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CAN MODELLING TOOLS HELP CHINA ACHIEVE CARBON TARGETS?

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ABSTRACT

Modelling tools are frequently used to study China's carbon policies while central and local governments initiate and implement carbon targets. Reviews of these low-carbon-planning tools and their usefulness, however, are not sufficient. In this regard, we review eight often used tools in China and suggest their applications and limitations. Tools are classified into four categories: computable general equilibrium, cost-optimization, benchmarking, and accounting tools. For China, application cases are recognized in addressing three research questions, i.e., emission scenario building, policy optimization, and carbon-policy impact analysis. From these studies, it is found that while tools usually require significant assumptions, the disclosure of them are in shortage and lack standardization and comparability. Tools also exclusively focus on policy-planning phase without attention to policy-implementation and policy-evaluation phases. Since the Chinese government has initiated three rounds of low-carbon-pilot-city programs, therefore, it is recommended that tool developers learn from some empirical evidence to integrate real policy outcomes into tools, e.g., policy effectiveness, expected implementation barriers, and required administrative power. Hence, analysts can complete a more holistic, evidence-based, and local-oriented policy suggestion. Standardization of model disclosure rules and evidence-based assumption-making are suggested to enhance comparability and mutual learning. Finally, modules to track progress in policy implementation and evaluation process can be added into tools for policy iteration and evidence collection.

Keywords: Carbon policy, China, Low-carbon planning, Cost-optimization, Scenario analysis

1. INTRODUCTION

China needs to formulate and implement new carbon policies for its national determined contribution according to the Paris agreement. The target is to peak China's carbon emission by 2030. This policy agenda has enkindled considerable research interest. For example, we observe exponential growth in number of research articles addressing low-carbon planning in China [1]. In these studies, a recent trend indicates that research focus is evolving from the national level to the local level as the national government devolves carbon reduction targets to regional governments and announced its three rounds of Low-Carbon-Pilot-City program [2]. Sophisticated models and tools are gradually utilized to evaluate regional carbon emission, test policy scenarios, and make policy suggestions to local government officials [3]. These efforts are made not only by academic institutes but often by international organizations for their interest in delivering practical changes [4]. However, the result and efficacy of these studies in helping governments achieve low-carbon targets are in doubt as there has not been an effort attempting to review their outcomes. This paper intends to complete this goal. Particularly, in Section 2, we review tools used by analysts and scientists to recommend low-carbon policies. In Section 3, previous studies are organized by research topics and we discuss their usefulness and potential improvement. Conclusions are made in the end.

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2. OVERVIEW OF LOW-CARBON-PLANNING TOOLS

Tools reviewed in this paper are defined as low-carbon-planning tools. It is necessary to illustrate what the terminology, “low-carbon-planning tool”, suggests. Inspired by Dixon and Mischke [5] as well as Karlsson [3], this study considers low-carbon-planning tool as a mathematical model developed for building carbon-policy scenarios or plans for a clearly defined region. The model should be used by scholars and policy analysts as an existing tool instead of requiring them to write all equations into computer codes. Only publicly available tools are reviewed. There are eight frequently used tools identified after a review of published papers and reports. We classify them into four categories.

2.1 Computable general equilibrium (CGE) tools

CGE models are mainly applied to investigate policy impacts on macroeconomic factors such as sectoral productions, household consumptions, and tax revenues [6, 7]. Recently, it has been used to study low-carbon policies’ effect on the economy, energy consumption, and carbon emission levels [8-10]. Based on the CGE theory, the National Institute for Environmental Studies of Japan developed the AIM/CGE (Asia-Pacific Integrated Model/CGE) tool which had been used to construct low-carbon roadmaps for Japan [11]. Several other institutes make attempts to build the CGE model into tools as well [12].

Mathematically, the model is based on the input-output table and elasticities of substitution [13, 14]. It requires modeler to specify the studied economy into usually sectoral levels and clearly configure the monetary and energy flows. Analysts can then specify how a policy scenario will cause changes on some factors and recalculate the model to know the impact. For example, carbon tax can make direct changes on energy prices and the CGE tool is used to calculate the effect of changed energy prices on sectoral production and consumption. While it sounds straightforward, CGE tools usually suffer from significant data requirement and assumptions, i.e., sectoral economic data and assumptions on substitution factors [15].

