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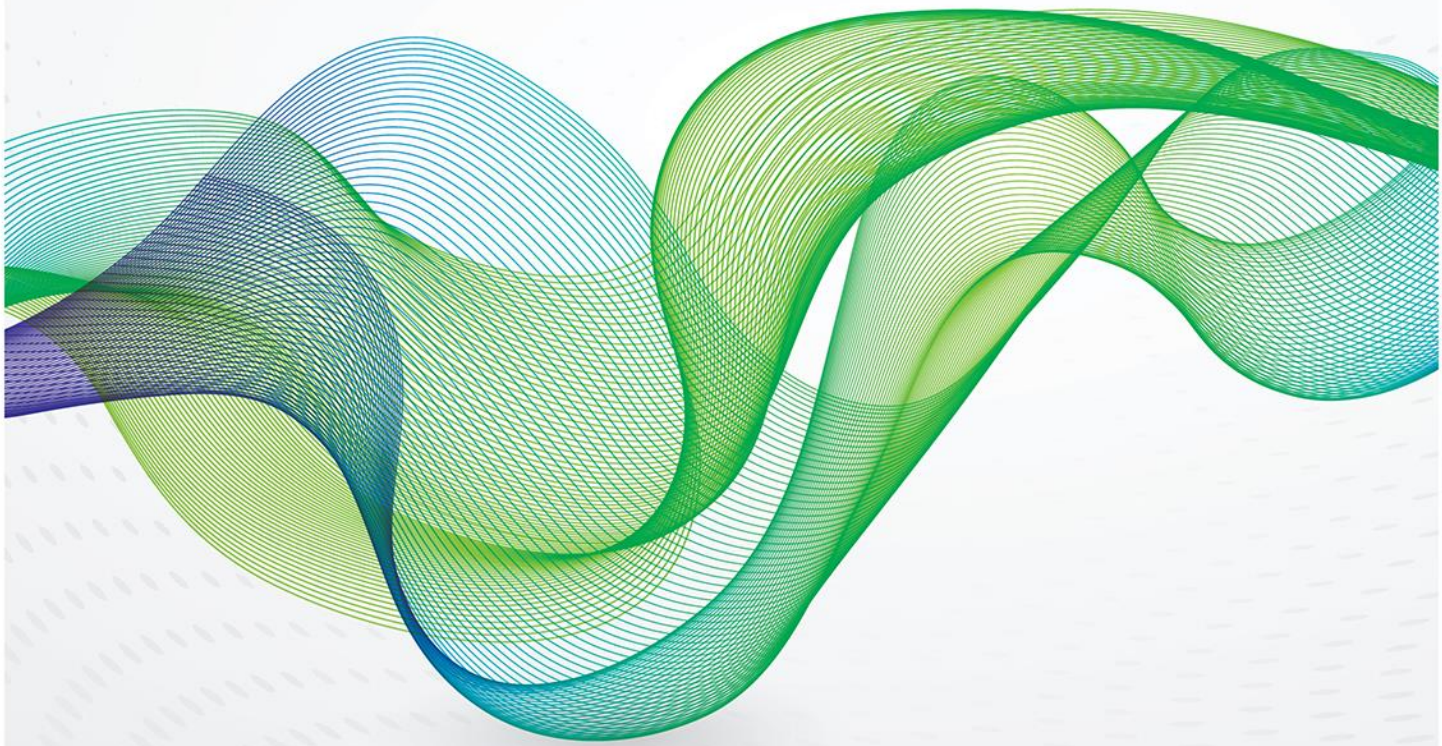
Natural gas in China: a regional analysis



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Preface

The importance of China as a growing market for natural gas can hardly be overstated. From 35 Bcm in 2000, consumption by 2014 had grown to 186 Bcm, requiring imports, whether pipeline gas or LNG in addition to domestic production from 2009. In anticipation of a continuation of such growth trends, international upstream players embarked upon projects to cater for high future import requirements – be they in the form of pipeline gas or LNG. However, the slowdown in Chinese gas demand growth in 2014 appears to be even more pronounced in 2015, although no official figures are as yet available.

This highlights the difficulty in predicting future demand trends in energy markets especially for a country as large and complex as China, where natural gas is still a relatively minor portion of the energy mix. The growing gap between past demand projections based on 'top down' extrapolation and recent reality clearly emphasise the need for a more considered approach to understanding China's gas market.

This paper by Xin Li identifies the drivers of gas consumption in general and applies these in a detailed sectoral analysis at the provincial level, focussing on two examples of wealthy regions (Guangdong and Beijing), two gas producing regions (Sichuan and Shaanxi), and other regions (Shandong). While patterns of consumption and share of the energy mix vary between regions, the Author is able to reach sound conclusions for the period in question.

As China enters what is now generally known as the 'new normal' the conclusions of this paper suggest that the potential for gas demand growth will be in the residential and commercial space heating sector (subject to adequate distribution infrastructure), the power sector where air quality drives a move away from coal (policy) and to a degree in substituting for coal in industry for the same reason. Pricing is a challenge which the recent price reforms have yet to resolve.

The Oxford Institute for Energy Studies Natural Gas Programme is committed to undertaking research on markets which have a material impact on the increasingly 'connected' global gas system and in terms of importance China certainly stands out more than most in this regard. I thank Xin Li for this excellent contribution to our research.

Howard Rogers

Oxford 2015

Abstract

The transition between 2013 and 2014 represents a milestone for China's gas market. On the supply side, though the progress in the shale gas industry to date is slow, China has made arrangements to secure sufficient future pipeline gas imports given the growing projected gap between supply and demand. On the demand side, the decade long double-digit growth (e.g. 13.9% in 2013) has come to an end. The annual growth of gas demand suddenly dropped to 8.3% in 2014. A number of studies have addressed the gas production and consumption patterns in China from a national perspective. However, for a country as large as China in terms of population, geographic extent and demographics, any analysis of natural gas market development needs to capture its regional variations.

In this study, we aim to investigate the historic production and consumption patterns of natural gas in China's regions to provide a better understanding of the market dynamics and demand drivers which would not be possible using an aggregate national 'top-down' approach. The key research questions addressed in this paper are:

- Using the data available is it possible to form a coherent picture of gas production and consumption at the provincial level?
- Are there any obvious qualitative correlations between provincial gas consumption and key drivers such as local gas production, enabling infrastructure, specific gas-intensive industries, income per capita, for example?
- From the above are there any emerging patterns which may assist in forming a view of the trajectory of future Chinese gas consumption, accepting that the transition to the 'new normal' phase is something of an economic and environmental discontinuity?

This study found that energy consumption growth in China is likely to remain moderate in the next decade. The role that gas can play is likely to change from taking a share of the growing demand to replacing the existing energy supply from other sources (mainly other fossil fuels). In general, such replacement will depend on several factors, such as the relative price levels of gas compared to alternative energy sources, the environmental impacts, and whether there will be a sufficient and secure supply. At the sectoral level, one of the main factors that determine gas consumption in different regions is the structure of the regional economy. A regional economy where industry represents a higher proportion of total GDP tends to use a higher proportion of gas in industry, though its share in total gas consumption has been declining; whilst for a regional economy dominated by services, the use of gas in the residential and commercial sectors is more significant. Residential gas consumption is growing in most regions with the improving gas infrastructure. Together with the growing trend of urbanization, residential consumption represents a significant opportunity for the future growth of gas, especially in the wealthy coastal regions. Furthermore, power and heating use of gas is expected to grow in coastal regions due to government policies on limiting the use of coal in power generation and the increasing differences between peak and valley power demand.

Acknowledgements

The author is very grateful for the invaluable comments provided by Howard Rogers with this research. I also would like to thank Bassam Fattouh for his support. Many thanks to Kate Teasdale and John Elkins for their help in preparing it for publication. All errors in this paper remain the author's own.

Contents

Figures

Tables

1. Introduction

The transition between 2013 and 2014 represents a milestone for China's gas market. On the supply side, the Chinese government has revised its shale gas production target for 2020 from 60 – 80 Bcm down to 30 Bcm, which acknowledged slow progress in China's shale gas industry to date. With the growing projected gap between supply and demand, China has made arrangements to secure sufficient future pipeline gas imports. On 21 May 2014, the decade-long negotiation with Russia on gas supply finally reached an agreement. Gazprom will provide 38 Bcm/ year from East Siberia to China's Bohai Bay region for a period of 30 years from 2018. The long-term large-scale pipeline gas supply to the coastal regions can help to alleviate the gas shortage in China's wealthy regions, but could also have a significant impact on the potential LNG supply to the Bohai Bay gas markets[1]. Six months later, a memorandum of understanding was signed between Beijing and Moscow to deliver a further 30 Bcma of gas for 30 years from the Western route, which is also known as the Altai deal. The Altai deal could be beneficial to both China and Russia as the former seeks to diversify its importing sources (other than from Central Asian countries) and the latter wishes to diversify its export markets and reduce reliance on Europe[2]. But again, the deal is a set-back for the potential LNG exporters targeting China as their main exporting destination. With the growing requirement for gas imports, the previous Chinese gas pricing mechanism was considered to be a barrier, because the higher cost of imported gas does not fit into the cost-plus pricing mechanism that was implemented when cheaper domestic gas was sufficient to meet demand. China's Midstream and Upstream players had experienced significant losses when they purchased high cost gas from the international gas market and sold at low prices in China's domestic market due to this distorted pricing mechanism[3]. After two years of trials in Guangdong and Guangxi, the major gas pricing reform represents an important step forward from cost-plus pricing to netback market value pricing in all provinces. This more market-oriented gas pricing reform was implemented in June 2013 in order to alleviate the losses caused by the price distortion, which in turn could provide incentives for upstream investment[4].

On the demand side, the annual growth of gas demand suddenly dropped to 8.3% in 2014 from a decade long double digit growth (for comparison, the annual growth rate was 13.9% in 2013). Several factors may explain the sharp decline in the annual growth rate. First, the growth of China's primary energy consumption had dropped to its lowest level since 2000 with an annual growth rate of 2.6%. This is because the Chinese economy has entered into the 'new normal' phase, which has a lower growth rate but represents a more sustainable pathway (with a higher proportion of services and consumption and a lower proportion of industries and investment in its GDP composition; otherwise known as economic rebalancing). Secondly, the competitiveness of gas has diminished due to the plunge of oil and coal prices in the context of the recent gas pricing reform. For example, China's domestic steam coal prices fell to the lowest level in six years during the first half of 2014[5]. Furthermore, in response to the falling oil price, the National Development and Reform Commission lowered the retail prices of gasoline and diesel twelve times in a row between June 2014 and January 2015. By the end of 2014, the retail prices for 90# gasoline and 0# diesel were 33% and 43% lower than their price levels six months before. By contrast, the end-user gas price has experienced an increase since the gas pricing reform in June 2013. While gas has suffered on a pure price competitive basis, the effort to mitigate severe environmental pollution that is caused by the excessive

[1] Paik (2015)
[2] Henderson (2014)
[3] PetroChina's gas businesses incurred a loss of more than 20 billion RMB in 2011. (http://www.chinagasholdings.com.hk/siteen/aspx/News_Infor.aspx?id=731)
[4] Chen (2014) examines the pricing mechanism reform in China's natural gas market in detail and discusses its implications on China's gas market.
[5] Cornot-Gandolphe (2015)

use of coal is of huge significance. For instance, the Beijing, Tianjin and Hebei region (known as the Jing-Jin-Ji region) together aims to reduce coal consumption by 63 million tonnes by 2017 compared to the 2012 level[6], which is equivalent to an additional 48 Bcm gas demand if coal is replaced by gas. Thus, although the annual growth in gas demand fell significantly in 2014, its growth still remained moderate.

A number of studies have addressed the natural gas consumption in China from a national perspective. However, for a country as large as China in terms of population, geographic extent and demographics, any analysis of natural gas market development needs to capture its regional variations. Figure 1 shows a map of China with all its provinces.

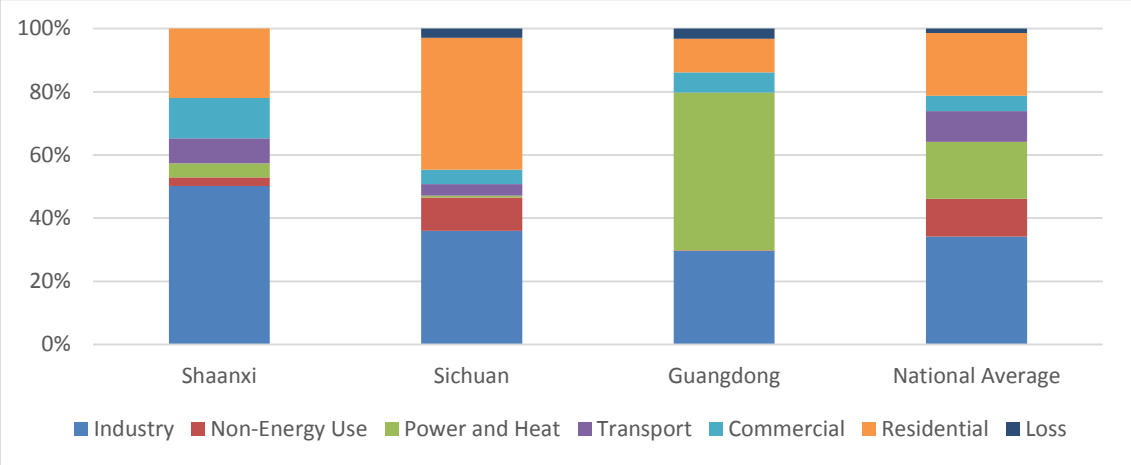
Figure 1: Map of China

China's regions have very distinctive features in terms of gas supply and demand. Firstly, natural gas resources are unevenly distributed and often remote from the demand centres. For example, by the end of 2012, only 5 provinces were self-sufficient in gas, and able to export gas, these being Heilongjiang, Sichuan, Shaanxi, Qinghai and Xinjiang, although 21 provinces have natural gas production. These net exporting regions are remote from the demand centres around the coast areas. Second, different regions have distinctive gas consumption patterns. For example, Shaanxi and Sichuan are two of the largest gas producing regions that are also adjacent to each other. In 2012, Shaanxi was the largest gas producer, and accounted for 29% of China's total gas production (31.1 Bcm). It consumed 21% of its own gas production, which ranks the province ninth in terms of gas consumption. Industrial use accounted for half of the total gas consumption, followed by residential (22%) and commercial use (13%)[7]. Sichuan consumed 63% of its own gas production, which makes

[6] Ministry of Environment Protection (2013)
[7] The balance of 15% was transport (8%), power and heat (4%) and non-energy use (3%).

the province the largest gas consumer in China. Of Sichuan's total consumption, industrial and residential uses accounted for 36% and 42%, respectively. Power and heat supply only accounted for less than 1% of the total gas use[8]. By contrast, for Guangdong, the second largest gas consumer in China, 50% of natural gas consumption was in power and heat supply followed by industrial use (30%) and residential use (11%)[9]. For context, at the national level in the same year, China's industrial, residential and power and heat consumption represented 34%, 20% and 18% of the total gas consumption, respectively (See Figure 2 for a comparison).

