Paper 1

Energy Models in China
A Literature Survey

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The BASIC Project is a capacity strengthening project – funded by the European Commission – that supports the institutional capacity of Brazil, India, China and South Africa to undertake analytical work to determine what kind of climate change actions best fit within their current and future national circumstances, interests and priorities. Additional funding for BASIC has also been kindly provided by the UK, Department for Environment, Food and Rural Affairs and Australian Greenhouse Office. For further information about BASIC go to http://www.basic-project.net/

About BASIC

The BASIC Project supports the institutional capacity of Brazil, India, China and South Africa to undertake analytical work to determine what kind of national and international climate change actions best fit within their current and future circumstances, interests and priorities. BASIC has created a multi-national project team linking over 40 individuals from 25 research and policy institutions, the majority based in BASIC countries. Project activities comprise a mix of policy analysis, briefings, workshops, conferences, mentoring and training clustered around five tasks lead by teams as follows:

- Task 1 – Mitigation and sustainable development (China Team);
- Task 2 – Adaptation, vulnerability and finance (India Team);
- Task 3 – Carbon markets, policy coherence and institutional coordination (South Africa Team);
- Task 4 – Designing international climate change policy and enhancing negotiations skills (Brazil Team); and
- Task 5 – Creation of developing country expert group/mechanism on a long term basis (All Teams).

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About this Paper

The views and opinions expressed in this paper have been put forward by the BASIC Task 1 Team for discussion and do not express the views or opinions of the funders or the BASIC Project Team as a whole. Task 1 is coordinated by the BASIC China Team which comprises: Lu Xuedu, Ministry of Science and Technology, Beijing, Lin Erda and Li Yue, Chinese Academy of Agricultural Sciences, Beijing, Jiahua Pan and Ying Chen, Chinese Academy of Social Sciences, Beijing and Duan Maosheng, Global Climate Change Institute, Tsinghua University, Beijing.

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Other papers produced by BASIC Task Team 1 include:

- A Preliminary Analysis of Modelling Results Relevant to China from the International Emissions Scenarios Database, Ying Chen, Jiahua Pan and Guiyang Zhuang, Chinese Academy of Social Sciences, Lu Xuedu, Ministry of Science and Technology, China
- Energy Requirements for Satisfying Basic Needs, China as a case for illustration, Jiahua Pan and Xianli Zhu, Chinese Academy of Social Sciences, China
- The Role of Policies and Measures for Climate Mitigation in China: Rob Bradley and Hilary McMahon, World Resources Institute, USA
- Technology Transfer by CDM Projects: Erik Haites, Margaree Consultants Inc., Canada, Maosheng Duan, Tsinghua University, China, Stephen Seres, Climate Change Analyst/Economist, Canada
- Climate Change Impacts, Vulnerability and Adaptation in China, Li Yue, Xiong Wei and Wu Yanjuan, Institute of Environment and Sustainable Development for Agriculture, Chinese Academy of Agricultural Sciences

Abstract

This paper describes the current top down and bottom up models used by Chinese modellers covering a variety of inter-linked topics including energy, environment and the economy. It explains the strengths and limitations of these models and the purposes for which they are used by a diversity of policymakers ranging from environment ministries to finance and planning ministries. The paper concludes that more work is needed to elaborate some of the key models as they do not take the characteristics and specificities of developing countries into account. The paper suggests “an energy modelling forum for Chinese modellers and policymakers” be created to help the diversity of domestic and international actors who now need to understand “the China story” get to grips with the significance of modelling results as well as to enable modellers to develop a set of standard reference and policy scenarios which currently vary widely among the reviewed models. Whilst this paper is focused on China which has a high capacity to undertake modeling, it makes a contribution to broader capacity development by helping climate researchers and policymakers from other developing countries as many of the models discussed in the paper are increasingly being deployed elsewhere.

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Executive Summary

This study addresses the current models used by Chinese modellers covering a variety of inter-linked topics including energy, environment and economy. The aim of the study is to illuminate the current models being employed and their value in terms of their application and results. The analysis was carried out by Global Climate Change Institute (GCCI), Tsinghua University, under the framework of the BASIC project.

This study came to the following conclusions:

1. **In China, several bottom-up and top-down models have been developed by Chinese modellers to study the interaction between energy, environment and the economy in China.** The timeline below (see Figure 1.) provides a summary of the history of modelling practice. According to the most recent survey, CGE and bottom-up models are generally preferred by Chinese modellers. Only two top-down models based on input-output technology are reported here. The macroeconomics model is absent in the toolbox of Chinese modellers although some bottom-up models contain a macroeconomic module.
2. **Some important characteristics and specificities of developing economies (e.g. energy price regulation, non commercial resources, etc.) are still not represented in existing models.** Some examples of the specificities of the China case include rapid technological change, greater levels of non-commercial energy in rural areas, price regulation in energy sector etc. These specifics are not given enough attention in existing modeling practices.
3. **The reference scenarios and policy scenarios in the reviewed models are very different and does not allow for comparisons between models.** It should be understood by policymakers that the results of different models are based on different model structures and the different assumptions underlying each model, e.g. scenario setting, elasticity estimation, production function etc.. An energy model forum for Chinese modellers and policymakers would help them clarify such challenges and, develop a set of standard scenario in the future to be employed as a basis for modeling.

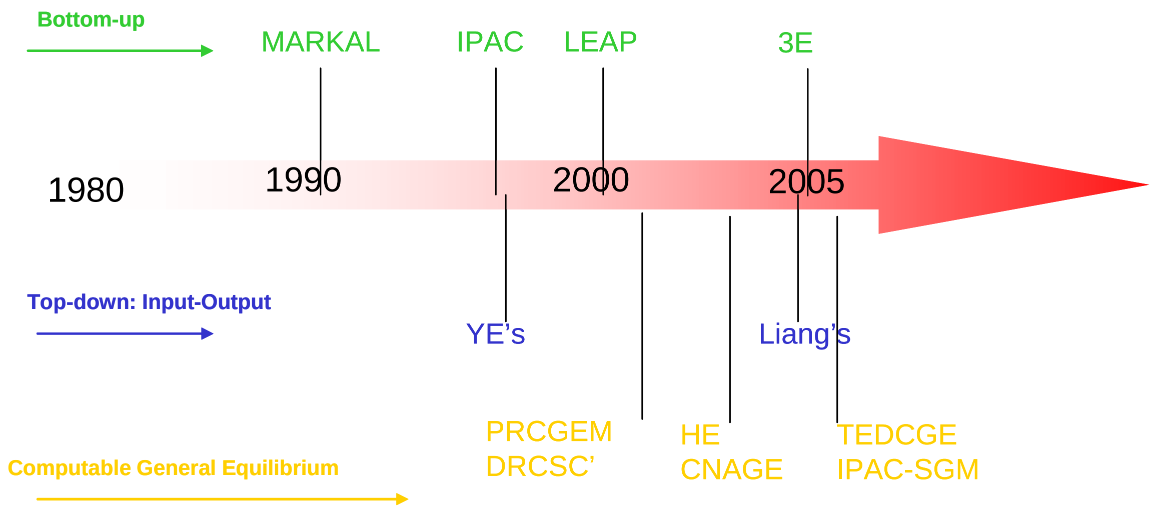
4. **There is no such thing as the wrong model, only the wrong application.** Every model is mathematically logical, and therefore, every model is correct. The statement that one model is more useful than another is correct only under some given circumstance. For example, when policymakers need to identify the key technology for mitigation, bottom up models can supply more useful insight. But when policy makers care more about the welfare impact of a carbon tax scheme, the CGE model would be more appropriate. A link should be made between Chinese policymakers and modellers to exchange this information and best practice.

General Introduction

Since the oil crisis in 1973, governments have been acutely aware of the important interaction between energy and the economy. Starting in the 1980s, this was combined with increasingly attention to the impact of energy use on the environment, especially with respect to global warming. A wide range of energy-environment-economy models have been developed to help us understand the complex interaction between energy policy, environmental concerns and the economy.

Generally speaking, these models can be divided into two types: top-down and bottom-up. The essential difference between these two models is the treatment of technology. In bottom-up models technology is modelled from a viewpoint of engineering through specific technical description, industrial economic parameters and so on. In top-down models the technology is abstracted within the production function which models the substitution among different production factors. Substitution among production factors causes the movement of equilibriums in factor markets and the behaviour of economic agents. Until recently, computational constraints have meant that the energy sector and the feedback relationship among energy, environment and the economy can not be modelled in detail simultaneously, though computational advantages are now making this possible. In this article, the traditional classification of top-down model and bottom-up model is still used.

Figure 1: Timeline of energy model development in China



The existing research work on energy-environment-economy models in China began at the end of the 1980s and the beginning of the 1990s. The earlier works focused on energy planning, using related energy planning models[1]. Following increasing concerns around the environmentally friendly use of energy resource and sustainable development issues more generally, an increasing amount of energy models were developed by Chinese researchers to analyze broader energy policy issues, e.g. the macroeconomic impacts of energy policy, issues around greenhouse gas emissions and the potential of the Clean Development Mechanism for China. In the following section, several of the most widely employed and important energy models developed by Chinese researchers are introduced including top-down and bottom-up models .

Bottom-up models

The general method of establishing a bottom up model includes identifying the impacts on the economy based on micro-economic changes in technology use and the effects of such change. A variety of technologies and process-flows are described in detail. While assessing the alternative effects of resource production technology, a reliable and detailed description of resource consumption is required, including a measurement of GHG emissions. What is excluded from the model is feedback from general economic and non-technology factors.

The energy models considered for the purpose of this study can be divided into energy system models, energy economy models and part-system models. The energy system models aim to cover whole energy system actions such as a state, country and region or global areas. The macro economic driving factors in such a model will be exogenous. The energy economic models aim to include the wider energy system and its impacts. The part-system model is a sector model. The optimization model will generally be a linear program of the energy system, which will maximum the cost based on the exogenous energy demands. The maximum will be calculated under some constraints (the technology available, supply=demand, emissions etc.). For example, the MARKAL model, LEAP model and AIM model, and the 3E model. The main models are shown in the following Table (Table 1).

