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Study on Integrated Simulation Model of Economic, Energy and Environment Safety System under the low-carbon policy in Beijing

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Abstract: In the near future, energy conservation and pollution reduction became two of the most significant factors in economic development and social circulate. For analyzing the issue, several models were applied involving the fields of mathematical optimization, economics theory, dynamics model and industrial management. Specifically, they are MARKAL model, Input-Output model, LEAP model and Systemic Dynamics model. In the paper, a collaborative distributed database and an integrated simulation were developed for the Economics-Energy-Environment (3E) system, especially four models were firstly synthesize in a unique way which achieve securities economically, environmentally, as well as in a sense of energy source. The integrated matrix inherits the advantages of all methodologies mentioned above. At last, a flawless integration of the 3E-Safety system was presented and applied in a practical manner in the case of low-carbon development.

***Keywords**:* 3E, City Security, Low-carbon, Integrated Simulation.

1. INTRODUCTION

During the past 30 years, China experiences the quickly economic growth in the world for its annual average GDP growth of 9.6%. Meanwhile, what accompanied the most dazzling economic growth is the sharp standard coal consumption increase from 539 million tons in 1979 up to 3.1 billion tons by 2009. More seriously, the emission of the greenhouse gas also presents surprising growth. In order to handle the severe challenge from the global climate change, China promised stately in Copenhagen Summit that China would cut its CO2 emission per unit of GDP by 40-45% by 2020, compared with the level in 2005. As the capital of China and the political, economic and cultural center, it shall be its obligatory duty for Beijing to become forerunner to contribute the promise for the government of China.

On the base of the practical situation of Beijing, the paper utilized the relevant research result, domestic and international, to introduce a set of 3Es comprehensive integration model for the purpose to provide the scientific foundation for the formation of the economy, energy and environment policies which would be considered to boost the low-carbon economy. The model considered the current situation of Beijing statistic system and statistic data, and generally covered the three systems of economy, energy and environment. More valuable addition is that the model innovatively took into account an important factor, the urban security of Beijing as a capital.

2. MODELS OF ECONOMIC-ENERGY-ENVIRONMENT (3E) SYSTEM

Based on current economy-energy-environment system, the paper focuses on the method of measuring and calculating the interaction level among the three systems with the purpose to make the social development system keep balanced and coordinative in the fields of economy, energy and environment, which was shown by Deng et al. [2006].

2.1 Panorama of 3E system

There were many mature economy-energy-environment models. Each of the models has its individual research priority and approach. However, all the 3E models can be divided into two modes, top-down and bottom-up, which was shown by Economy [1978].

The top-down analysis method considers the macro economy and uses the economics model wherein the energy price and economy elasticity are the main economic indicator to present the relationship between energy consumption and energy production. The top-down analysis method is mainly applicable to the macro economy analysis and the research on energy policy making. However, it cannot control the impact of technology progress on the economy. The CGE model based on General Equilibrium Theory and the Input-Output model belong to the top-down mode.

The bottom-up analysis method presents the engineering technique model to make a detailed description and simulation to the technique used for energy consumption and energy production, and mainly aims at energy consumption and production mode for supply-demand forecast and environment impact analysis, which was shown by Toshihiko [2004]. However, the method overestimates technology progress effect.

The bottom-up model has two branches in terms of research, which was shown by Wei [2005]: □ The first is based on energy supply and conversion to analyze the introduced efficient energy technique and its effect. The typical models include MARKAL model developed by the dominant International Energy Agency (IEA) and EFOM model developed by EU; □ The second is that analyzes and calculates in detail the change at energy demand and consumption caused by the human activities. The typical models include MEDEE model developed by France and LEAP model developed by Stockholm Environment Institute.

In order to establish the low-carbon emission based 3E model, we shall consider economy growth, energy demand by each economic sector and terminal, and their impact on the environment. We shall also pay attention to energy technique, energy structure optimization and energy conversion technique so as to reduce the pollutant emission on the base of effective cost control. Neither the top-down nor bottom-up model can meet the requirement of the complicated goal.

