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Full-length article

China's new growth pattern and its effect on energy demand and greenhouse gas emissions

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Abstract: China's economic transformation and new growth pattern have significant implications for energy demand and greenhouse gas emissions. Using an extended version of a large computable general equilibrium model of China, we explore alternative futures for the Chinese economy and its energy needs over the period from 2015 to 2030. The simulation results show that encouraging household consumption and accelerating economic transition from investment-led to service-led growth will boost China's economic growth. Capping coal consumption will improve China's energy consumption structure and reduce greenhouse gas emissions significantly. The simulation exercises imply that, with a well-designed policy, the Chinese government can meet the challenges of strong economic growth, lower carbon emissions, environmental benefits, and energy security. Moreover, the Chinese government's goal of peaking carbon emissions at 2030 is achievable.

Keywords: Dynamic computable general equilibrium model, Economic transition, Energy demand, Greenhouse gas emissions, Economic effects.

1 Introduction

China's rapid economic growth during the last four decades has been accompanied by strong growth in energy demand and increasing carbon dioxide (CO_2) emissions. Fig. 1 (left panel) shows that by 1994, China's energy consumption had doubled from 0.4 billion tonnes of oil equivalent (toe) in 1979. After 1994, growth in China's energy demand increased significantly. By 2014, energy consumption had reached nearly 7.5 toe. Interestingly, up to 2010, energy consumption and CO_2 emissions followed similar upward paths. However, after 2010, growth in CO_2 emissions started to decline relative to growth in energy demand. (Carbon intensity is the amount of carbon dioxide generated (in metric tonnes) per unit of energy consumed (in million toe).) In terms of CO_2 intensity (emissions per unit of energy consumption), China experienced a mild decline up to 2014 (see Fig. 1, right panel). By 2014, China's carbon intensity was 3.3 per cent, down from previous levels, but still significantly higher than that of the rest of the world.

One reason for the high CO_2 intensity in China is its energy structure, which is dominated by coal. In 2014, China consumed about 3 billion toe of coal, which comprised 66 per cent of China's total primary energy consumption. This was 10 percentage points higher than India, 38 percentage points higher than Japan, and 46 percentage points higher

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than the United States (see Fig. 2). Concerns for self-sufficiency and energy security have also led to high levels of coal usage and high rates of production from domestic resources. Coal self-sufficiency, as measured by the ratio of domestic coal production to consumption, was 94 per cent in 2014. Although countries such as Indonesia and the United States are completely self-sufficient with respect to coal supply and are net exporters, coal accounts for a much smaller share of their total primary energy consumption because large volumes of other fossil fuel resources are available.

Despite the concern for self-sufficiency, coal's share of China's total energy consumption has fallen gradually from 87 per cent in the mid-1960s to 66 per cent in 2014, with increasing shares of natural gas and renewables in the primary energy mix, particularly since 2000 (see Fig. 3).

Furthermore, coal has played a dominant role in China's electricity generation. In 2014, coal accounted for 72 per cent of the electricity generation mix, although it had declined from 81 per cent in 2007. Despite this relative decline, the total electricity output generated by coal increased from 2.7 trillion kWh in 2007 to 4 trillion kWh in 2014. Moreover, electricity generation accounted for more than 50 per cent of China's total CO_2 emissions from fuel combustion.

With this as background, in this paper, we use an extended version of a large computable general equilibrium model of China (called CHINAGEM) to explore alternative

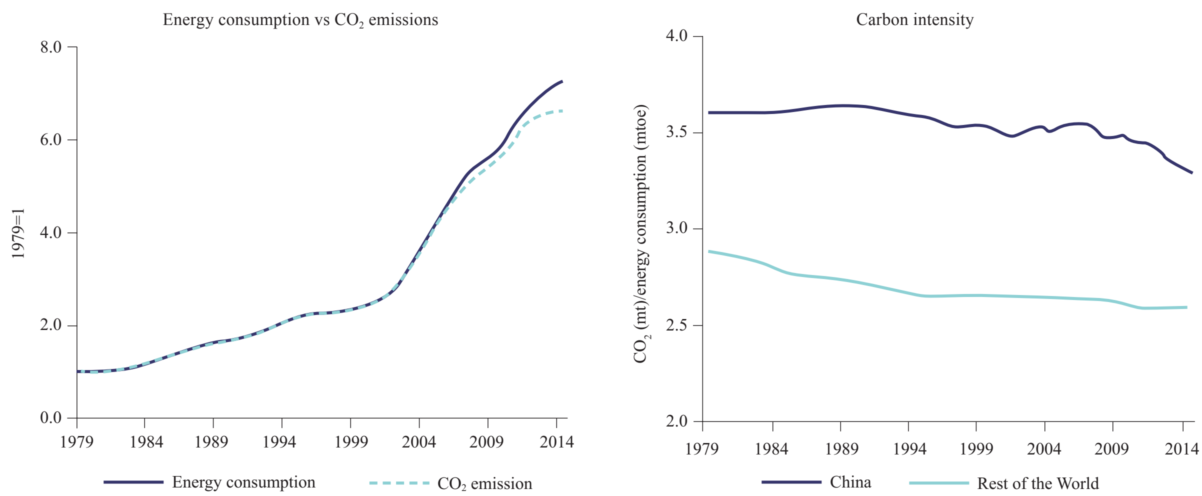


Fig. 1 Relationships between energy consumption and CO_2 emissions and carbon intensity in China, 1979–2014

CO_2 = carbon dioxide; mt = metric tonnes; mtoe = million tonnes of oil equivalent
Source: [1] and authors' calculations.

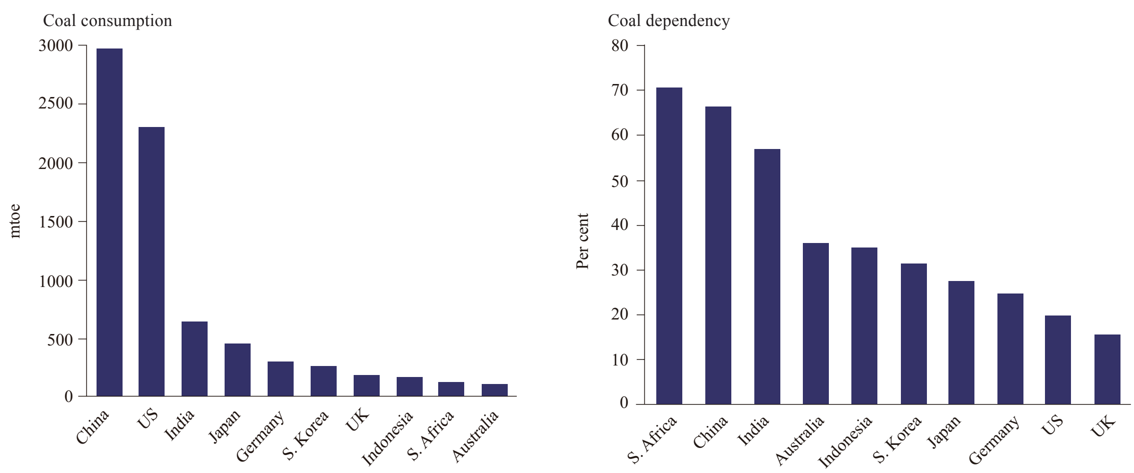


Fig. 2 Total coal consumption and coal dependency for selected countries, 2014

mtoe = million tonnes of oil equivalent; UK = United Kingdom; US = United States
Source: [1] and authors' calculations