2.2 Cost-optimization tools

Cost-optimization tools are popular in academic research [16]. AIM/Enduse, MARKAL (Market-Allocation), TIMES (The Integrated MARKAL-EFOM System), and IPAC (Integrated Policy Assessment Model for China) are four examples [15, 17]. Contrary to CGE tools simulating economic activities in a region, the cost-optimization tools take economic productions and energy consumptions as granted. The focus is on how sectoral energy demands can be serviced by different technologies using various energy types, e.g., gasoline cars and subways for personal transportation demand [18]. The calculation is based on cost-optimization method evaluating initial, maintenance, and fuel costs of technologies [19, 20]. Some constraints can be implemented to make the calculation more reasonable such as maximum technology penetration rate [21]. Policy scenarios can be incorporated into the model usually through considering how these scenarios will affect capital investment flows, cost factors, and sectoral energy demands. Common difficulties of using the tool are estimating future technology costs and predicting energy demands which are exogenously input.

2.3 Benchmarking tools

BEST Cities (Benchmark and Energy Saving Tool for Low Carbon Cities) developed by Lawrence Berkeley National Laboratory and TRACE (Tool for Rapid Assessment of City Energy) developed by World Bank are categorized as benchmarking tools [22, 23]. The primary purpose of these tools is to identify carbon policies having high emission reduction potentials and high applicability for a certain region. Usually, there are two databases in each tool, i.e., sectoral carbon intensity database and sectoral carbon policy database [24]. After inputting the studied region’s sectoral carbon intensity data, these tools compare these intensity metrics with other regions’ performance data stored in the carbon intensity database. Sectors of high emission intensity gap with other regions are considered as possessing high emission reduction potentials. Then, sectoral policy recommendations will be made from the policy database. These policies have categorized characteristics about implementation cost, required time range, required administrative capacity, and so on. Therefore, analysts could filter these policy suggestions according to local conditions. The main effort in using these tools is collecting reliable sectoral carbon intensity data.

2.4 Accounting tools

We consider LEAP (Long-Range Energy Alternative Planning, developed by Stockholm Environment Institute) as a unique accounting tool [25]. LEAP does not make any normative analyses but gives descriptive results about energy use and carbon emission trends. It is a structured accounting framework requiring users to specify changing rates of future energy demands, availability of energy-supplying technologies, and energy sources [26, 27]. Then, according to user-specified rules, it calculates future energy demands and figures out how these demands are met by various energy sources. It gives no normative policy suggestion but only helps analysts evaluate the impact of their assumptions quickly and structurally. For example, how much emission reduction would be achieved if 90% of travels are made by municipal subway. Therefore, it requires modelers being very clear about their prediction of sectoral energy demands and how these demands can be reasonably supplied [28, 29].

3. APPLICATIONS IN CHINA

Low-carbon-planning tools are adopted to analyze both national and regional energy-use dynamics and its corresponding carbon emission. In China's context, we found tools are used to address three kinds of questions: how energy use and carbon emission evolve under different socioeconomic and policy scenarios, what policy mix should be taken to achieve predetermined carbon targets, and what impact carbon policies have on economic, energy and environmental systems. We will briefly review these studies and then suggest what have been learned from these tool applications.

3.1 Application cases

The first question is frequently studied and these studies are usually defined as scenario analysis. Analysts outline their assumptions about socioeconomic indicators and policy mix [30, 31]. Then, these assumptions are built into models through a numerical approach. For example, Zhang et al. [32] develop a LEAP model for Beijing city and specify three scenarios in the model. Main conclusions are that Beijing's energy consumption and carbon emission will inevitable rise until 2026 even under the most aggressive scenario. Industrial sector is calculated as having the largest reduction potential in the near term while transportation and building sectors are considered as promising in a longer term. Overall, the primary purpose of scenario analysis is to investigate how different combinations of policy tools present us some different energy and carbon futures.

Secondly, while some governments have already made promises on carbon targets, such as China, uncertainties remain in how they can be achieved. For this rationale, policy analysts might be consulted by government officials to research on some optimal policy pathways or roadmaps [33, 34]. An AIM/GCE study completed by Dai et al. [10] about China's Copenhagen climate commitment is one instance of these. The study starts from illustrating China's Copenhagen target, i.e., reducing carbon intensity by 40% to 45% in 2020 compared to 2005's level. It then estimates 2020's intensity level in a current-policy scenario. The result indicates that a 38.94% decrease is achieved. The authors suggest that the leftover reduction can be made by compulsory carbon constraints such as carbon tax or emission trading. These target-oriented studies can be of more use when nations and regions gradually publicly announce their climate goals.