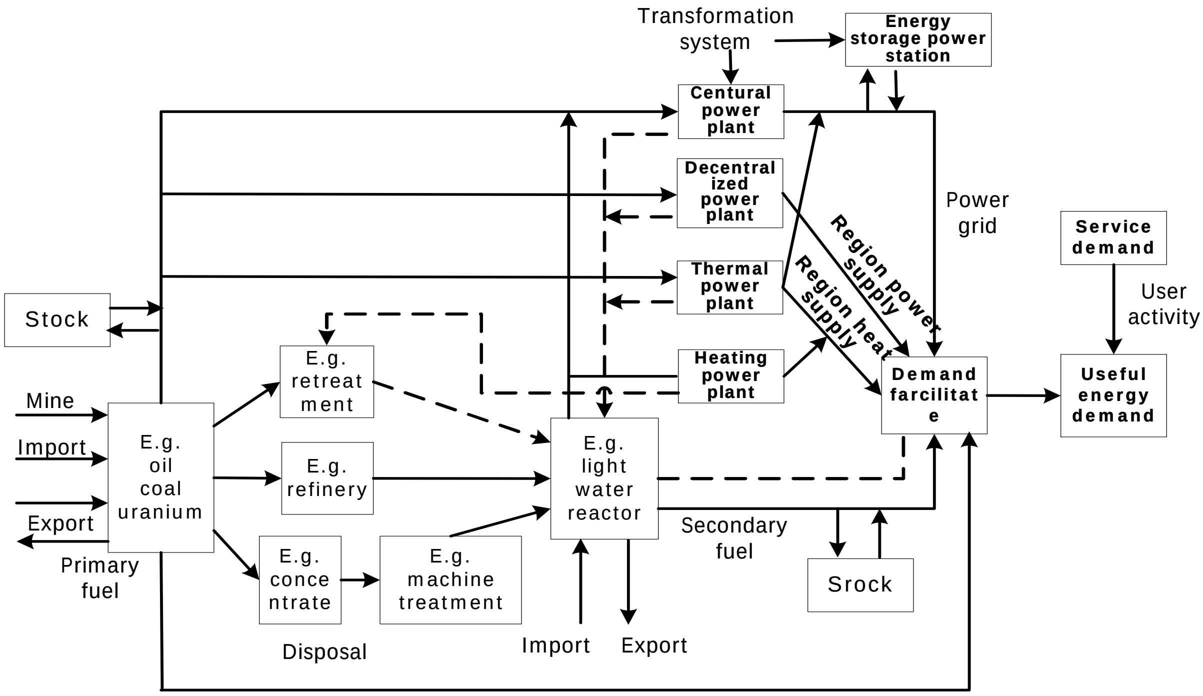
Table 1 Summary of bottom-up models in China

Name	Status	Object	Time Horizon	Emission Covered	Technology Detail
MARKAL	accomplished	optimization path of energy system, emission forecast	1995-2050	CO_2	5 sectors 71 technologies
LEAP	all functions will be improved continually	optimization path of energy system, emission forecast	1999-2030	CO_2	
AIM	accomplished	Based on the Asian centre to describe the problem and policy analysis	1990-2100	CO_2	
3E	accomplished, but some functions should be improved	optimization path of energy system, emission forecast	2000-2050	CO_2	

MARKAL Model

The MARKAL Model was developed by Brookhaven National Laboratory (BNL) in the USA and KFA in Germany. This model is a large multi-period linear programming model of an energy system, designed to provide a common non-country-specific framework for energy policy evaluation. It is a flexible analytical tool which can be readily adapted to model different energy systems at the national, state and even local level in developed or developing countries. The MARKAL Model provides a rigorous and proven framework for assessing the overall energy system costs of different policy options or strategies.

Figure 2 MARKAL model energy flow chart [2]



The MARKAL Model is designed to determine the lowest cost method of satisfying demand for energy services. The total cost includes the energy exploitation cost, import and export cost, costs as a result of the type of process technologies and transformation technologies, machine investment, fixed and variable operation cost, the transmission & distribution cost of electricity, the transmission cost of heating, etc. Meanwhile, the objective function covers the remaining investment costs. [3, 4]

The main constraints of the MARKAL Model include: (1) the total fuels, total energy carrier equilibrium constraints; (2) technology capacity limits and product operation limits; (3) electricity and low heat special constraints; (4) total primary energy supply constraints during the whole period. [5]

Applications

- The MARKAL Model was introduced into China at an early stage. Up to now, the Institute of Nuclear and New Energy Technology, Tsinghua University and Shanghai Environment Science Research Institute are the users of this model in China.
- The MARKAL-MACRO Model is designed to study the impacts of carbon emission reduction on GDP growth. Based on the future CO2 emission scenarios fed into the model, current GDP loss function is given. This allows for a comparison between different reduction scenarios.[6]
- The Shanghai Environment Science Research Institute adopted the MARKAL model to estimate the repercussions of an adjustment in energy structures. The scenarios included

energy efficiency, energy structure adjustment of energy supply side and the end use energy consumption structure.

Limitations

- In principle, the MARKAL Model is a strict sector energy model. It can establish the relationship with other national economic sectors. There is no relationship however between the model and the economy factor, as with the IOA. Energy and technology cost data only appear during sensibility analysis research.
- As a pure energy sector model, there is no endogenous economic section in the MARKAL Model. There is no detailed regional distribution module. A variety of market factors are not considered in the model.
- The MARKAL Model is usually applied independently and the sector energy demand is generally provided exogenously. The fixed energy demand does not reflect the impact of energy price. In the end, the MARKAL Model is linked with the MACRO Model using energy service demand. The MARKAL-MACRO Model is a dynamic nonlinear program, whose objective function optimizes the total discount utility during the planning period.
- The MACRO Model is a macro economic model, the production function adopts the simple nested constant elasticity of substation (CES) production function. The inputs consist of capital, labour and sector energy service demands. The MACRO Model solves for an optimal consumer utility level, which is determined by optimal aggregate investment level and demand for energy service.

Table 2 Application of MARKAL model in China

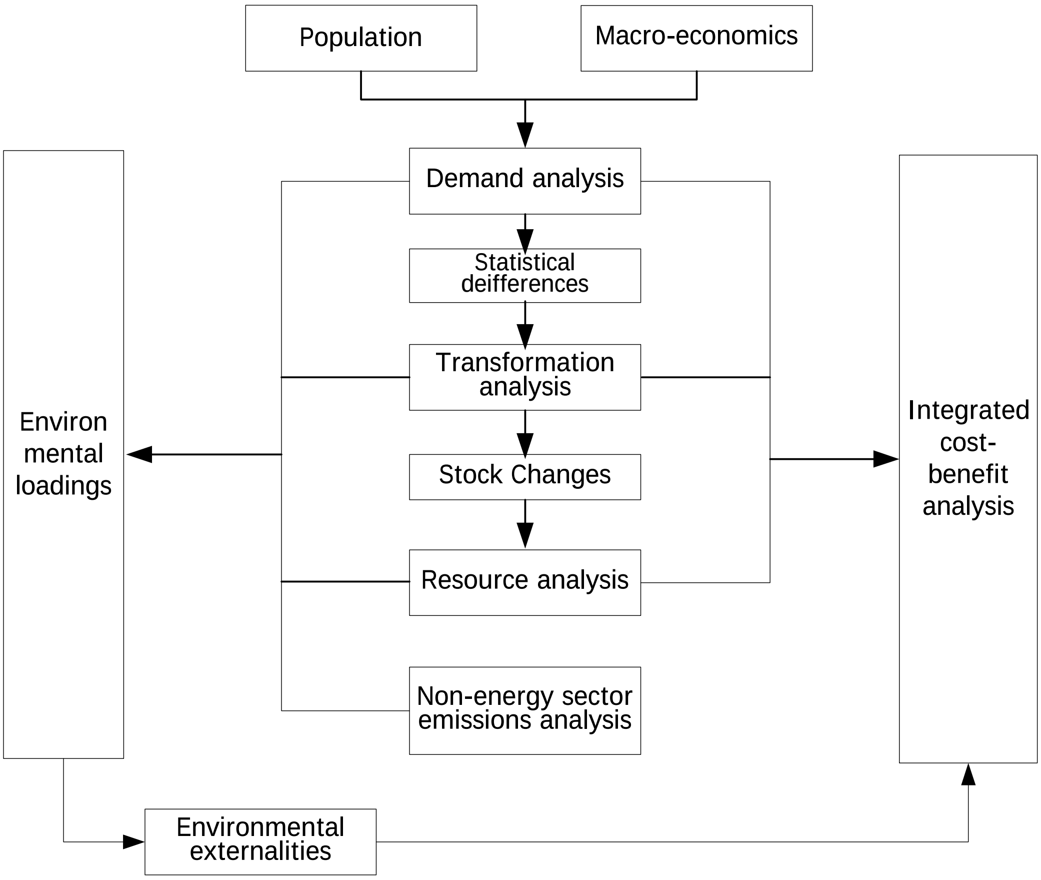
Research institute	Period, basic data requirements	Destination	Results and Conclusions
Tsinghua University-China MARKAL-MACRO model	1995-2050; five year intervals The basic capital stock, the added value of capital ratio in GDP, capital-labour elasticity of substitution for energy services Sector: five sectors: agriculture, industry, resident, service and transport, 30 sub-sectors in detail There are about 20 coal transmission technology, 3 natural gas transmission system, 3 oil transmission system and 9 renewable energy technology and 1 nuclear technology	The China MARKAL-MACRO model, an integrated energy, environment and economy dynamic non-linear programming model, is developed to generate a reference scenarios for China's future energy development and carbon emission and to analyze the potential impact of carbon emission reductions on the energy system.	China MARKAL-MACRO model was used to study the impacts of carbon emission reduction on the GDP growth for future carbon emission reduction in China. The future end use energy consumption will reach 106.5EJ in 2050 from 28.7EJ 1995. The total carbon emissions will reach about 2.394Gt. For the industry structure and production mix adjustment, the energy efficiency growth and energy substitution, carbon emission intensity per GDP (1995 US$) will reach 0.172 kg/US$ in 2050 from 1.156 kg/US$ in 1995. Six carbon emission reduction scenarios were designed. The final results covered the current GDP loss under kinds of emission reduction scenarios, total GDP loss under different emission reduction scenarios. The results showed that the GDP loss rate would be in 0～2.5% for reduction rates of 0～45%. The quantitative GDP loss predictions for the whole planning horizon for the different reduction scenarios indicated that the GDP would start to decline at around 10 years before setting the reduction constrains, and the GDP losses would gradually increase and last for several years after setting the reduction constraints. If the start of the emission reductions is the year of 2030, 2020 or 2010 instead of 2040, then the undiscounted total GDP losses in the whole planning horizon would be 0. 58～0. 74, 1. 00～1. 32, o r 1. 10～1. 83 times.