Figure 2: Gas consumption by sector in different regions in 2012



Source: Own estimation. Data from National Bureau of Statistics (2013)

This study aims to investigate the historic production and consumption patterns of natural gas in China's regions to provide a better understanding of the market dynamics and demand drivers, which would not be possible using an aggregate national 'top-down' approach.

The key research questions addressed in this paper are:

- Using the data available is it possible to form a coherent picture of gas production and consumption at the provincial level?
- Are there any obvious qualitative correlations between provincial gas consumption and key drivers such as local gas production, enabling infrastructure, specific gas-intensive industries, income per capita, for example?
- From the above are there any emerging patterns which may assist in forming a view of the trajectory of future Chinese gas consumption, accepting that the transition to the 'new normal' phase is something of an economic and environmental discontinuity?

Of the 32 provinces 5 are selected in this analysis: Sichuan and Shaanxi, representing the largest producing region; Guangdong and Beijing, representing the largest consuming region; and other regions represented by Shandong. Due to data constraints, the most recent sectoral gas consumption data are from 2012[10]. Thus, most of the analysis is limited to 2012 unless specified otherwise.

The structure of the report is organized as following: Section 2 introduces the background of China's energy consumption, the share of gas demand in the energy mix and the key factors that determine gas demand in China at national level. Section 3 identifies the regional variations by introducing the regional context, energy consumption, share of gas in the energy mix, gas supply and demand patterns. Section 4 concludes this research.

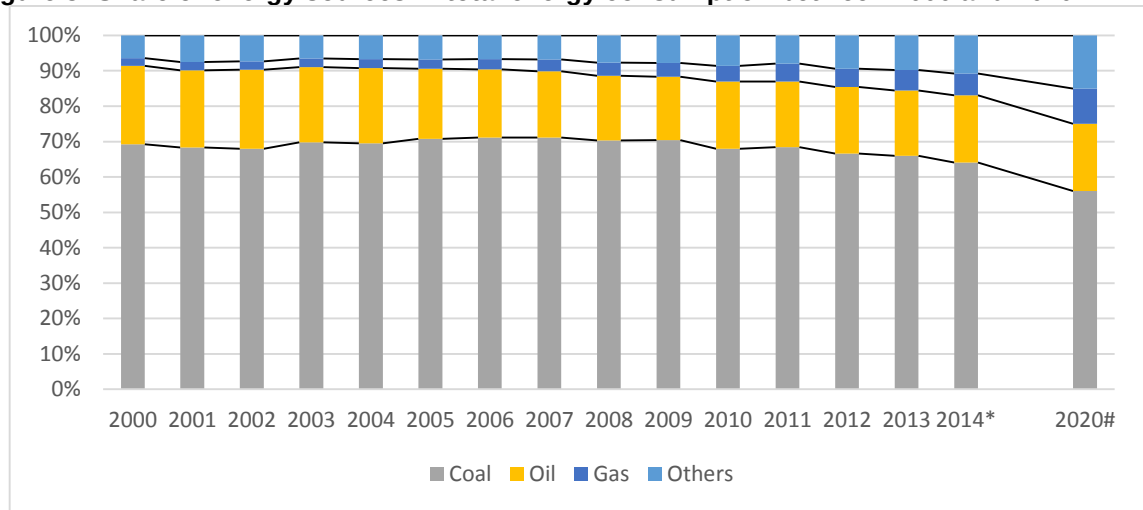
[8] The balance of 23% was non-energy use (11%), commercial use (5%), transport use (4%), and losses (3%).
[9] The balance of 9% was commercial use (6%) and losses (3%).
[10] All data used on and before 2012 are from various Energy Statistical Yearbooks (2000 – 2013)

2. The role of natural gas in energy consumption

2.1 Energy consumption in China

China's total energy consumption increased from 1,470 million tonnes of coal equivalent (Mtce) in 2000 to 4,260 Mtce in 2014[11]. Coal has dominated China's energy consumption since 2000, accounting for about 70% of total energy consumption up to 2009. However, its share started to decline from 2010 and dropped to 66% by the end of 2014. The share of oil in total energy consumption has been stable over this time period (between 18% and 19%). The combined government policy requirements for improving air quality and lowering CO_2 emissions have begun to drive an adjustment of the energy mix in China, with the aspiration of achieving a greener and more efficient energy system. In response, we have witnessed the beginnings of a trend to replace coal by natural gas and non-fossil fuels (including hydro, nuclear and renewables) in recent years. For example, the contribution of natural gas to total energy consumption increased from 2.2% in 2000 to 6.2% in 2014; the share of other energy sources increased from 6.4% to 10.7 % over the same period. In 2014, the State Council issued the Energy Development Strategy Action Plan (2014 – 2020), which aimed to reduce the use of coal (limited to 4.2 billion tonnes/year) and increase the share of natural gas and non-fossil fuels in total energy consumption by the end of 2020. Figure 3 presents the share of different energy sources to total energy consumption between 2000 and 2020.

Figure 3: Share of energy sources in total energy consumption between 2000 and 2020



Source: National Bureau of Statistics website[12] for data between 2000 and 2013; Own estimates for 2014 data based on National Bureau of Statistics (2015). Own estimates for 2020 data based on State Council (2014). Assumptions are made based on the future share of oil in total energy consumption remaining at 2014 levels (19%).

A number of recent studies have examined the driving forces of China's energy consumption growth during the past decades. For instance, Li (2015) used an input-output based structural decomposition analysis (SDA) to examine the key drivers of China's energy consumption between 2007 and 2010. The author concluded that capital formation was the main driving force of China's energy consumption growth between 2007 and 2010. A large proportion of this investment was related to the 4 trillion RMB stimulus package, which aimed to sustain the economic growth in China during the global financial crisis in that period. By contrast, energy consumption related to exports declined,

[11] The total energy consumption increased by 2.2% to 4.26 billion tce (or 4,260 Mtce) in 2014, according to the National Bureau of Statistics (National Bureau of Statistics, 2015).
[12] National Bureau of Statistics (2015) Available from http://data.stats.gov.cn/english/easyquery.htm?cn=C01

although it still accounted for over 30% of the total energy consumption in 2010. Lin and Polenske (1995) examined the changes in energy use in China between 1981 and 1987 using an SDA. The study reached a similar conclusion that the increase in capital formation contributed most to the energy consumption growth between 1981 and 1987, followed by exports, rural and urban household consumption. Similar research was conducted by Guan et al. (2009) focusing on CO_2 emissions[13] between 2002 and 2005. The authors concluded that China's emissions growth was largely driven by exports (accounting for one-half of the total emissions growth), followed by capital formation (one-third) and household consumption (one-sixth). As the economic rebalancing in China starts to take hold, the Chinese economy is switching from an industry-based economy to a service-based economy, and from an investment-driven to a consumption-driven economy. This changing economic policy will inevitably change the drivers of China's energy consumption growth in the future but to what extent is as yet unclear. Furthermore, this approach has merit in explaining the drivers of energy demand in aggregate, but it is difficult to apply this approach to gas consumption in China at regional level as the most recent available input-output data are from 2010 when China's gas consumption remained at a lower level.

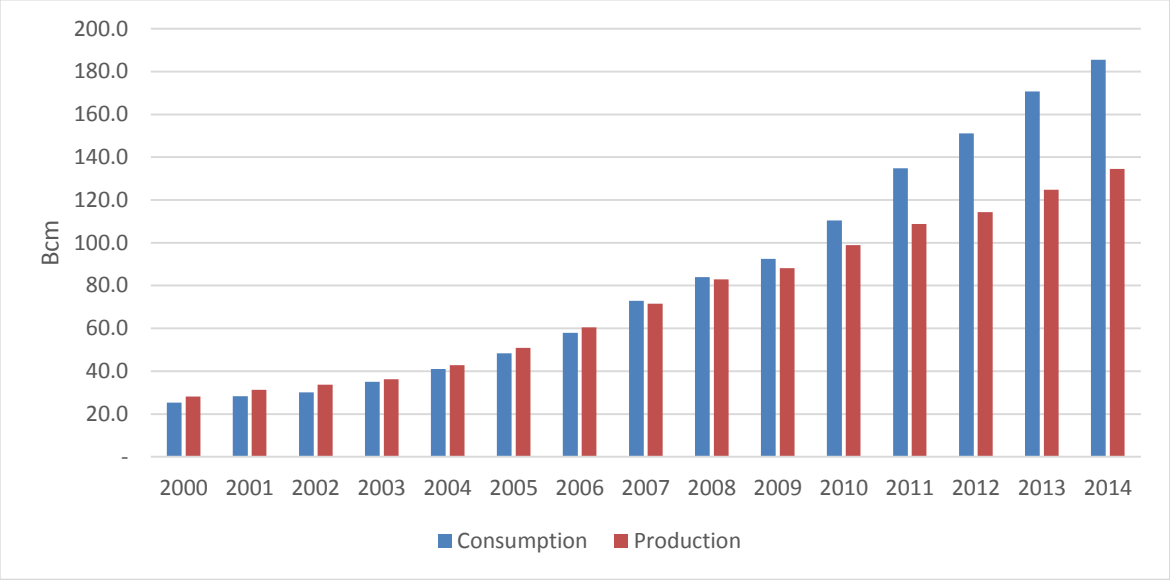
2.2 Natural gas consumption in China

Between 2000 and 2014, total annual natural gas consumption increased from 25.3 to 185.5 Bcm[14]. Industry and energy analyst/agency projections are very optimistic regarding China's gas demand growth. IEA (2014) projected that China's gas demand in 2019 will reach 315 Bcm. Based on this projection, IEA believes that the golden age of natural gas will extend to China over the next five years. China's policy makers are also very positive about gas demand growth: they first projected 230 Bcma demand by 2015 in the Twelfth-Five Year Natural Gas Development Plan (NDRC, 2012), and then projected a 360 Bcma demand by 2020, which would result in gas representing 7.5 % and 10% of the total energy demand, respectively. This growing demand is important to the global gas market. In 2013, China's gas demand increased by 13.3%, which accounted for half of the increasing gas demand in the world. IEA projections show that China will account for 30% of the increasing gas demand between 2014 and 2019[15]. Although the decrease of annual growth rate from 13.9% in 2013 to 8.3% in 2014 was a big shock to global gas suppliers who are targeting the Chinese gas market and who hope to benefit from its prospective gas 'Golden Age', the IEA Gas Medium-Term Report 2015[16] still believed that China's gas demand will double between 2014 and 2020 with an annual growth rate of 10% which is higher than the growth rate seen in 2014.

To achieve a demand target of over 300 Bcm by 2020, China needs to increase its gas consumption by at least 20 Bcm each year on average between 2015 and 2020. Despite an average annual growth rate of 11.8% between 2000 and 2014, domestic gas production since 2006 has been unable to keep pace with consumption. In 2014, domestic gas production, mainly from the three gas basins – Tarim, Ordos and Sichuan – reached 134.5 Bcm. Figure 4 presents the gas consumption and production between 2000 and 2014. It shows that the gap between supply and demand has been increasing since consumption first outweighed production in 2007.

[13] CO_2 emissions usually follow the similar change patterns as energy consumption in China since the majority of China's energy consumption is supplied by coal.
[14] Data are from BP (2015). Note that, for years before 2013, data from BP (2015) are slightly higher than data from various China Energy Statistical Yearbooks.
[15] IEA (2014)
[16] IEA (2015a)

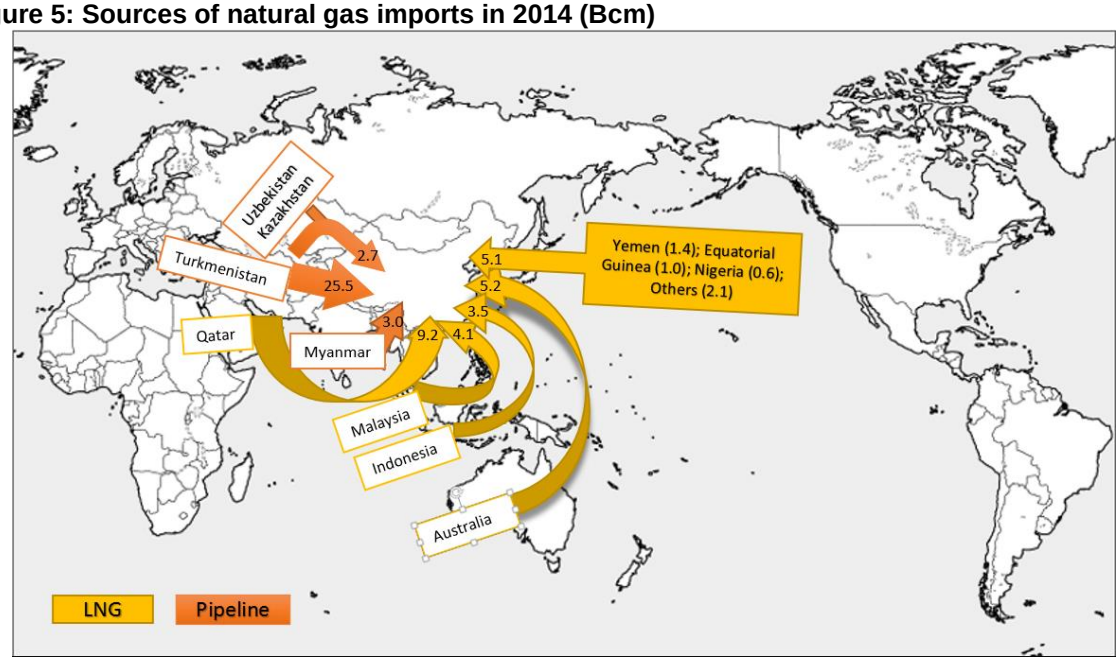
Figure 4: Gas Consumption and Production between 2000 and 2014



Source: Data from BP (2015)

Consequently an increasingly larger proportion of China's gas requirements will be met in future by imports. Figure 5 shows the sources and volumes of gas imports in 2014.

Figure 5: Sources of natural gas imports in 2014 (Bcm)



Source: Own calculation. Original data from Pang (2015)

Although China's natural gas imports have been growing in absolute terms, it has experienced a much lower growth rate in 2014 than in previous years. Table 1 shows China's pipeline and LNG imports between 2010 and 2014. The growth rates of both LNG and pipeline gas imports in 2014 were significantly lower than in previous years.