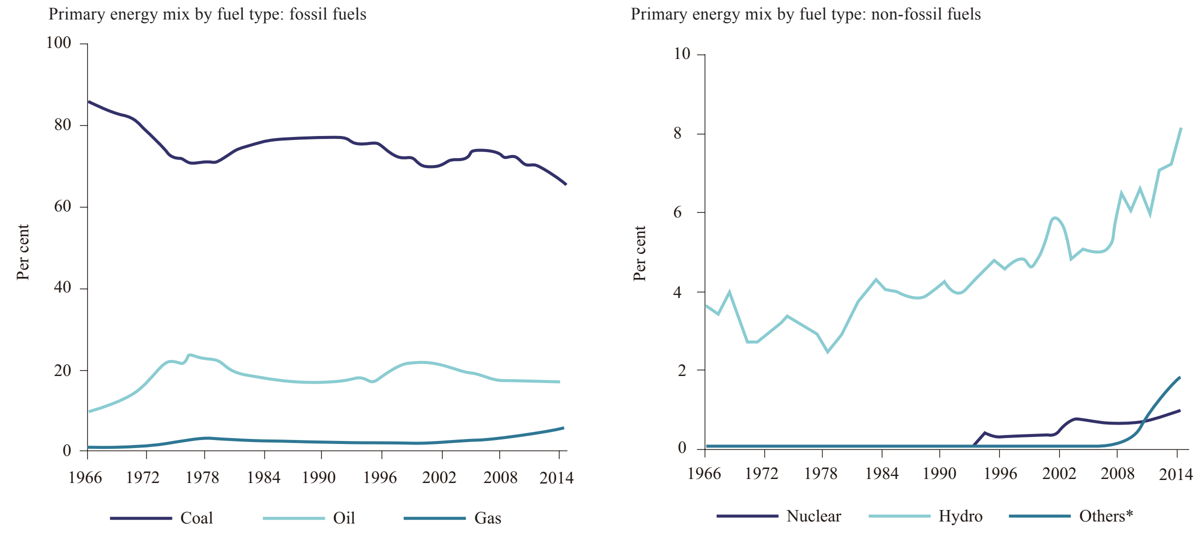


Fig. 3 Trends in China's primary energy mix by fuel type, 1966–2014

Note: Other types of fuels include solar, wind, geothermal, and biofuel-based energy.
Source: [1] and authors' calculations

futures for the Chinese economy and its energy needs.

We report the results for five scenarios, starting in 2014 and ending in 2030.

The first scenario is a baseline. The baseline is based on business-as-usual assumptions for China's development and is the control scenario against which the alternative scenarios are compared.

The four alternative scenarios and their policies are as follows.

- Scenario 1 – accelerating the economic transition (increasing the share of the service sector in the economy). In this scenario, China's future growth is driven more by consumption and less by investment. Included in this scenario is an increasing secular trend towards the use of gas (away from coal) for heating in household consumption.
- Scenario 2 – capping coal consumption by 2020. In this scenario, China's policy makers impose a cap on coal consumption after 2020. This policy is currently under consideration in China.
- Scenario 3 – accelerating unconventional gas production. In this scenario, there is a significantly increased investment in unconventional gas production facilities in China, reflecting current concerns that China is and will be relying too much on imported gas.
- Scenario 4 – The policies of Scenarios 1, 2, and 3 combined.

The rest of this paper is organized as follows. In Section 2 we provide some more background to the current energy situation in China. An overview of the modelling framework used in the analysis is given in Section 3. Section 4 presents the baseline scenario, while Section 5 discusses the policy scenarios and simulation results. Section 6 summarizes the key findings and concludes the paper.

2 Economic transition and a new energy policy

China's policy makers are facing trade-offs between energy security, cost, and environmental outcomes, particularly CO_2 emissions reductions, as shown in Fig. 4. These trade-offs comprise the "energy policy trilemma" [2], which describes the challenge of simultaneously achieving energy security, access to affordable energy service, and environmentally sensitive production and use within an economy. (https://www.worldenergy.org/work-programme/strategic-insight/assessment-of-energy-climate-change-policy/)

The World Energy Council publishes the Energy Trilemma Index, which ranks countries in terms of their likely ability to provide sustainable energy policies. Countries are scored on the three dimensions of the energy trilemma:

- Energy security: the effective management of primary energy supplies from both domestic and external sources, the reliability of the energy infrastructure, and the ability of participating energy firms to meet current and future demands.
- Energy equity: the accessibility and affordability of energy across the population.
- Environmental sustainability: the achievement of supply- and demand-side energy efficiencies and the development of energy supplies from renewable and other low-carbon sources.

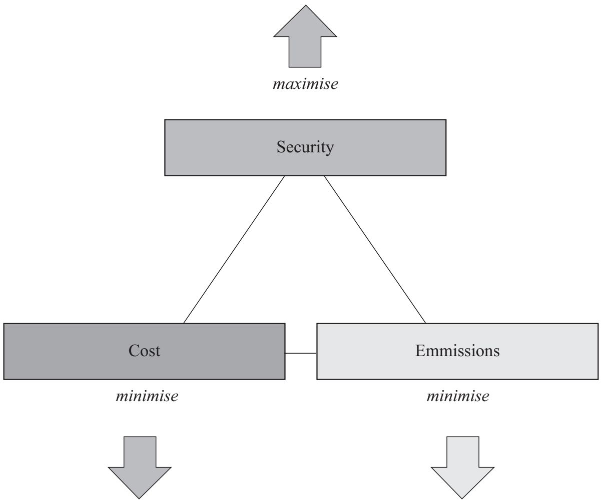


Fig. 4 Energy policy trilemma [14]
Source: [2]

On the Energy Trilemma Index Ranking (Table 1), China's energy security is relatively strong (ranked 21st). However, environmental sustainability remains a challenge (China is ranked 129th in the world for environmental impact mitigation).

Table 1 Energy Trilemma Index ranks for selected countries, 2015

Country	Total rank	Energy security	Energy equity	Environmental mitigation
India	107	53	104	122
China	**74**	**21**	**79**	**129**
Brazil	37	43	78	17
Japan	32	83	19	49
Australia	17	6	14	110
Germany	13	25	46	44
United States	12	3	1	95
Canada	7	1	2	71

Source: [3]

Several main factors have combined to change China's economic growth pattern: increasing air pollution and decades of other environmental debts [4], rapid demographic transition and decreasing growth in China's population caused by the one-child policy [5,6,7,8], and poor economic performance in major Western economies and accumulation of current account imbalances [9]. China's economic growth pattern has changed

- from export-oriented growth to domestic consumption-driven growth;
- from capital intensive, industry-led growth to a growth that is balanced between investment and consumption; and
- from high mineral and energy-intense growth to "green development."

A green development strategy seeks to combine continued rapid growth with ambitious targets for energy efficiency, natural resource management, and environmental sustainability. This reorientation of China's growth pattern has significant implications for its energy demands. First, a growth that is balanced between investment and consumption implies a faster growth of service industries and a rising share of consumption in GDP expenditure. Second, the goals of energy efficiency, low carbon emission, and environmental sustainability will slow the increase in (or even reduce) the demand for coal while augmenting the increase in the demand for gas and other clean energy.