LEAP Model

In 1997, SEI-Boston joined forces with five leading international research and training institutes - EDRC (South Africa), ENDA (West Africa), ETC (Europe), FAO-RWEDP (Asia), IDEE (Latin America) – to create a new suite of tools for integrated energy-environment analysis. Funded by the Netherlands Ministry of Foreign Affairs (DGIS), the LEAP2000 Initiative is designed to meet the needs of energy and environmental professionals around the world. [7]

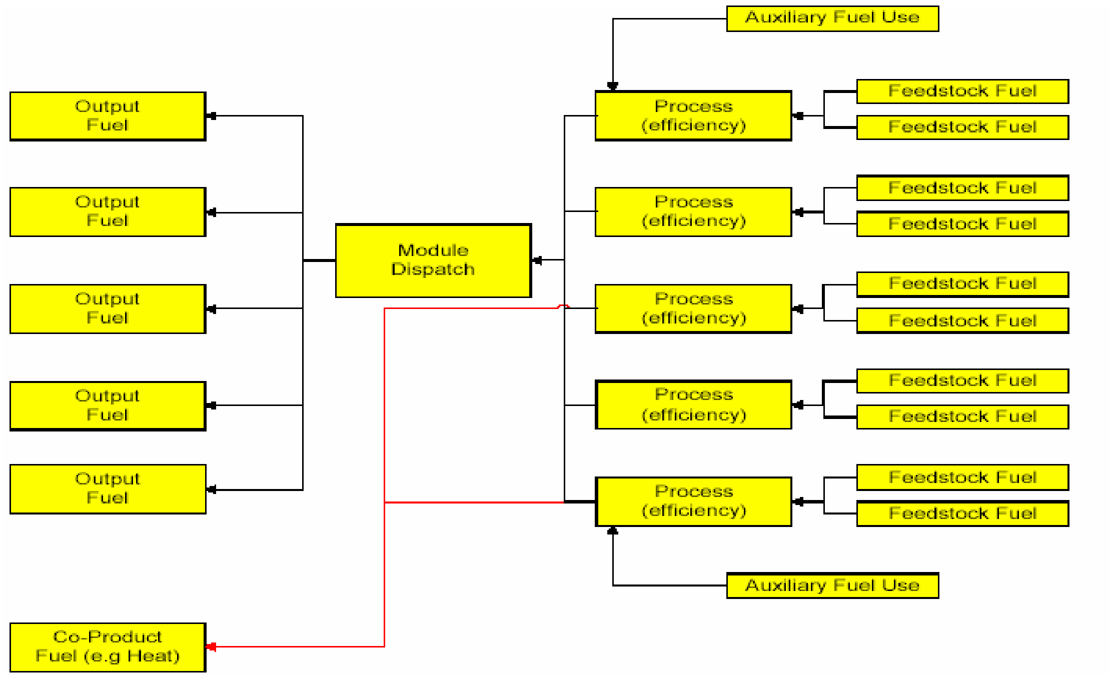
The LEAP Model has been used to develop local, national and regional energy strategies, conduct greenhouse gas mitigation assessments, and train professionals in sustainable energy analysis. LEAP 2000 is a scenario-based energy-environment modeling tool. Its scenarios are based on a comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price etc.. With its flexible data structures, LEAP allows for an analysis as rich in technological specification and end-use detail as the users chooses. [8]

Figure 3 LEAP model calculation process



The transformation sector uses special branches called modules to model energy supply and conversion in sectors such as electricity generation, refining, or charcoal production. Each module contains one or more processes, which represent an individual technology such as a particular type of electric plant or oil refinery, and produces one or more fuels. These represent the energy products produced by the module. This basic module is shown below: [9, 10]

Figure 4 LEAP module structure



Applications

- The applications of LEAP model are very broad in China. ERI, the Institute of Nuclear and the New Energy Technology (INET), Tsinghua University, and Shanghai Environment Science Research Institute have adopted the LEAP Model for the purpose of its research.
- In 1999, ERI of NDRC adopted the LEAP Model for the sustainable development scenarios research for China. In 2003, ERI finished the 《China sustainable development energy and carbon emission scenario analysis》 project. There were three sustainable development energy demand scenarios, which considered the sustainable development target in China, but for different scenarios, different policies extension, and different energy technology selection. [11]
- INET of Tsinghua University adopted the LEAP Model for China energy systems analysis and considered a future Northeast Asia cooperation scenario. The main outcomes of this research include a comprehensive energy database covering every sector of the energy system; e.g. three energy balance sheets of the object year show the flow of energy; a relatively full-rounded evaluation of the energy system on the environment. [12]
- The Shanghai Environment Science Research Institute adopted the LEAP Model to explore low carbon emission development in Shanghai to reduce energy demand and air pollution. The model was used to make policy suggestions relating to health and pollution issues.

Limitations

- The LEAP model does not automatically generate optimization or market-equilibrium scenarios, although it can be used to identify least-cost scenarios. Important advantages of LEAP are its flexibility and ease-of-use, which allow decision makers to move rapidly from policy ideas to policy analysis without having to employ more complex methods.
- The LEAP Model does not attempt to estimate the impact of energy policies on GDP or employment (the interaction between the macroeconomics module and others remains open), although such models can be run in conjunction with LEAP.

Table 3 The applications of LEAP model in China

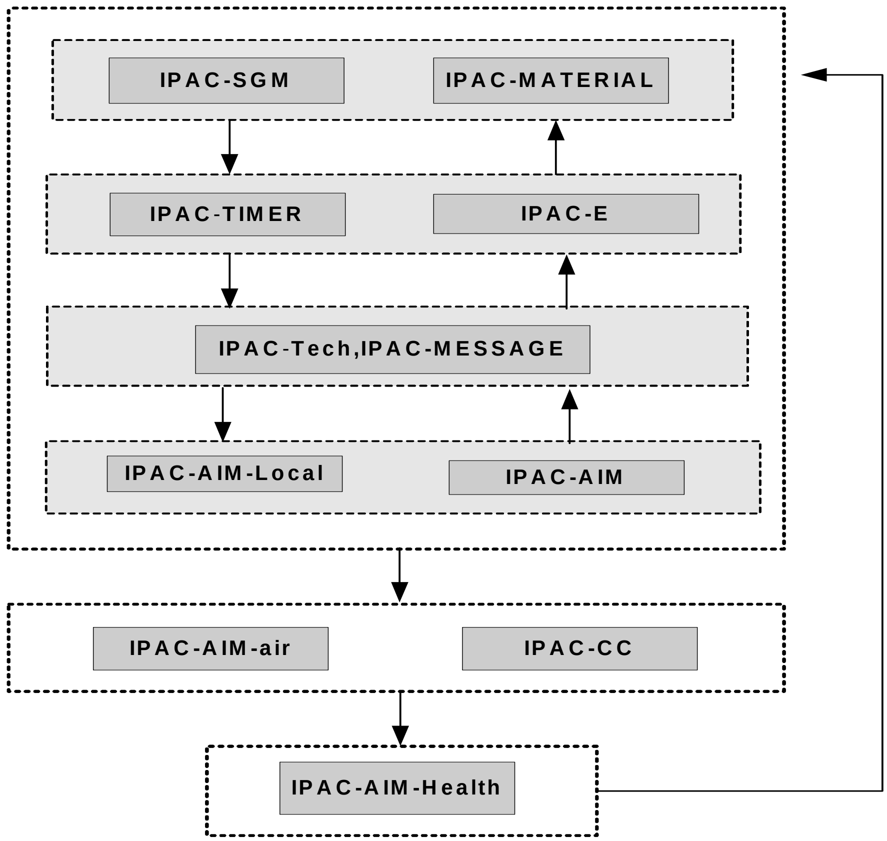
Research institute	Period, basic data requirements	Destination	Results and Conclusions
ERI of NDRC	1998-2020; The basic macro factors: population growth rate, urbanization rate, GDP change, industrial structure adjustment and other important energy and energy saving policy assumptions. Sector data: activity level, energy efficiency and energy consumption of steel and iron, non-ferrous, papermaking, chemistry, oil and oil refining, power, building materials, residential and transport sectors.	There are three scenarios for China's sustainable energy demand analysis. S1 scenario is focused on the energy efficiency increment as a result of economic development, S2 is focused on the optimistic sustainable development and energy development scenario, S3 is the ideal scenario.	For the requirements of China sustainable development of energy demand, policy assessment and other indeterminacy factors, the LEAP model is adopted to conduct research for policy-makers. The results of the project cover the total energy consumption of three scenarios in 2020, S1, S2 and S3 will reach 3100Mtce, 2761Mtce, 2318Mtce separately. The total carbon emissions for three scenarios reach 1899.9Mtc，1659 Mtc，1265.3 Mtc separately.
INET of Tsinghua University	1999-2030; Macro economic factors: GDP, population, household scale, transport turnover, main industrial production and so on. Energy demand data: sector/sub-sector energy demand, end-use activity level and energy intensity. Energy transmission data: efficiency, product capacity, fuel mix. Energy supply data: capital stock. Available technology data: new technology capital and operation cost, efficiency etc..	Based on the energy, fuel demand, investment and GHG emissions, Nox, SO2 emissions, there are three scenarios: BAU scenario, H-E scenario (natural gas import) and H-I scenario (nuclear, renewable energy)	Calculation results show that the primary energy demand in these three scenarios (BAU, H-E, H-I respectively) can reach 2967、2842、3119Mtce respectively, with import taking up 21%、31%、13% respectively of the total primary energy supply in these scenarios. CO2 emission will reach 6236、5568、5568Mt respectively and SO2, NOx emissions will amount to 30.2、21.6、27Mt and 23、17、21Mt respectively. The above information displays the situation of the energy system in three scenarios. Analysis shows that the H-E and H-I scenarios as alternative development pathways to BAU can both increase energy diversification and improve the environment, but the costs vary due to the different technologies choices used in the two scenarios. Based on the analysis of the calculation results, policy implications are drawn in order to strengthen cooperation with other northeast countries in the energy field; geopolitical factors must be fully understood in energy strategy development; problems resulting from the increase of domestic transportation activities are given special attention.

