Megacity Food-Energy-Water Pathway Analysis based on A Systems Thinking Dynamic Circular Economy Calculator

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Abstract

Circular economy is regarded as a policy for fulfilling the sustainable development which has been implemented for 9 years by the government in many cities of China. Chinese circular economy view insists to overcome the dilemma between the economic depression and energy shortage in the nationwide. However, a circular economy may have a different flavor in different megacities, depending on geographic, environmental, economic or social factors. Besides, few literatures contribute to checking the efficiency of current circular economy policies, especially in the aspect of regional wide, which will be practically helpful in guiding China's future development. In this paper, we proposed an Urban Circular Economy Calculator based on a full Excel version emergy-based urban dynamic model, which is a feasible approach to help the policy-makers create circular economy pathway under different food-energy-water (FEW) policies. The scenario analysis approach has been used in this Urban Circular Economy Calculator to illustrate a greener economy under alternative assumptions of the FEW Circular Economy policy. What's more, long-term simulation will be provided by the calculator to test the trajectories of Circular Economy policy effects under the assumptions of the associated levels. Taking Beijing city as a case, the impact of different circular economy policies can be observed by using real scientific data. This model can be applied to other cities as well in the light of their actual situation respectively. In that case, suggestions on regional management, which make sure our cities achieve friendly and sustainable development over a long period of time can be proposed for our government accordingly.

Keywords: *Emergy analysis, Urban dynamic model, Circular economy, Food-Energy-Water (FEW) policies, Scenario analysis*

1. Introduction

1.1 Circular economy theory and practice

The acceleration of industrialization and urbanization process have brought significant environmental burdens such as global warming and resource scarcity in China (Liu et al., 2016), contributing a lot to the popularity of the circular economy (CE) policy. The circular economy (CE) policy has already been

adopted as a national regulatory policy after 9 years' implementation, which has brought a series of policies packages to achieve resource conservation and pollutants reduction (Zhu, 2008). Furthermore, from its introducing for China's harmonious development (Sun et al., 2016) numerous scientific literature emerges focusing on the environmental and economic contributions of circular economy (Feng et al.,2007; Su et al.,2013; Yap, 2005). Geng et al. (2009) found out that by the improvement of energy use efficiency and the levels of reuse, recycling and recovery, the city can obtain potential values. They also have already analyzed the barriers and challenges to the implementation of the CE policy in China (Geng et al., 2008). What's more, research about the discussion of indicators for the assessment of CE strategies in the nationwide can also be found at present (Geng et al., 2012). A concept which emphasizes the benefits of reusing waste materials in the area of industrial ecology even has obtained consensus (Yuan et al., 2006). Nevertheless, few studies are focusing on how to measure the efficiency of the existing circular economy policies, let alone the researches on regional efficiency.

Since urban circular economy may look different depending on local needs, copy-pasting solutions from elsewhere will not be effective. The industrial profile of a city or region plays an important role, with, for example, service and resource-intensive sectors each calling for different types of support. This study aims to fill this gap, proposing an Urban Circular Economy Calculator based on a full Excel version emergy-based urban dynamic model to analyze the effectiveness of the present CE policies under different food-energy-water (FEW) approaches in a scenario view. Taking Beijing city as a case, long term simulation will be provided by the calculator to test the trajectories of Circular Economy policy effects under the assumptions of the associated levels.

1.2 The challenges of megacity

As the capital city of China, Beijing is experiencing unprecedented rapid growth (Liu et al., 2011), becoming one of the world's most populous and affluent cities, and making sustainable supply of resources and associated environmental impacts the biggest challenges at the same time. As is shown in our simulation, the ecological and agricultural assets of Beijing fall slowly from 1999 to 2039. Furthermore, the urban assets achieve its peak and then fall down as well. Therefore, many CE policy and technology solutions are proposed to address the supply stress of resources shortage. As a vital component of city, water is a key point of the development of city, various measures have been taken to ease the heavy burden of water shortage (Liu et al., 2010), such as South-to-North Water Transfer (Yuan et al., 2008), recycle of waste water, household and industrial water saving technologies. Diverse measurements on energy have also been developed to keep the balance of energy supply and demand in Beijing, including renewable energy, combined heat and power and concentrated heating and different energy-saving technologies. Besides, there are some the food regulatory policies to address food shortage issue such as bio-fermentation hydrogen production, aerobic composting and anaerobic digestion.

