Forecast on Mid-and Long-Term Energy and Emission in Guangdong Province, China

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Abstract. Guangdong, the most affluent province with significant energy consumption in China, faces tough jobs in sustaining economic growth while not at the expenses of excessive energy consumption and environmental degradation. However, the knowledge on Guangdong’s energy consumption as well as the resultant environmental impacts has been insufficient. To solve this problem, the present study constructs TIMES-Guangdong model to reveal the detailed information on Guangdong’s energy system and its related environmental emissions. Moreover, a business-as-usual (BAU) scenario towards presented to forecast future energy and emissions. The results show that final energy demand will increase on the whole model horizon, and electricity takes the top place for final energy consumption. It is found that the total emission will increase from 2012 to 2030, accompanied by a decreasing trend of their emission intensities in part due to the evolution of energy demand mix and electricity generation mix.

1. Introduction
Guangdong Province is located in the southern part of China and adjacent to the two special administrative regions Hong Kong and Macao, is now the most affluent province in China. Guangdong’s significant economic success is fuelled by a huge amount of energy, which reached up to 283.8 million tons of standard coal equivalent (tce) in 2018\textsuperscript{1}, leading to a considerable discharge of carbon dioxide (CO\textsubscript{2}) and various air pollutant emissions. Accordingly, there is a serious conflict between economic growth and environmental protection, and it is necessary to analyse Guangdong’s energy situation in the medium and long term.

The relationship between the scenario forecast and feasible policy packages has attracted increasing attention in recent years. Xu, et al. (2015) used a new GM-ARMA model based on HP Filter to forecast the energy consumption in Guangdong from 2013 to 2016 to discuss Guangdong’s probability of completing the reduction target, and this paper found that this issue of energy saving and emission reduction would be very serious in the next few years\textsuperscript{2}. Cheng, et al. (2015) assessed the impacts of carbon emission trading scheme (ETS) policy on air pollutant emission reduction in Guangdong with a dynamic CGE model\textsuperscript{3}. Cheng, et al. (2016) analysed the impacts of the low-carbon policy in the power sector of Guangdong on its energy and carbon emission targets by 2020 using a regional CGE model with seven scenarios\textsuperscript{4}. Lin, et al. (2019) provided a quantitative assessment of the economic and carbon dioxide emission impacts of transitioning to electricity markets in China, focusing on Guangdong Province\textsuperscript{5}. However, the evaluation of policies’ effects still remains a key challenge due to the absence of reliable energy and emissions forecast under certain policy packages in the medium-
long term.

In this study, we propose the TIMES-Guangdong based on the most advanced TIMES optimization modeling framework to better understand possible energy and emissions evolution of Guangdong Province on the medium-long term and provide effective information for local decision makers. In Section 2, the internal structure and data sources of TIMES-Guangdong is presented. In Section 3, we focus on main results towards final energy consumption, electricity consumption, electricity generation, carbon dioxide emission and local air pollutants, succeeded by conclusions.

2. Methodology

2.1. The model generator
TIMES (the Integrated Markal-EFOM System) is a model generator platform. The core part of TIMES model is the energy database, covering primary energy supply, energy technologies and a wide range of energy-economic-environment parameters, which provides a technology-rich basis for estimating energy dynamics over a long-term.

2.2. The system of the Times-Guangdong model
The Times-Guangdong model constructed by the current study goes from 2012 to 2030. All the economic costs are measured by China Yuan (CNY), and the annual discount rate is set as 5% for this study.

The framework/scheme of TIMES-Guangdong model is illustrated in Figure 1, which includes modules of trade, parameters input, primary energy supply, energy transformation, etc. Each box in Figure 1 represents a type of commodity, parameter input or a group of technologies to transform commodities into other commodities. The flows of CO\textsubscript{2}, SO\textsubscript{2}, NO\textsubscript{X} and PM\textsubscript{2.5} emissions caused by energy transformation, energy final consumption and energy trade process are indicated by dotted lines. The TIMES-Guangdong model has seven end-use sectors: agriculture, industry, construction, commercial, transport, residential and non-energy sectors.

![Figure 1. A simplified framework of TIMES-Guangdong reference energy system](image_url)

2.3. Assumptions
The BAU scenario is characterized by assumptions on socio-economic parameters, various sectors projection and emission factors, hence illustrating assumed values as follows.
2.3.1. Socio-economic parameters. Projections of several socio-economic parameters in Guangdong were supported by a previous study and some secret commercial reports. Population will increase from 114.0 million on 2020 to 125.0 million by 2030. In the case of energy consumption per GDP measured by tons of standard coal equivalent per GDP, a decreasing trend will be found towards the four sectors, namely agriculture, industry, construction and commerce.

2.3.2. Various sectors projection. Energy service demands of transport services are determined by income, population, and the weighted average service cost of various transportation modes and technologies. The weighted average service cost is calculated by prices adopted; Besides electricity imports, Guangdong’s electricity demand can be satisfied by indigenous electricity. Electricity output is calculated by multiplying the product of installed capacity with annual available hour. Energy and environmental regulations already in place at provincial levels are taken into account.

2.3.3. Emission factors. In this model, carbon emissions from fossil fuels combustion, petroleum refineries, gas works, industrial production and electricity imports are estimated. Notably, petroleum refineries and gas works are energy sources transformation processes, and hence their emissions factors are lower than that of fossil fuels combustion. Carbon emissions from cement and steel production are taken into account, due to their significant contributions to carbon emissions.