AIM Model

The Integrated Policy Assessment Model for China (IPAC) is an integrated assessment model jointly developed with the Japan National Institute for Environmental Studies, based on work developed by the Energy Research Institute (ERI) since 1992. [13, 14]

The structure of the model is shown in figure 5:

Figure 5 IPAC model structure



The IPAC-AIM/Energy Technology model is a detailed technology assessment model, which incorporates a bottom-up technique. This model assesses technology policy and GHG emissions policies. The model also analyzes the medium and short-term energy and GHG emission scenarios for a given country. There are detailed energy services, facilities status and future development trends included. This model also simulates energy consumption trends. The most important contribution of the model lies in the impact of different technology strategies on the technology imports and GHG emissions.

The AIM/Energy technology model adopts the minimum cost analysis, and thereby selects the minimum cost technology for energy service provision. The linear program method is adopted in this model, and it analyzes the complex energy application process, not only the technology itself. During the analysis process, a variety of parameters are adopted through different standards and methods, which enlarge the analysis field and provide a factual approach. [15]

The technology selection in the AIM/Energy technology model is very simple. If a carbon tax and subsidy are fed into this model, the technology selection will change, leading to a change in energy consumption and CO2 emissions.

Applications

As a result of the complexity of the AIM model, there is but one organization, the ERI using this model for the assessment of GHG emission reduction strategy for China.

Applications of this model in China include:

- China medium and long-term energy and emissions scenario research;
- China GHG emission reduction technology assessment;
- Asia-Pacific urban transport technology selection research;
- China power system emission reduction technology assessment;
- China energy strategy research;
- Beijing clean energy scenario research in 2020;
- Guangdong energy demand research.

Limitations

- In the residential and commercial sector, the optimization selection isn't obtained in as a result of choosing one combination over another. In order to get the effective technology combination selection, the AIM model makes use of the linear program to establish a technology combination. [16, 17]
- As a bottom-up model, the AIM model shares the same shortcoming with other bottom-up models: there is no feedback into macroeconomic modules, as a result, indicators for economic losses (e.g. impacts of reduction on GDP) are unavailable.
- Only existing technologies are considered in the AIM model. Backup technologies are not included as alternatives therefore the CO_2 emission reduction will be underestimated.

Table 4 The applications of AIM model in China

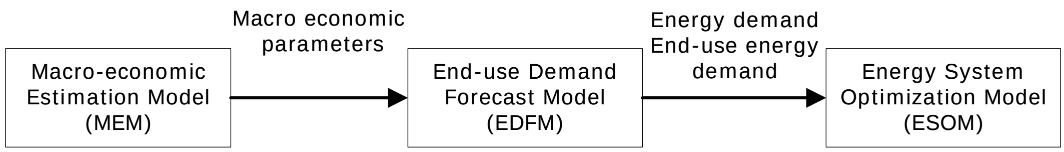
Research institute	Period, basic data requirements	Destination	Results and Conclusions
ERI of NDRC	1990-2100 Macro economic data: population, GDP growth rate, GDP mix, international trade; Energy technology efficiency, energy technology annual margin cost increment; non-conventional energy utilization, the proportion of renewable energy Energy utilization by sector	To comparing future GHG emission reduction pathways in China, six scenarios are designed based on some major factors. For economic development, three patterns are given high, medium, and low level. Population development is divided into high level and low level. These factors are combined, and six GHG emission scenarios are provided in the end.	From the results of the six scenarios, the total energy demand in 2010 would vary in a large interval, in 2050 the total energy demand varied from 2.8 billion tce to 7 billion tce, this figure spans from 3.9 billion tce to 10.2 billion tce in 2100. These results explain the diversity of future energy demand. CO2 emissions increase and span a large interval from 1.67 billion tons of carbon to 4.01 billion tons of carbon in the moderate economic development scenarios. In the end, technology plays an important role for climate change mitigation. As s developing country, technology plays a very important role in energy saving, environmental protection and climate change. Technology development policy is combined with climate change policy. Making use of the national natural resources and focusing on clean energy technology, China could become a technology leader in the world, which has advantage in the energy environment development and economic development.

3E Model

The Institute of Nuclear and New Energy Technology of Tsinghua University has developed the Energy-Environment-Economy (3E) model. Under the lead of Prof. HE Jiankun and Prof. ZHANG Aling, the 3E model is proposed for CO2 mitigation cost analysis. [18]

The 3E model includes three modules: a macroeconomic model (MEM), an end use forecasting model (EDFM), and an energy system optimizing model (ESOM). MEM is a macro model based on the EVIEWS software to estimate Chinese economic long-term development; EDFM is an end use energy demand forecast model according to the energy intensity index, flexibility coefficient method and econometrics method; ESOM is a multi-period linear program model based on an energy flow system. The model employs GAMS software. The framework of hte 3E model is shown in figure 6.

Figure 6 3E model structure



In a complete 3E model, the MEM would include the added value of every sector from 2000 to 2050 and the national income and other economic parameters; the EDFM would calculate energy service/end use energy demand levels based on the macro economic parameters provide by the MEM; and according to the energy service and end use energy demand level;, the ESOM would make use of the linear program and optimize the total energy system cost with a view to resources and environmental constraints. Other sector margin costs of emission reduction, energy system investments and energy system costs are also calculated by this model .

MEM model

The MEM model is based on the China macro economic model, the model is a demand-oriented econometrics model. GDP in the model is calculated by product method. There are 93 functions: 54 behaviour functions and 39 definition functions. All these behaviour functions are estimated by EVIEWS software.

There are 118 variables: 92 endogenous variables and 25 exogenous variables. The model is divided into 8 sections: end use demand, government and national income, banking, price, labour, fixed asset investment and fixed capital form, production function and others.

EDFM model

The EDFM model analyzes the relationship between energy service/end use energy demand and population, urbanization level, GDP, the added value of industries, per capita income and other macro parameters.

From the MEM model, population, urbanization level, GDP and the added value of industries are calculated for this model. The EDFM model estimates the end use demand involving industry, agriculture, transportation, commercial services, the residential sector and man other, providing in total 31 sector estimates.

ESOM model

The ESOM model is a multi-period linear program optimization model based on the energy flow system. The objective function adopts the NPV of energy system costs during a planned period. The base year is 2000 in this model, the planned period spans from 2000 to 2050, with five year intervals.

The decision variables in the ESOM model include energy activity variables, technology capacity variables, new added capacity variables, technology innovation capacity variables, output variables, energy service variables and other parameters.

69 energy transfer technologies (36 coal-based, 5 oil-based, 12 gas-based, 15 renewable and 1 nuclear technology) and 123 end-use technologies in five end-use sectors (43 in industry sector, 6 in agriculture sector, 15 in service sector, 24 in transportation sector and 35 in residents sector) are considered in ESOM. Not only mature and commercialized technologies, but backup technologies are also included in the technology set.

Applications

The Institute of Nuclear and New Energy Technology of Tsinghua University systematically and quantitatively analyzes the marginal cost, branch marginal cost, prophase expense, prophase investment, and temporal distribution of expense of CO2 abatement under a uniform framework provided by the 3E model. It further analyzes the energy structure shift and technical options due to CO2 abatement, and compares the cost of CO2 abatement under different energy development strategies.

Limitations

- The ESOM model is a multi-period linear program model based on the energy flow system. The output variables mainly include activity levels of kinds of technologies, energy consumptions of end use energy technology, intermediate transfer technology, pollution emissions and technology investment and cost. In the end the outputs are listed according to the technology order not the sectors or industries order.

Table 5 The applications of 3E model in China

Research institute	Period, basic data requirements	Destination	Results and Conclusions
Institute of Nuclear and New Energy Technology, Tsinghua University	2000-2050 the macro economic parameters of population the energy service/end-use energy consumptions of industries, agriculture, transportation, commercial services and residential sectors, total of 5 sectors and 31 sections from 2000-2050 Energy import separately come from mining, net import and renewable energy This model included 1 renewable energy technology, 6 fuel energy exploitation technologies, 9 energy import technologies, 69 energy transfer technologies, 123 end-use energy application technologies The investment cost, operation and maintenance cost, energy net import and annual emission tax	According to the different abatement start year and abatement proportion, some comparison results are given. From 2015 to 2030, CO2 marginal abatement cost for China, CO2 branch marginal cost, CO2 prophase expense, CO2 prophase investment and CO2 abatement expense temporal distribution were analyzed quantitatively. The energy structure shift and technical options due to CO2 abatement are also analyzed. The costs of CO2 abatement under different energy development strategies are compared and contrasted.	The margin abatement cost for China from 2015 to 2030 is given. (This dissertation is security level for five years). Branch abatement marginal costs are different from each other, and are affected differently by CO2 abatement. The transportation sector has the highest abatement cost and the lowest abatement potential; the power sector and industry sectors have the large abatement space. The power sector, industry sector and residential sector are three large abatement potential sectors.