Table 1: LNG and pipeline gas imports between 2010 and 2014 (Bcm)

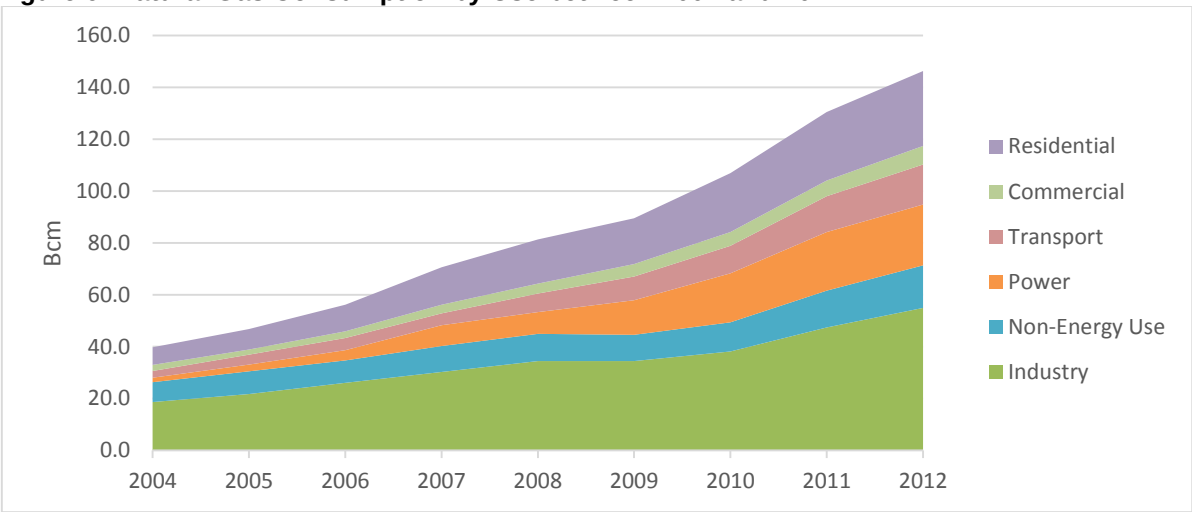
	LNG	% growth	Pipeline Gas	% growth
2010	12.7	-	3.6	-
2011	16.6	30.5%	14.1	291.6%
2012	20.0	20.2%	21.5	52.4%
2013	24.5	22.6%	27.3	27.0%
2014	27.0	10.2%	31.3	14.7%

Source: Pang (2015)

2.3 Natural gas consumption at sectoral level

Natural gas only became important in the non-industrial sectors in the 2000s. Gas use in the Extraction of Petroleum and Natural Gas represented the largest consumption sector of gas use during the 1980s, which was then exceeded by use in the Production of Chemical Products (gas as both feedstock and fuel) in the 1990s.The consumption structure has changed in the 2000s as the residential sector, power generation and transport started to take a larger share of total consumption. For example, in 2012, industry still accounted for the largest share of gas consumption (34%), followed by residential consumption (20%) and power generation (18%). Non-energy, transport and commercial use accounted for 12%, 10% and 6% of total consumption, respectively[17]. Figure 6 shows the natural gas consumption by sector between 2004 and 2012.

Figure 6: Natural Gas Consumption by Use between 2004 and 2012



Source: Data from National Bureau of Statistics (2013) Energy Balance Table 5-1

A diverse range of factors can have impacts on China's gas demand, including proximate resource endowment, access to gas supply (infrastructure), industry structure, urbanization, income, gas and alternative energy prices, environmental awareness, government priorities, seasonal weather variations and so on. In addition the impact of these drivers on gas consumption may differ by sector. For example, gas demand for heating purposes is very significant in China's northern regions, where district heating is required in winter. In Beijing, the gas demand during the heating supply season amounted to 8.5 Bcm in 2014 (total gas demand in the region was 11.3 Bcm). To ensure secure supply, gas use in other sectors was restricted during times of peak heating demand. In addition, the recent pricing reform has had a significant impact on the different categories of end-users. Paltsev

[17] The original natural gas consumption also includes agriculture and construction. Given their small amount of usage (around 0.1 bcma), this study does not include them in the figure.

and Zhang (2015) argued that gas consumption for industry, power and space heating, which accounts for over 50% of China's gas demand, might experience a significant price increase, due to the pricing reform. Similarly, transport gas consumption may also see a big increase in price. These can create effects contradicting the government efforts to promote the growth of gas consumption relative to other fuels. In comparison, a tiered residential gas price will be introduced by the end of 2015. The scheme will offer an unchanged gas price for the volume that is sufficient for 80% of households, though additional demand (above the first tier volume) will be more expensive.

At national level, the varying regional impact of these demand drivers is hidden in the average. For example, in 2012, the proportion of the urban population of China that has access to gas was 33.9%. At regional level, there was a large range from the highest (76.6%) in Beijing to the lowest (0%) in Tibet. In terms of environmental awareness, coastal regions implemented stricter policies to restrict the use of coal and to promote the growth of natural gas (such as the Jing-Jin-Ji Air Pollution and Mitigation Strategy). In a recent OIES publication Chen (2014) discussed the future growth of gas demand in different regions. The study grouped China into three regions, namely the coastal region, central region and western region, and shows that future demand could derive from different sectors in different regions. For example, growing demand in coastal regions will come from the power and heat sector due to the government policy on the replacement of coal-fired boilers with cleaner fuel by 2017. At the same time, the central region will see growing demand in residential and industrial sectors due to the growing trend of urbanization and industry relocation. This underlines the importance of understanding the dynamics of gas demand in different regions.

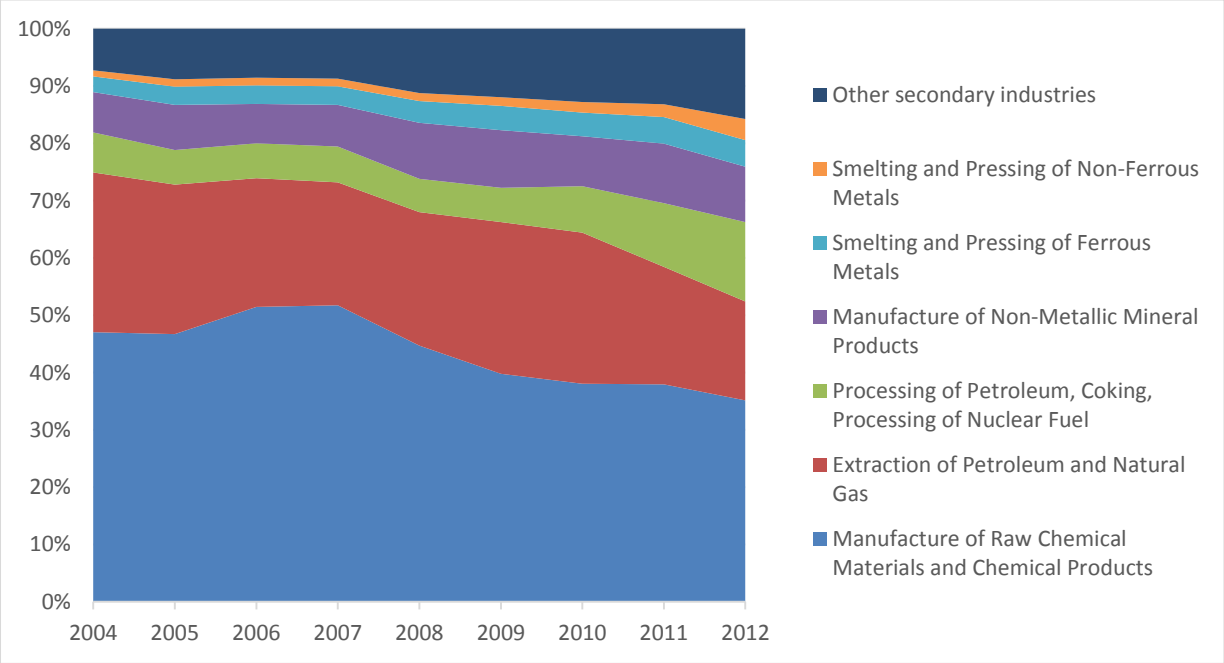
In the present study, we will first examine the factors that drive the growth of gas demand in different sectors and then take into account regional variations. In terms of sector classification, we focus on industrial, residential, transport, and power and heat use.

2.3.1 Industrial gas consumption

To the best of our knowledge, there is no study which addresses the driving forces of industrial gas consumption in China, though industrial gas use represents the largest share in total gas consumption. The National Bureau Statistics (NBS) presents the gas use in thirty-six secondary industries[18]. The top six industrial sectors accounted for 84% of the total industrial gas consumption, all of which are energy-intensive industries (See Figure 7 below). Two traditional industrial gas user sectors, namely the Extraction of Petroleum and Natural gas and the Manufacture of Raw Chemical Materials and Chemical Products, accounted for 52% of the industrial gas consumption in 2012 though their share declined from 75% in 2004. Another 30 industrial gas user groups saw a gradual increase during this period. Consumption is usually classified into two groups: gas use for energy and gas use as feedstock. Gas use as feedstock represented a larger share in the early 2000s. Its share started to decline along with China's economic growth, which was closely linked to the growth of heavy industries and manufacturing during the past 10 years.

[18] The data from the NBS website and the Energy Statistical Yearbook (ESY) are not identical. For example, industry consumption from the NBS website is about 5 Bcm higher than the data from the ESY. Power and Heat use is about 5 Bcm higher in the ESY than the NBS website. Here we use the NBS data which have more details at sector level.

Figure 7: Natural gas consumption by industrial sector between 2004 and 2012



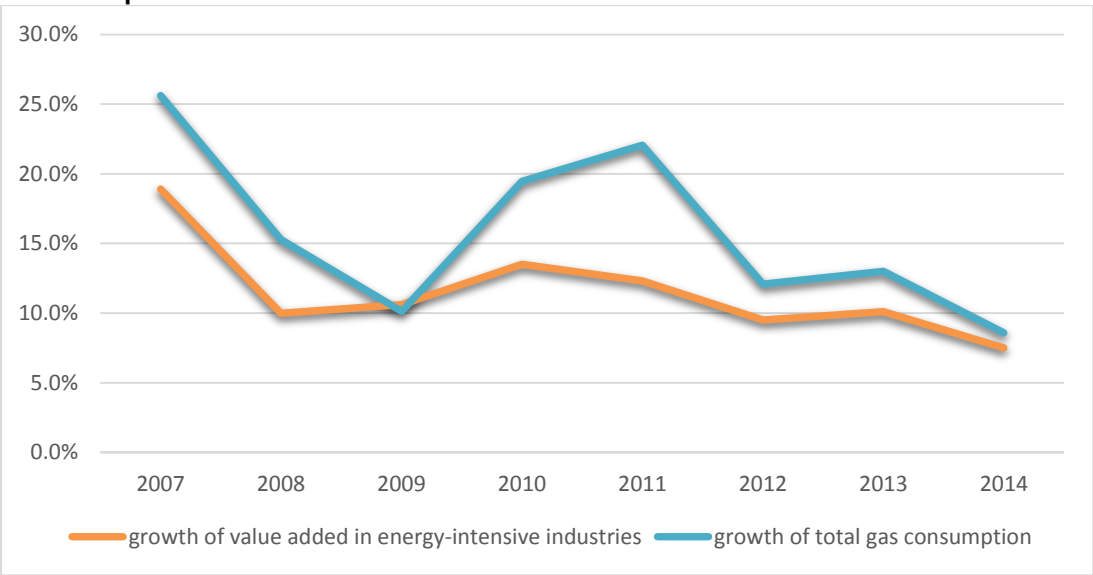
Source: National Bureau of Statistics website

The gas consumption structure is similar to China's industrial total energy consumption structure in which energy-intensive industries also represent the majority of consumption[19]. Some studies argue that the growing role of capital accumulation since 2000 has driven the shift of China's economic structure towards more energy-intensive sectors. Following that, China's energy consumption accelerated. This rapid energy consumption growth was not expected by policy makers. During the Tenth Five Period (2000 – 2005), the government projected that total energy consumption would double between 2000 and 2020. In reality, the total energy consumption has more than tripled between 2000 and 2014 and is expected to almost quadruple the annual consumption of 2000 by 2020. Since 2007, the NBS has started to report the value added annual growth rate of energy-intensive industries[20]. Figure 8 shows that the annual growth of total gas consumption is following a similar trend as annual growth of value added in energy-intensive industries between 2007 and 2014. Thus, **the growth of energy-intensive industries in the economy** has a significant impact on gas use in China.

[19] The top six energy-consuming industrial sectors in China are Smelting and Pressing of Ferrous Metals, Manufacturer of Raw Materials and Chemical Products, Manufacture of Non-Metallic Mineral Projects, Processing of Petroleum, Coking and Processing of Nuclear Fuels, Smelting and Pressing of Non-Ferrous Metals and Mining and Washing of Coal, which represent more than 70% of industrial energy consumption.

[20] By definition, NBS includes Power and Heat Generation and Distribution as one of its six energy-intensive industries instead of Mining and Washing of Coal.

Figure 8: Annual growth of value added in energy-intensive industries and the growth of total gas consumption between 2007 and 2014



Source: growth of valued added in energy-intensive industries is from the various statistical communiqués on national economic and social development; growth of total gas consumption is own calculation based on data from BP (2015)

In the recent years, the **increasing environmental awareness** has promoted the coal-to-gas switch in China, especially in the wealthy and populous coastal regions. The switch presents an opportunity to reduce air pollution by industries which is caused by the excessive use of coal. At present, the switch has only been initiated in small-scale industries, which does not cause a gas demand surge. According to the Ministry of Environmental Protection (2015), the switch has caused an increase of 0.75 Bcm in gas consumption during the first half of 2015. There are several reasons why the switch is not more wide-spread at the moment: First, shortage of gas supply has characterised China's gas development since 2000, up until the slowdown in gas demand growth in 2014. A large-scale coal-to-gas switch would further exacerbate the shortage of supply[21]. Second, small-scale industries are usually less energy-efficient which causes higher emissions than large-scale industries for the same unit of output. Last but not least, the potential capital and operational cost of the switch can be significant, which leads us to the third main drivers of industrial gas demand: **the relative price of gas and alternative energy sources.** Gas is much more expansive than coal for the same unit of energy output. Taking the Jing-Jin-Ji region as an example, the coal-to-gas switch will induce an additional cost of 150 billion RMB by 2020, without considering the capital costs of purchasing new equipment[22]. In addition, the economics of natural gas in comparison to oil have been tempered by the oil price plunge and the recent reform of gas pricing. By the first half of 2015, China's average industrial gas price was about 20% higher than the average price of LPG and fuel oil, which erodes the competitiveness of gas to LPG and fuel oil in industry (see Table 2).

[21] To ensure supply to end-users that cannot be interrupted (such as residential and heating use), the NDRC issued the Natural Gas Utilization Policy in 2012. The Policy classifies the gas use by different end-users into four categories: the prioritised group, the allowed group, the limited use group and the restricted use group. Industrial gas use was prioritised only if the users can bear interruptive gas supply.