From 2000 to 2014, China's gas consumption showed a seven-fold increase with a compound annual growth rate (CAGR) of more than 15 per cent (see Fig. 5). During the same period, China's gas production increased five-fold, with a CAGR of around 12 per cent. The slow growth of gas production with respect to gas consumption has led to increasing gas imports. China began importing liquefied natural gas (LNG) in 2006. Imports of pipeline natural gas from Central Asia began in 2010, followed by imports from Myanmar in 2013. In 2014, pipeline gas imports accounted for 53 per cent of the total imports of natural gas. Import dependency has increased from 2 per cent in 2007 to around 30 per cent in 2014. China was the world's third largest LNG importer and the world's sixth largest importer of pipeline gas in 2014.

Using a dynamic general equilibrium approach, this

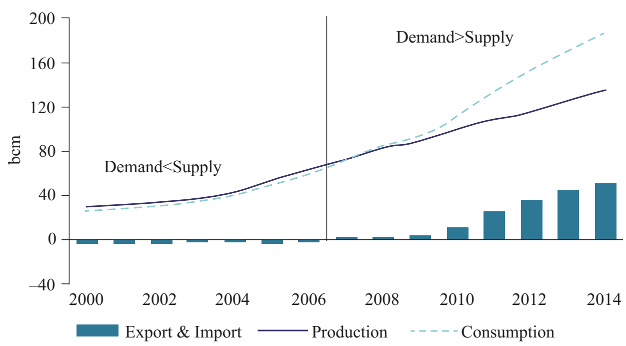


Fig. 5 Natural gas balance, 2000 – 2014
bcm = billion cubic meters
Source: [1] and authors' calculations

study investigates how changes in China's economic growth pattern affect its energy demand, especially for natural gas and LNG imports.

3 Modelling framework

3.1 CHINAGEM

The standard version of CHINAGEM consists of 137 sectors. However, for this study, we incorporated a climate change module that also includes energy accounting and carbon emission accounting. The extended CHINAGEM model includes 143 sectors with 2007 database. The core CGE structure of CHINAGEM is based on ORANI, a static CGE model of the Australian economy [10], and the dynamic mechanisms of CHINAGEM are based on the MONASH model of the Australian economy [11]. CHINAGEM captures three types of dynamic links: physical capital accumulation, financial asset/liability accumulation, and lagged adjustment processes in the labor market.

In CHINAGEM, production is modelled using nested constant elasticity of substitution (CES) and Leontief production functions, which allow substitution between domestic and imported sources of produced inputs (the Armington assumption) and between labour, capital, and land (see Fig. 7). The production functions assume constant returns to scale. Household demand is modelled by the linear expenditure system. Trade is modelled using the Armington assumption for import demand and a constant elasticity of transformation for export supply. China is treated as a large economy in the import markets for some commodities whose Chinese import shares comprise over 10 per cent of the world market. Changes in China's imports for these commodities are allowed to affect world prices. For the remaining commodities, foreign import prices are determined in world markets in isolation from developments in China. Chinese exporters are assumed to face downward-sloping world demand schedules.

3.2 Energy extensions of CHINAGEM

The original version of CHINAGEM lacks the capacity to model energy issues in detail. In this version, primary energy is supplied by only two industries: the coal industry and a composite crude-oil and gas industry. There are also two secondary energy industries, which produce refined oil products and electricity.

For this study, we modified CHINAGEM to enable more detailed energy modeling. Specifically, we

- split the crude oil and gas industry into two separate industries;
- disaggregated domestic gas production into separate conventional and unconventional gas producers;
- identified two sources of imported natural gas - pipeline gas and LNG;
- disaggregated electricity generation across six unique fuel technologies - coal, gas, oil, nuclear, hydro, and other renewables and introduced inter-fuel substitution into electricity generation;
- made allowance for cost-responsive changes in the relative supplies of conventional and unconventional gas; and
- defined price-responsive substitution mechanisms that allow for substitution between pipeline gas and LNG demands.

3.2.1 Disaggregation of oil and gas

The initial database represents crude oil and gas production as a single industry producing a single product. We separate this industry into three parts: crude oil, conventional gas, and unconventional gas. We also separate the single commodity into crude oil and gas. The crude oil industry produces only crude oil and is the only domestic industry that does so. The two gas industries each produce a single product (gas) and are the only domestic industries that do so. Oil and gas are also imported. For each commodity, total supply equals domestic production plus imports.

3.2.2 Cost-responsive changes in the relative supplies of conventional and unconventional gas

By introducing a two-industry structure for gas supply, we provide the model with the means to implement cost-responsive changes in relative supplies. This is illustrated in Fig. 6.

Initially, the intersection of market supply and demand

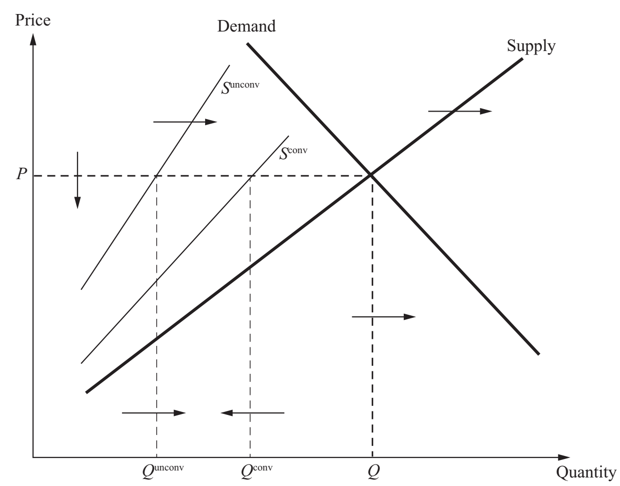


Fig. 6 Cost-responsive changes in the relative supplies of conventional and unconventional gas

determines the overall quantity of gas supplied (Q) to match demand at the market price (P). At this price, the amount of unconventional gas supplied is Q^{uncon} and the amount of conventional gas supplied is Q^{conv}. For example, suppose that there is a change in supply brought about by, say, a cost-reducing change in the technology for producing unconventional gas. As indicated in Fig. 6 by the black arrow, this shifts the supply schedule for unconventional gas to the right. If the supply schedule for conventional gas remains unchanged, there will be a shift to the right in market supply. If the market demand schedule remains unchanged, this leads to a lower market price and increased overall supply. For the total supply, the share of unconventional gas supply rises and that of conventional gas falls.

3.2.3 Two sources of imported gas supply

China's demand for natural gas is met by domestic production and imports. As explained above, domestic gas is supplied by conventional and unconventional producers. There are two primary sources of the imported supply: pipeline gas and shipments of LNG.

To model the two sources of gas imports, we require data on expenditure by source of supply for each gas user represented in the model. Currently, such data are not available for individual users. Accordingly, we use national shares to allocate the purchases of imported gas for each user to pipeline and LNG sources.

To model the alternative sources of imported gas, we assume that pipeline gas is an imperfect substitute for LNG. Thus, the landed cost, insurance, and freight (CIF) price of pipeline gas can differ from the landed CIF price of LNG, and any change in the relative price will lead to a change in the ratio of use. This is illustrated in Fig. 7, which shows the input structure for gas for a typical gas user in the model. At the top level, overall demand for gas is met by a combination of domestically produced gas and imported gas. The aggregator function has a CES form. As explained above, domestic gas can be sourced from conventional and unconventional producers.

The idea that domestically produced gas is an imperfect substitute for imported gas is a part of the existing model structure. To this, we add a new specification that allows for imported gas to be sourced from LNG and pipeline gas. Again, the aggregator has a CES form.