Top-Down models

In top-down models, a detailed description of energy supply technologies, end-use and energy conversion technologies are generally omitted. The technology is described by the production functions through the substitution of different factors. Such treatment doesn't mean the top-down model is highly aggregated and inattentive to detail; on the contrary, the top-down model includes more detailed complex interactive relationship among economic sectors (e.g. input-output models) or the behaviour basis of these interactions (e.g. Computable General Equilibrium models). Generally speaking, the top-down energy policy models can be categorized into three different types: macroeconomics model, input-output model and computable general equilibrium model (CGE). Almost all top-down models developed by Chinese researchers can be categorized into the last two types. In the following sections, several most important and popular IO and CGE models are introduced. A summary of top-down models is listed in Table 6.

Table 6 Summary of top-down models in China

Name	Structure	Sector	Region	Consumer group	Other aspects
YE	Dynamic input-output model	23	1	2	Base year:1987
Liang	Input-output analysis + scenario analysis	40	1	1	Base year:1997
HE	Static CGE	9	1	1	
PRCGEM	Static CGE	118	30	1	
DRCSC's	Dynamic CGE	40	1	1	13 pollutions
TEDCGE	Dynamic CGE	10	1	2	
CNAGE	Static CGE	---	1	1	unemployment
IPAC-SGM	SGM CGE	20	10-20	1	

YE's Model [19]

The input-output model is based on the input-output table. The Input-output approach provides a useful framework for tracing energy use and other activities such as environmental pollution associated with inter-industry activity. In the basic input-output analysis, there are n sectors in the economic system, the output of ith sector is denoted by X_i, x_{ij} is the output of jth sector consumed by ith sector. The final product of ith sector is denoted by Y_i. Then a coefficient $a_{ij}=X_{ij}/X_j$ can be defined to show how many units of output of jth sector is needed to produce one unit of ith product. a_{ij} Is called direct consumption coefficient to show the technical relationship among sectors. The basic input-output analysis model only represents the relationship among economic sectors, not the interactive relationship between economic system and energy demand and consumption. The basic input output model can be extended to address energy and environmental problems [20]. Energy input-output typically determines the total energy required to deliver a product to final demand, both directly as the energy consumed by an industry's production process and indirectly as the energy embodied in that industry's inputs. The inputs to the production process includes fuels (direct energy) and non-energy goods and services. Then the input-output framework can be extended to trace the energy flows instead of only material flows.

YE[19] developed a multi-sectors, multi-period nonlinear input-output model: YE. YE maximize the aggregate consumer utility function while only the utility, a consumer, is included in the objective function, and the utility induced by environment quality is not considered. The consumers in YE are divided into two categories: urban residents and rural residents. Constrains of YE include input-output balance constraint, natural resource constraint, investment constraint, foreign exchange constraint etc.. Some sectors in the input-output table are divided into more detailed sub-sectors to show the substitution and complementarity among different factors according to the status of different technologies. For example, in YE, the electricity sector is divided into the hydropower sector, the nuclear power sector, the normal coal-fired power sector, the advanced coal-fired power sector, the renewable energy sector etc. In the same sector, different technologies can produce the same products but with different input-output coefficients. The different coefficients can reflect the substation among factors, technical progress and technical choice under different conditions. Three greenhouse gas sources are considered in YE: combustion of fossil fuel, emissions during the production process and the by-products of some other products. The data basis of YE is the 33 sectors from a 1987 input-output model. The original input-output tables is reorganized into 21 production sectors and 2 fuel sectors. In his dissertation, YE used the YE model to analyze the emission reduction potential of greenhouse gas in China, the selection of reduction standards for greenhouse gases, the best reduction path under cumulative emission control and the corresponding industrial structure adjustment and technical choice.

Application

With the YE model, YE analyzed different abatement schemes and their impacts on GDP. A per sector reduction scheme (every sector has a reduction goal of 10%, .20% or 30%) will cause a higher

GDP loss than a total reduction goal (10%, 20% or 30% reduction for the total emission). The corresponding GDP loss is listed below (Table 7):

Table 7 GDP loss of the per sector reduction scheme compared with the total reduction scheme.

Year	1995	2000	2005	2010	2015	2020
GDP loss(%)	16.62	23.78	27.78	28.83	26.55	22.74

A total reduction goal is better than the per sector scheme because it gives the opportunities of trading emissions among different sectors with different abatement cost, which is forbidden in a per sector reduction scheme.

YE also analyzed the best reduction path under different reduction goals and the impacts of carbon tax on the abatement goals which are listed below.

Table 8 The impacts of carbon tax

Carbon Tax (Yuan/tC)	2000 (MtC)	Reduction (%)	Carbon Tax (Yuan/tC)	2010 (MtC)	Reduction (%)	Carbon Tax (Yuan/tC)	2020 (MtC)	Reduction (%)
130	796.8	10	110	1184.2	11	110	1474.6	10
200	734.1	17	170	1061.7	20	170	1304.4	21
400	609.9	31	340	923.9	30	340	1139.5	31

Limitations

The YE model is based on an dated data set, a 1987 input-output table. The data needs to be renewed so that the results from the YE model can be compared with that from other models. The dynamic input-output framework is not very suitable for a long-run policy analysis which will be discussed further in the last section.

Liang's IO model

LIANG et al [21] used input-output analysis and a scenario analysis method to predict the energy demand and energy intensity during the period of 2010-2020 in China. The impact of different social economic factors on energy demand and energy intensity are also analyzed in their model. The final demand is calculated through predicting the average consumption per capita. For updating and projecting coefficients in the future, a RAS technique is used in Liang's IO model. The model is based on a dataset from 1997 covering 40 sectors input-output tables. The energy demand and energy intensity for 2010 and 2020 is predicted using this model.

Applications

Six scenarios are defined in Liang's model to represent the impacts of different factors: economic development, the change of consumption and production patterns, population growth and urbanization level. Scenario A is based on real data from 1997. Scenario B is based on scenario A but includes the technical progress factor. Scenario C is based on scenario B and includes population growth: a population of 1.38 billion in 2010 and 1.41 billion in 2020. Scenario D is formed by scenario C and factors oin average income increase and change of living patterns. Scenario E includes assumptions from scenario D and the increase in urbanization: 45% in 2010 and 58% in 2020. The last scenario F is based on scenario E with a more aggressive prediction for population growth and the urbanization rate: 1.4 billion residents and 48% urbanization rate for 2010, 1.45 billion residents and 60% urbanization rate for 2020.

Limitations

The RAS procedure employed in Liang's IO model assumes a temporal stability in terms of the direct input coefficient and those coefficients for the target year. Such a procedure is not very suitable for developing countries such as China due to its rapid development and change. The RAS technique is acceptable for a short-term prediction or a medium-term prediction for a mature economy, but in a rapid changing economy such as that of China, a more appropriate and behaviour-oriented model should be employed to help policymakers understand the interaction between within the economic system.

Table 9 Comparison of input-output models

Developer	Description	Objective	Result and Conclusion	Remark
Tsinghua university	Data source: 1987 33*33 sectors input-output table. Maximize the utility function of a representative consumer. The consumers in the YE model are divided into urban residents and rural residents. The constraints of the YE model include input-output balance constraints, natural resource constraints, investment constraints, foreign exchange constraints etc. Some sectors in the input-output table are divided into more detailed sub-sectors to show the substitution and complementarity among different factors according to the status of different technologies.	To compare different abatement schemes and calculate the optimal reduction path under a given reduction goal.	A total reduction goal is better than the per sector scheme because it provides the opportunity to trade emissions among different sectors with different abatement costs, which is forbidden in a per sector reduction scheme. YE also analyzed the best reduction path under different reduction goals and the impacts	The data set should be renewed.
China Academy of Science	Data source: 1997 40*40 sectors input-output table, other data came from a 'National communiqué 1997 on national economic and social development in China' Scenario setting: 6 scenarios are considered: A, statistic data in year 1997; B, based on A while technical progress is considered; C, based on B while population growth is considered; D, based on C while average income increase and change of living patterns are considered; E, based on D while urbanization rates and change of consumption patterns are considered; F, based on E but with a more aggressive prediction for population growth and urbanization rate.	Year 1997 is set as the base year in this model. Energy demand and energy intensity are predicted.	Energy demand: population growth has a higher impact than the average income per capita and the urbanization rate in the first industry. For the second and third industry, the impact of average income per capita is higher than the population growth and urbanization rate. Energy intensity: energy intensity is only slightly influenced by the population growth, average income per capita and urbanization rate. Base on the prediction, the energy intensity will decrease by on average 0.913% per year from 1997-2010 and 0.625% per year from 2010-2020.	RAS procedure is not very suitable for the rapid change economy in China.

HE Model[23]

CGE models are based on assumptions concerning the optimizing behaviour of consumers and producers. That is, consumers maximize their utility or satisfaction, while producers maximize profits (and minimize costs). These models attempt to represent the circular flow of goods and services in the economy. There is a commonly perceived dichotomy between top-down CGE models and bottom-up energy system models dealing with energy issues. Bottom-up models provide a detailed description of the energy system from primary energy processing via multiple conversion, transport and distribution processes to final energy use but neglect interactions with the rest of the economy. Furthermore, the formulation of such models as mathematical programs constrain their direct application to integral equilibrium problems; many interesting policy problems involving initial inefficiencies can therefore not be handled. CGE models on the other hand are able to capture market interactions and inefficiencies in a comprehensive manner but typically lack technological details that might be relevant for the policy issue at hand.

In general, CGE analysis employs a deterministic calibration procedure to specify parameters of functional forms, benchmark quantities and prices (together with exogenous elasticity). An econometric estimation of parameters would be preferable but often fails as a result of data availability. Therefore, most of the following CGE model not only rely on econometric technology but also expert estimation which make them very sensitive to their parameter settings. A sensitive analysis may help the modeller to solve this problem. Only the TEDCGE model executed a sensitive analysis to identify the most suitable parameters.

Juhuang HE [23] developed a static CGE model to analyze the impacts of carbon tax on the national economy. Apart from the general assumptions in CGE model, the following assumptions are also included in HE model: the coal, oil (including natural gas), capital and labour can substitute each other while other intermediate inputs can not substitute each other and can not be substituted by coal, oil (including natural gas), capital and labour. The carbon tax is collected from the production and import of coal, oil and natural gas.