In the 3E-S model introduced herein, we applied comprehensively the Input-Output mode in the top-down analysis method and the LEAP model (energy demand and consumption in attention) and MARKAL model (energy technique in attention) in the bottom-up analysis method to achieve the organic combination and mutual correction of the various focuses respectively stressed by the models so as to form complex giant system which could effectively imitate and simulate the actual energy system and then apply the method of the system dynamics to constitute a simulation model which would be used to verify the above result achieved by the optimization in terms of economy safety, energy safety and environment safety.

2.2 Independent analysis models

- Input-Output Model(I/O model)

1936, Leoniief first raised his I/O model, which is still considered as one of the most effective theories to solve the problem of balanced economic growth, which was shown by William [1980]. It could help working out the chessboard type of input-output statement and setting up the corresponding linear algebraic equation set to form an economic mathematical model, which could imitate the structure of the actual national economic system and the social reproduction process, to analyze and confirm comprehensively the complex relationship among all the sectors in the national economic system and the key reproduction proportional relationship.

In 2001, Lei separated two main environment protection measures---resource recovery and pollution governance-from the traditional industrial sector to form a virtual environment protection industry---resource recovery sector and pollution governance sector. He utilized the calculation to get the actual data about resource consumption, pollutant emission, resource recovery and pollution governance, and used the data to create a relatively complete I/O statement about resource-energy-economy-environment, and built up the green I/O accounting method, which finally helped originating an assessment method frame for resource-environment-economy, which was shown by Lei [2001].

- LEAP Model

LEAP model is an econometric model jointly developed by Stockholm Environment Institute and Tellus Institute. The model follows the sequence of "resource", "transition" and "demand", to assess the energy demand and supply balance at certain region. It could be used to design the energy consumption mode against various development situations on the base of the current energy demand of each sector and the forecast to the social and economic development in the future years by different policy packages and technique selection modes. The combination of various development modes and their comparison could provide the reference for the decision-making about the regional economic and energy development planning.

Usually, LEAP is called as 'terminal energy consumption model', which was shown by Joost [2004], and mainly focuses on the achievement of the balance in demand and resource transition by the calculation. Moreover, LEAP utilized the existing energy technique and environment database to analyze the balance program in terms of cost and pollutant. So, the LEAP model is suitable to be applied for scenario analysis. It is feasible to depend on various policies to draft some scenes and then analyze the advantage and shortcoming of them. Its shortcoming is unable to be used for optimization.

- MARKAL Model

MARKAL (Market Allocation) model is an energy system analysis tool based on multi-objective linear planning method. In 1976, International Energy Agency (IEA) developed MARKAL model and promoted many nations. MARKAL is a partial equilibrium model mainly composed of energy database and linear planning software. It pays great attention to the energy technique, uses 21 kinds of constraint equations to assure supply-demand balance and economic growth, and sets up the objective function to get an energy program which aim to lowest cost or minimum pollutant emission, able to be used for optimization and solving, which was shown by Evasio [2004] and Barry [2003]..

- System Dynamic Model (SD model)

The System Dynamics is a system simulation method developed by Jay Forrester W. with MIT in 1956, applicable to the modeling and simulating to a complex system. On the base of the research on the structure model of the system, it analyzes the cause-and-effect relationship among the factors inside the system and depends on the computer simulation to quantitatively analyze the structure of the information feedback system and the dynamic relation between function and behaviour, which was shown by Wang [1994].

The SD is characterized in that it could depend on the inherent mechanism of a large system to simulate it. Thus, once the model is calibrated, it could be used to rightly forecast the system state. However, its shortcoming is that the input data necessary for the operation of SD model all need external generation.

3. ECONOMIC-ENERGY-ENVIRONMENT-SAFETY (3E-S) MODEL

On the base of I/O model, LEAP model, MARKAL model and SD model, the paper developed a set of 3E-S comprehensive integration model, as shown as Figure 1, which fully considered the current situation of Beijing data and generally covered the three systems of economy, energy and environment. More valuable is that the model innovatively takes into account an important factor, the security of Beijing as a capital.

The 3E-S model is composed of four relatively independent modules among which the data are exchanged by the opening interface.