[22] Meng and Sun (2014)

Table 2: Industrial fuels cost comparison ($/MMBtu)

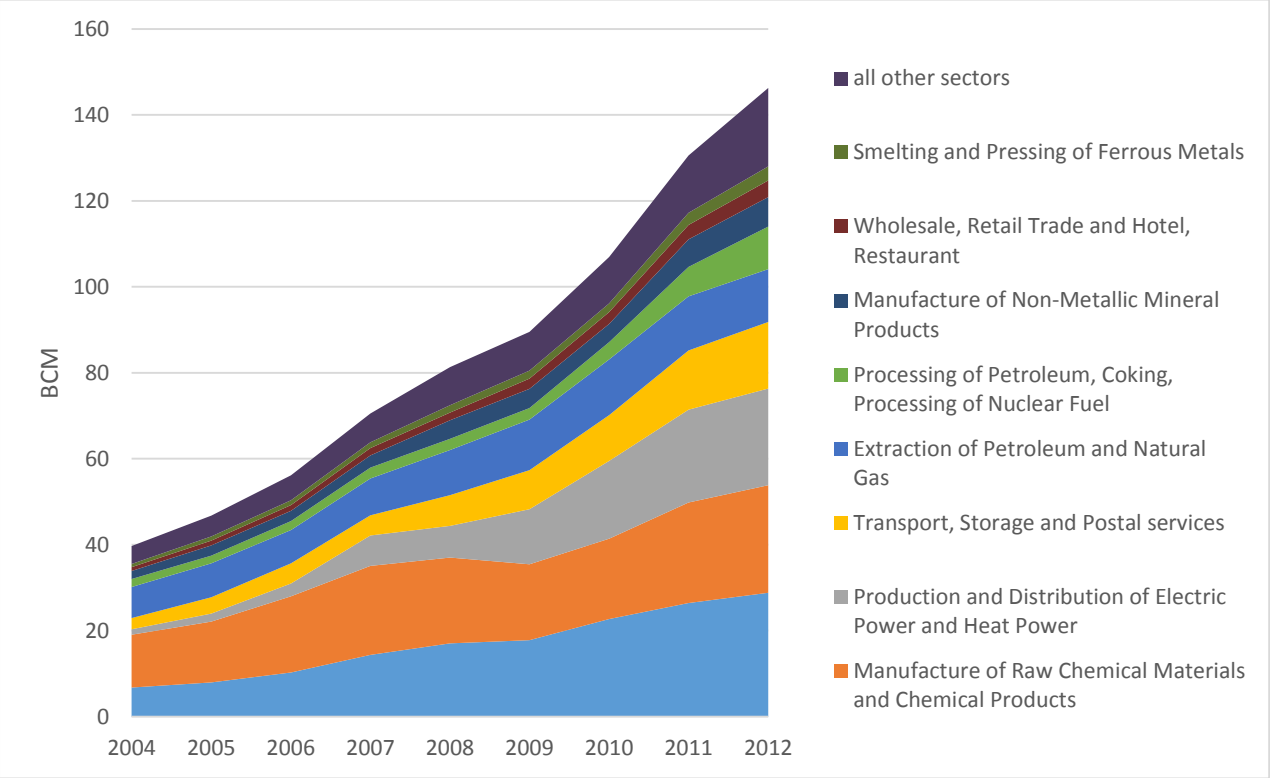
	1st half 2015	2nd half 2014	Changes
Average of LPG + fuel oil price	9.06	16.13	-7.06
Spot LNG price (NE Asia)	7.71	12.13	-4.43
China gas price	11.20	13.30	-2.10

Source: Argus (2015)

2.3.2 Residential gas consumption

In contrast to slowing demand growth in industry, residential gas consumption has been increasing in recent years. One of the main characteristics of China's residential gas demand is **price cross-subsidization.** Cross-subsidization, through which industrial users pay higher gas prices than residential users has a long history in China's gas market. It is not unique to gas pricing, and also applies to the electricity market where, similarly to gas, residential electricity users account for approximately one-quarter of total consumption and pay lower prices than industrial users. This creates a distorted pricing system since residential energy use usually requires higher infrastructure costs. On the other hand, residential users are very sensitive to gas price change: a 1% increase in the gas price rise would reduce residential gas consumption by almost 3%[23]. For this reason, the lower residential price level helps to create a sizeable market within a relatively short time period. By the end of 2012, residential gas consumption accounted for the largest share in total natural gas use at a sectoral level (28.8 Bcm) in 2012, followed by Manufacture of Raw Chemical Materials and Chemical Products (25.0 Bcm)[24] and Production and Distribution of Electric Power and Heat (22.5 Bcm) (See Figure 9). For comparison, residential gas consumption was only 3.2 Bcm in 2000.

Figure 9: Top 10 natural gas consuming sectors between 2004 and 2012



Source: National Bureau of Statistics (2014)

[23] Wang and Lin (2014).
[24] Gas use for energy purposes and as feedstocks.

Differences in **the level of gas-access-rate** (or gas infrastructure development) affect the growth of gas demand between regions. Gas-access-rate measures the proportion of urban population that has access to gas. According to the Urban-Rural Construction Statistical Yearbook 2012[25], the national gas-access-rate was 33.9% in 2012 (total urban population was 711.8 million and the population that uses gas was 241.3 million). Smaller but economically advanced regions have higher gas-access-rates, such as Beijing (76.6%) and Shanghai (62.1%). Gas-producing regions also have above average gas-access-rates, such as Xinjiang (71.4%) and Sichuan (57.0%). However, there are 22 out of 31 regions in China which have gas-access-rates less than 40%. These regions include the less advanced regions, such as Guizhou (4.3%) and Yunnan (3.0%) and also, surprisingly, economically advanced regions, such as Zhejiang (22.6%) and Guangdong (16.4%). These economically advanced regions have lower gas-access-rate because: a) the large urban population (34.6 million for Zhejiang and 71.4 million for Guangdong) compared to other regions (such as 17.8 million for Beijing and 9.8 million for Xinjiang) and b) the absence of infrastructure (the first shipment of LNG from Australia arriving at the Dapeng LNG terminal in 2006 marked the beginning of gas use in Guangdong[26] .

Furthermore, residential gas demand is also associated with **urbanization and income level.** Urban residences dominate residential gas consumption in China. In 2012, rural residences consumed 0.078 Bcm of natural gas, compared to 28.749 Bcm for urban residences. Although almost half of the Chinese population still lives in rural areas, the remote location of, and lower disposal income in, rural areas deter investment in infrastructure which would allow rural residences to have access to gas. A growing proportion of the population lives in urban areas, where natural gas has become popular. By the end of 2014, the urban population accounted for 54.8% (or 749.2 million people) of the total population. The urbanization rate is expected to continue its rise in the medium term to nearly two-thirds of the total population by 2030, which will be broadly in line with other countries with a similar per capital income[27]. Rising disposal income will also drive the growth of gas demand. For instance, Li et al. (2014) concluded that residential gas demand will increase by around 12% with an increase of disposal income of RMB 2,000.

One of the other important factors that promote the growth of gas consumption in the residential sector is the **competitiveness of gas against other energy sources.** Table 3 presents a comparison of the prices of natural gas, LPG and electricity for residential users in June 2015 on an energy equivalent basis. Although tiered gas pricing will be implemented in 2015, the gas price will remain low for first-tier gas users which cover over 80% of residential gas users.

Table 3: The prices of natural gas, LPG and electricity for residential users in June 2015

Fuel Type	$/MMBtu
Natural gas	11.4
Electricity	25.4
LPG	25.0

Data from: CEIC (36 cities average price for natural gas, LPG and electricity), own calculation (exchange rate: 1$ = 6.1169 RMB)

Residential gas use for cooking and water heating purposes (especially in large and medium cities) **is prioritised in the National Gas Utilise Policy**[28] (NDRC, 2012), which means that in a period of gas shortage, residential gas consumption will be guaranteed.

[25] Ministry of Housing and Urban-Rural Development (2013)
[26] Fridley (2008)
[27] World Bank and Development Research Center (2013)
[28] NDRC (2012)

2.3.3 Transportation gas consumption

The Transport sector[29] accounted for 15.6% of total energy consumption in China in 2010. The share is expected to increase with the growing trend of urbanization and rising income level. Oil products, such as gasoline, diesel and heavy fuel oil, accounted for over 90% of the total energy consumption in the transport sector in 2010[30]. It is believed that transportation-related emissions are one of the major sources of air pollution in China. Natural gas vehicles (NGVs) are considered as a promising alternative which have lower levels of emissions of most air pollutants when compared with oil-fuelled vehicles. For instance, TIAX (2007) indicates that NGVs have lower emissions of nitrogen oxides (by 85%), volatile organic compounds (by 18%), and toxics (by 40%), compared with gasoline vehicles. Other studies show that the life-cycle GHG emission and energy consumption of NGV is 28% and 14% lower than for diesel vehicles[31]. Thus, the development of NGVs provides an opportunity for China to achieve its air pollution mitigation and carbon emission reduction targets in the near and medium term in the transport sector.

By the end of 2013, China had over 3 million NGVs[32], which is a significant increase from 6,000 in 2000. They accounted for about 13% of the total gas consumption by 2013. NGVs became popular in recent years, receiving **government support**, including waived highway tolls, subsidies for NGVs and R&D funding for NGV technology development. However, the share of NGVs to total civil vehicles was only 1.8%. The major factors that drive the use of gas in the transport sector include sufficient gas supply, competitiveness of gas compared with gasoline and diesel, and the availability of gas infrastructure (pipelines and refuelling stations)[33].

Sufficient gas supply is considered as one of the most significant factors in natural gas development. Gas producing regions tend to have more NGVs for this reason. For example, in 2013, Xinjiang and Sichuan accounted for 33% of total NGVs in China. The share of NGVs in total vehicles is 27.8% in Xinjiang. However, the largest ownership of NGVs is in Shandong, which has plentiful gas supply from the Shengli and Zhongyuan oil fields and West-East Transmission I. The total number of NGVs in Shandong was 694,500 in 2013, which accounted for 21.5% of the total NGVs in China. The top ten NGV regions represented over 80% of China's total NGV fleet, which are mostly located in northwest China[34].

The number of gas stations can have a significant impact on the development of NGVs. An oversupply may result in lower return on investment, which makes refuelling station less profitable and could damage the interest of investors; while an undersupply may lead to unwillingness of potential NGV owners in purchasing NGVs. Therefore, a vehicle-to-refuelling-station index (VRI) has been introduced as an indicator to reflect the balance between supply (refuelling stations) and demand (number of vehicles). Yeh (2007) suggested that the optimal VRI is usually around 1,000 vehicles to 1 refuelling station. At present, China has 3,732 refuelling stations, the number of gas refuelling stations being associated with the ownership of NGVs in each region. For example, Shandong has the most fuelling stations (473), followed by Xinjiang (362) and Sichuan (315). These regions have higher VRI ratios than the optimal level suggested by Yeh (2007). On average, the VRI in China is about 867:1, which is slightly lower than the optimal VRI.

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[29] Transport sector covers road, railway, air and water transportation.
[30] Yin et al., (2015)
[31] Ou et al.,(2010)
[32] The majority of the vehicles are fuelled by CNG. The total number of CNG and LNG vehicles are 3.2 million and 0.1 million, respectively. For CNG vehicles, see Li (2014) from <http://www.ngvchina.com/uploads/soft/140723/2-140H3105425.ppt> (in Chinese); for LNG vehicles, see Xinhua (2013) <http://news.xinhua08.com/a/20131206/1282146.shtml> (in Chinese). We only report the CNG numbers in the following sections since we do not have detailed data on LNG vehicles.
[33] Wang et al., (2015)
[34] The top ten NGV regions at the end of 2013 were Shandong, Xinjiang, Sichuan, Ningxia, Henan, Inner Mongolia, Hebei, Gansu, Shaanxi and Anhui.

The selection of NGVs is also dependent on their relative costs compared to gasoline and diesel vehicles. This includes the purchase cost of NGVs compared to that of conventional vehicles and the operational and maintenance costs. In general, the cost of NGVs is 10% higher than the cost of conventional oil-based vehicles (COV). The mechanical conversion from a COV to a NGV does not require a substantial investment. The relative cost of gas to gasoline (for the same distance travelled) can provide incentives to potential NGV owners if the ratio is low, but discourage the purchase if the ratio is high. The western regions have a very low ratio, which was around 0.4 in 2013[35]. This could explain the higher NGV ownership in these regions. However, the recent gas price adjustment and the oil price plunge together have damaged the economics of gas for transport use. Taking Sichuan as an example, the average price of 93# gasoline has dropped from 7.73 RMB/litre[36] in May 2014 to 5.76 RMB/litre in September 2015 (by 25.5%). During the same time period, the transport use CNG price dropped from 4.0 RMB/m^3 to 3.7 RMB/m^3 (by 7.5%).

2.3.4 Power and heat generation gas consumption

Power generation in China is one of the largest single sources of global CO_2 emissions. It represents over half of China's coal consumption. Owing to the abundant coal supply and high cost of gas, the use of gas in power and heat generation is very limited compared to international standards. By the end of 2013, gas consumption in power generation was 30.2 Bcm[37]. The absolute volume of gas used in the power sector is significant, since only six countries consume more gas in power and heat generation than China[38]. Total gas generation capacity was 42.7 GW with total power generation of 116.4 TWh in 2013, which accounted for 3.4% and 2.2% of the national total, respectively[39].

Most of the gas-fired power plants are located in the coastal regions as they were constructed in association with the LNG terminals as well as large-scale gas transmission corridors (the west to east transmission pipelines) in China. For example, four gas-fired plants (with total capacity of 4.56 GW) were constructed in association with the Guangdong Dapeng LNG project; in Fujian, the first phase Fujian LNG project includes the construction of three gas-fired power plants. These gas import-associated power plants serve two purposes at the early stage of gas power plant development: first, they present **a source of long term gas demand** which reduces the demand risks for upstream investors; second, constraints on transport capacity limit coal imports from the supply centres in the interior regions to the power demand centres in coastal regions. Thus, **alternatives to coal power generation** are needed.

In recent years, gas has also started to replace coal in power and heat generation due to **environmental considerations** in coastal regions. A number of regional government policies have limited the development of coal-fired power plants in order to alleviate their adverse environmental impacts. With limited renewable energy sources such as wind or solar, two viable options for the coastal regions to provide sufficient power supply are gas-fired power generation and power imports. In addition, the increasing peak-trough demand differences (falling load factor) may support the growth of natural gas-fired plants, where gas is **cost-competitive in providing peaking services[40]**. However, the **administratively-based power pricing** in China does not provide favourable conditions for gas to compete in the power market[41]. Power prices are mainly pre-determined by the national and regional price bureau with minor adjustment after negotiations between suppliers and the price bureau, which do not reflect the dynamics of supply and demand in real time. Furthermore, the era of power shortages of the past decade seems to have come to an end as the Chinese economy

[35] Chen, (2014)

[36] The IV standard 93# wholesale gasoline price (category 1), Data from Sichuan Development and Reform Commission (SCDRC) Available from: <http://www.scdrc.gov.cn/more1_tzgg.htm> [in Chinese]

[37] IEA (2015b)

[38] These six countries are Russia, US, Japan, Saudi Arabia, Iran and United Arab Emirates.

[39] Own calculation. Data from the China Electric Power Yearbook, CEPY (2014)

[40] Kahrl et al., (2013)

[41] Hu et al., (2013)

enters into its 'new normal' phase. With the **slowing down of power demand growth together with the fast expansion of generating capacity**, the average operating hours of fossil fuel based power plants (mainly coal) have been declining. In 2014, the average was 4,706 hours, compared to the 'normal' or designed operating hours of 5,500 hours. It is projected that the operating hours may further decline to less than 4,500 hours in 2015. Compared with normal operating hours, the total surplus in power generation capacity is between 96 and 170 GW[42]. Nevertheless, the competitiveness of gas-fired power generation is very poor compared to coal-fired power generation without considering the externalities.

2.4 A gas demand matrix at national level

Table 4 below summarizes the gas demand matrix that explains the major driving forces of gas demand in the different sectors at national level.