In the HE model, the national economy is divided into 9 sectors: 1) coal mining, 2) oil and natural gas production, 3) agriculture, 4) electricity, 5) manufacturing industry, 6) construction industry, 7) transportation and communication, 8) commercial and 9) service. In those 9 sectors, 3 are energy sectors while other 6 sectors are non-energy sectors.

The primary energy is represented by the following formula in the production function:

$$E(t) = A_K[\delta_K V_1(t)^{-\rho_E} + (1-\delta_K)V_2(t)^{-\rho_E}]^{-\frac{1}{\rho_E}}$$

Where V_1 and V_2 is the coal and oil (including natural gas) consumption for production, σ_E represents the price substitution elasticity between coal and oil. The labour, capital and energy are aggregated through the (K,L)E fashion. In the production function, the price substitution elasticity between coal and oil is assumed as $\sigma_E = 1.25$, the substitution elasticity between energy and capital is set as $\sigma_h = 0.3$, while the substitution elasticity between labour and energy-capital aggregation is fixed as $\sigma_V = 0.91$.

The HE model is a static CGE model which uses the 1997 input-output table as the basis of calibration. The 40*40 1997 input-output table is reorganized into a 9*9 input-output table. The exogenous parameters are generated from 1997 Social Account Matrix (SAM) which is also based on the 9*9 reorganized input-output table.

For international trade, a standard small country assumption and the Armington assumption are included in the HE model. The substitution elasticity between domestic energy products and imported energy products are listed below:

Table 10 Substitution elasticity between domestic energy products and import energy products

Sector	Coal	Oil and gas	Electricity
Price elasticity of import goods and domestic goods	3	3	0.9
Price elasticity of export goods and domestic sales goods	4	4	0.5

Though not declared [23], the carbon tax in the HE model is a unit tax on fossil fuel production therefore the CO_2 emission within industrial process is not considered.

Applications

With the HE model, Junhuang HE [23] analyzed the impacts of carbon tax on the emission reduction and national economy. The result under a balance tax theme is given in [23]. The analysis shows that the carbon tax only has a minor impact on the GDP. The marginal abatement cost of CO_2 reduction is also given:

Table 11 Marginal abatement cost of CO_2

CO_2 Reduction (%)	10.5	15.5	20.5	24.5	30.5
CO_2 Reduction (million tons)	83.1	122.7	162.2	193.9	241.4
Marginal Abatement Cost (Yuan/ton)	88.4	146.4	219.9	289.4	418.2

In the HE model, the marginal abatement cost is measured by the GDP loss caused by reduction constrain.

Keting SHEN [24] used the HE model to analyze the potential of the Clean Development Mechanism (CDM) in China. Four types of factors which can influence emission reductions are considered: economic structure adjustment, technical progress, energy structure adjustment and energy efficiency. Those four factors are treated as exogenous parameters while economic structure adjustment and technical progress are aggregated as a economic-technical factor, energy structure adjustment and energy efficiency are aggregated as a energy factor. The Business As Usual (BAU) case is based on carbon intensity in the year 1997 and fixed within 5 years to 2002. The emissions under different economic-technical and energy factors are calculated. The difference between them and BAU emission is identified as the CDM potential. In their economic-technical case (which assumes a 5% improvement in total factor productivity per year), the energy intensity decreases about 4.2% per year from 1997 to 2002 and the CDM potential is estimated as 35 million tons of carbon in 1997 and 200 million tones of carbon in 2002.

Limitations

Most CGE models developed by Chinese researchers share the same limitations which will be discussed in the last section of this chapter.

PRCGEM Model[25]

The PRCGEM model was developed by Quantity economy and technique economy Institute of the Chinese social science academy and Monish University of Australia. It is a large scale CGE model composed of 118 sectors and 30 regions. A simplified version of the 34 sectors is also available. One of the main objectives of PRCGEM is to simulate and analyze trade liberalization policy. When considering the substitution among energy factors and emission equations, PRCGEM also can be used to analyze the impacts of environmental policy and CO_2 reduction on the national economy.

In the PRCGEM model, the production function is a nested Leontief/CES production function which admits the substitution among labour, capital, energy and land. Energy is aggregated with other factors through CES method, while coal, oil, natural gas and electricity are aggregated through the Cobb-Douglas method. Such treatment means a constant substitution elasticity among energy factors. The nested fashion is (K,L) E.

Only one representative consumer is considered in PRCGEM. The data basis of PRCGEM is the 1992 input-output table. The SAM is not selected as the calibration basis because of data problems.

The PRCGEM model only considers the emission caused by fossil fuel combustion, while the emissions in industrial processes and non industrial sources are not included. The carbon tax theme in PRCGEM is a unit tax on the carbon content in fossil fuel instead of on carbon dioxide emissions.

Applications

The PRCGEM has been used to analyze the cost of CO_2 abatement under different abatement objectives: 5%, 10% and 20%. The short-term abatement cost and long-term abatement cost are clarified. When calculating the short-term abatement cost, the wage is fixed and capital is limited within the same sector, therefore a non-equilibrium exists. When calculating the long-term cost, the wage is variable and capital can flow freely among sectors so that all factor markets are clear. The short-term and long-term effects of CO_2 abatement are listed below:

Table 12 Short-term and long-term effects of CO_2 abatement

CO_2 Reduction (%)	5%	10%	20%
Short-term effect (non balance carbon tax theme)			
GDP loss (%)	-0.22	-0.47	-1.06
Carbon tax(Yuan/tC)	13.75	29.13	66.11
Short-term effect (balance carbon tax theme)			
GDP loss(%)	-0.05	-0.12	-0.34
Carbon tax(Yuan/tC)	14.68	31.24	71.69
Long-term effect (non balance carbon tax theme)			
GDP loss (%)	-0.06	-0.13	-0.36
Carbon tax(Yuan/tC)	13.23	28.21	64.91
Long-term effect (balance carbon tax theme)			
GDP loss (%)	-0.014	-0.01	-0.06
Carbon tax(Yuan/tC)	13.54	28.96	67.09

DRCSC's CGE Model[26]

The DRCSC' CGE model was developed by Development Research Center of State Council. This model tries to help answer the following questions:

1. What is the future trend of industry structure in China?
2. What is the environment impact of these trends?
3. If pollution limitation policy is adopted, what is the impact of such a policy on economic growth and industry structure?
4. What is the environment impact of trade liberalization and globalization in China?

The DRCSC's CGE model is a recursive dynamic multi-sector CGE model including 24 production sectors. There are two representative consumers: urban residents and rural residents. The primary productive factor include land, capital, labor, factory and professionals. In the DRCSC's model, the labor can flow freely among sectors while the capital cannot.

The production function is a nested CES production function with assumption of constant return to scale. The aggregation among capital, labor and energy is (K,E)L fashion. But the aggregation among energies is not reported in their report.

The dynamic properties of the DRCSC's model is characterized by the following factors:

1. The increase in the amount of productive factors.
2. The improvement of total factor productivity and technical progress.
3. The increase in the number of mature workers caused by human capital resource.
4. The vintage change of capital structure.

Applications

The DRCSC's CGE model focuses on the environmental policy instead of global warming policy. The pollution is represented by a pollution vector composed by 13 different types of pollution. These pollutants includes: toxicoid emitted into water, air and soil; toxicoid mental emitted into water, air and soil; atmosphere pollutions: (SO_2, NO_2, CO, volatile organic pollutants and TSP), and other water pollutions. Carbon dioxide is not included in the pollution vector. The pollution emission coefficients of production and consumption behavior are estimated to construct a pollution emission coefficient matrix which connects the production, consumption and emission of pollution.

TEDCGE[27]

In the TEDCGE model, the national economy is divided into 10 productive sectors: agriculture, heavy industry, light industry, transportation, construction, services, coal, oil, natural gas and electricity. The production function is nested CES production function with (K,E)L. The coal, oil, natural gas and electricity are aggregated through CES. There are two reprehensive consumers in The TEDCGE: urban residents and rural residents. The Armington assumption and small country assumption are followed in TEDCGE.

In the TEDCGE, an eclectic treatment is used which is based on the carbon content of fuel, the fraction of stored carbon, and the fraction of carbon oxidized. The energy consumption is converted to CO_2 emissions but the carbon tax is collected on the production and the importation of the primary energy. The TEDCGE also includes the carbon dioxide emission from the industrial process, especially the cement production.

Applications

Can WANG analyze the impacts of four different tax themes:

1. Only the carbon tax exits.
2. The government income from carbon tax will be transferred to consumers.
3. 50% of carbon tax income will be transferred to consumers while the government reduce other enterprise tax to maintain the government income unchanged.
4. Maintain the government income unchanged through decreasing other indirect tax.

Can WANG analyze the impacts of these different tax themes? In the authors dissertation, the abatement cost is defined as the additional investment in technology. At different abatement levels, the author calculated different additional investments for technology and estimated the marginal abatement cost function in China. Further, he also calculated the total social cost caused by emission reductions which is defined as the GDP loss by emission reduction. He used the Hicks equivalents as a measure for welfare loss by carbon dioxide reduction. Finally, the impacts of different carbon tax themes on other macroeconomic indexes (total production, consumption, investment, wage, price and so on) are also analyzed.

Using the marginal abatement cost function generated by TEDCGE, Can WANG also develop a partial equilibrium model TRCW which shares the same model structure with CERT of the World Bank? Given the marginal abatement cost functions, reduction objectives, market structures (e.g. competitive or monopoly) and other exogenous parameters (e.g. whether the U.S. takes part, whether hot air can be traded etc), the market clearing carbon price and quantity can be calculated. Such results can be used for the assessment of the CDM potential of China.

CNAGE

The CNAGE model was developed by the Bureau of State statistics and the Norwegian Bureau of Statistics. The model structure of CNAGE is not very clear because of the lack of publications on the topic. In CNAGE, the production function is a constant return to scale Cobb-Douglas production function with the aggregation fashion of (L, E, K). The energy includes 19 commercial energies with 5 types suitable for final consumption. In this case the investment structure is not adjusted according to different carbon tax level. All carbon tax is assumed to be reinvest. In

CNAGE, the technology is assumed independent to the energy cost and the energy consumption structure, fixed within each sector,, means an identical growth rate for the consumption of different energy products in the same sector.