The third research stream centers on policy impact on not only carbon emission but also the economy and the environment. Consequence on the economy is discussed through estimating marginal abatement curves (MAC) and reduction on the GDP level. For instance, Chen [35] calculates the MACs of 2010, 2020, and 2030 on a MARKAL tool and indicates that the cost varies from 12 US$/tC to 216 US$/tC nationally. Correspondingly, the national GDP loss can reach over 2.5%. Relying on modeling results, she argued that China was still a developing country and should pursue for some "sustainable development" instead of accepting a carbon ceiling. Some other scholars focus on co-benefits of carbon policies on other emission pollutants, e.g., NOx, SOx, and PM2.5. Dong et al. [36] apply the AIM/CGE model to conclude that co-benefits of carbon policy on SO2, NOx and PM2.5 emission reduction are 2.4 Mt, 2.1 Mt and 0.3 Mt in 2020 under the stated scenario for China. These integrated studies are helpful in completing a holistic policy analysis. Policy officials usually are balancing on different agendas in the real decision-making process. Therefore, they want and need to know costs and other benefits of carbon policies.

3.2 Observations and tool improvements

While many studies have been published, we consider two important questions to be asked. First, whether policy recommendations in these analyses are executable and suitable for the local context. Although policy analysts usually are experts in their research fields and have some local knowledge of studied regions, it is found that policy scenarios in models are often constructed from a very high-level perspective. Tools allow analysts to specify how policies will affect modeling parameters but give not too much consideration on how policies can be formulated, implemented, and evaluated in a governmental organization. BEST Cities and TRACE have attempted to integrate policy formulation process into the tools by establishing a policy database. Other tools generally do not have this function. The second question is whether analysts make evidence-based assumptions when using tools. Every tool requires more or less assumptions in economic indicators, material and monetary flows, technology costs, and more. Analysts or scientists usually rely on disclosed policy measures and historical patterns to construct assumptions. However, in some studies, these assumptions are not sufficiently reported and supported with evidence [9]. As a result, the extent to which analysts manipulate or are discretionary in making assumptions are hard to estimate. Such a phenomenon also reduces the comparability among studies. It is recommended that some standard disclosure framework in making assumptions should be stipulated with the knowing that it is generally difficult for an analyst to ground all assumptions on strong empirical evidence.

Several tool improvements are suggested to address limitations mentioned above. Since China has implemented low-carbon strategies at the local level for many years, there are reasonable amount of lessons to be drawn [37]. Lessons include effectiveness, efficiency, costs, unexpected administrative barriers, public or business acceptance of various carbon policies piloted in diverse regions [38]. For instance, this empirical study completed by Kostka and Hobbs [39] suggests that China's energy efficiency targets can be integrated with local agenda to enforce implementation. Hartog et al. [40] review 3 low-carbon development projects in Shanghai, concluding that sustainability is not expectedly achieved. It is envisioned that these evidence are most useful if they are collected and built into tools and platforms for analysts to learn from and consider when making their own models and assumptions. It would be useful for holistic policy selection process as shown in BEST Cities and TRACE tools but the two tools' database are outdated and lack China's local evidence. In addition, communications within the research community are important [41, 42]. It can be promoted by standardizing model disclosure rules and encouraging sharing of empirical evidence in policy outcomes. Moreover, currently, these tools focus on the policy-planning phase only. We think other phases such as policy implementation and evaluation are important as well. These tools can have modules in monitoring these phases. It is believed that these modules would be helpful for evidence-based modelling, policy iteration, and for practitioners to track their progress and make necessary adjustments.

4. CONCLUSIONS

Modelling tools are gradually used to study China's carbon policies and plans. Eight tools frequently adopted by scientists and analysts are reviewed in this paper. Application cases in China are summarized into three research streams including scenario building, path or policy optimization, and impact analysis. Among these studies, two limitations are identified. First, policy recommendations made by analysts using these tools lack consideration of implementation process such as policy effectiveness, administrative barriers, public and business acceptance. Second, assumptions made in models are not sufficiently disclosed, resulting in low comparability. Thus, potential tool improvements are suggested. As pilot programs are implemented by China's governments, these tools can learn from some empirical evidence to integrate real policy outcomes into them, e.g., policy effectiveness, expected barriers, and required administrative power. As a result, analysts can complete a more holistic, evidence-based, and local-oriented policy suggestion. Moreover, we recommend some standardization of model disclosure to enhance comparability and a platform or community being organized to encourage evidence sharing. Finally, modules to monitor progress in policy implementation and evaluation phases can be added into tools for policy iteration and evidence collection.