3.1 Economy development and energy demand forecast module (I/O model)

The economy development and energy demand forecast module consists of two sections. One is an economy development forecast and industry structure optimization module, which uses the Beijing I/O data of years to build up the forecast data sequence and model to predict the future trend of the economy development, and optimizes the industry structure, and promotes each sector under the national economy system for proportional and coordinative development; Another is a terminal energy demand forecast module which, based on economy forecast and industry optimization structure analysis and terminal demand technique database, relies on the input-output analysis to get the terminal energy consumption forecast data of Beijing in terms of industry and energy. The main formula listed as follows:

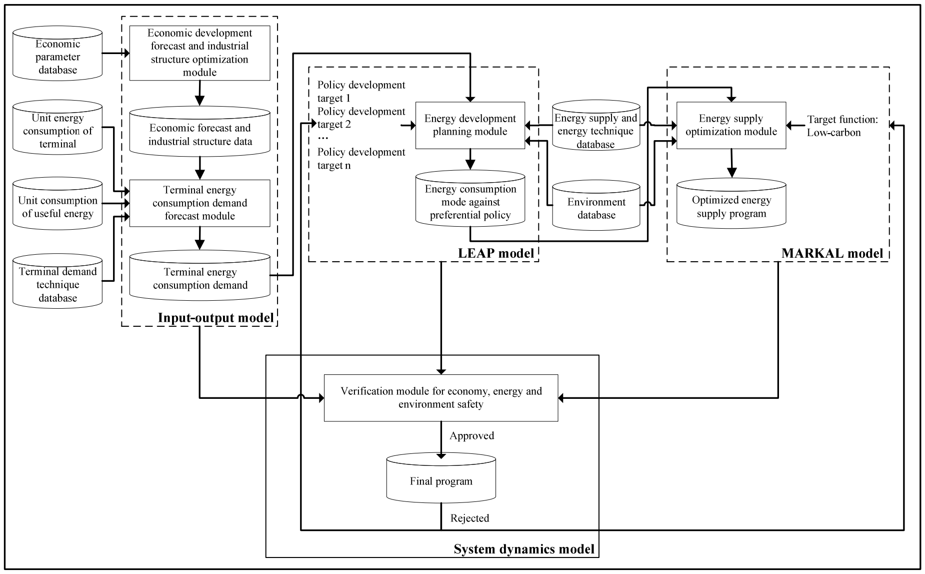

Figure 1. Structure of 3E-S model

$$Y^{(L)} = Y^{(0)}[A_1^{-1}(I-\Lambda_1)+\Lambda_1][A_2^{-1}(I-\Lambda_2)+\Lambda_2]...[A_L^{-1}(I-\Lambda_L)+\Lambda_L] \qquad (1)$$

Wherein, $Y^{(L)}$ means random output able to be used for reinvestment at L^{th} year, its value subject to R_+^{n} ={X: X means $1\times n$ non-negative vector}; $A^{(t)}(\omega), t \geq 1$ means random consumption coefficient matrix of t^{th} year; $\Lambda^{(t)}(\omega), t \geq 1$ means consumption coefficient matrix of t^{th} year.

The research on industry structure is mainly based on direct consumption coefficient, complete consumption coefficient, induction coefficient, impact coefficient, distribution coefficient, finally-adopted structure coefficient and added-value proportion coefficient, etc. For the example of impact coefficient, it is used to analyze the impact and conformance of the demand change at certain sector on and with the production demand of each sector under the national economy system. The calculation formula listed as follows:

$$E_i = \frac{\sum_{j=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}}, i = 1,2,....,n \qquad (2)$$

Wherein, $\sum_{j=1}^{n} b_{ij}$ means the sum of i^{th} row in the Leotieff invertible matrix; $\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}$ means the average of the sum of all the rows in the Leotieff invertible matrix.

The terminal energy demand forecast module mainly introduces the energy consumption coefficient matrix in terms of sector and energy consumption and uses the input-output data and applies the following main formula to get:

$$\Delta E_{-i} = e(I - \hat{\alpha}A)^{-1}\Delta Y \qquad (3)$$

Wherein, ΔE_{-i} is the complete consumption coefficient of energy in i^{th} sector; e means direct energy consumption coefficient matrix; A means I/O direct consumption coefficient matrix; ΔY means the selection matrix which corresponds to the section under attention; $\hat{\alpha}$ means the degree of self sufficiency of the local city; *I* means unit matrix.