Applications

Taoyuan WEI [28] analyzed the short-term and long-term impacts of different carbon tax levels ($5 and $10) on the national economy and on different sectors. The main result of the CNAGE model is listed in the following table:

Table 13 Long-term and short-term effect of carbon tax

Carbon Tax ($)	0	5	10
Short-term effect (First year after carbon tax collection)			
GDP loss (billion yuan and %)	629.5	-0.43	-0.85
Total Emission (Million ton C)	4099.95	-7.58	-13.75
Long-term effect (2020)			
GDP loss (billion yuan and %)	2909.8	-0.10	-0.07
Total Emission (Million ton C)	1009.78	-2.10	-4.00

The short-term effect of a carbon tax is very notable while with a high short-term cost. In short the GDP will decrease 4% and 9% under different tax level and the unemployment will increase 2.4 million and 4.6 million. The long-run effect of the carbon tax is minor because the investment accumulation and the improvement in productivity.

IPAC-SGM Model[29]

The IPAC-SGM model was developed by the Energy Policy Research Institute, North west laboratory of U.S. based on the Second Generation Model (SGM). SGM is a global model which includes 10-20 regions. There are 20 sectors in IPAC-SGM including 9 energy production sectors, and 11 energy consumption sectors.

The economic system in the SGM model is composed of the residential sector, government , agriculture, energy and other sectors. The decision makers in SGM include residents, government and producers. The productive factors in SGM include capital, labor and land while the model assumes that the resident owns the land, labor and private capital. Residents decide the supply of labor and land according to the factor price in factor markets. The supply will affect the profit, tax, substitute, income and saving. The saving is determined by the interest. The government collects tax from the previously mentioned economic activities and spends them on government service, general service, defense and education.

According to the reality on the ground in China, the EPRI modified the SGM model in the following ways:

- To consider two kinds of labor: urban labor and rural labor to show the cost difference between these two labors.
- A more realistic population growth model to calculate the specific population growth in China.
- The investment for nuclear power and hydro power is under the control of central government in China.
- Specific substitute elasticity to show the market reality in China.

Applications

The energy demand and greenhouse gas emission scenarios are analyzed through IPAC-SGM by the EPRI. The abatement cost, GDP loss and abatement strategies are discussed but the result are still not published.

Limitations of CGE models in China

According to [30], the applied CGE models can be divided into five categories:

- Multisectoral growth model (MSG) following Johansen's tradition.
- Herverger, Scarf, Shoven and Whalley approach
- Structuralist and other social accounting matrix based models
- Econometric models in the tradition of Jorgenson and his disciples.
- Intertemporal optimization models by Manne and his followers.

Almost all the CGE models developed by Chinese researchers can be categorized as Multi-Sector Growth models (MSG), one of the traditional CGE models. This implies that, institutional characteristics do not feature in their models. The CGE models used in energy studies show that such models are suitable for studies on energy-economy interactions. They provide more insights to the various policy debates than macroeconomics models and traditional IO models. However, since all models are simplified representations of a reality, and because models need data support and parameter estimation, some important issues should be treated carefully when the CGE approach is used to address the energy policy problem in China:

- Elasticity estimation: It is generally agreed that the elasticity values are the most important parameters that affect results. Because of the lack of econometric work, Chinese modelers tend to use different elasticity values to construct their model. Most of the differences among their results can be explained by the varied elasticity value.
- Choice of model structure: As previously discussed, most models can be categorized as MSG models where the assumption of a fully competitive market is unsuitable for the reality in China. In China, the price of coal, oil, natural gas and electricity are still regulated by a national agency while the investment in the energy sector is also controlled by the State Development and Reform Council. These special issues are ignored in the present models. Generally speaking, a structuralist model should be more suitable to modeling the economic system in China.
- The description of technology: Generally, the technologies in CGE models are represented by production function, but the detailed description is distinctive for the long run energy policy model because the backup technologies can't be represented by an econometric based production function. In the long run, technical progress plays a key role in the energy sector. A more complex CGE model should be developed to integrate the bottom-up and top-down methodology which will give some new insights on the interaction between energy and the economy.
- Non commercial resources: CGE is a price-driven model so that the non-commercial energy is difficult to consider. In developed countries, most energy supply have been commercialized. But in the rural area of China, non commercial resources still play an important role in the daily life of rural residents although the share is decreasing every year. How does one consider the non commercial energy resource in the CGE model? This issue presents a challenge for researchers.

Suggestion

According to the previous discussion, the following suggestion can be given:

- Some fundamental econometric research should be addressed in the future to help the modelers to complete the data and reduce the occurrence of different results. A sensitivity analysis can help the modelers judge the robustness of their results.

- A more comprehensive welfare analysis for different consumer groups should be analyzed to show the different impacts on different consumer group.
- The specific market condition and price regulation should be emphasized in the CGE model so that the reality can be simulated and analyzed better. Then some structuralist CGE model will be the future direction for CGE model development.
- Non commercial energy resources should be considered in the following CGE model because they play an important role in the rural sector in China. The non commercial energy resources are very important in order to understand the welfare implications for rural residents under different carbon tax schemes which are absent from the existing literature.
- Efforts should be made to treat the issues around technology development and deployment in detail. In the long-run, policy models need to consider technological progress and technology change. In China, the middle run analysis may also need some detailed technology descriptions because of rapid changing in this area.

Table 14 Comparison of CGE Models

Name	Description	Objective	Result and Conclusion	Remark
HE	Static CGE model 9 sectors: coal mining, oil and natural gas, agriculture, electricity, manufacturing, construction, transportation and communication, commercial, services. CES production function with (K,L)E fashion. 1997 input-output table Unit carbon tax collected on the fossil fuel production. Armingtion assumption and small country assumption.	To analyze the impacts of a carbon tax on the national economy	Carbon tax only has a minor impact on the GDP. See table 11 and table 12.	
PRCGEM	Dynamic CGE model. 118 sectors version and 34 sectors version. Energy is aggregated with other factors through CES , while coal, oil, natural gas and electricity are aggregated through Cobb-Douglas. The nested fashion is (K,L) E. Only one representative consumer. Data basis: the 1992 input-output table. The SAM is not selected as the calibration basis because of data problem. Only the emission caused by fossil fuel combustion is considered. A unit tax on the carbon content in fossil fuel instead of carbon dioxide emission.	To analyze the impacts of trade liberalization. Carbon tax also can be analyzed when energy is included as a productive factor.	See table 13.	
DRCSC's		To analyze the impacts of globalization and trade liberalization on environmental pollution.	No	
TEDCGE	Dynamic CGE model. 10 productive sectors: agriculture, heavy industry, light industry, transportation, construction, services, coal, oil, natural gas and electricity. Nested CES production function with (K,E)L nested fashion.	To analyze the impacts of a carbon tax on the national economy	In 2010, a carbon tax of 100yuan/tC is needed for 10% reduction, 470yuan/tC is needed for 30% reduction. The heavy industry has	

	Two reprehensive consumers: urban resident and rural resident. The Armington assumption and small country assumption. An eclectic treatment for emission based on the carbon content of fuel, the fraction of stored carbon, the fraction of carbon oxidized. The carbon tax is collected on the production and import of the primary energy. Also includes the carbon dioxide emission from the industrial process, especially the cement production.		the most abatement potential. The CDM potential in China is 61 million ton, almost 40% of the global CDM potential. The substitution elasticity between capital and energy and among different energies are the most important ones.
CNAGE	Static CGE model. Constant return to scale Cobb-Douglas production function with the aggregation fashion of (L, E, K). 19 commercial energy products while 5 types for final consumption. The labour market is not clear for the unemployment and determined by the profit maximization behaviour of producers. The investment structure is not adjusted according to different carbon tax levels. All carbon tax is assumed to be reinvested.	To analyze the impacts of a carbon tax on the national economy	See table 14
IPAC-SGM	The economic system includes the residential sector, government sector, agriculture, energy and other sectors. Two kinds of labour: urban labour and rural labour to show the cost difference between these two types of labour. The investment for nuclear power and hydro power is under the control of central government.	To analyze the impacts of a carbon tax on the national economy and possible strategy for abatement.	No result published

Scenario comparison

Future GHGs emissions are the result of many complex dynamic driving forces such as demographic and socio-economic development and technological change. The scenarios outlined in this study cover a wide range of the main demographic, economic and technological driving forces of GHGs. Each scenario represents a specific quantitative interpretation of one storyline. Most of the models described above are based on different scenario settings. It is therefore important to organize the available information (some models remain black-boxed), to provide common and comparable information for researchers and policy makers. The objective of following comparison doesn't provide a normative choice of one scenario over the other, but only a description of existing scenarios.

Reference Scenarios:

The available reference scenarios in the reviewed models are listed in the following tables. The reference scenarios are organized into five terms: population, GDP (only GNP is available for TEDCGE), primary energy consumption, primary energy structure (indicated by share of coal) and carbon emissions for selected years, say base year, 2010, 2030 and 2050 (if available).

