, we took Anhui, the coal energy supply base of the Yangtze River Economic Belt (YREB), as an example. We took the key stage of rapid development of regional economic integration and accelerated the realization of carbon emission reduction targets in YREB [9].

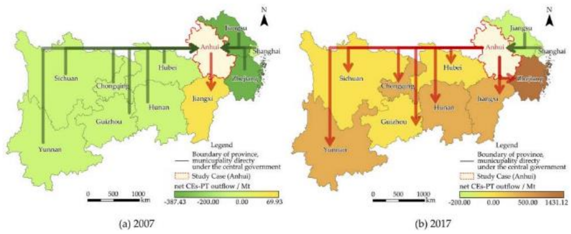

Figure 6. Spatial－temporal evolution of the net ECEs-IPT outflow in Anhui among the YREB from 2007 (a) to 2017 (b)

3.2.4 Urban analysis

In terms of application at the urban scale, we calculated the pull coefficient of the modern logistics industry in Pingliang City, Gansu Province on the equipment manufacturing industry. Through the model established by the supply coefficient, we can calculate the promotion of the modern logistics industry to the intelligent manufacturing industry. The pull coefficient of Pingliang modern logistics industry to the manufacturing industry ranks 7th in the province, with a pull coefficient of 0.001. The interactive relationship between Pingliang's intelligent manufacturing industry and modern logistics industry still needs to be improved.

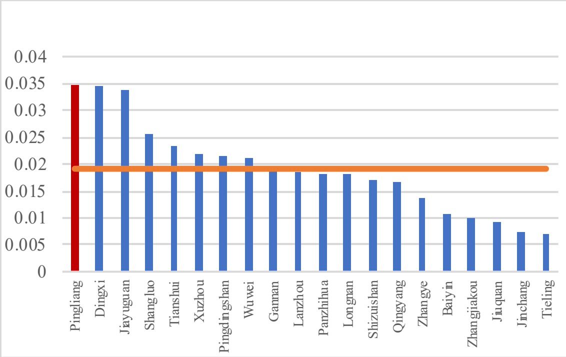

Figure 7. The driving effect of the logistics industry on the building materials industry in Pingliang, other cities in Gansu and key cities in the building materials industry

4. DISCUSSION

SD model and MRIO model, as two essential quantitative analytical tools, provide strong support for regional ecological-economic research. The SD model, with its capacity for dynamic simulation, is effective in capturing complex feedback mechanisms and long-term system evolution within regional ecological-economic systems. In the future, SD is expected to play an increasingly important role in assessing ecological-economic benefits and risks in cross-border regions.

MRIO, with its structural analysis capabilities, offers distinct advantages in examining the interplay between regional economic activities and environmental impacts. It will have broader applications in areas such as cross-border trade, regional ecological governance, and low-carbon transitions, becoming a key instrument for advancing high-quality international cooperation.

At present, research on System Dynamics (SD) and Multi-Regional Input–Output (MRIO) models within the context of China–Mongolia–Russia cross-border cooperation remains at a preliminary stage. Due to challenges related to data availability, consistency, and cross-border policy coordination, an integrated analytical framework combining SD and MRIO models has not yet been established, and their practical application in trilateral cooperation is still limited.

Given the complementary strengths of the SD model in simulating dynamic processes and the MRIO model in analyzing spatial flows of resources, integrating the two approaches holds great potential. In the future, the combined use of SD and MRIO models can be widely applied to key areas such as ecological risk assessment and joint prevention, comprehensive evaluation of cross-border infrastructure, monitoring of regional sustainable development goals (SDGs), analysis of ecological impacts of international trade, and cooperation in transboundary nature conservation. These applications can offer systematic support for addressing ecological-economic challenges in transboundary regions.

5. CONCLUSION

In summary, SD model and MRIO model demonstrate significant potential in regional ecological-economic research. As model accuracy improves and interdisciplinary integration deepens, the combined application of SD and MRIO models will significantly enrich the theoretical and empirical foundation of cross-border ecological economics. It will also provide stronger scientific support for transboundary resource management and international cooperation, contributing to the coordinated advancement of ecological protection and green development, and facilitating the achievement of regional sustainable development goals in the China–Mongolia–Russia region.

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REFERENCES

[1] J. Liu, et al., “Spatial-temporal differentiation of the coupling coordinated development of regional energy-economy-ecology system: A case study of the Yangtze River Economic Belt,” *Ecological Indicators*, vol. 124, p. 107394, 2021. Available: doi: 10.1016/j.ecolind.2021.107394

[2] B. Kiani, and M. A. Pourfakhraei, “A system dynamic model for production and consumption policy in Iran oil and gas sector,” *Energy Policy*, vol. 38, no. 12, pp. 7764–7774, 2010. Available: doi: 10.1016/j.enpol.2010.08.036

[3] R. Ma, et al., “Distribution of CO2 emissions in China's supply chains: A sub-national MRIO analysis,” *Journal of Cleaner Production*, vol. 345, p. 130986, 2022. Available: doi: 10.1016/j.enpol.2010.08.036

[4] Q. Liu, et al., "Research on the sustainable development mode of resource-oriented regions on plateaus—A case study for Gannan Tibetan autonomous prefecture," *Sustainable Development*, vol. 32, no. 4, pp. 3581–3600, 2024. Available: doi: 10.1002/sd.2862

[5] H. Cheng, et al., "A circular economy system for breaking the development dilemma of 'ecological fragility–economic poverty' vicious circle: A CEEPS-SD analysis," *Journal of Cleaner Production*, vol. 212, pp. 381–392, 2019. Available: doi: 10.1016/j.jclepro.2018.12.014

[6] F. J. Li, S. C. Dong, and F. Li, "A system dynamics model for analyzing the eco-agriculture system with policy recommendations," *Ecological Modelling*, vol. 227, pp. 34–45, 2012. Available: doi: 10.1016/j.ecolmodel.2011.12.005

[7] S. J. Xu, "China's Fishery International Trade Pattern and Pull Effect," *M.S. thesis*, Liaoning Normal University, 2023.

[8] H. Cheng, et al., "Multiregional input-output analysis of spatial-temporal evolution driving force for carbon emissions embodied in interprovincial trade and optimization policies: Case study of Northeast Industrial District in China," *Environmental Science & Technology*, vol. 52, pp. 346–358, 2018. Available: doi: 10.1021/acs.est.7b04608

[9] M. H. Zhang, et al., "Spatial–temporal evolution and improvement measures of embodied carbon emissions in interprovincial trade for coal energy supply bases: Case study of Anhui, China," *International Journal of Environmental Research and Public Health*, vol. 19, no. 24, 2022. Available: doi: 10.3390/ijerph192417033