3.2 Energy development planning module (LEAP model)

The energy development planning module holds the purpose to utilize the merit that the LEAP model is good at scenario analysis to make a comparison analysis to the different policies in order to select the best policy which could achieve a rational balance between cost control and environment benefit.

The model in total presets 11 scenes which belong to four types, e.g. pollution control enhancement scene and powerful new energy development, etc. The calculation based on the LEAP model could the energy development planning for supply-demand balance against various policy packages. The comprehensive comparison between policy cost and policy environment benefit from the planning would achieve an optimal balance point. The steps for the above course are shown as Figure 2.

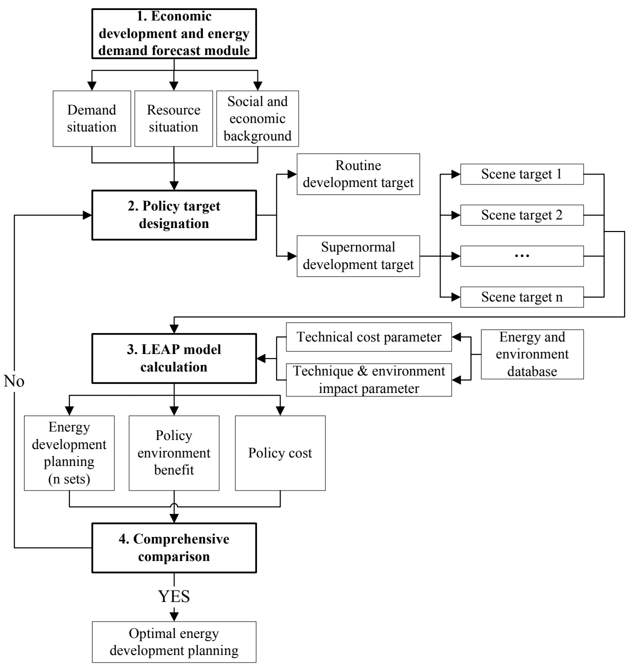

Figure 2. Flow chart about formulation of energy development planning

3.3 Energy supply optimization module (MARKAL model)

The planning target of Beijing based on the MARKAL model is to maximize the comprehensive environment benefit so as to realize the low-carbon target of Beijing. The constraint equation mainly includes the following five:

□Gross restriction of primary energy supply (the gross of the primary energy supply shall not be more than the resource input level): $X_i \leq SUP$; □Energy carrier balance across each link (the energy conversion amount in each link shall be at least equal to the consumption of next link): $E_i X_i - X_{i-1} \geq 0$; □Terminal energy demand balance (the terminal energy supply shall be at least equal to the demand): $E_2 X_2 \geq DEM$; □Technology capacity limit and production operating limit (The energy yield shall not be beyond the technology capacity or production operating limit): $E_i X_i \leq CAP_i$; □Total cost restriction (The total cost shall be less than the product of the cost achieved from the optimal program which is based on the energy development planning module with the allowance coefficient): $\sum C_i \bullet X_i \leq \mathrm{C_M} \bullet \lambda$.

Wherein, X_i means unknown energy flux vector of all the links present at the flow from primary energy product to terminal energy demand, i.e. solution of planning issue; C_i means the cost coefficient matrix of all the known links; E_i means the energy conversion efficiency matrix; SUP means energy resource vector; DEM means terminal energy demand vector; CAP_i means technology capacity vector.

Figure 3 shows the RES (Reference Energy System) for the economy, energy and environment system of Beijing formulated in accordance with the model.