Table 4: Gas demand matrix at national level

	Driver 1	Driver 2	Driver 3	Driver 4
Aggregate	Sufficient gas supply (S)	Affordability of gas relative to other fuels (S)	Increasing environmental standards (S)	
Industrial	Size and growth of energy-intensive industries (S)			
Residential	Price cross-subsidization (S)	The gas-access-rate (S)	Urbanization and income level (S)	
Transport	Availability of gas refuelling stations (M)	Favourable government policy (M)		
Power and heat	A source of long term gas demand (S)	Alternative to coal (M)	Cost-competitive in providing peaking services (M)	Administrative-based power pricing (W) Stagnant power demand growth (W)
Note: Do drivers support gas demand growth? Strongly (S) /moderately (M) /weakly (W)				

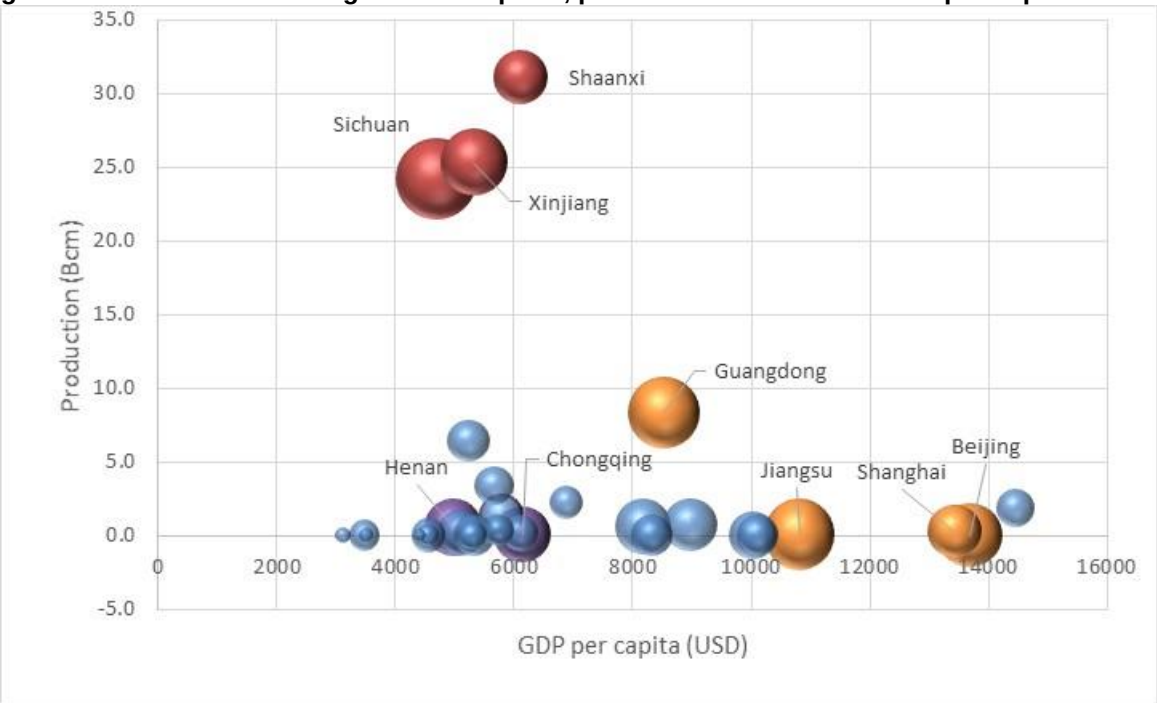
3. Regional consumption: is gas an energy source for the more wealthy provinces?

China's total natural gas consumption was 146.3 Bcm in 2012. Four out of the thirty regions consumed more than 10 Bcm each in 2012, including Sichuan (15.3 Bcm), Guangdong (11.6 Bcm), Jiangsu (11.3 Bcm) and Xinjiang (10.2 Bcm), and together accounted for about one-third of the total gas consumption in China. The top 10 consuming regions together accounted for 62.8% of gas consumption in total. Figure 10 presents the natural gas consumption, production and level of GDP per capita of all 32 provinces in China. Most of the top 10 consumers are either gas resource rich (the orange bubbles) or wealthy provinces (the green bubbles), except Henan and Chongqing (the yellow

[42] Yi, (2015)

bubbles). However, these two regions are adjacent to gas producing regions (e.g. Henan to Shaanxi and Chongqing to Sichuan). Bubble size represents the volume of gas consumption.

Figure 10: Provincial natural gas consumption, production and level of GDP per capita in 2012

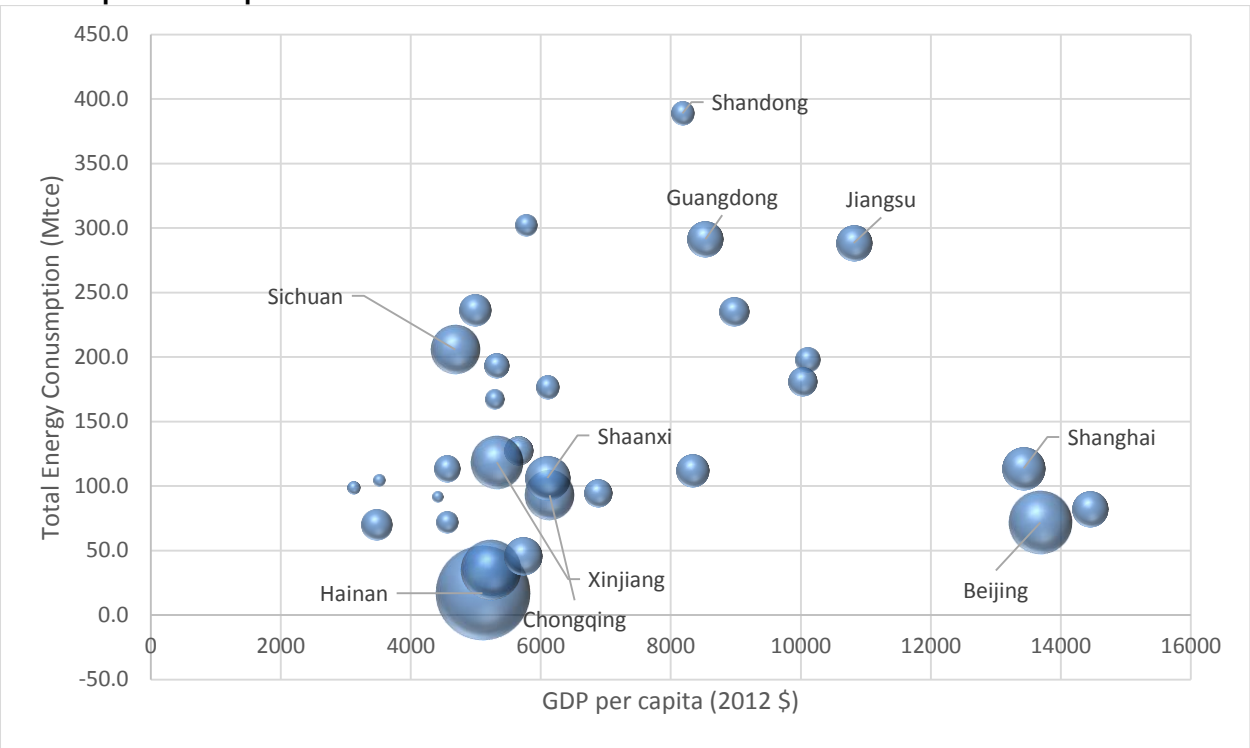


Note: Orange: gas producing regions; Green: wealthy regions; Yellow: adjacent to gas producing regions; blue: other regions

Source: Own estimation. Gas consumption and production from National Bureau of Statistics (2013); GDP/capita data from various provincial statistical yearbooks.

Due to the energy-dependent nature of the Chinese economy, coastal regions (affluent due to industrial activity) tend to have larger energy consumption. However, larger gas consumption volume does not necessarily mean higher share in total energy consumption. For example, natural gas accounted for only 6.3% of the total energy consumption in Guangdong, which is the second largest gas consuming region in China in 2012 with total consumption of 11.7 Bcm. Hainan, in the South China, derives a higher proportion of its energy consumption from natural gas than all other provinces in China. Natural gas accounted for 37.4% of its total energy consumption. Figure 11 presents the total energy consumption, GDP per capita and share of natural gas in total energy consumption of all provinces in 2012. The size of the bubble represents the share of natural gas in total energy consumption. It shows that natural gas tends to have larger shares in lower energy consuming regions. The share of natural gas in total energy consumption is the highest in Hainan Province (37.4%), a region which has the lowest level of energy consumption among all regions in China (16.9 Mtce), but has a fair level of gas consumption (4.6 Bcm).

Figure 11: Total energy consumption, GDP per capita and share of natural gas in total energy consumption of all provinces in 2012



Source: Own estimation. Gas consumption and total energy consumption data are from National Bureau of Statistics, (2013); GDP per capita data are from various provincial statistical yearbooks.

The following subsections illustrate the gas consumption patterns of various provinces in China. The selected regions can be considered as representatives of: the wealthy regions (Guangdong and Beijing), the gas producing regions (Sichuan and Shaanxi), and other regions (Shandong).

3.1 Guangdong

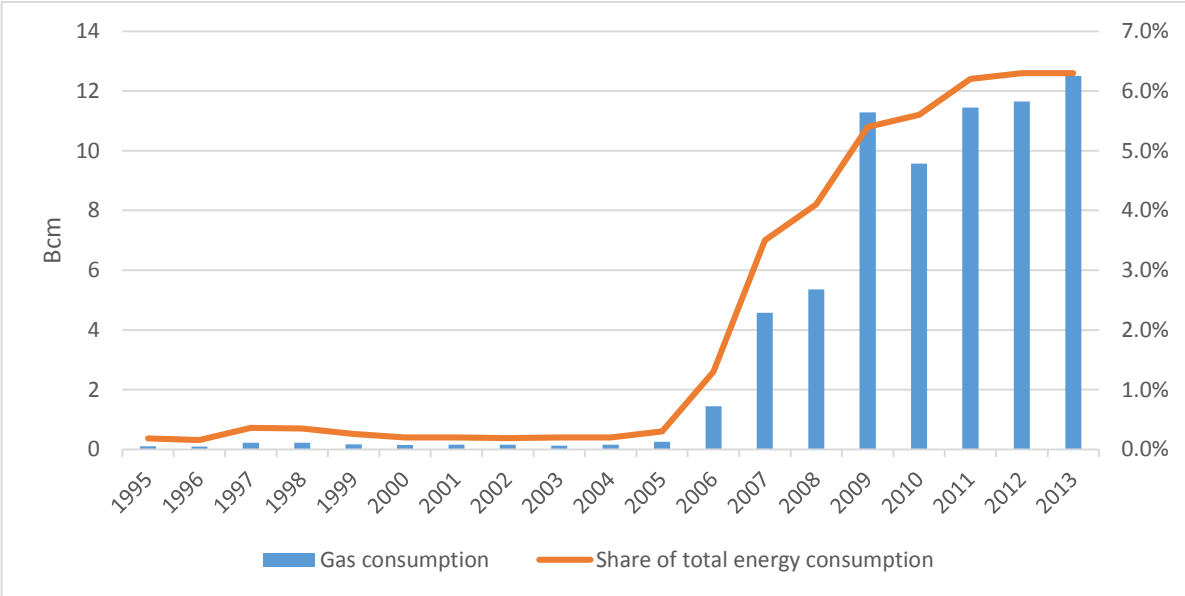
Basic Information	
Nominal GDP in 2014 (million USD)	1,103,605
Population in 2014	107,240,000
Total energy consumption in 2013 (Mtce)	256
Total gas consumption in 2013 (Bcm)	12.5
Share of gas in total energy consumption in 2013 (%)	6.3

Guangdong is located in South China, next to Hong Kong. It is one of the most affluent provinces in China, with higher total GDP than any other province in 2014[43]. It had a very low level of gas

[43] For comparison, Guangdong has a larger GDP than the Netherlands (866,354 million USD) and a smaller GDP than Spain (1,406,855 million USD) in 2014.

consumption until 2005, when the total gas consumption was only 0.25 Bcm. Between 2006 and 2013, gas consumption increased from 1.5 Bcm to 12.5 Bcm[44]. Despite the significant growth, the share of natural gas in total energy consumption was still at a low level (6.3% in 2013). Figure 12 shows the volume of gas consumption and its share of total energy consumption in Guangdong between 1995 and 2013.

Figure 12: Gas consumption and share of total energy consumption in Guangdong between 1995 and 2013



Source: Own estimation. Data from various Energy Statistical Yearbooks (1996 – 2013) and Guangdong Statistical Yearbook (2014)

The Guangdong Twelfth-Five Year Energy Development Plan (published in September 2013) proposed a sharp increase in the share of natural gas to 13.2% of total primary energy consumption that is limited to 359 Mtce (which is equivalent to about 36.7 Bcm). The planned supply capability will reach 43 Bcm by 2015 in order to satisfy the growing demand[45]. The major sources of gas supply are listed in Table 5. In general, there are three sources of gas supply to Guangdong, namely LNG imports from Australia, Qatar, and Malaysia, pipeline imports from the West-to-East gas transmission (which includes gas supply from Central Asia) and offshore gas production. Along with the increase in gas supply capability, the length of the transportation and distribution network will reach 3,300km by 2015.

[44] Own calculation. The 2013 data is from the Guangdong Statistical Yearbook, Table 7.2. The data gives the primary energy consumption (256.5 Mtce) and the share of gas (6.3%) in Guangdong. Conversion factors are 1 Mtce = 0.774 Bcm based on 1 Mtce = 0.697 Mtoe and 1 Bcm = 0.9 Mtoe.

[45] Guangdong Development and Reform Commission (2013) Guangdong Twelfth-Five Year Energy Development Plan, <http://www.gddpc.gov.cn/fzgggz/fzgh/zxgh/sewzx/201410/t20141027_264355.html>

Table 5: Sources of gas supply in Guangdong

Source	Capacity (Bcma)	Status
Shenzhen Dapeng LNG terminal	8	In operation
Zhuhai Hengqin Island offshore NG terminal	2	In operation
West-to-East gas transmission phase II	10	Due in 2015
Zhuhai LNG terminal	4.7	Under construction
South China Sea Zhuhai Gaolangang offshore NG terminal (Phase I)	8 – 10	Under construction
Shenzhen Diefu LNG terminal	2.6	Under construction
West-to-East gas transmission phase III	10	Planned
PetroChina Shenzhen LNG terminal	4	Planned
East Guangdong (Xieyang) LNG terminal	2.6	Planned
West Guangdong (Zhanjiang) LNG terminal	4	Planned

Source: NDRC (2012) the status of gas supply and demand in Guangdong. Available from: http://yxj.ndrc.gov.cn/zttp/trqyfddzl/2012trqdd/201211/t20121114_514085.html

Gas consumption has not followed the trajectory designed by the Guangdong DRC (2013). Apart from a sharp rise between 2008 and 2009, gas demand growth has been moderate during the last five years. Between 2010 and 2013, the average annual growth rate was 9.3%. Assuming this growth rate also applies to the following years in the twelfth-five year period, the total gas demand will only reach 14.9 Bcm in 2015.