2. Methodology

2.1 Emergy-based urban dynamic model

As an effective environmental accounting method, emergy is a bridge between the ecological system and the social economic system which can estimate the environmental resources the society acquired from the nature directly and indirectly (Chen et al., 2009). The emergy-based urban dynamic model established in this paper is a system dynamic model based on the urban emergy flow. This model can be applied to demonstrate the changes of energy and material flow in a system, and therefore measure or estimate whether the development of this social economic system is sustainable. Fig. 1 presents the emergy flow of Beijing city, besides, can indicate the emergy changes brought by the current Circular Economy policies, which could be divided into the opening-source-policy, throttling-policy and inn-loop-policy.

Based on the analysis of the above major features among all the components involved, the emergy-based urban dynamic model of Beijing is constructed with three main aspects including more than twenty kinds of scenario approaches.

The simulation results provide a picture of the transition during the interim years. It is worth noting that this transition will need to happen over a long timeframe with key decision points along the way. The Calculator helps the policy-makers create circular economy pathway based on different food-energy-water (FEW) tactics and provides system dynamics permitting the prediction of developing trend of a system. The structure of Beijing is understood as the compound of three subsystems: food, energy and water.

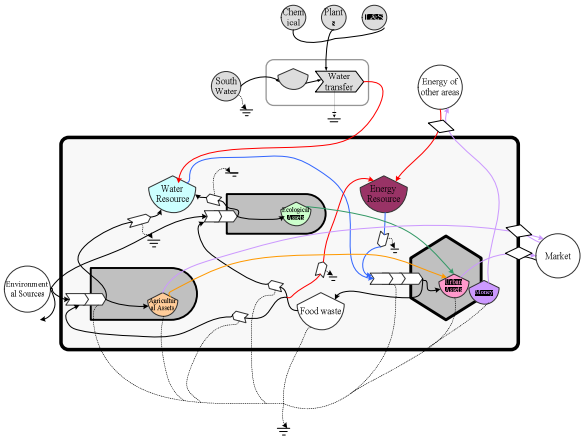

Fig.1. Systems diagram of the simulation model

The simplified stock-flow is shown in Fig. 1, which illuminates the interrelationships among different subsystems by considering interactions among a quantity of related factors. Hence, the various interactions of this environmental–economic–social system can be expressed dynamically by using this model.

The boundary of this emergy-based urban dynamic model is in the light of the geological boundary of Beijing city. With the simulating horizon from 1999 to 2039, this model is briefly established to reveal the changes of Beijing's assets during these years including urban assets, ecological assets and agricultural assets (Liu et al., 2012). The realization of model validation is in line with the historical data from 1999 to 2006, along with scenario analyses from 2006 to 2039 subsequently developed. The data sources in this inventory are various including governmental statistics such as public-issued yearbooks and some academic papers including the research of Liu et.al (2014), most of which used are from the official data.

2.2 Systems Thinking Dynamic Circular Economy Calculator

The design of the calculator is based on the emergy-based urban dynamic model. As mentioned above, the circular economy policy is divided into three categories including the opening-source-policy, throttling-policy and inn-loop-policy. What's more, there are different FEW pathways under each of the three policies. In this Calculator, we selected (a) 10 water-related policies, e.g.: South-to-North Water Transfer; different water saving technologies; (b) 8 food related policies, e.g.: bio-fermentation hydrogen production; aerobic composting; anaerobic digestion; (c) 10 energy-related policies, e.g.: renewable energy; combined heat and power and concentrated heating; different energy-saving technologies. Each of the policies matches a pathway in Figure 1. Therefore, by clicking on the path we can choose the combination of circular economy measures. Furthermore, the calculator will provide the analysis including urban assets, urban efficiency and sustainable index of your selection. In this way,

by shown in Fig. 2, this thinking calculator is able to realize a visual dynamic scenario simulation of circular economy policies.