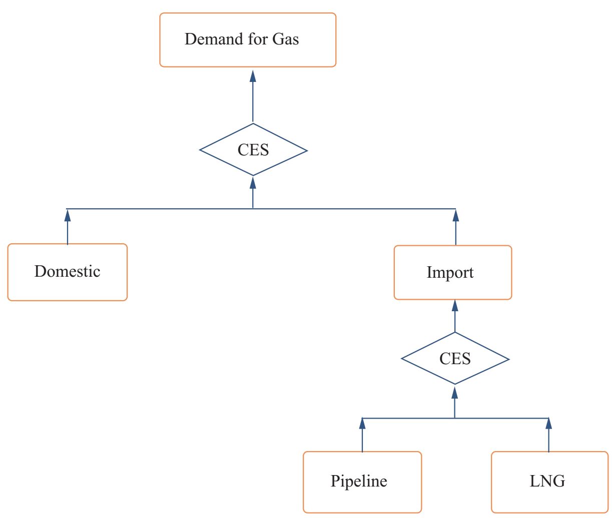


Fig. 7 Demand for gas from alternative imported sources
CES = constant elasticity of substitution

3.2.4 Electricity disaggregated by generation type and supply

The current CHINAGEM recognizes one electricity sector that generates electricity as well as provides services associated with its transmission, distribution, and retailing. Intermediate inputs to electricity, including fuels, are combined in fixed proportions. Accordingly, there is no possibility of inter-fuel substitution in the electricity generation.

Following Adams and Parmenter [4], we correct this by introducing inter-fuel substitution in electricity generation using the "technology bundle" approach. In the revised model, we split the composite electricity sector into generation and supply. Electricity-generating industries are distinguished based on the type of fuel used. The end-use supplier (electricity supply) purchases generation and provides electricity to electricity users. When purchasing electricity, it can substitute among the different generation technologies in response to changes in generation costs. Such substitution is price induced, with the elasticity of substitution among the technologies typically set at five.

The model distinguishes six types of electricity generation. Coal, oil, and gas generation use fossil fuels; nuclear generation uses imported nuclear fuel; and hydro and other renewable methods of generation rely on renewable energy sources. The model treats each type of electricity generation as one industry with a unique output, such that electricity produced by different fuels may, and indeed are likely, to have different prices in different scenarios. The electricity generation industries sell only to the electricity supply industry. The electricity supply industry sources from these electricity generation industries according to a CES substitution function (Fig. 8). We set the value of the substitution elasticity to five. (If the value of the substitution variable is 0, then this effectively creates a Leontief production structure. This reflects the fact that dispatching orders in China's electricity market react more to administrative orders than price signals.)

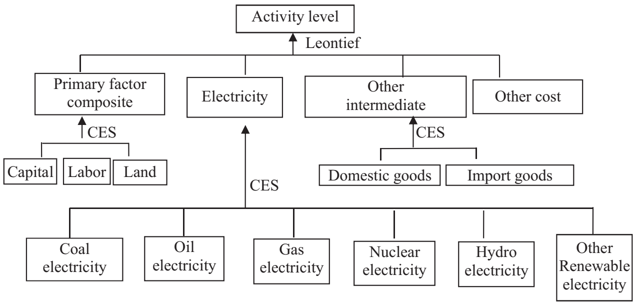


Fig. 8 Nested production structure in CHINAGEM model

4 Baseline Scenario

The baseline forecast is a business-as-usual scenario for the Chinese economy over the period from 2014 to 2030. It is constructed on the assumption that there will be no changes in government policies beyond those already announced. More specifically, for the macro variables, the baseline is developed under the assumptions that

(1) the Chinese economy will continue to grow strongly, but, following recent trends, overall growth will slowly diminish;

(2) the pattern of growth will favor consumption and consumption-related industries at the expense of investment and investment-related industries;

(3) import growth will exceed export growth; and

(4) growth in the service sector will exceed growth in the industrial sector.

Table 2 shows the calibrated growth rates of the GDP components and three industry groups in the baseline scenario. These numbers are used as shocks to CHINAGEM under the forecast closure, yielding the assumed growth of real GDP for the forecast simulation from 2014 to 2030.

For the key energy industry assumption in the baseline scenario, we use the International Energy Agency (IEA)'s current policies scenario from its *World Energy Outlook 2015*, which comprises a suite of cross-cutting policies,(Cross-cutting policies refer to policies that have multiple impacts.) power-sector policies, and industry-sector policies (see Table 3). Other assumptions, such as lower growth for steel production and higher efficiencies in metallurgical coking operations, are also included in Table 3.

According to the IEA's current policy scenario [12], China's coal consumption is projected to increase from 2,144 million toe in 2020 to 2,410 million toe in 2030 (see Fig. 9) and the share of coal in the primary energy mix will decline from 61.2 per cent in 2020 to 57.5 per cent in 2030. The share of gas in the primary energy mix will increase from 7.2 per cent in 2020 to 8.8 per cent in 2030.

Table 2 Baseline scenario: calibrated growth rate of GDP components, industry groups, and other variables (%)

	Average annual growth rate				
	2014	2015–2016	2017–2020	2021–2025	2026–2030
Household consumption	8.84	8.37	7.79	7.22	6.64
Investment	7.10	6.72	6.25	5.79	5.33
Government consumption	7.70	7.29	6.79	6.28	5.79
Exports	8.17	7.73	7.20	6.67	6.14
Imports	10.15	9.60	8.94	8.28	7.62
Agriculture	3.87	3.88	3.73	3.57	3.40
Industry	8.00	7.61	7.31	7.00	6.68
Services	7.59	8.01	7.70	7.38	7.04
Employment	0.35	–0.21	–0.21	–0.04	-0.29
Population	0.42	0.44	0.44	0.22	0.06
Real GDP	**7.40**	**7.00**	**6.50**	**6.00**	**5.50**

GDP = gross domestic product

Source: Employment and population data are from [13], the growth rates of the GDP components and three-industry group from 2014 to 2016 are from the World Bank's development indicators, and those from 2017 to 2030 are the authors' assumptions.

Table 3 Key energy and industry assumptions/scenarios for baseline forecast

Cross-cutting policy assumptions by scenario	Power-sector policies and measures by scenario	Industry-sector policies and measures by scenario
Implementation of measures in the 12th Five-Year Plan, including a 17 per cent cut in CO_2 intensity by 2015 and a 16 per cent reduction in energy intensity by 2015 compared with 2010. Increase the share of non-fossil fuels in primary energy consumption to around 15 per cent by 2020.	Implementation of measures in the 12th Five-Year Plan. 290 GW of hydro capacity installed by 2015. 100 GW of wind capacity installed by 2015. 35 GW of solar capacity installed by 2015.	Small plant closures and the phasing out of outdated production, including the comprehensive control of small coal-fired boilers. Mandatory adoption of coke dry-quenching and top-pressure turbines in new iron and steel plants. Support of non-blast furnace iron making. Three industries - iron smelting, steel making and steel rolling - are assumed to grow at a low rate and will stop growth from 2020 onwards.