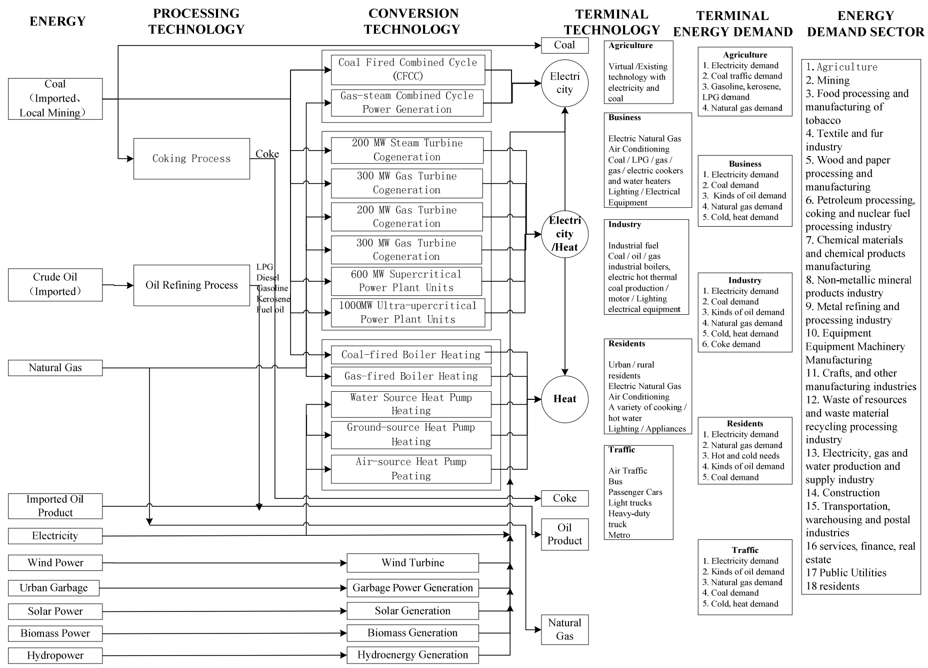

Figure 3. RES network structure of Beijing 3E system

3.4 Economy, energy and environment safety index verification module (SD model)

In this module, on the base of the comprehensive consideration to the subsystems in terms of energy, economy, population, science & technology and environment, etc., the system dynamics method is used to constitute a SD simulation model for the Beijing 3E system. And then input the parameters of economy, energy and environment obtained by the above three modules into the SD model and use the operating simulation model to observe the reach wherein the economy safety index, energy safety index and environment safety index of Beijing changes so as to judge the safety of the program. Figure 4 shows SD simulation model frame of Beijing 3E system. Then the safety index of the economy, energy, environment in Beijing can be calculated as follows.

Economy safety index: The first is resource safety index. The resource includes raw material, energy, human resource, capital and technique, etc. The resource safety index means the ratio of the consumption of certain resource to it supply. When the ratio is more than certain “threshold value”, it would be concluded unsafe. The second is industry competitiveness index. If the main industries of one city lose its competition force, the city would also face very high economy safety risk.

Energy safety index: It means the ratio of the energy consumption to the energy supply. When the ratio is more than certain “threshold value”, it would be concluded unsafe. The energy consumption shall consider production and life consumption related to energy structure, energy utilization technique level and efficiency. The energy supply shall consider energy supply technique level, energy reserve ratio, ratio of dependence (degree of self sufficiency of energy).

Environment safety means the quality, function and adjustment capability of the environment factors is within the acceptable and recoverable range of the environment itself. Environment safety coefficient=pollutant emission /environment capacity. The larger the value is, the more unsafe the environment would be. The environment capacity means the top limit of the pollutant emitted that the environment could bear. It could be replaced with the relevant standard formulated by the environment administration.