At sectoral level, power generation accounted for the largest share of gas consumption growth since 2006, except in 2009 when industrial use overtook power generation by 2% (44% vs 42%)[46]. In 2012, half of Guangdong's gas supply was consumed in power generation, followed by industrial use (30%) and residential use (11%). Four gas-fired power plants with a total generation capacity of 4.56 GW are constructed, and are associated with the construction of the Dapeng LNG terminal project. Gas consumption in power generation (amounted to 2.3 Bcm) accounted for 55% of the LNG imports from Australia. By the first quarter of 2014, total gas-fired generation capacity was 11.1 GW[47], 13% of the total power generation capacity in Guangdong. With the increasing requirement for better air quality and the restrictions on coal power generation, gas-fired capacity is expected to double by the end of 2020[48]. However, there are uncertainties associated with the power pricing mechanism. For example, Shan points out that the 9F-Class gas turbines installed before the twelfth five period in Guangdong are able to recover their costs since they pay the LNG price imported from Australia in 2003 (a low priced contract). With the increasing price of imported gas, gas units built after the twelfth-five period have been struggling to recover costs.

Industrial gas use represented the second largest gas consumption sector, 30% of the total gas consumption in 2012. In the same year, industry accounted for 48.5% of the total GDP in Guangdong. Residential gas use accounted for 1.2 Bcm or 11% of the total gas consumption in 2012. The lower level of gas consumption is due to the low gas-access-rate (it was 16.4%, compared with the national average of 33.9%). The share of gas consumption represented by the commercial[49] and transport

[46] There is no empirical evidence that can explain the sudden jump of industrial gas use in 2009.

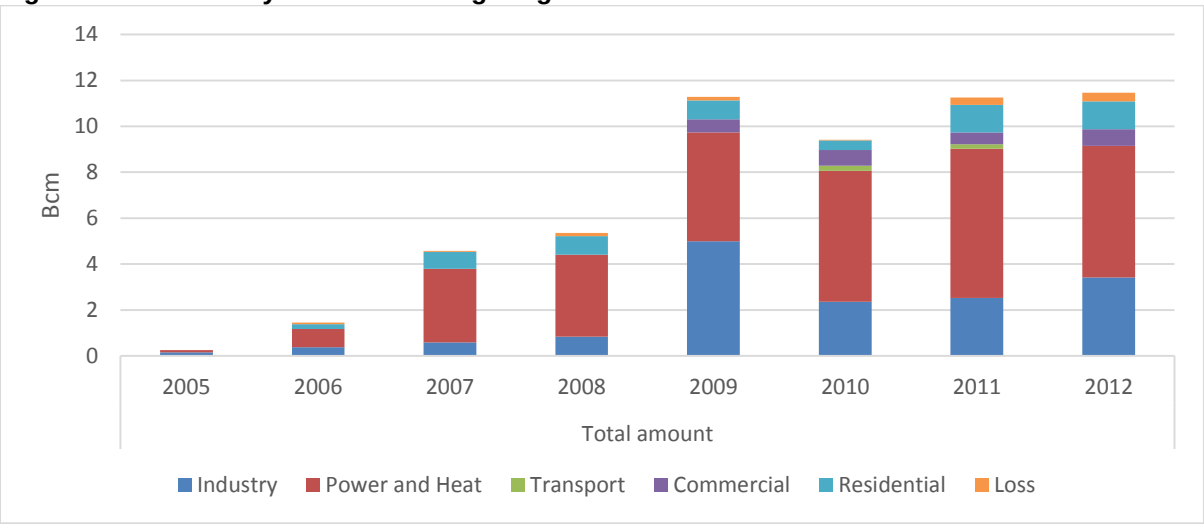
[47] By the first quarter 2014, Guangdong had 49 gas-fired units, including 13 9F class gas turbines (with generation capacity of 390 MW) and 31 9E Class gas turbines (with generation capacity of 180 MW), and other gas turbines. The 9E Class gas turbine is one of the most fuel-flexible gas turbines in the industry. It can use natural gas, light and heavy distillate oil, crude oil and other types of fuel. The 9F Class gas turbine is more efficient and has the lowest life cycle cost in its class.

[48] Shan (2014)

[49] The Commercial sector include two subsectors, 1) wholesale, retail trade and hotels, restaurants; and 2) Others. There is no clear definition of what 'Others' include in the energy statistical yearbook. The author assumes it represents the rest of the service industries, such as financial services, real estate services and so on.

sectors remained low over this period. Figure 13 shows the natural gas consumption by sector in Guangdong between 2005 and 2012.

Figure 13: Gas use by sector in Guangdong between 2005 and 2012



Source: Own estimates. Data from various Energy Statistical Yearbooks (1996 – 2013)

3.2 Beijing

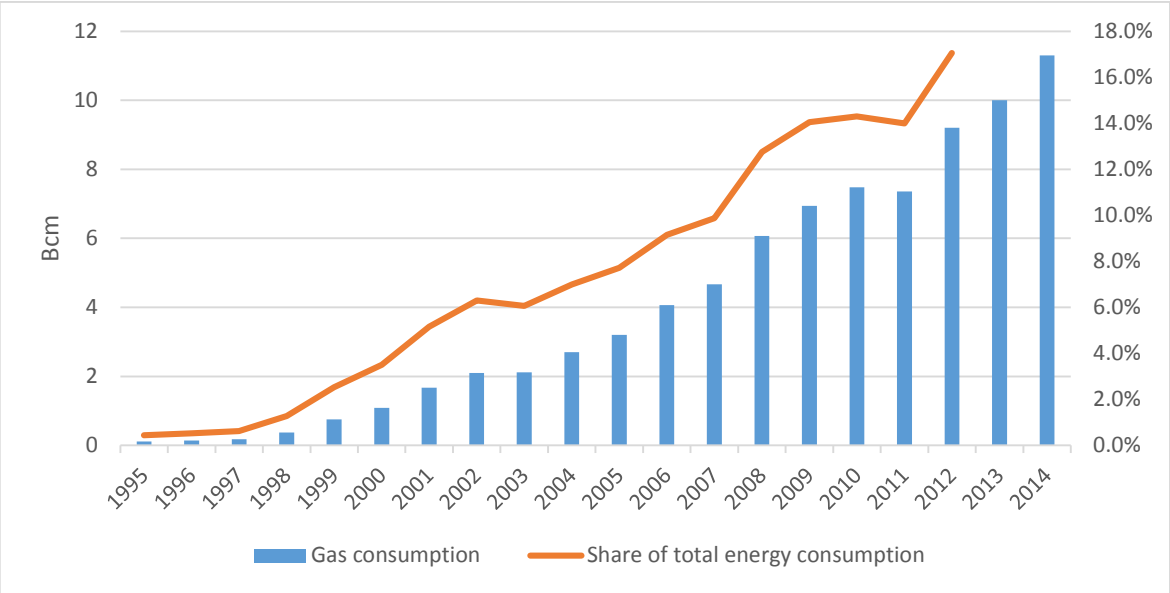
Basic Information	
Nominal GDP in 2014 (million USD)	347,249
Population in 2014	21,516,000
Total energy consumption in 2013 (Mtce)	74
Total gas consumption in 2013 (Bcm)	11.3
Share of gas in total energy consumption in 2013 (%)	13

By the end of 2014, Beijing had one of the highest levels of GDP per capita ($16,278) in China[50], second only to Tianjin ($17,126). The region consumed 11.3 Bcm of natural gas in 2014, this being a 13% increase on 2013 (compared to the 8-9% increase at national level[51]). The return to double-digit growth results from a higher demand in the heat supply season (usually between November and March). The warmer winter in 2013 reduced gas demand to 6.4 Bcm during the heat supply season. In contrast, gas demand at the same period was 6.8 Bcm in 2012 and 8.5 Bcm in 2014[52]. The sharp increase of gas demand in 2014 was also due to the installation of nine gas-fired heat and power generation units in the northwest and northeast part of Beijing as well as the demolition of coal-fired

[50] For comparison, Beijing's total GDP in 2014 is larger than Denmark (340,806) and smaller than Austria (437,123).
[51] IEA (2015a)
[52] Data from NRDC (2012 – 2014) various Beijing natural gas peaking supply work summaries (2012 – 2014), the 2012 data is available from: <http://yxj.ndrc.gov.cn/zttp/trqyfddzl/2012trqdd/201304/t20130427_538903.html>

boiler capacity (6,595 steam tonnes or 4,617 MW[53]). The region has shown a growing trend in natural gas use in terms of both the absolute amount and the share of total energy consumption in recent years, despite a minor decline in 2011 (See Figure 14). However, seasonal variations are significant. The gas use during the heat supply period accounted for more than 65% of the total gas use in 2013. The ratio of daily peaking demand to daily trough demand is consistently above 10. On average, gas use will increase by 1.8 – 2 million m^3 /day with a 1°C fall in temperature.

Figure 14: Gas consumption in Beijing and its share in total energy consumption between 1995 and 2014



Source: Own estimates. Data between 1995 and 2012 are from various Energy Statistical Yearbooks (1996 – 2013); the 2013 and 2014 gas consumption data are from NDRC (2014, 2015)[54]

According to the Beijing Twelfth-Five Year Gas Development Plan[55], natural gas consumption will reach 18 Bcm in 2015, which will account for over 20% of the total primary energy consumption in Beijing. To achieve the growing demand, the plan proposed to make available gas supply from the Shaanxi to Beijing Gas Transmission project, the Datang coal-to-gas project and Tangshan LNG imports, which have supply capabilities of 20 Bcma. In fact, Beijing's gas supply has been at the top of the gas development agenda of the national government. In the late 1990s and 2000s, the Shaanxi-Beijing pipeline phases I and II were constructed to supply a total amount of 15.6 Bcma of gas to Beijing and its surrounding areas (such as Tianjin, Shandong and Hebei). In 2011, Phase III of the Shaanxi-Beijing pipeline was completed with a gas supply capacity of 15 Bcma. Phase IV of the pipeline was approved by the NDRC in 2014 and is due for completion in 2016, with a planned supply capacity of 30 Bcma, which will secure gas supply to the Beijing and the Bohai Bay area[56].

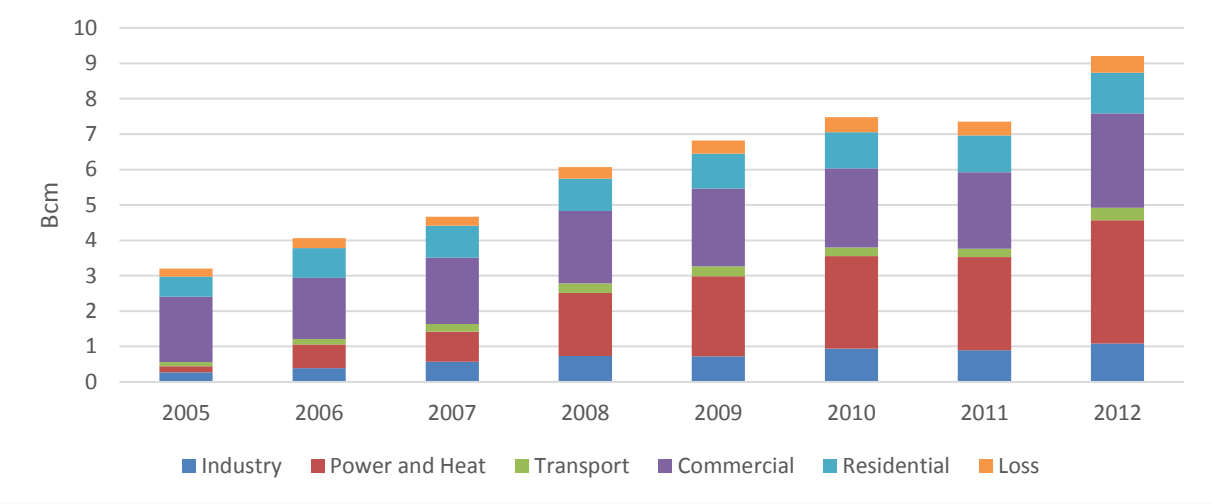
At a sectoral level, Beijing shows a different evolving consumption pattern compared to Guangdong. Commercial use accounted for the largest share in gas consumption until 2008. Power and Heat Generation then overtook the commercial sector to become the largest gas consumer in 2009. By the end of 2012, it accounted for 38% of total gas consumption in Beijing, followed by 29% in the commercial sector and 13% in the residential sector. Commercial gas use includes gas consumption

[53] One steam tonne represents one ton of steam produced by a specific boiler per hour. Usually, 1 steam tonnes is equal to about 0.7 MW.
[54] NDRC (2014,2015) Beijing 2013, 2014 Gas Peaking Service work summaries
[55] Beijing Municipal Commission of City Administration and Environment, (2011)
[56] NDRC (2014a)

in a) the wholesale, hotels and restaurant (WHR) sector, and b) other services. For the Wholesale, Hotel and Restaurant sector, gas can be used for either heating or cooking purposes. As the potential use of natural gas in other service industries is quite limited (mainly for space heating, water heating and cooling), gas consumed in other services is mainly for heating purposes. In Beijing, gas consumption in the WHR sector has varied between 0.45 and 0.53 Bcm from 2005 to 2012; for other services, gas consumption increased from 1.35 to 2.13 Bcm during the same period. The purpose of gas consumption in the residential sector is very similar to that found in commercial sectors.

Beijing does not have a large industrial base as the city serves as the cultural and administrative centre of China. In 2014, industry accounted for 21.4% of the GDP with the majority of it represented by services (77.9%) and 0.7% by agriculture[57]. Industrial gas use has remained at around 12% during this period (See Figure 15).

Figure 15: Gas use by sector in Beijing between 2005 and 2012



Source: Own estimates. Data from various energy statistical yearbooks

3.3 Sichuan

Basic Information	
Nominal GDP in 2014 (million USD)	464,555
Population in 2014	81,402,000
Total energy consumption in 2013 (Mtce)	178
Total gas consumption in 2013 (Bcm)	14.8
Share of gas in total energy consumption in 2013 (%)	11.1

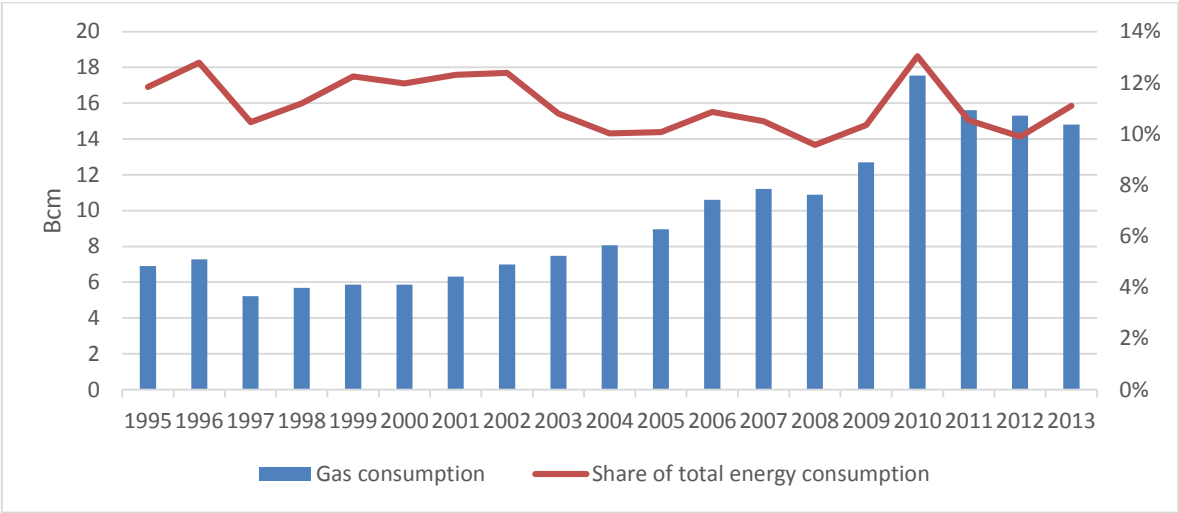
Sichuan is located in the upper reaches of the Yangtze River, in Southwest China. Total GDP reached 465,555 million USD by the end of 2014, which is larger than the GDP of Austria (437,123) but smaller than Norway (500,244). It is the third largest gas producing province in China. Total gas

[57] Beijing Bureau of Statistics (2015)

production reached 26.5 Bcm in 2013[58]. Over half of its gas production (55.8%) was consumed in the province, making Sichuan the largest gas consumer in China in that year. However, natural gas consumption has declined since 2010, when it reached a peak of 17.5 Bcm. In 2013, gas consumption was 14.8 Bcm, a slight decline from 15.3 Bcm in 2012. In addition, the share of natural gas in total energy consumption dropped from 13% in 2010 to 11.1% in 2013 (See Figure 16). Gas exports from Sichuan to other provinces increased from 4.8 Bcm in 2005 to 16.4 Bcm in 2013.