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REFERENCE

[1] L. Huang, S. Kelly, K. Lv, D. Giurco, A systematic review of empirical methods for modelling sectoral carbon emissions in China, Journal of Cleaner Production, 215 (2019) 1382-1401.

[2] W. Liu, B. Qin, Low-carbon city initiatives in China: A review from the policy paradigm perspective, Cities, 51 (2016) 131-138.

[3] P. Mischke, K.B. Karlsson, Modelling tools to evaluate China's future energy system – A review of the Chinese perspective, Energy, 69 (2014) 132-143.

[4] F. Teng, A. Gu, M. Duan, Energy Models in China A Literature Survey, Global Climate Change Institute, Tsinghua University. September, (2007).

[5] T. Dixon, 'Low carbon' scenarios, roadmaps, transitions and pathways: an overview and discussion, (2011).

[6] L. Taylor, S.L. Black, Practical general equilibrium estimation of resource pulls under trade liberalization, Journal of international Economics, 4 (1974) 37-58.
[7] S. Robinson, D.W. Roland-Holst, Macroeconomic structure and computable general equilibrium models, Journal of Policy Modeling, 10 (1988) 353-375.
[8] R. Xing, T. Hanaoka, Y. Kanamori, H. Dai, T. Masui, An impact assessment of sustainable technologies for the Chinese urban residential sector at provincial level, Environmental Research Letters, 10 (2015) 065001.
[9] W. Li, H. Li, S. Sun, China's Low-Carbon Scenario Analysis of CO2 Mitigation Measures towards 2050 Using a Hybrid AIM/CGE Model, Energies, 8 (2015).
[10] H. Dai, T. Masui, Y. Matsuoka, S. Fujimori, Assessment of China's climate commitment and non-fossil energy plan towards 2020 using hybrid AIM/CGE model, Energy Policy, 39 (2011) 2875-2887.
[11] K. Gomi, K. Shimada, Y. Matsuoka, A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city, Energy Policy, 38 (2010) 4783-4796.
[12] M. Kainuma, P.R. Shukla, K. Jiang, Framing and modeling of a low carbon society: An overview, Energy Economics, 34 (2012) S316-S324.
[13] K.i. Matsumoto, T. Masui, Analyzing long‐term impacts of carbon tax based on the imputed price, applying the AIM/CGE model, Management of Environmental Quality: An International Journal, 22 (2011) 33-47.
[14] P. Thepkhun, B. Limmeechokchai, S. Fujimori, T. Masui, R.M. Shrestha, Thailand's Low-Carbon Scenario 2050: The AIM/CGE analyses of CO2 mitigation measures, Energy Policy, 62 (2013) 561-572.
[15] K. Oshiro, T. Masui, M. Kainuma, Quantitative Analysis of Japan's 2030 Target Based on AIM/CGE and AIM/Enduse, in: Post-2020 Climate Action, Springer, 2017, pp. 143-156.
[16] G. Tosato, Introduction to ETSAP and the MARKAL-TIMES models generators, in: International energy agency: Neet workshop on energy technology collaboration, 2008.
[17] C. Yang, S. Yeh, S. Zakerinia, K. Ramea, D. McCollum, Achieving California's 80% greenhouse gas reduction target in 2050: Technology, policy and scenario analysis using CA-TIMES energy economic systems model, Energy Policy, 77 (2015) 118-130.
[18] D. McCollum, C. Yang, S. Yeh, J. Ogden, Deep greenhouse gas reduction scenarios for California – Strategic implications from the CA-TIMES energy-economic systems model, Energy Strategy Reviews, 1 (2012) 19-32.
[19] K. Gomi, Y. Ochi, Y. Matsuoka, A concrete roadmap toward a low-carbon society in case of Kyoto City, Journal of Renewable and Sustainable Energy, 2 (2010) 031004.
[20] K. Gomi, Y. Ochi, Y. Matsuoka, A systematic quantitative backcasting on low-carbon society policy in case of Kyoto city, Technological Forecasting and Social Change, 78 (2011) 852-871.
[21] C. Yang, S. Yeh, K. Ramea, S. Zakerinia, D. McCollum, D. Bunch, J. Ogden, Modeling optimal transition pathways to a low carbon economy in California: California TIMES (CA-TIMES) model, (2014).
[22] L. Price, N. Zhou, D. Fridley, H. Lu, L. Hong, C. Fino-Chen, J. Ke, S. Ohshita, H. Min, Y. Zhou, Energy-Efficiency and Greenhouse Gas Mitigation Policy Options: Assisting Chinese Cities in Prioritizing and Choosing Strategies, (2014).
[23] E. Martinot, Renewable energy investment by the World Bank, Energy Policy, 29 (2001) 689-699.
[24] L. Price, N. Zhou, D. Fridley, S. Ohshita, N. Khanna, H. Lu, L. Hong, G. He, J. Romankiewicz, H. Min, Low-Carbon City Policy Databook: 72 Policy Recommendations for Chinese Cities from the Benchmarking and Energy Savings Tool for Low Carbon Cities, in, Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States), 2016.
[25] S. de la Rue du Can, L. Price, Sectoral trends in global energy use and greenhouse gas emissions, Energy Policy, 36 (2008) 1386-1403.
[26] B. Sana, A. Iftikhar, A. Sajid Rashid, Low-Emission Modeling for Energy Demand in the Household Sector: A Study of Pakistan as a Developing Economy, Sustainability, 10 (2018) 1-17.
[27] N.V. Emodi, C.C. Emodi, G.P. Murthy, A.S.A. Emodi, Energy policy for low carbon development in Nigeria: A LEAP model application, Renewable and Sustainable Energy Reviews, 68 (2017) 247-261.
[28] Y. Huang, Y.J. Bor, C.-Y. Peng, The long-term forecast of Taiwan's energy supply and demand: LEAP model application, Energy Policy, 39 (2011) 6790-6803.
[29] L. Tian, Z. Ding, Y. Wang, H. Duan, S. Wang, J. Tang, X.e. Wang, Analysis of the Driving Factors and Contributions to Carbon Emissions of Energy Consumption from the Perspective of the Peak Volume and Time Based on LEAP, Sustainability, 8 (2016).
[30] W. Cai, C. Wang, J. Chen, K. Wang, Y. Zhang, X. Lu, Comparison of CO2 emission scenarios and mitigation opportunities in China's five sectors in 2020, Energy Policy, 36 (2008) 1181-1194.

