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The evolution of cities: “brains” or “parasites” of sustainable production and consumption processes in China

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Abstract

In the last two decades, remarkable progress in the promotion and implementation in China has occurred and generated a huge change of land use, energy and other resources demand, as well as environmental problems. It is therefore of paramount importance to explore the driving forces and the consequences of such a trend, as far as environmental integrity and resource availability are concerned. Special focus must be placed to possible changes in driving forces, in order to understand to what extent such a trend is continuous and irreversible or, instead, if sustainable metabolic processes in cities are likely to slow down as a consequence of the expected decline of available energy and material resources. Previous studies have already recognized the importance of the energy and material basis in support to urbanization trends and expressed concerns about the environmental consequences resulted from urbanization. What is missing is an integrated approach capable of establishing a bridge across the three legs of urban sustainability: (i) economic viability; (ii) social desirability; and (iii) ecological compatibility.

This paper describes the development of a forecasting model, named the thermodynamic-based urban dynamic model, capable of accurately simulating the observed resource consumption, economic growth, and environmental impact of Dalian from 2000 to 2050. This model differs from previous urban dynamic models by monitoring the negative effects to human well-being and ecosystem integrity in the developing urban systems. Statistical information and calibration were also considered in this dynamic accounting. The results showed that the production and consumption processes in Dalian are heavily relied on non-renewable resources. Although the economic structure of Dalian was generally optimized, Dalian continued to face enormous resource and environmental pressures caused by the rapid economic growth. This study advances the temporal dynamic principles through integrating upstream and downstream evaluation methods to quantify the environmental impact by addressing specific damages to human health and ecosystem’s integrity and by linking such impacts to a supply-side environmental cost evaluation.

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1. INTRODUCTION

As a city is a dynamic system it is important to understand trends in energy use over time. Like the human body, the socio-economic system can be characterized by its metabolism, where energy and materials are used as input and waste as output [1]. The metabolism approach is a powerful metaphor for the illustration of the processes that mobilize and control the flows of energy and materials through a socio-economic system. Understanding how a socio-economic system works as an ecological system will help take control of the vital links between human actions and the quality of the environment. Hence, the knowledge of human-induced energy and material flows with comparison to those of natural flows is a major step towards the design of sustainable development and ecological wisdom schemes.

Policy makers have attempted to explain trends among socio-economic systems for various indices of metabolic performance based primarily on economics density, industrial structure and efficacy and environmental impacts, with varying results. However, most of these indices have problems associated with their inability to describe the complexity of 'sustainable' development, lack of comprehensiveness, and arbitrary or subjective assumptions regarding normalization and weighting. It is important to be able to see the indicators reflecting sustainability of cities so that poor ecological performers can be identified. We use the unit of 'city' as a basis for environmental impact rank because a government's decisions affecting the state of the environment can be realistically best made at this level.

As an effective tool for system analysis, emergy, which can connect the social economic system with the ecological system, is a well-suited approach for the evaluation of an urban ecosystem composed of multiple social, economic, and ecological elements [2]. The corresponding indicators are directly linked to urban ecosystems in an integrated way through the combined values of the ecosystem services [3]. Therefore, we attempted to propose an urban dynamic development process analysis to determine whether the overall conditions are better (toward a sustainable path) or worse. The emergy indicators, i.e., measures of system order and stability, are used to perform an assessment of the dynamic behavior and sustainable trends of an urban system's trajectory.

2. METHODOLOGY

The dynamic model was integrated from 10 state variables, including Agricultural Land (LA), Agricultural Assets (AA), Ecological Land (LE), Ecological Assets (AE), Water Resource (WR), Urban Land (LU), Urban Assets (AU), Waste (W), Money (M), and Population (P). All of these state variables are linked by a coefficient k (k101, k102, …) and composed into nonlinear complex relations. A validation test was necessary and significant for checking the structure and stability of the model. Five state variables were selected for the validation, and the results were compared with the historical data of Dalian from the years 2000 to 2050. The model fits the real system's behavior with a relative error of $< 10\%$.