The projection of natural gas demand, similar to Guangdong and Beijing, overestimated the growth potential. The Sichuan Twelfth Year Energy Development Plan (published in 2011) set a target of 26 Bcm gas demand by 2015, which would account for 13.1% of the total primary energy consumption in Sichuan[59]. Given its large domestic gas reserves, the region aims to increase its production capacity to over 40 Bcm by 2015 and increase the gas access rate to 90% in the residential sector.

Figure 16: Gas consumption in Sichuan and its share in total energy consumption between 1995 and 2013



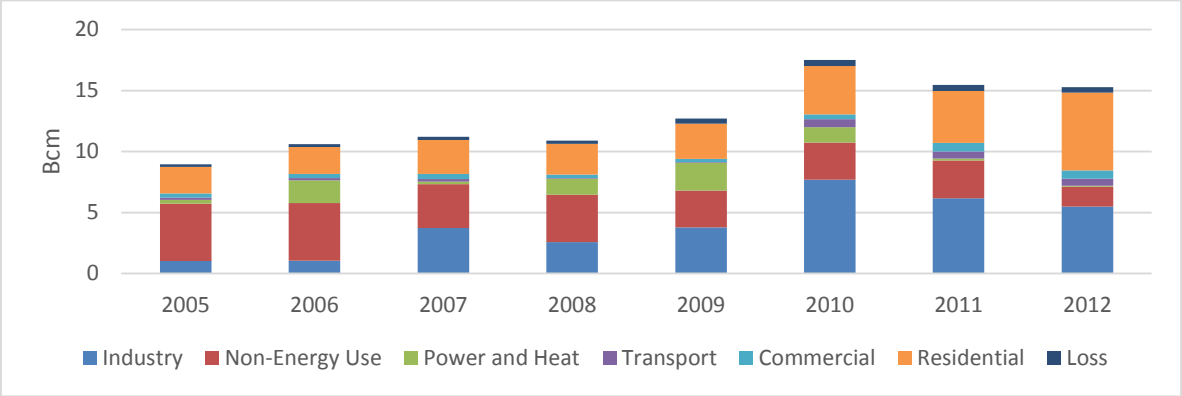
Source: Own estimates. Data for 1995 till 2012 are from various energy statistical yearbooks; Data for 2013 are from the Sichuan Statistical Yearbook (2014), Table 6-8.

Sectoral gas consumption in Sichuan shows a variable pattern. For example, power generation accounted for 18% of total gas consumption in 2006, but dropped to 2% in 2007 and bounced back to 12% in 2008. In 2012, gas use in power generation represented only 1% of total gas consumption. One possible explanation for this variable gas usage in power generation is the large amount of hydropower generation in Sichuan, which also has large annual variations. For example, hydropower outputs[60] increased from 97.9 TWh in 2009 to 202.4 TWh in 2013, 66.2% and 76.7% of the total power generation, respectively. The Sichuan energy policy creates favourable conditions for hydropower development. The Sichuan Twelfth Five Year Energy Development Plan proposes the construction of a 700 MW gas-fired power plant with total investment of 2.4 billion RMB, compared to the 30.2 GW expansion plan for hydropower plant with total investment of 300 billion RMB between 2010 and 2015. Industrial gas use accounted for 10% of the total gas consumption in 2006, increasing to 33% in 2007 and dropping to 24% in 2008. By contrast, residential gas usage increased from 2.2 Bcm in 2005 to 6.4 Bcm in 2012, with the largest share in gas consumption in 2012 (42%),

[58] Data from the Sichuan Statistical Yearbook (2014) Table 6-8 [In Chinese].
[59] The projection is based on the gas consumption level in 2010 of 17.5 Bcm with an annual growth rate of 8.25%.
[60] The original data states defined the category as 'total hydropower, nuclear power and other power generation sources'. However, Sichuan has one nuclear power plant (Sanba Nuclear Power Plant), which is not in operation until 2014. Total installed wind power capacity is 157 MW by the end of 2013. Other power generation sources (solar power) are also very limited. Based on these, the author assumes this category represents hydropower outputs in Sichuan in 2013.

followed by industrial use (36%) and non-energy use (11%). By the end of 2012, the gas access rate was 57% (20 million out of 35 million urban population), which was among the highest in the country. In fact, Sichuan is among the first provinces to use natural gas in China and has a relatively mature gas infrastructure due to its endowment in gas resources. By the end of 2004, it owned the majority of the gas transport capacity in China, which allowed the region to distribute up to 11 Bcma of natural gas production. Fertiliser production was one of the main gas users from the early 2000s thanks to the development of transmission infrastructure built primarily to supply gas to fertiliser manufacturers. It accounted for 52% of total gas consumption in 2005 but declined to 11% in 2012. Figure 17 presents the sectoral gas use in Sichuan between 2005 and 2012.

Figure 17: Gas use by sector in Sichuan between 2005 and 2012



Source: Own estimates. Data from various energy statistical yearbooks

3.4 Shaanxi

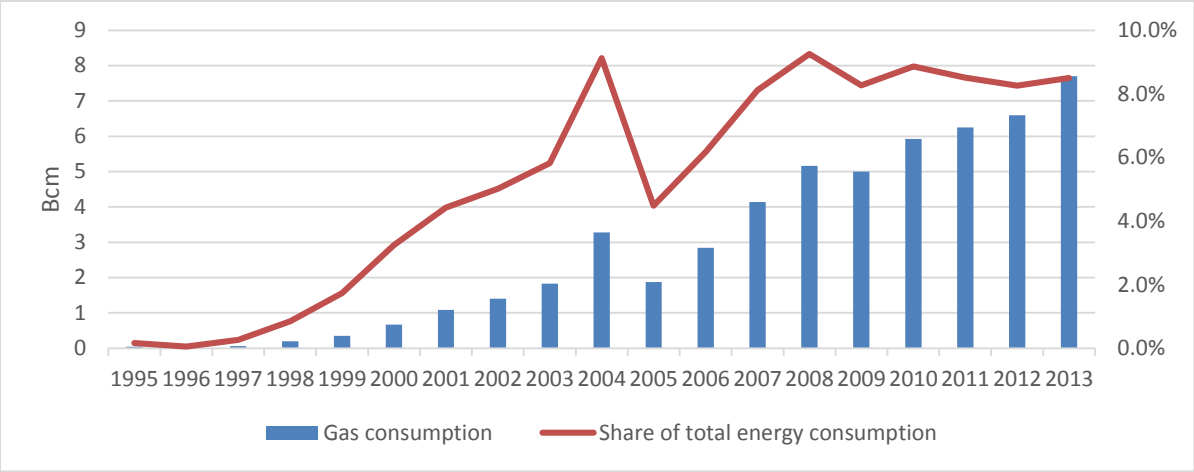
Basic Information	
Nominal GDP in 2014 (million USD)	287,978
Population in 2014	37,751,200
Total energy consumption in 2013 (Mtce)	118
Total gas consumption in 2013 (Bcm)	7.7
Share of gas in total energy consumption in 2013 (%)	8.5

Shaanxi is located in the Northwest of China. The region ranked 16th out of the 31 provinces in terms of nominal GDP in 2014 but is endowed with a range of energy sources. Total energy production amounted to 446 Mtce in 2013, of which only about one-quarter was consumed within the region (118 Mtce). Shaanxi was the third largest coal producer in 2013, behind Inner Mongolia and Shanxi; and is also the largest gas producer, accounting for 29% of China's total gas production in 2012 (31.1 Bcm).

As the main supplier to the Shaan-Jing gas transmission system, the majority of the gas production in Shaanxi is exported to other provinces, which made Shaanxi only the 9th largest gas consuming

province in China with a total consumption of 7.7 Bcm in 2013[61]. Figure 18 shows the total gas consumption and its share of total energy consumption in Shaanxi between 1995 and 2012. Despite a sharp decline between 2004 and 2005, gas consumption in Shaanxi experienced a steady growth from 2005. Its share in total energy consumption showed a downward trend after reaching its peak in 2008 (9.3%). In 2013, gas represented 8.5% of the total energy consumption in Shaanxi. The Shaanxi Twelfth Five Year Energy Development Plan projects that gas consumption will reach 12.5 Bcm by the end of 2015, which will represent about 12% of the total primary energy consumption in Shaanxi. At the same time, gas exports will reach 30 Bcm, which means an additional 22.5 Bcma of gas production between 2011 and 2015.

Figure 18: Gas consumption in Shaanxi and its share in total energy consumption between 1995 and 2012

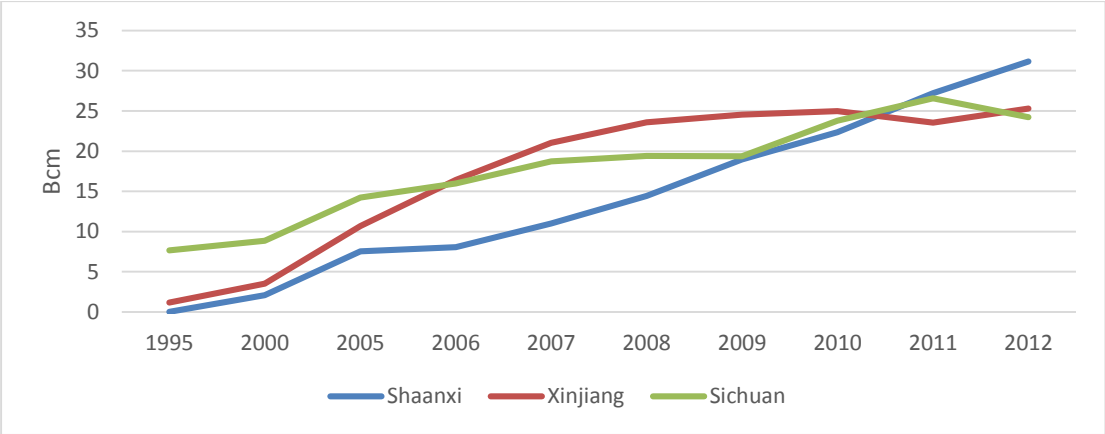


Source: Own estimates. Data from various statistical yearbooks

At sector level, industrial use dominates gas consumption in Shaanxi, with 53% of the total gas consumption in 2012, followed by residential (22%) and commercial use (13%). This corresponds to the large share of industry in Shaanxi's GDP, 54.8% of total GDP ahead of services (36.4%) and agriculture (8.8%). Transport gas use has been growing since 2009, and represented 8% of total gas use in 2012. By the end of 2013, the total number of NGVs is 100,500 with 227 gas-refuelling stations. Power and heat generation was one of the main gas users. It accounted for 17% of total gas consumption in 2005, but dropped to 4% in 2012. Unlike Sichuan, residential consumption does not represent a significant share in total gas consumption, because Shaanxi has a lower level of gas-access rate (45.2%), compared to Sichuan (57%) owing to the later development of gas production. Figure 19 compares gas production in Sichuan, Xinjiang and Shaanxi between 1995 and 2012, and shows that gas production in Shaanxi only become significant in the later 2000s. In addition, Shaanxi has a smaller urban population, 18.8 million by 2012 compared with 35.2 million in Sichuan.

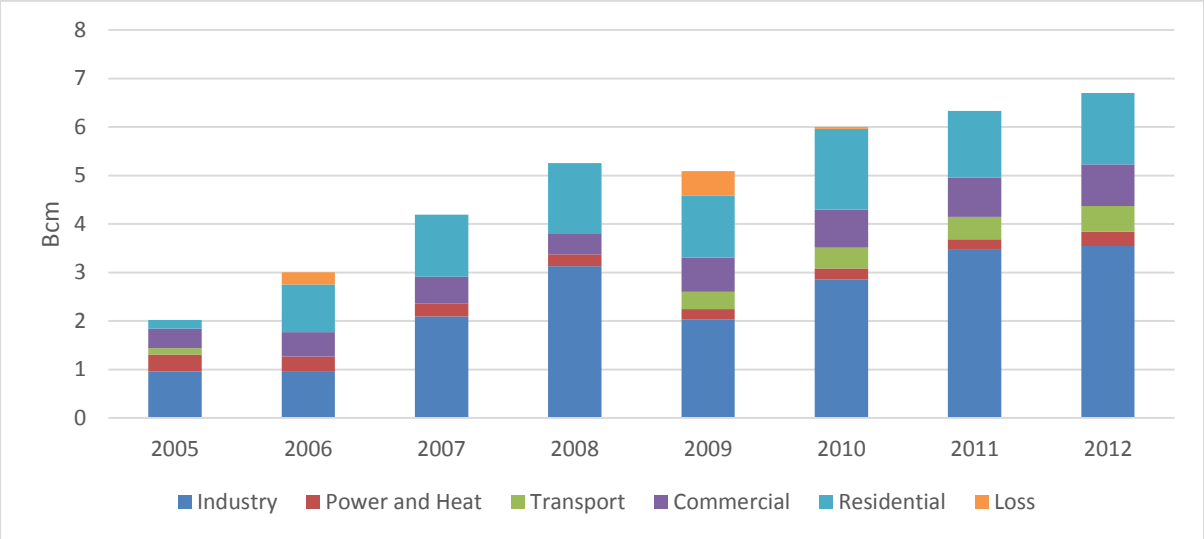
[61] Own calculation. Data from Shaanxi Statistical Yearbook (2014), which shows that daily gas consumption was 21.19 mcm/day in 2013.