3. Results and analysis

3.1. Final energy consumption
As shown in Figure 2, total final energy consumption reaches 420.6 Mtce in 2020, 498.7 Mtce in 2025, and 569.9 Mtce in 2030. The amount of total final energy consumption in 2030 is about twice as that in 2012. Average energy consumption growth rates are 5.12%, 4.96%, 3.71% and 2.86% for periods of 2012-2015, 2015-2020, 2020-2025 and 2025-2030, respectively. Apparently, there is a decrease of energy consumption growth rates, along with the increase of total final energy consumption. Industrial sector is the leading final energy consumer, followed by transport, commercial and residential sectors. The non-energy use sector shows a tiny change in its market shares, but its absolute value has an increase trend.

Following the increase of total final energy consumption, there is an increase of a majority of kinds of fuels, except for biomass (see Figure 3). In particular, natural gas, heat and electricity have the most remarkable increase (respectively, natural gas from 7.2 Mtce in 2012 to 25.6 Mtce in 2030, heat from 5.1 Mtce to 11.4 Mtce, electricity from 181.1 Mtce to 361.2 Mtce). Electricity is the most important category of final energy consumption on the over time horizon. In 2030, coal, coal gas, gasoline, diesel, LPG, other petroleum products, natural gas, heat, electricity and biomass account for 14.9%,
0.1%, 5.2%, 6.5%, 2.0%, 8.6%, 4.0%, 1.8%, 56.7% and 0.2% of total final energy consumption, respectively.

3.2. Emission

3.2.1. Carbon dioxide. No carbon-constraint policies are considered in the BAU scenario, leading to a considerable increase of carbon dioxide emission from 71.5 Mt in 2012 to 126.0 Mt in 2030 (see figure 4). Power plants contribute the largest amount of CO$_2$ emissions throughout the model horizon, followed by industrial and transport sectors. However, CO$_2$ emissions from power plants takes smaller share as the low-carbon renewable energy and nuclear energy gain more weight in energy structure. In addition, the emission indicator “CO$_2$/GDP” decrease from 13.1 t/kCNY in 2012, to 11.8 t/kCNY in 2015, 9.6 t/kCNY in 2020, 8.2 t/kCNY in 2025, and 7.2 t/kCNY in 2030.

3.2.2. Nitrogen oxides. The total amount of nitrogen oxides emission will reach 3740.1 kt in 2030, which doubles its amount in 2012 (see Figure 5). On the overall time horizon, transport sector is the largest contributor of the total nitrogen oxide emission, whose market share increase from 43.8% to 50.9%. On the contrary, power plants and industrial activities decrease their shares (respectively, power plants from 23.0% in 2012 to 16.7% in 2030, industrial activities from 26.1% in 2012 to 24.1% in 2030). Obviously, more attention should be paid to the transport sector than power plants towards nitro oxides emission control. In terms of nitrogen oxides emission per GDP, Guangdong’s value will decrease from 34.9 kg/kCNY in 2012 to 21.2 g/kCNY in 2030.
3.2.3. Sulfur oxide. As shown in Figure 6, total sulfur oxide emission increases by 73.4% on the whole time horizon. In 2030, the share contributed by the industrial sector is 38.0%, while power plants and commercial activities account for 29.2% and 21.3%, respectively. The remaining shares are derived from the residential sector, the construction sector, the transport sector, etc. Only a tiny share of sulfur oxide emission is traced back to the large amount of vehicle, benefitting from low sulfur contents of petroleum products stipulated by mandatory oil standards. Regarding an emission indicator measured by sulfur dioxide emission per GDP, Guangdong’s value will decrease from 17.2 kg/kCNY in 2012 to 9.4 g/kCNY in 2030.

![Figure 6. Sulfur oxide emission by source](image6.png)

3.2.4. Particulate matter. Economic development and the absence of mandatory particulate matter emission control policies in the BAU scenario entail a raise of the total particulate matter emission, which increase from 941.3 kt to 223.5 to 408.4 kt in 2030 (see Figure 7). Particulate matter emission by source is characterized by an increasing contribution of the transport sector, the commercial sector and petroleum refineries, as well as a decreasing contribution of power plants (during 2012 -2030, the transport sector from 28.2% to 34.2%, the commercial sector from 9.9% to 12.6%, petroleum refineries from 6.6% to 7.9%, power plants from 35.9% to 28.4%). In addition, a fluctuating trend can be found in the market share of industrial sector, which increases from 12.4% in 2012 to 13.0% in 2020, and decreases to 11.9% in 2030. Moreover, particulate matter emission per GDP will decrease from 4.1 kg/kCNY in 2012 to 2.4 g/kCNY in 2030.

![Figure 5. Nitrogen oxides emission by source](image5.png)
4. Conclusion
Two conclusions can be drawn based on the scenario analysis. In this study, a detailed approach to construct TIMES-Guangdong is presented in this paper. First, the final energy consumption of Guangdong increases constantly from 2012 to 2030. In terms of quantity, electricity is the most important one the over time horizon, followed by natural gas and heat. Driven by the ever increasing market share of electricity demand, more fuels should be transforms into electricity rather than be used directly for final energy demand. In contrast, biomass is phased out due to its high cost and low efficiency in the BAU scenario, implying innovation is needed for biomass technologies. Second, carbon dioxide and local air pollutants per GDP will decrease in the future, although the total amounts of emissions increase on the whole time horizon. The largest contribution to carbon dioxide emission is the energy transformation process initiated by power plants, and the transport sector ranks as the top contributor to nitrogen oxides and particulate matter emissions, while the industrial sector accounts for the largest market share of sulfur oxide emission. Due to sectoral emissions variations, policies aiming at emissions control should be developed from different perspectives, such as end-of-pipe control in power plants, oil quality improvement, energy saving in the industrial sector, etc.

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