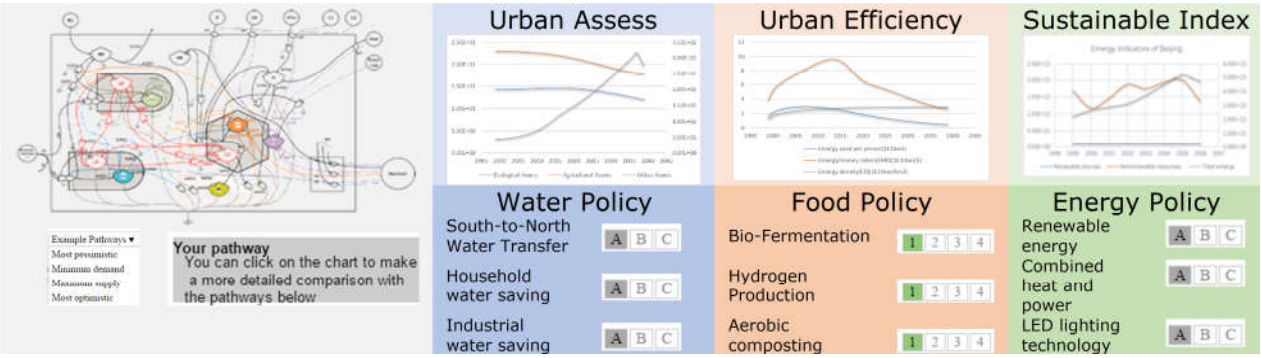

Fig.2. The dynamic scenario simulation of circular economy policies

3. Results and Discussion

Our simulation shows that the opening-source-policy postpones the peak of the accumulation of urban assets, but accompanies by a faster urban recession. Throttling-policy reduces the peak but achieves an economic soft landing. Inn-loop-policy improves the urban efficiency and sustainability.

3.1 Scenario analysis

(1) Simulated results based on water-related policies

Untrammeled water resource supplies might take economic and environmental crisis to the megacity. It is indicated that the accumulation of urban assets will accelerate significantly after the accomplishment of the South–North Water Transfer. The supply of water resources brings vigor to urban production. A higher peak of urban assets will emerge in the case of the open-source measure, however, it doesn't the recession of urban can be avoided. The urban assets will fell down with a sharper decline compared with the original simulation. According to the simulation, the available water resource will satisfy the agricultural and urban production activities and the foreign investment will be stimulated, which brings the increase of financial assets. But the financial assets will eventually decrease due to considerable consumption caused by the expansion of the city can't be met.

(2) Simulated results based on food-related policies

Management activities towards the top of the hierarchy are more sustainable ways of managing waste than those lower down. Disposal to landfill should be the very last option for dealing with waste. Compared with various recycling methods, all composting facilities shows relatively low economic efficiency.

(3) Simulated results based on energy-related policies

Combined energy-saving technologies provide the megacity a better balance between development and environment with a low energy. The simulation illustrates that the rate of urban assets increases with a slow pace before 2020. The scale of urban production will diminish around 2040 due to the decreasing energy input, and urban construction begin to slow down. In terms of the simulation results, a slow recession in a low-power state of Beijing can be retained. The extravagant acts in economic activities which are not particularly critical should be cut down or even prohibited. What we need to preserve is the most significant component enough to meet the general needs of the city. Generally speaking, Beijing can maintain a good balance the external environment in virtue of the energy-saving measures.

3.2 Economic analysis related to the scenario selection

The Urban Circular Economy Calculator provides a cost estimating tools based on the pathway compared with another, allowing simple variation in cost estimates as follows. The biggest cost change and the whole cost will change accordingly if you select the different scenarios. For instants, if the Greening of the coal power is changed from trajectory A to D (that means the IGCC technology is widely adopted and there is a significate drop in its operating cost), the fossil fuel power will be almost doubled and the whole cost of the pathway will be slightly increased in Figure 3.