CO_2 = carbon dioxide; GW = gigawatt

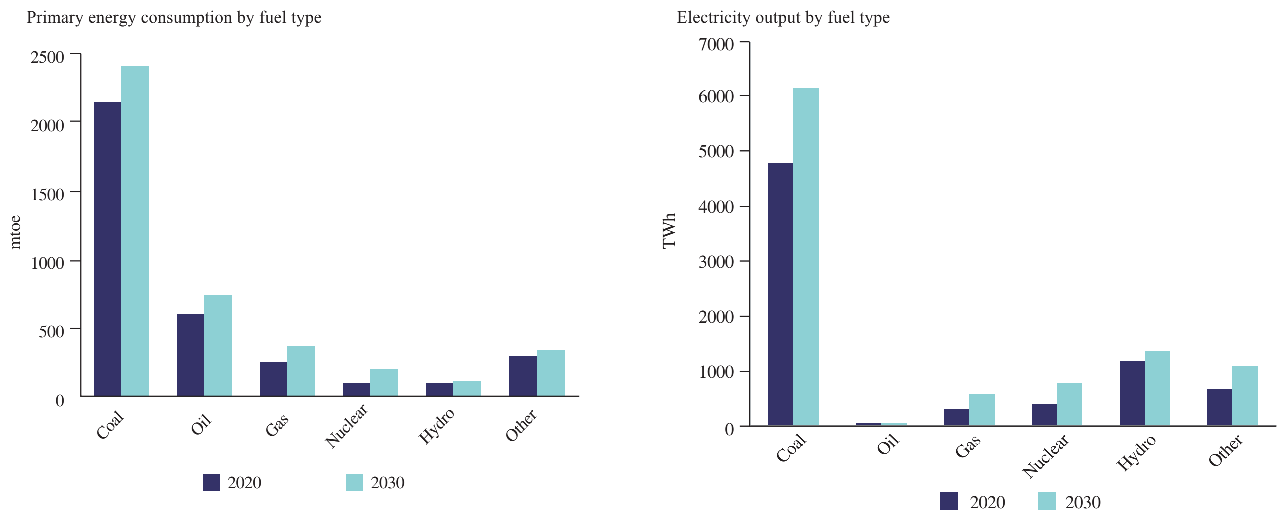


Fig. 9 Forecasted primary energy consumption and electricity generation mix by fuel type

mtoe = million tonnes of oil equivalent; TWh = terawatt hours
Source: [12] for China's current policies.
Note: The Current Policies Scenario assumes no changes in policies from the mid-point of the year of publication (i.e., from about June).

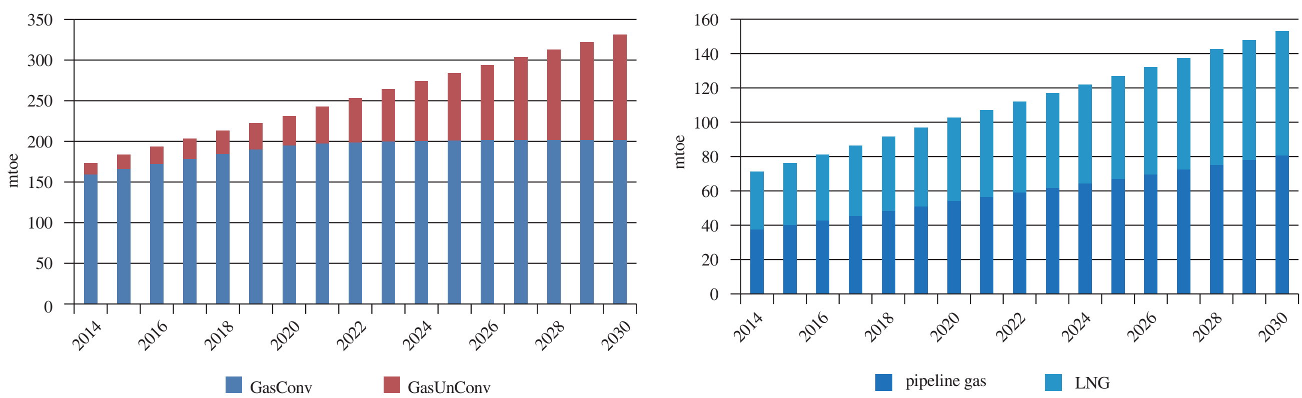


Fig. 10 Forecasted gas production and imports

mtoe = million tonnes of oil equivalent.
Source: [12] for China's current policies.

In the baseline scenario, China's gas production will continue to grow. Following the IEA, we assume that the production of unconventional gas will grow quickly (Fig. 10). The share of unconventional gas in the domestic gas production will increase from less than eight per cent in 2014 to 39 per cent in 2030. The size of China's gas imports will continue to grow while the shares of pipeline gas and LNG, which are around 50% each, will remain roughly the same as in 2014.

5 Policy scenarios and simulation results

5.1 Policy scenarios

The aim of a policy simulation is to explore how the economy would evolve when subjected to various shocks or changes in economic policy relative to the baseline (forecast) simulation. For this paper, we report on four policy scenarios.

5.1.1 Scenario 1 — faster structural transition by increasing the share of the service sector

Scenario 1 models an accelerated economic restructuring by increasing the share of the service sector. Specifically, we assume that the share of the service sector in GDP will be about 5 per cent higher in 2030 than it is in the baseline scenario (see Table 4).

The reasons for assuming a faster increase in the share of service sector than in the baseline scenario are as follows. (1) China is relying more on domestic consumption rather than the investment to drive growth and consumption has a higher service share. (2) Urbanization can be an indirect driver of consumption growth [14]. According to the UN's World Urbanization Prospects, China's urbanization rate will increase from 56 per cent in 2015 to 61 per cent in 2020 and then to 71 per cent in 2030 [15]. (3) China's sustained growth in income will stimulate service demand growth. According to the World Bank, the demand for services is rising as income increases because people are becoming less concerned about material needs. For households, this leads to an increasing demand for services such as health, education, and entertainment services. In the business sector, companies recognize that many activities can be handled more efficiently by a service provider. These activities include sales and marketing, accounting, technology, service delivery, management, human resources, and finance.

To implement this scenario, the share of the service sector is treated as an exogenous variable. The targeted trajectory for the services share is imposed via endogenous (model-determined) changes in the average propensity to consume (APC). (Consumption is oriented towards service sectors. Thus, an increase in the average propensity to consume, all else unchanged, will lead to increased consumption and a shift in the economy towards services production.) We also assume the following.

- Household preferences will shift towards service goods. As Chinese consumers become wealthier, they will spend more money on service products such as education, communication, travel, and finance services. We assume that if prices and income remain at their baseline values, then Chinese consumers will increase the share of services in their overall budget by 5 per cent per year. (This number is calibrated at a rate which would be required to increase the service share in consumption from the current level in China to a level consistent with the Australian share of services in household consumption at the similar income level.)
- Household preference for gas will be higher than in the baseline scenario. As their income increases, households can afford and are more likely to choose cleaner energy, e.g., gas rather than coal. Moreover, rapid urbanization means that more people will live in the city, where people normally consume more gas than coal. The calibration of this shock is based on the subjective judgement that urbanization will reduce household consumption of coal by 2030 by around 80 per cent compared with baseline levels. (This shift is calibrated such that, initially, the household sector's use of energy does not change, only the mix of that energy (i.e. towards gas and away from coal).)

Table 4 Comparison of economic structures of the baseline and Scenario 1

Year	Agriculture		Industry		Service	
	Baseline	Scenario 1	Baseline	Scenario 1	Baseline	Scenario 1
2015	9.0	8.9	45.8	45.8	45.2	45.3
2020	7.7	7.2	44.6	43.7	47.7	49.2
2025	6.6	5.7	42.9	40.6	50.6	53.7
2030	5.6	4.5	40.7	36.9	53.7	58.6

Source: CHINAGEM baseline and policy simulations.