[31] Y. Zhou, F. Hao, W. Meng, J. Fu, Scenario analysis of energy-based low-carbon development in China, Journal of Environmental Sciences, 26 (2014) 1631-1640.
[32] L. Zhang, Y. Feng, B. Chen, Alternative Scenarios for the Development of a Low-Carbon City: A Case Study of Beijing, China, Energies, 4 (2011).
[33] J. Kejun, H. Xiulian, Z. Xing, L. Qiang, China′ s Low-carbon Scenarios and Roadmap for 2050 [J], Sino-Global Energy, 6 (2009) 21-26.
[34] M.-S. Tsai, S.-L. Chang, Taiwan's 2050 low carbon development roadmap: An evaluation with the MARKAL model, Renewable and Sustainable Energy Reviews, 49 (2015) 178-191.
[35] W. Chen, The costs of mitigating carbon emissions in China: findings from China MARKAL-MACRO modeling, Energy Policy, 33 (2005) 885-896.
[36] H. Dong, H. Dai, L. Dong, T. Fujita, Y. Geng, Z. Klimont, T. Inoue, S. Bunya, M. Fujii, T. Masui, Pursuing air pollutant co-benefits of CO2 mitigation in China: A provincial leveled analysis, Applied Energy, 144 (2015) 165-174.
[37] S. Schuman, A. Lin, China's Renewable Energy Law and its impact on renewable power in China: Progress, challenges and recommendations for improving implementation, Energy Policy, 51 (2012) 89-109.
[38] Y. Liang, B. Yu, L. Wang, Costs and benefits of renewable energy development in China's power industry, Renewable Energy, 131 (2019) 700-712.
[39] G. Kostka, W. Hobbs, Local energy efficiency policy implementation in China: Bridging the gap between national priorities and local interests, China Quarterly, (2012) 765-785.
[40] H. den Hartog, F. Sengers, Y. Xu, L. Xie, P. Jiang, M. de Jong, Low-carbon promises and realities: Lessons from three socio-technical experiments in Shanghai, Journal of Cleaner Production, 181 (2018) 692-702.
[41] O. Lugovoy, X.-Z. Feng, J. Gao, J.-F. Li, Q. Liu, F. Teng, L.-L. Zou, Multi-model comparison of CO2 emissions peaking in China: Lessons from CEMF01 study, Advances in Climate Change Research, 9 (2018) 1-15.
[42] G.J. Blanford, E. Kriegler, M. Tavoni, Harmonization vs. fragmentation: overview of climate policy scenarios in EMF27, Climatic Change, 123 (2014) 383-396.