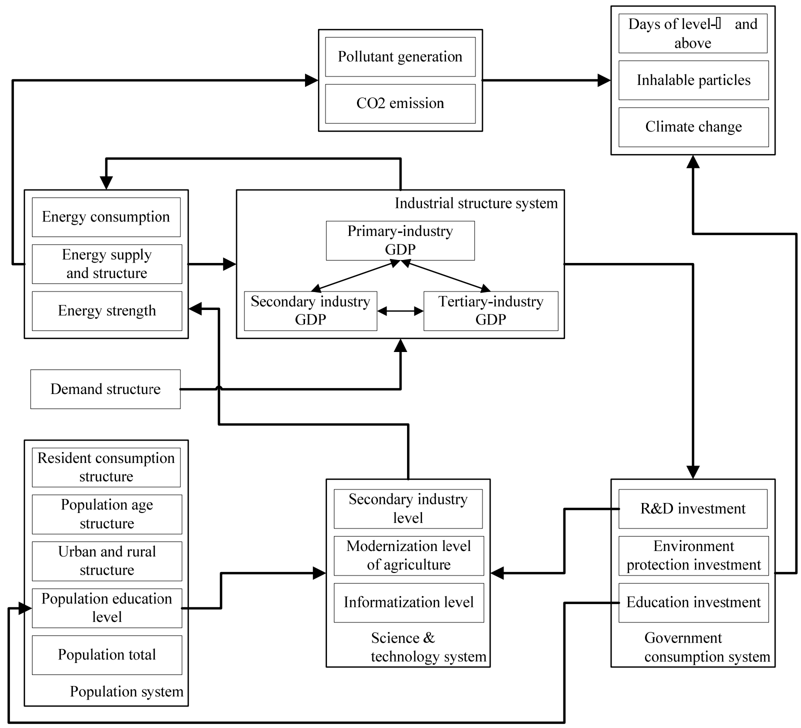

Figure 4. SD simulation model frame of Beijing 3E system

4. SIMULATION INTEGRATION OF 3E-S MODEL

On the base of 3E-S model principle, we developed the distributed visual demonstration platform---3E-S RIMSP (Remote Integrated Multi-simulation System Platform), which integrates data analysis, system simulation and decision-making imitation, to show the economy, energy and environment safety of the capital Beijing. Figure 5 shows the system infrastructure. The platform could function as follows:

(1) Integration of resource data with decision-making data

By through database design, the data, including economy parameter, energy supply, energy technique and environment parameter, are collected into the SQL Server database to achieve the resource data sharing and assure the data consistency; in addition, the secondary data or result data formed during the model operating, i.e. decision-making data, are also collected into the SQL Server database for uniform management and data transfer and sharing among the modules.

(2) Integration of service flow

The 3E-S RIMSP platform uses the J2EE infrastructure in the aspect of technique, wherein the core calculation section of the four modules are implemented respectively by various softwares: The economy development and energy demand forecast module is directly by Java; the energy development planning module uses the LEAP software to complete the core calculation; the energy supply optimization module uses ilog software to complete the linear planning calculation; the safety index verification module uses the Vensim software to develop the SD model. The development utilizes the Java interface of the above softwares to achieve successfully the integration of the service flow.

(3) Integration of user interface

The 3E-S RIMSP platform uses the B/S structure mode to form a multiple-layer system structure based on WEB, middleware and large database. The user in the LAN could use the browser to operate the 3E-S RIMSP simulation platform. The unified man-machine interface integrates data management, command input, operating status show and result analysis to achieve calling the four modules in the 3E-S model.

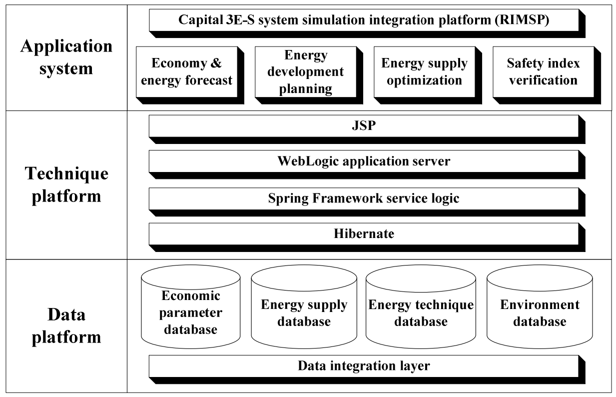

Figure 5. System infrastructure of Beijing 3E-S RIMSP platform

5. CONCLUSION

The Beijing 3E-S model integrates into several typical models of mutually supplementary function to relatively completely achieve the simulation to the Beijing economy, energy and environment system. Meanwhile, it initially introduces the safety index verification module to obtain the ability to launch the safety evaluation to the optimization program raised by the model and finally complete the computer implementation to the model and develop the 3E-S RIMSP integral simulation platform. The Beijing 3E-S model presents the new energy strategy, which including energy supply structure, conversion technology, and low-carbon emission economic development.

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