5.1.2 Scenario 2—stronger action to limit coal consumption using a cap on total coal consumption by 2020

China is seeking to cap coal consumption at a maximum of 5 billion metric tons of standard coal equivalent by 2020. This cap was contained in the Five-Year Plan for 2016 to 2020, which was released in March 2016. To achieve this cap by 2020, we assume that the growth rate of primary coal consumption will gradually decline from 2015 to zero after 2020. Meanwhile, we allow the coal-use efficiency to improve for industries using coal as an input. Capping coal consumption will reduce the share of coal in the primary energy and electricity generation mixes, and the CO_2 intensity (i.e., CO_2 emissions per unit of energy consumed).

5.1.3 Scenario 3—higher unconventional gas production

Scenario 3 models the effect of an increase in unconventional gas production using the IEA New Policies Scenario for China as a guide [12]. The increase in unconventional gas production is achieved by improving the technology in the unconventional gas sector through investments in gas infrastructure as well as unconventional gas exploration and production.

5.1.4 Scenario 4—a composite scenario

Scenario 4 integrates all the assumptions in Scenarios 1, 2, and 3.

5.2 Policy results analysis

5.2.1 Macroeconomic effect of the various policy scenarios

Table 5 displays the deviations of macroeconomic variables for each of the different policy scenarios from the baseline case. By the end of the simulation period (2030), the real GDP in Scenario 1 is nearly 7 per cent higher than that of the baseline, whereas it is almost one per cent lower in Scenario 2 and there is almost no change in Scenario 3. The combined shocks of the three policies result in a higher real GDP in Scenario 4. As Table 5 shows, the higher GDP (5 per cent higher than that of the baseline) in Scenario 4 is mainly driven by the policy in Scenario 1, which is to accelerate the change in economic structure with a higher share of service sectors in the GDP.

The remaining commentary on macroeconomic effects focusses on the results for Scenario 1.

The higher share of the service sector in the GDP in our model is achieved by encouraging households to spend more and save less, with spending shifted towards service goods. Because service sectors are more labour intensive than the industry and agricultural sectors, the increase in household spending stimulates the development of service sectors and creates more employment opportunities than would occur in the baseline scenario. By 2030, employment is projected to be nearly 5 per cent higher in Scenario 1 than in the baseline. The positive correlation between capital and labour means that the growth in employment drives up the growth of the capital stock if all else being equal. Apart from employment growth, there is one more factor that stimulates the capital stock growth: the improvement of terms of trade (discussed in the next paragraph). The simulation results show that capital stock will be 10 per cent higher than in the base scenario. Higher employment and capital increases the real GDP.

Table 5 Macroeconomic effect of the policy simulations in 2030 (cumulative deviation from the baseline scenario %)

Variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Real GDP	6.99	-0.99	0.0	5.07
Capital stock	10.2	-0.26	-0.03	9.37
Employment	4.8	-0.37	0.05	3.94
Real wages	6.4	-0.78	-0.16	4.82
Investment	15.6	-1.26	0.22	13.8
Real household consumption	21.1	-0.56	-0.06	18.9
Exports	-24.8	0.33	-0.37	-24.3
Imports	15.1	0.89	-0.31	15.6
Terms of trade	7.32	0.25	-0.23	7.56

Source: CHINAGEM simulation results.

On the expenditure side of GDP, the increased real GDP is absorbed primarily by increased real household consumption. By the end of 2030, real household consumption will be more than 20 per cent higher than in the baseline scenario.

It is assumed that government consumption is linked to household consumption. Thus, the percentage change in government consumption matches the percentage change in household consumption.

The increase in capital (relative to baseline levels) requires an increase in investment. If consumption (C + G) and investment (I) increase by more than the real GDP (Y), the balance of trade (X − M) must deteriorate. The mechanism is the real appreciation of the Chinese RMB, which increases imports and reduces exports. Table 5 shows that imports will be 15 per cent higher and exports will be nearly 25 per cent lower than in the baseline scenario. For exports, we assume that China faces downward-sloping foreign demand curves for the majority of its exportable goods. Thus, the contraction in exports causes an improvement in the terms of trade (7.3 per cent higher).

The improvement in terms of trade increases the GDP deflator relative to the price of domestic final demand (the average price deflator of consumption and investment). This is because the GDP deflator includes the price of exports and excludes the price of imports, where the opposite is true for the price of the final domestic demand. In the long run, the rate of return on capital in China will be little affected by the shocks associated with each of the policy scenarios. Thus, with the rental price of capital (the numerator in the rate of return) moving with the price of investment (the denominator), improvements in the terms of trade tends to reduce the rental price of capital relative to the price of the GDP. In other words, in the final few years of the simulation, there is a fall in the real cost of capital for the economy. At this time, as employment increases and technology remains fixed, the reduction in the real cost of capital causes the economy-wide ratio of capital to labour to rise. This leads to a percentage increase in capital that is larger than the percentage increase in employment.

By the end of the simulation period, the real wage rate is projected to be 6 per cent higher than in the baseline (see Table 5).

Note that in Scenario 2, capping coal consumption without other compensating policies will slightly harm the macro economy with a real GDP that is almost one per cent lower in 2030 than in the baseline. (This will occur because capping coal consumption will increase the cost of the downstream industries that use coal as intermediate input and therefore reduce their output. Because most coal-using industries are capital intensive, the contraction of these industries will reduce the demand for capital. The decline of capital stock will drive the demand for labour down. Employment is hence 0.37 per cent lower than in the baseline. The lower employment combined with lower capital stock hence creates a lower GDP growth in Scenario 2.) However, capping coal consumption will improve China's energy consumption structure and reduce carbon emission significantly (Table 8), which we discuss in the next section.

The natural gas industry has grown rapidly in recent years as a result of the government's effort towards green development; however, its share of the whole economy is still very low, only 0.5 per cent in 2014. Even though there is a large investment increase in the unconventional gas sector to promote its production, the effect of this policy on the macro economy is very small (Table 5).

5.2.2 Effects on China's energy structure and carbon emissions

Table 6 displays the simulation results of the primary energy mix, electricity generation mix, and carbon emissions for the various policy scenarios. Scenario 2 (capping coal consumption) has a relatively large effect on China's energy consumption structure. With the cap in place from 2020, the share of coal consumption is projected to reduce significantly to 52.7 per cent in 2030 (compared with 60.3 per cent in the baseline). Meanwhile, the shares of natural gas and alternative fuels will increase. Furthermore, the share of coal-generated electricity will drop significantly to around 54.4 per cent, which is nearly 10 percentage points less than that of the baseline. A further consequence of this policy is a reduction in CO_2 emissions and carbon intensity. (This study does not explicitly examine how introducing a tax on coal and energy pricing will affect the coal share in the primary energy mix and CO_2 emissions. The revenues from a coal tax could partly be applied towards clean energy development, with a higher potential for fueling economic growth [16]. China introduced an emissions trading scheme in 2017 covering the power sector and heavy industry. This scheme will help curb the appetite for coal, and lead to a slowing growth and then reduction in China's CO_2 emissions around 2030 [12]. Nevertheless, taxes and price will influence investment decisions regarding coal and other alternative fuels.)

Table 6 shows that, by 2030, coal-based carbon emissions will be 2.7 billion tonnes lower than that of the baseline, and natural gas-based carbon emissions will be 0.1 billion tonnes higher than that of the baseline. The small increase in CO_2 emissions from gas reflects strong substitutions among coal, gas, and renewables. As a result, CO_2 emissions are 19 per cent lower and carbon intensity is eight per cent lower than the baseline by 2030.

In Scenario 1, increasing household consumption and household preference for gas (relative to baseline levels) results in slightly higher economy-wide shares of gas and non-fossil fuels by the end of the projection period. The cleaner energy consumption structure reduces the carbon emissions. Table 6 shows that in 2020 in Scenario 1, total CO_2 emissions are 0.2 billion tonnes lower than in the baseline scenario. This lowers carbon intensity by around one percentage point.