Table 15Comparison of reference scenarios

	MARKAL -MACRO	LEAP	3E	HE	DRCSC's	YE*	TEDCGE
Population (billion)	1.211 (1995)	1.259 (1999)	(2000)	(1992)	(1997)	1.143 (1990)	(1997)
2010	1.386	1.377	---	---	---	1.414	---
2030	1.560	1.472	---	---	---	1.550	---
2050	1.575	1.525	---	---	---	1.611	---
GDP (billion $)**	736	1004	1104	519.4	892.2	404.5	GNP 838.3
2010	2254.7	2113.2	2372.2		2379.1	2306.6 2354.6	1992.8
2030	6579.0	7100.6	7771.3		---	7065.9 7471.9	---
2050	14415.2	---	15418.5		---	13132.9 13676.3	---
Primary Energy (Mtce)	1290	1628	1312	1160	---	978	1379
2010	1867	----	1845	2430	---	2242 2200	2416.5
2030	3102	3061	3083	---	---	3556 3493	---
2050	4818		4198	---	---	4358 4747	---
Share of Coal in Primary Energy	76.8%	60.4%	66.1%	75.4%	---	84.4%	76.39%
2010	68.3%	---	64.2%	64%	---	79.1% 80.2%	---
2030	57.8%	50.5%	59.4%		---	79.1% 80.2%	---
2050	50.2%		55.8%		---	79.3% 80.3%	---
CO_2 emission (Mt)	819	867	774		---	590.1	813.5
2010	1077	---	1073		---	1324.37 1306.71	1398.5
2030	1655	1701	1710		---	1854.93 1825.35	---
2050	2394	---	2266		---	2159.3 2125.1	---

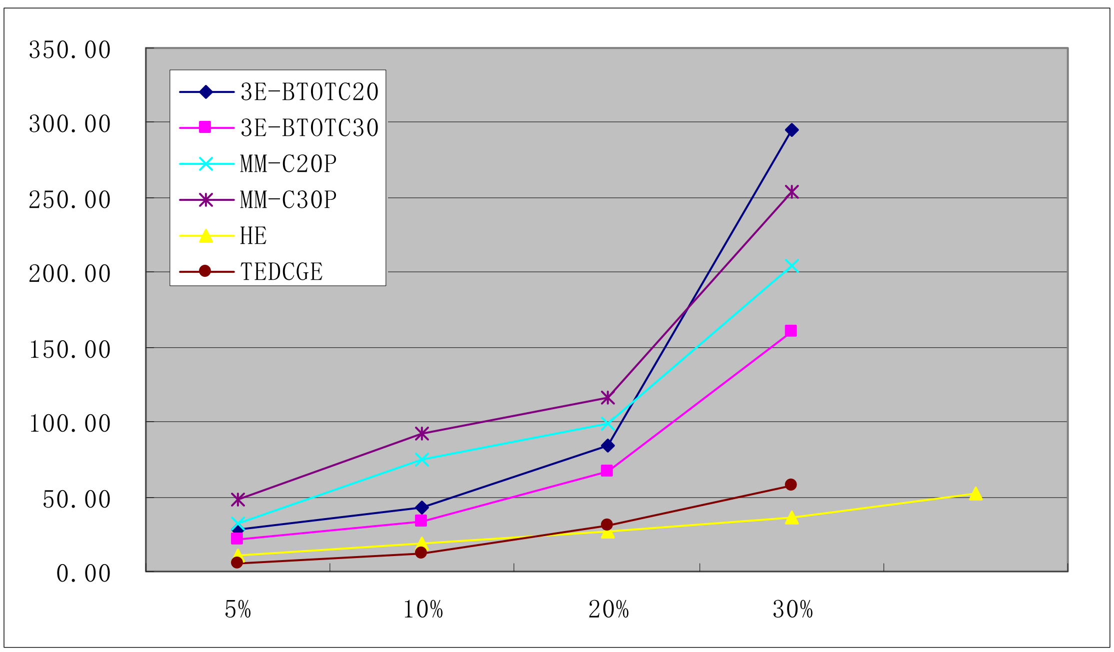
** Including a high growth reference scenario and a low growth reference scenario.*
*** Adjusted to year 2000 price according to GDP deflator.*

The top-down models tends towards a higher estimation of primary energy consumption and CO_2 emission levels. For example, the primary energy consumption in 210 from HE and TEDCGE is about 30% higher than that from MARKAL-MACRO and 3E, and likewise for CO_2 emission. Disregarding the inconsistencies among the details of the energy demand scenario settings, such differences could be attributed to the alternative model structures: for example, a general equilibrium framework for CGE and a partial equilibrium framework for bottom-up models.

Policy Scenarios:

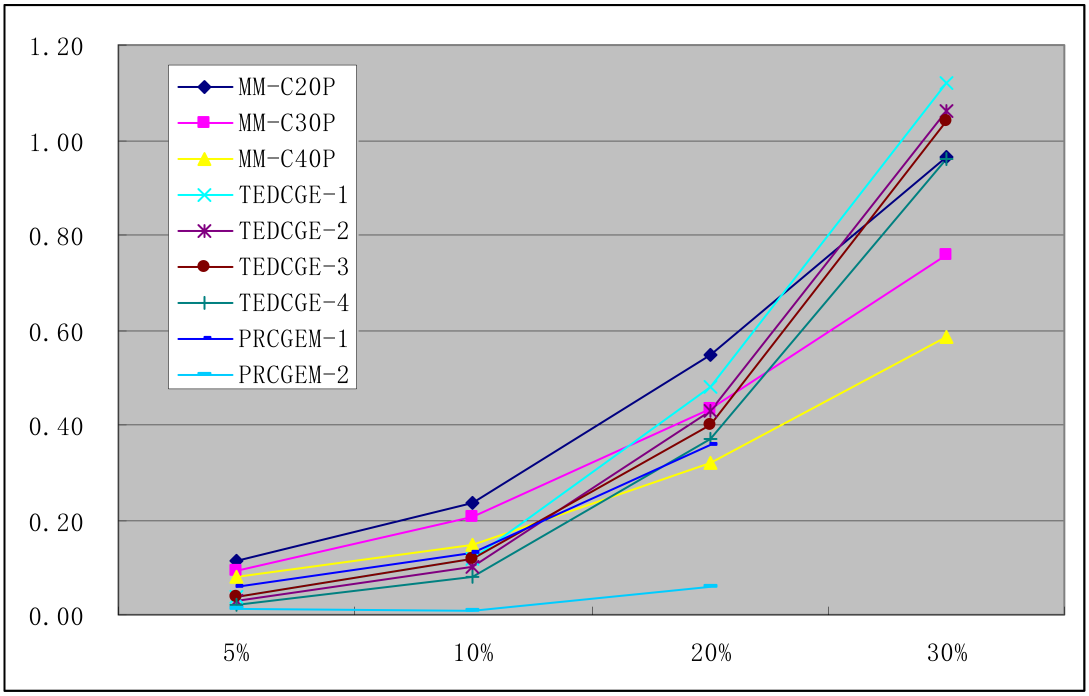
Many policy scenarios have been developed in the existing models to indicate the economic impact of different policy schemes: e.g. different reduction rates, different reduction start times, different carbon tax levels and different technology sets. Most of the policy scenarios are incomparable because of these differences. Therefore, in the following section, these policy scenarios are compared in two alternative ways: marginal abatement cost (MAC) and GDP loss under different reduction rate.

Figure 7 Comparison of policy scenarios in terms of MAC and reduction rate.



Although the selected year for these policy scenarios are different, it is clear that the result from top-down models and results from bottom-up models are very different. The CGE models tend to underestimate the marginal abatement cost (MAC) compared with the bottom-up models. One reason for such underestimation may be attributed to the abstracted production function. The deep reduction of GHGs needs to employ more recent and expensive technologies which is only a small fraction of existing portfolios and often ignored by econometric estimation. The description of technology is more and more important when the reduction rate is deeper and the time horizon is longer. The difference among the same type of models can be explained as the result of many complex factors such as the base year selection, production function form, elasticity estimation etc..

Figure 8 Comparison of policy scenarios in terms of GDP loss and reduction rate.



Compared with the results from the bottom-up models, the GDP loss estimate from CGE models are often higher when reduction rates are low, but lower when reduction rates are high. Such systematic differences among model types can also be attributed to the equilibrium feature (general or partial) and production function description.

Summary and CONCLUSIONS

Based on the latest literature survey, twelve models developed by Chinese modellers are presented in this report. 8 of them are top-down models (2 input-output model and 6 CGE models), and 4 of them are bottom-up models. Not one specific model is more useful than another. The usefulness of each model is not only determined by the model structure, scenario setting, assumption made but also deeply influenced by the needs of policymakers. These 12 models are compared each other based on the criteria below.

Table 16 Comparison of models in terms of model structure and policy question.

	MM	LEAP	AIM	3E	YE	Liang	HE	PRCGEM	DRCSC	TEDCGE	CNAGE	IPAC-SGM
Model Structure												
Technology representation (: 60+)												
Sector representation (: 100+; :20+; : less than 20)												
Region representation (: 20+, -: only one region)	-	-	-	-	-	-	-		-	-	-	
Consumer group representation (: more than one; : only one; -: none)	-	-	-	-								
Emission covered (: all; : CO_2+CH_4; :only CO_2)												
Economic feedback (: detailed; : simple; -: none)		-	-	-								
Policy question												
To identify the key mitigation technology	●	●	●	●	○	○	○	○	○	○	○	○
To assess the economic impact of mitigation	●	○	○	○	●	●	●	●	●	●	●	●
To assess the welfare impact of mitigation	○	○	○	○	●	●	●	●	●	●	●	●
To assess the welfare impact of different consumer group	○	○	○	○	●	○	○	●	●	●	○	●
To assess the regional impact	○	○	○	○	○	○	○	●	○	○	○	●
To assess different carbon tax schemes	○	○	○	○	○	○	●	●	●	●	●	●
To identify the CDM potential	●	●	●	●	●	●	●	●	●	●	●	●

Which model is most appropriate will be decided in large part by the specific policy goal. If policy makers need to identify appropriate technologies for energy efficiency or GHG mitigation, bottom-up models can supply useful insights. When investigating the welfare impact of a proposed carbon tax scheme, GCE models may be more appropriate.

At the same time, it is equally essential to understand the limitations of the models. Most are built at least in part on models developed for modeling OECD energy and emissions, and the assumptions built into them are not always appropriate. For instance, the rate of technology change in China is much more rapid than in OECD countries, the use of non-commercial energy is much more widespread and energy price regulation is more pervasive. As with all models, these help us understand better the interplay between energy, economic growth and emissions, but at present at least their usefulness in generating strong guides for policy is debatable.

The overview presented here helps us in identifying the criteria which need to be considered in any modeling exercise and the usefulness of one model over another in generating policy guidance. This research should therefore be used as a guide to identify the gaps and the strengths of current modeling work in China, in order to inform future research.