Concerning the goal of a harmonious society set by the government, environmental issues have recently gained great importance. At this point, we must find a way to "internalize" the types of "externalities" and place emphasis on the impact of emissions on an ecosystem and human integrity by transferring these losses to the system accounting. In this study, a preliminary damage assessment of losses was performed according to the framework of the Eco-Indicator 99 assessment method [4]. Such methods, like all end-point life cycle impact assessment methods, suffers from very large uncertainties intrinsically embodied in its procedure for assessment of final impacts. Yet, it provides a preliminary - although uncertain - estimate of impacts to be used in the calculation procedure of total emergy investment. Damages to natural capital are expressed as the Potentially Disappeared Fraction (PDF) of species in the affected ecosystem, while damages to human health are expressed as Disability Adjusted Life Years (DALY). Six kinds of environmental impacts are considered, which include carcinogenic effects on humans, respiratory effects on humans caused by organic substances, respiratory effects on humans caused by inorganic substances, damages to human health caused by climate change, damage to ecosystem quality caused by ecotoxic emissions, and damage to ecosystem quality caused by the combined effect of acidification and eutrophication. Thus, we pointed out the nature of emergy losses associated with process waste generation.

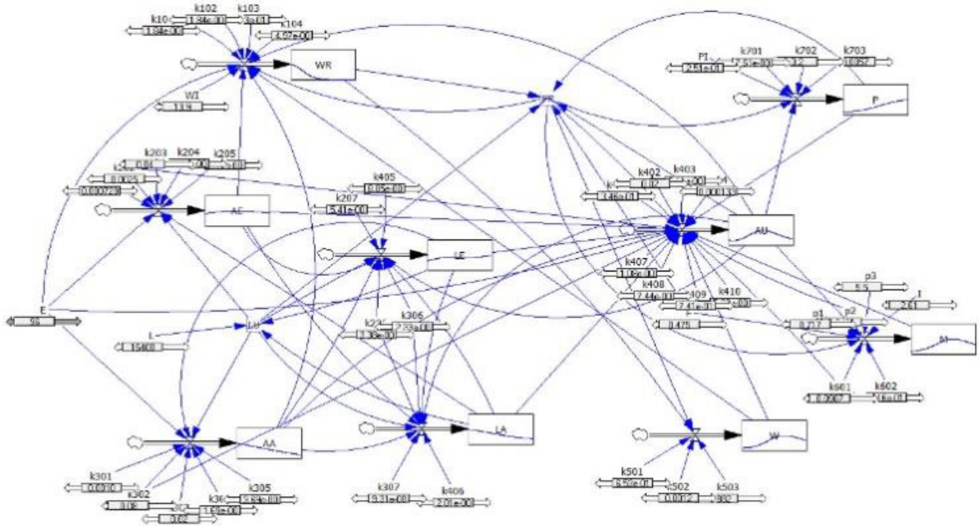

Fig. 1 Emergy-based urban dynamic model in Vensim®

Table 1 Spreadsheet for the equations

Description	Variable	Equation
Ecological Assets	AE	dAE/dt=k201*AE*E-k203*AE-k202*AE-k204*AE*LA-k205*AE*LU
Agricultural Assets	AA	dAA/dt=k301*AA*E-k303*AA-k302*AA-k304*AA*LE-k305*AA*LU
Urban Assets	AU	dAU/dt=k401*PR+k202*AE+k302*AA+k601*M/p2-k409*E*LE*AE-k410*E*AA*LA-k404*AU*P-k403*W-k402*AU-k407*LE*AU-k408*LA*AU
Ecological Land	LE	dLE/dt=k206*LA*AE+k207*LU*AE-k306*LE*AA-k405*LE*AU
Agricultural Land	LA	dLA/dt=k306*LE*AA+k307*LU*AA-k206*LA*AE-k406*LA*AU
Urban Land	LU	LU=L-LE-LA
Water Source	WR	dWR/dt=k101*E*AE*AU+k102*E*AA*AU+WI-k103*PR-k104*WR*W

Waste	W	dW/dt=k501*PR-k502*WR*W-k503*W
Population	P	dP/dt=k701*AU*P+k702*PR*PI-k703*P
Gross Domestic Product	M	dM/dt=k602*PR*p1+AU*I-k601*M-F*AU*p3