Table 6 Energy demand and carbon emissions in 2030 (%)

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total energy consumption					
Primary energy mix (%)					
Coal	60.3	58.9	52.7	60.3	51.1
Gas	7.5	8.1	10.5	7.9	10.7
Oil	17.6	17.0	19.9	17.5	18.5
Non-fossil fuel	14.6	16.0	16.9	14.3	19.7
Electricity generation mix (%)					
Coal	63.9	63.7	54.4	63.8	49.7
Gas	5.0	4.8	6.7	5.1	6.7
Oil	0	0	0	0	0
Non-fossil fuel	31.1	31.4	38.9	31.1	43.5
Carbon Emissions (billion tonnes)					
Coal	10.7	10.5	8.0	10.7	8.1
Gas	0.6	0.6	0.7	0.7	0.8
Petrol refinery	2.3	2.3	2.3	2.3	2.3
Total	13.6	13.4	11.0	13.7	11.2

Source: CHINAGEM baseline and policy simulations.

The effects of Scenario 3 (increasing unconventional gas production) on China's energy structure are relatively small. This is because the share of gas (conventional and unconventional) is small relative to that of other forms of primary energy and because the increase in unconventional gas tends to reduce the use of conventional gas, leaving overall gas consumption relatively stable. The reduction of conventional gas in Scenario 3 is a result of the increased competition between conventional and unconventional gas whereas the increased investment improves the technology of unconventional gas production and reduces its cost.

When all scenarios are combined, we find that by

2030, there will be significant changes away from coal in China's energy needs and significant reductions in CO_2 emissions (see Table 6 and Fig. 11). The share of coal in the primary energy mix will be reduced to 51 per cent in 2030 compared with 60.3 per cent in the baseline scenario, while the consumption of natural gas and non-fossil fuels will increase substantially. The share of non-fossil fuels will increase to 20 per cent, which reaches the goal that the Chinese government set in its Intended Nationally Determined Contribution. (On 30 June 2015, China submitted its Intended Nationally Determined Contribution. China has promised to increase the share of non-fossil fuels in primary energy consumption to around 20 per cent [17].) In the electricity generation mix, the share of coal-generated electricity will decline to below 50 per cent in 2030. Gas remains a minor input, growing to only 6.7 per cent by 2030. China will gradually come to rely on non-fossil fuels to provide its electricity. Non-fossil fuels will generate nearly 43.5 per cent of China's electricity in 2030, which is nearly 40 per cent higher than that of the baseline (31.1 per cent).

The change of China's energy structure will affect its carbon emissions profoundly. Fig. 12 shows that, in Scenario 4, total CO_2 emissions grow very slowly from 2020 to 2030, with 0.4 per cent CAGR, compared with around 2 per cent in the baseline scenario over the same period. As a result, by 2030, total CO_2 emissions in Scenario 4 are 11.2 billion tonnes, which is 2.4 billion tonnes below the emissions in the baseline (13.6 billion tonnes). With a slow annual growth rate, total carbon emissions come very close to peaking by 2030, in line with commitments from the Chinese government. (In its Intended Nationally Determined Contribution, China has promised to achieve peak emissions by 2030 and would make their best effort to peak early [17].

The simulated results also show that, among the total CO_2 emissions, coal emissions reduce to 8.1 billion tonnes in 2030 compared with 10.7 billion tonnes in the baseline, which is a reduction of 24 per cent (Table 6 and Fig. 12).

The slow growth of carbon emissions in the composite policy of Scenario 4 will also improve China's carbon intensity. The carbon intensity will be 10 per cent lower than in the baseline case.

5.2.3 Effects on China's natural gas production and import

Fig. 13 displays the simulation results of China's natural gas consumption under the various policy scenarios. Natural gas consumption in all four policy scenarios is higher than in the baseline. As outlined already, the reasons are as follows: the changes in household consumption towards natural gas, the substitution of gas for coal, and a reduction of gas cost because of technological improvements in unconventional gas production. (Given the current state of unconventional gas production technology in China, there is significant scope for productivity gains over time. Any productivity improvement lowers the unit cost of production and increases the competitiveness of unconventional gas in the national gas market. As the competitiveness of unconventional gas improves, so does its share in the national market. Hence, in Scenario 3, there is an increase in unconventional gas production relative to conventional gas production.)

China's natural gas imports are expected to expand to meet the continually increasing gas demand. Table 7 shows that natural gas imports are higher in both Scenarios 1 and

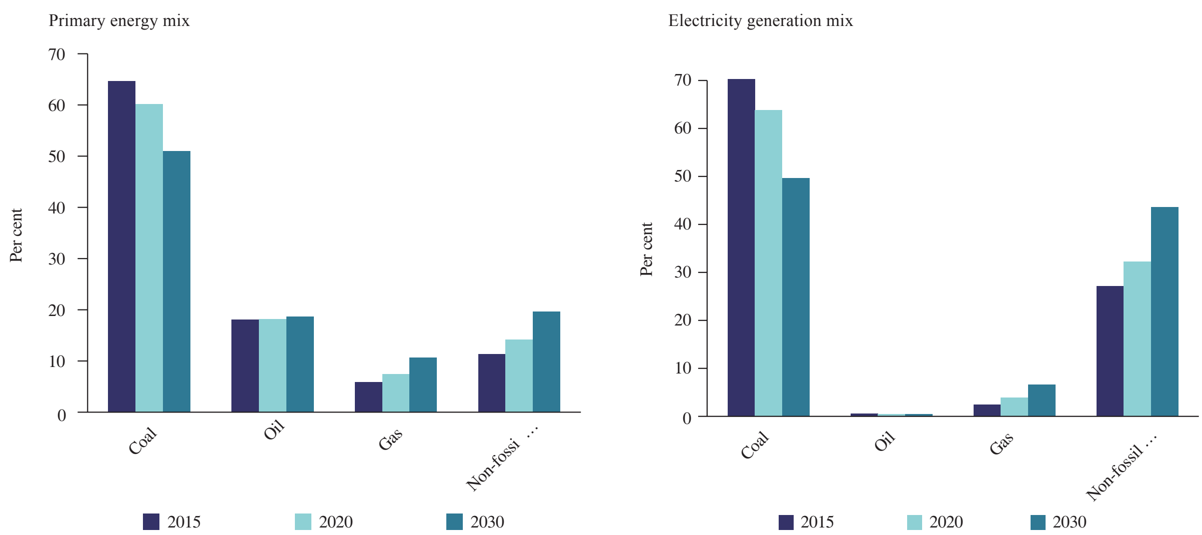


Fig. 11 Primary energy mix and electricity generation mix in Scenario 4, 2015–2030

Source: CHINAGEM policy simulation.