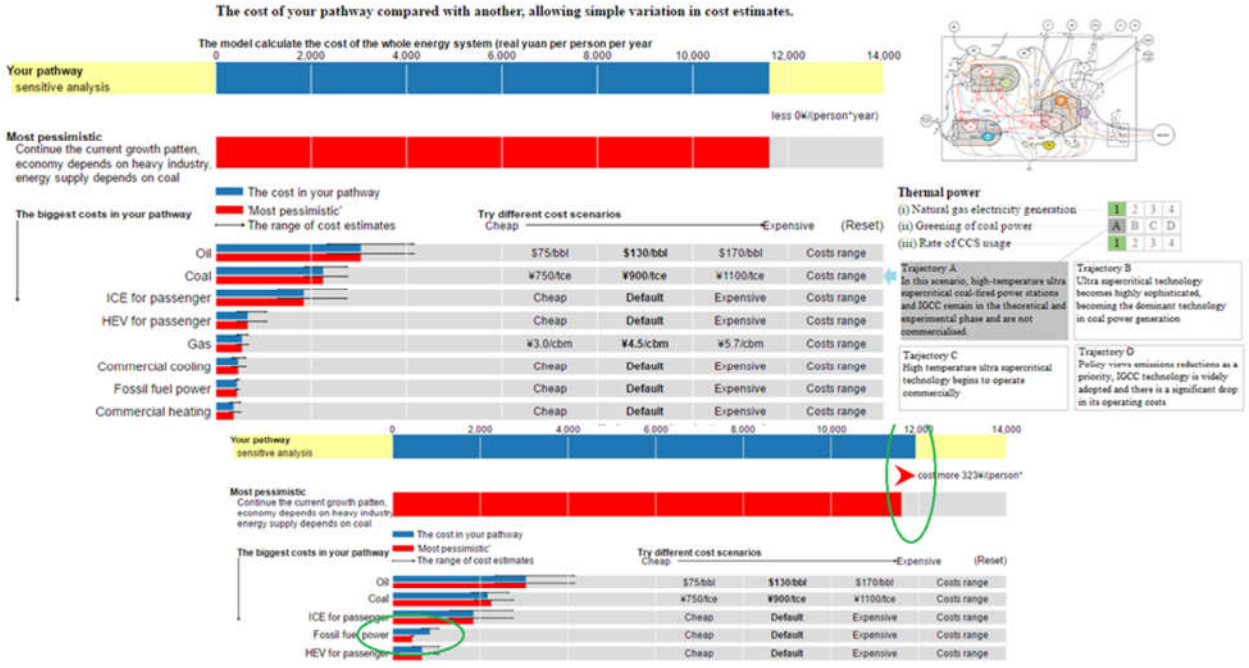

Fig.3. Cost estimates part of the Calculator

4. Conclusion

The emergy-based Urban Circular Economy Calculator bridges the gap between detailed Food-Energy-Water Pathway and regional economic indicators, and illustrates the flow and collection of energy and material intuitively. The scenario analysis dynamic approaches are capable of indicating the changes in different techniques or measures immediately. For this type of modeling, a huge amount of regional information is required to formulate a model that mimics real-world mechanisms in a satisfying manner of different areas. Not only does one need to estimate the parameters of the model, it is also required to assess the functional form of the relations. This poses severe restrictions on the shift from the special case such as Beijing to the general application.

So far, the emergence and promotion of the circular economy policy has attracted more and more attention (George et al., 2015). The published circular economy polices are rich with various approaches on opening-source, energy saving or recycling (Yu et al., 2013; Li et al., 2013; Geng et al., 2014). Among these, which one is the essential key that can open the door of sustainable development indeed? This paper aims to fill such a research gap by establishing an emergy-based urban dynamic model. We employ Beijing city as a case study approach so as to test the applicability of the existing CE policies. The simulation results reveal that open-source-policy is not an appropriate way to attain a harmonious environment. The urban assets can reach a higher peak under the open-source-policy but along with a faster recession as well. On the contrary, although the throttling-policy accompanied by a lower peak value of urban assets, it can reduce the rate of urban recession. Generally speaking, lower source consumption is the only way to achieve a more balanced and sustainable world.

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