The waste treatment system could effectively reduce waste (not to zero) through additional resources input. The human and natural capital emergy losses after waste treatment are denoted as $L_{w,1}^*$ and $L_{w,2}^*$. Furthermore, the damage associated with solid waste disposal can be measured by land occupation and degradation, which is denoted as $L_{w,3}$. The additional emergy investment for treatment is denoted as U_w and should, in principle, be lower than the damage-related losses $L_{w,n}$, to be feasible and rewarding. The waste treatment system is designed to recycle and reuse part of the emissions (flow Fb) through the use of eco-technologies. Such a recycle flow should allow a proportional decrease of the total emergy cost (U) by decreasing the use of local nonrenewable resources or by decreasing imports. Using concepts from Eco-Indicator 99 to quantify a process impact on ecosystem quality and human health has the advantage that the assessment relies on damages that can, in principle, be measured or statistically calculated. This method employs a top down approach by first weighting the three environmental damages (endpoints; human health, ecosystem quality and resources) and develop damage model for the most impact categories.

All the calibration methods and pathway coefficients rates for the derived calibration values are derived from our previous work [4-11]. Pathway coefficients, labelled as k's in this model, indicate how much flow there is on a pathway in terms of contributing forces or concentrations.

3. RESULTS

The results show that (1) the rapid increase of residential and commercial land use causes urban sprawl that is the extension of the urban perimeter, which cuts further into available productive land and encroaches upon important ecosystems. (2) the urban assets in Dalian increase rapidly (an inverted U pattern), which suggests the development of urban infrastructure facilities and the improvement of housing conditions for Dalian residents which are constrained by resource supplies. (3) the trends in AU loss reflect what may be termed a "crescendo effect" followed by a successive increase of AU and population. These trends indicate that the economic loss related to potential damages to human health will have no improvement, or aggravate, even after the slightly reduction in pollution emissions.

The challenge for integrating the ecological and economic losses into a strategy of urban sustainable development needs to be addressed more deeply to achieve a strategy where environmental revenues and losses can be suitably balanced in order to manage or limit the growth of the economy. This should be an important role of urban policymakers as an effort to secure a solid foundation for long-term urban sustainable wellbeing. We followed Huang and Chen's hypothesis (2005) and made several minor modifications of: 1) the land occupation for landfill and disposal, which results in land loss (irreversibly degraded); and 2) calculating the negative effect of wastes for emergy accounting. We emphasized the determinants of human health and ecosystem integrity in the urban development process according to the framework of the Eco-Indicator 99 for monitoring the negative effects of wastes. Our purpose was to gather information that would allow policy makers to manage systems with the goal of encouraging desirable economic and social tendencies while maintaining long-term environmental responsibility that leads to sustainability. We cannot know the full effects of emissions without indicators linked directly to the goals, measurable in common units and expressive of real values to the economy and society after accounting for the values of human health, society's wealth, and well-being.

This study's results could be improved by performing complementary tasks, mostly obtaining some data to be included in the simulation model. The data suggested to be included is: the life cycle assessment of the purchased fuels/goods and pollution-induced damage at an urban, regional and national level. In this sense, a polycentric approach might be an alternative for the problem, which means actions at various levels with active oversight of urban, regional, and national boundaries.

Because emergy analysis is based on a single common inventory of all the system's inputs and outputs, the systematic uncertainties are simultaneously performed on all calculated data and indicators simply by allowing for variable cells for all input quantities, as well as for the associated impact coefficients (intensity factors), in the spreadsheet-based calculation procedures. Quantifying direct and indirect flows of matter and energy to and from a system permits the construction of a detailed picture of the process itself, as well as of its relationship to the surrounding environment. In this study, the main energy, commodity, and environmental flow data used are from the official data based on the internet and publicly issued yearbooks. These data meet or exceed our data quality objectives because both sampling and non-sampling errors are considered, and the reliability of the data is reported as the coefficient of variation with its standard error.

4. CONSLUSION

To be sustainable, a system should achieve a large economic yield (not necessarily measured in monetary terms, but likely in terms of wellbeing) while causing low environmental stress. The success of this thermodynamic-based urban dynamic model enabled us to identify the most significant deviations of the system's trajectory and the model analysis allows us to determine whether or not a new path may emerge toward sustainability. This partly answers the scientific question of how to bring to balance the environmental revenues and losses. The results of our study will enable urban policy planners to understand these inter-linkages by addressing specific damages to human health and the ecosystem's integrity and by linking such impacts to a supply-side environmental cost evaluation. It particularly outlines how an urban subsystem model is linked and how some urban key factors, such as water resource and money flows, by their interaction with other indicators or factors bring profound changes to the entire system.

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Biography

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