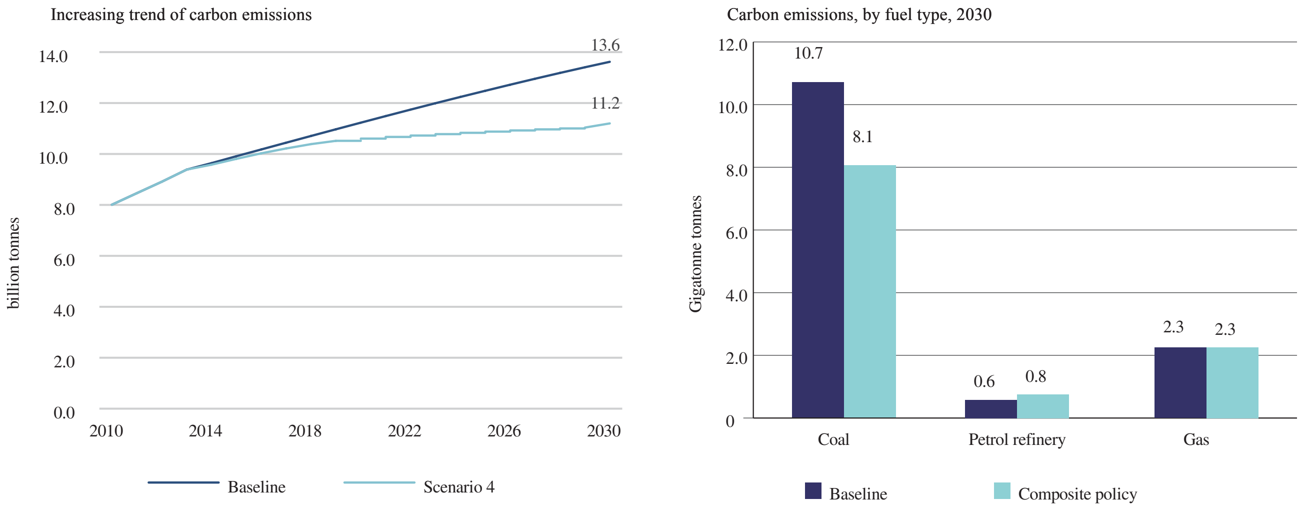
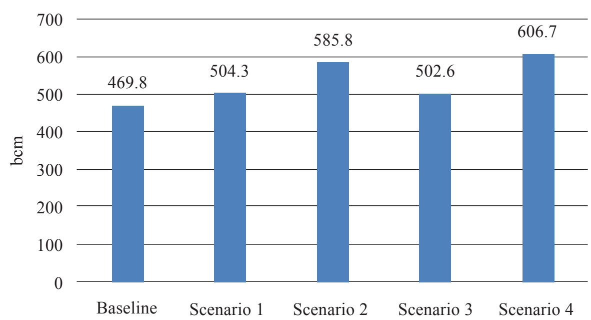


Fig. 12 Changes in carbon emissions: Scenario 4 vs baseline, 2015–2030

Note: China commenced its LNG imports in 2006 and pipeline gas imports in 2010.
Source: CHINAGEM baseline and policy simulations.



bcm = billion cubic meters;

Fig. 13 Total gas consumption by 2030 for various policy scenarios

Source: CHINAGEM policy simulation results

2. By contrast, the changes considered in Scenario 3 lead to increased consumption of domestically produced gas at the expense of imports. The increasing demand for natural gas after combining all the scenarios together drives China's gas imports up dramatically. Figure 13 shows that total gas demand in scenario 4 will be 606.7 billion cubic meters (bcm) in 2030, which is 29 per cent higher than that of the baseline scenario (469.8 bcm). As discussed in Section 1, China's gas imports consist of LNG and pipeline gas. Fig. 14 shows that LNG and pipeline gas imports will increase significantly in Scenario 4 compared with the baseline. As a result, China's import dependency for natural gas would increase from 32.6 per cent to 38.1 per cent (Table 7).

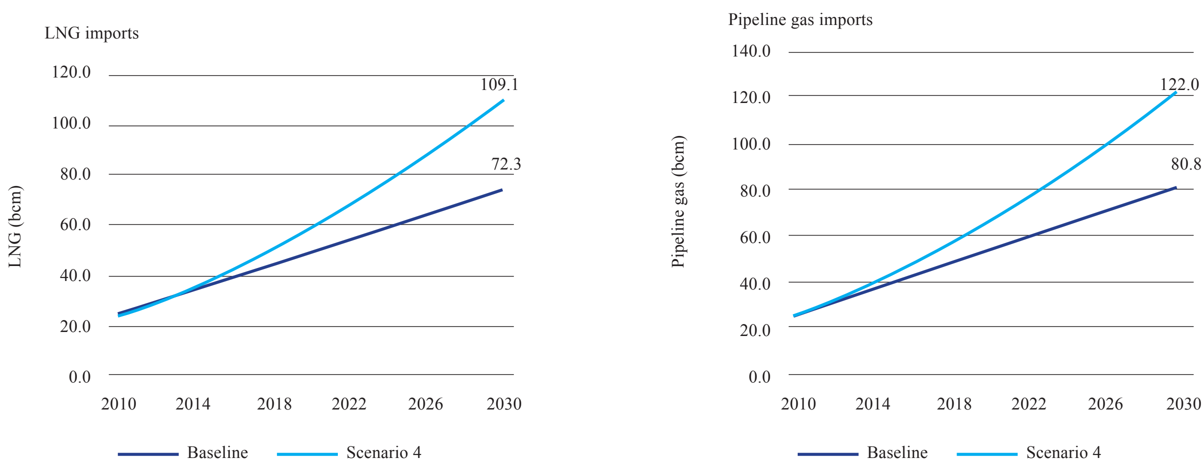


Fig. 14 Comparison of natural gas imports in Scenario 4 vs the baseline, 2010–2030

bcm = billion cubic meters; LNG = liquefied natural gas
Source: CHINAGEM baseline and policy simulations.

Table 7 Natural gas consumption, production, and imports in China in 2030 (bcm)

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Consumption	469.84	504.28	585.83	502.56	606.65
Production	316.77	331.08	371.94	367.54	375.56
Imported	153.07	173.2	213.89	135.02	231.09
LNG	72.29	81.8	101.02	63.77	109.14
Import dependency	32.6	41.3	36.5	26.9	38.1

bcm =billion cubic meters

Source: CHINAGEM baseline and policy simulations.

6 Conclusions

China's economic growth pattern is changing. Using a dynamic computable general equilibrium model of the Chinese economy, in this paper, we explore the effects of alternative economic growth patterns on China's energy demand, particularly the demand for natural gas. We present the results of five scenarios: the baseline (business-as-usual scenario), Scenario 1 (accelerating economic transition by increasing share of the service sector in the economy), Scenario 2 (capping coal consumption by 2020), Scenario 3 (accelerating unconventional gas production), and Scenario 4 (a composite scenario of Scenarios 1 to 3).

The simulation results show the following.

- Encouraging household consumption and accelerating economic transition from investment-led to service led growth will boost China's economic growth.
- Capping coal consumption without other compensating policies will slightly harm the macro economy. However, capping coal consumption will improve China's energy consumption structure and reduce carbon emission significantly.
- Investment in non-conventional gas will reduce the production cost of domestic natural gas and increase the competition between conventional and non-conventional gas.
- Combining all the three policies together will not only boost China's economic growth but also improve China's energy consumption structure. The model shows that in 2030, the share of coal consumption in the primary energy mix will reduce to 51 per cent, the share of natural gas will increase to 11 per cent, and the share of non-fossil fuels will increase to 20 per cent;
- Natural gas imports will grow faster to meet the increase in natural gas demand, which will cause the import dependency to rise to 38 per cent in 2030.
- China's total carbon emissions will reduce substantially, especially if coal consumption is capped.

These simulations imply that with a well-designed policy, the Chinese government can meet the challenge of strong economic growth, lower carbon emissions, environmental benefits, and energy security. Moreover, the Chinese government's goal of peaking carbon emissions by 2030 is achievable. Accelerating economic transition and capping coal consumption are the keys to achieving these goals.

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