Figure 19: A comparison of gas production in Shaanxi, Xinjiang and Sichuan between 1995 and 2012



Source: National Bureau of Statistics (2013)

Figure 20: Gas use by sector in Shaanxi between 2005 and 2012



Source: Own estimates. Data from various energy statistical yearbooks

3.5 Shandong

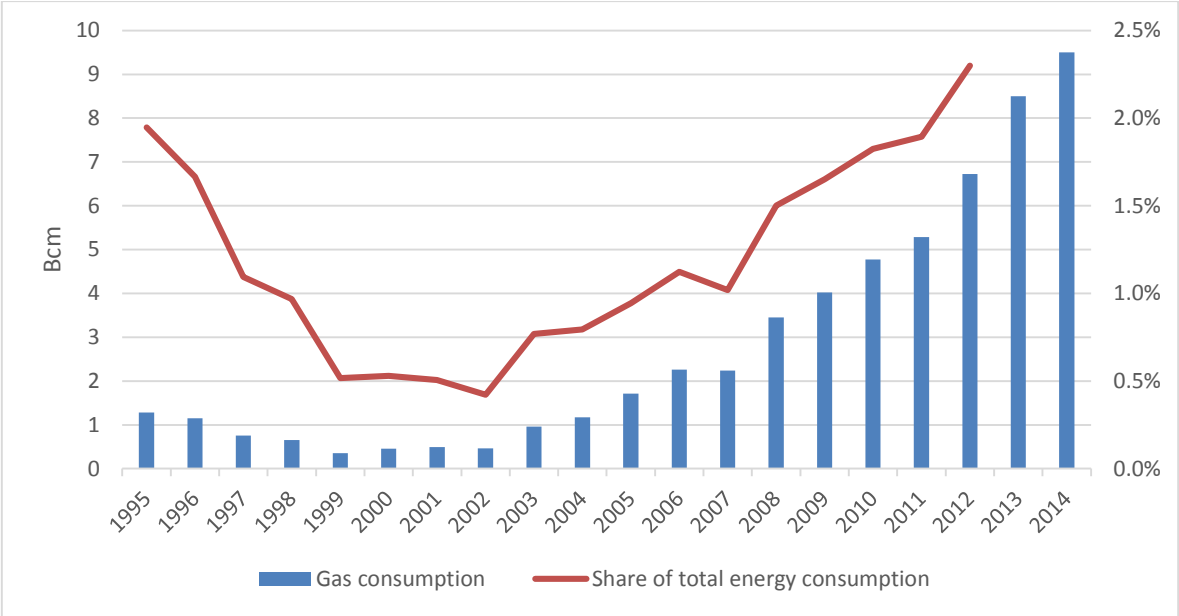
Basic Information	
Nominal GDP in 2014 (million USD)	967,419
Population in 2014	97,894,300
Total energy consumption in 2013 (Mtce)	394
Total gas consumption in 2014 (Bcm)	9.5
Share of gas in total energy consumption in 2012 (%)	2.3

Shandong is located on the Eastern coast of China. It has the 3rd largest economy among the 31 regions in China. Total GDP was 967,419 million USD in 2014, slightly larger than the Netherlands at 866,354 million USD. Total energy consumption was 394 Mtce in 2013[62], which made it the most energy intensive province in China. Industry accounted for 302 Mtce (or 76.6%). 73.8% of energy consumption is supplied by coal. In 2013, the region consumed 409 million tonnes of coal, which accounted for more than 10% of the national coal consumption and more than 5% of global coal consumption. The excessive use of coal has resulted in its SO_2 and NO_x emissions being the highest of all China's provinces. Therefore, the region aims to peak its coal consumption by 2015, according to the Shandong Air Pollution Mitigation Plan (2013 – 2020). A few options are proposed, including an increase in electricity imports, the development of renewable energy and the increase of gas consumption.

Shandong has a relatively long history of gas use due to associated gas production from the Shengli Oil Field, though the level of gas production is very low. Historically, one third of gas production is used in fertilizer production with the rest distributed to nearby industries and residential areas. Gas consumption has been increasing since 2002. In 2014, Shandong consumed 9.5 Bcm of natural gas. The share of natural gas in total energy consumption has been increasing since the early 2000s, but it still only contributed to 2.3% of the total energy consumption in 2012 (See Figure 21). The Shandong Air Pollution Mitigation Plan (2013 – 2020) encourages the use of gas to replace coal. It projects that natural gas consumption will reach 17 Bcma by the end of 2015 and 27 and 37 Bcma by 2017 and 2020, respectively[63]. The Plan also highlights the potential use of gas in the ceramics and glass industries as well as retiring 3,736 units of coal-fired boilers that have less than 20 steam tonne capacity. For gas use in transportation, it proposes that 90% (95%) of taxis, 40% (95%) of buses and 10% (15%) of civil vehicles will use CNG, another 15% (40%) of coaches and 5% (13.5%) of heavy goods vehicles will use LNG by 2015 (numbers in brackets represent the target for 2020). The 17 Bcm by 2015 target seems too high for Shandong to achieve. A revised annual gas consumption target was revealed in the Shandong Energy Saving and Low Carbon Development Action Plan (2014 – 2015), which states the new target of gas consumption as 12 Bcm by 2015[64].

[62] Data from Shandong statistical yearbook (2014). For reference, total energy consumption in Shandong is larger than South Korea (387 Mtce), the ninth largest energy consuming country in 2012.
[63] Shandong Government, (2013)
[64] Shandong Government, 2014)

Figure 21: Gas consumption in Shandong and its share in total energy consumption between 1995 and 2012

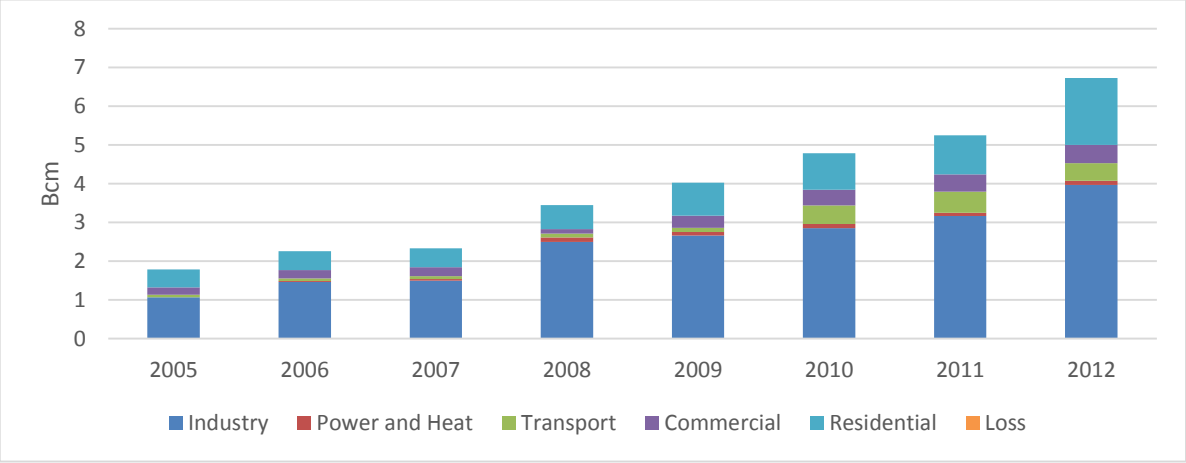


Source: Own estimates. Data for 1995 to 2012 are from various Energy Statistical Yearbooks. Data for 2013 and 2014 are from NDRC, (2014b) and NDRC, (2015)

Shandong hosts the Sinopec Qingdao LNG terminal the very first LNG terminal constructed by Sinopec. Phase I was completed in 2014, and has a receiving capacity of 4 Bcma (3mtpa). Besides LNG imports, pipeline gas from the Shaan-Jing Pipeline II and West-East Pipeline II are the major sources of Shandong's gas consumption.

Figure 15 shows the gas use in Shandong at a sectoral level. Industry accounted for the largest share between 2005 and 2012, 60% in 2012. Industrial production has accounted for over half of the economy of Shandong since 2000. Its share in total GDP reached 57.4% in 2006 and declined to 50.1% in 2013. Services represented less than 40% of the total GDP until 2012. However, its share has been growing since 2004 (when services accounted for 31.7% of the total GDP). The share of agriculture has seen a continuous decline from 15.2% in 2000 to 8.7% in 2013. Major cities, such as Jinan (the capital city of Shandong) and Qingdao, have seen a larger proportion of GDP contributed by services than industries. However, the majority of the other cities are still dependent on industrial production. Residential use of gas has been increasing from 0.5 Bcm in 2005 to 1.7 Bcm in 2012. It accounted for 26% of the total gas consumption in 2012. In comparison, residential energy consumption only represents 6% of the total energy consumption in Shandong. The region has an-above average gas-access-rate; 43.5% of its urban population had access to natural gas (or 22.1 million) in 2012. Gas use in the power sector was very limited over this period, and only accounted for less than 3% of the total gas consumption. Transport represented the 3rd largest source of gas consumption, which is associated with the high level of NGV ownership in Shandong.

Figure 22: Gas use by sector in Shandong between 2005 and 2012



Source: Own estimates. Data from various energy statistical yearbooks

4. Discussion and Conclusion

Energy consumption growth in China is likely to remain moderate in the coming years. The role that gas can play is most likely to change from taking a share of the growing demand to replacing the existing energy supply from other sources (mainly other fossil fuels). Such replacement will depend on several factors, such as the relative price levels of gas compared to alternative energy sources; the environmental impacts; a sufficient and secure supply.

In general, gas consumption is increasing in most of the selected provinces, except Sichuan. However, in gas producing provinces (such as Sichuan and Shaanxi), the share of natural gas in total energy consumption has exhibited a downward trend. At the same time, an increasing proportion of their gas production has been exported to other regions.

None of the regions is likely to meet their gas consumption target during the twelfth-five year period, set by different regional government policies. Table 6 below lists the government targets of gas demand in selected regions and their consumption level in previous years. It shows that regional government were very optimistic about the growth of gas demand during the twelfth-five year period. In 2013, China and most of its regions experienced gas supply shortages. This led to rationing supply in order to provide sufficient gas to the end-users that cannot be interrupted (such as residential use). This probably turned into a situation of over-supply by the end of 2014.

Table 6: Regional gas consumption and projections between 2012 and 2015

	2012	2013	2014	2015 (projected)
Guangdong	11.7	12.5	Not available	36.7
Beijing	9.2	10.0	11.3	18.0
Sichuan	15.3	14.8	Not available	26.0
Shaanxi	6.6	Not available	6.3	12.5
Shandong	6.7	8.5	9.5	17

Source: various regional energy statistical yearbooks

At sectoral level, one of the main factors that determine gas consumption in different regions is the structure of the regional economy. A regional economy in which industry represents a higher proportion of GDP tends to use a higher proportion of gas in industry. However, its share in total gas consumption has been declining. For economies that are dominated by services (such as Beijing), the use of gas in residential sectors is more significant. The future for natural gas use in industry presents

both opportunities and challenges. On the one hand, the economic rebalancing from an industrial-based to a service-based economy could result in a slowdown of industrial energy consumption, which in turn could lead to lower gas demand from industry. On the other hand, the coal-to-gas switch as required by the government in order to reduce the use of coal could mean opportunities for gas to replace coal in industrial energy use. Such a transition will reduce the amount of air pollution in the atmosphere.

Apart from the industrial sector, there are three main areas in the coal-to-gas transition including the demolition of small-scale and less-efficient coal boilers, residential coal-to-gas switching for cooking and water heating purposes, and the replacement of coal-fired power generation with gas-fired power generation. Meng and Sun (2014) estimated that the additional gas demand due to coal-to-gas transition in the Jing-Jin-Ji (Beijing-Tianjin-Hebei) region would require an additional 23 Bcma of gas by 2020. This includes the retiral of 25 thousand steam tonnes of coal boilers (15 Bcm), 15 million urban residences having access to natural gas (1.5 Bcm) and the replacement of 7.5 GW coal-fired power generation with gas-fired generation (6.5 Bcm). There are also significant challenges. First of all, the cost of the coal-to-gas switch can be significant: the additional cost as a result of gas consumption is likely to reach 150 billion RMB per year in the Jing-Jin-Ji region. Second, the growing demand for gas in the coal-to-gas transition may create a barrier for a gas supplier to meet the substantial peak demand in the winter heating season. Thus, a supportive government policy will be vital to the transition.

Residential gas consumption is growing in most regions. According to the China Urban-Rural Construction Statistical Yearbook, in 2012 the proportion of the urban population that has access to natural gas was highest in gas producing regions (71.4% in Xinjiang and 57% in Sichuan) and wealthy and smaller regions (77.6% in Beijing and 62.1% in Shanghai). By contrast, the national average access rate was 33.9%. The lack of infrastructure resulted in a lower level of gas access to large populations in other provinces. For example, the access rate in Zhejiang[65] was 22.6% and 16.4% in Guangdong in 2012. Together with the growing trend of urbanization, residential consumption presents a significant opportunity for the future growth of gas, especially in the wealthy coastal regions.

Power generation represents a significant proportion of total gas consumption in wealthy regions (such as Beijing and Guangdong). Several reasons may contribute to this higher share: first, gas-fired power plants present a secure source of gas demand; second, coal transportation from the interior regions to the coastal regions is constrained due to the growing volume of coal transport and the limited transport capability (bottlenecks). Alternative energy sources (such as natural gas) are therefore used to generation electricity to satisfy the growing demand. Last, the requirements of lower emissions and higher air quality in the wealthier regions are driving the growth of gas use in power generation, which has lower SO_2, NOx, CO_2 and other emissions (especially particulates) compared to coal. In order to combat the severe air pollution in the coastal regions, a number of national and regional policies have been issued to limit to use of coal. For example, The State Council issued the Air Pollution Prevention and Control Action Plan in September 2013. The plan stipulates that, with the exception of combined heat and power plant, new coal-fired power plant cannot be built in the coastal regions (including the Beijing-Tianjin-Hebei region, the Yangtze River Delta and the Pearl River Delta). The growing electricity demand needs to be met by an increase in the level of power exchange/interconnection with other regions, the development of non-fossil fuels and an increase in natural gas supply. Therefore, the share of natural gas in power generation is expected to grow in these regions.

[65] Zhejiang is located on the Eastern Coast of China. It is one of the most affluent regions, which ranks 4th in terms of GDP per capita in China.

So turning to the original research questions:

- Using the data available is it possible to form a coherent picture of gas production and consumption at the provincial level?

In this paper provincial level data for those regions selected has allowed us to construct a coherent rationale for gas demand development, albeit that the most recent data is for 2012. What emerges is that the answer depends on province-specific factors.

- Are there any obvious qualitative correlations between provincial gas consumption and key drivers such as local gas production, enabling infrastructure, specific gas-intensive industries, income per capita, for example?

The analysis here has identified these as important drivers of provincial level gas demand. In addition the need to reduce the SOx, NOx, CO_2 and particulate pollution resulting from coal-fired generation also emerges as a factor. At times however pricing distortions (as a consequence of government policy) create barriers and unintended consequences.

- From the above are there any emerging patterns which may assist in forming a view of the trajectory of future Chinese gas consumption, accepting that the transition to the 'new normal' is something of an economic and environmental discontinuity?

Clearly it is difficult to project an analysis based on data to 2012 into a future characterised by the 'new normal' focus away from energy intensive export industries towards services and domestic consumption. However, the potential for gas consumption growth both in the residential space heating sector (assuming infrastructure allows an improved access rate) and in the power sector in place of coal (assuming government policy overrides the relative prices of coal and gas) provides a basis for future Chinese gas consumption, quite apart from ongoing changes in the industrial sector.

5. References

Argus (2015). Argus China Petroleum (15062015): China rues Qatari LNG contracts.

Beijing Bureau of Statistics (2015). Statistical Communiqué of Beijing on the 2013 National Economic and Social Development (北京市 2014 年国民经济和社会发展统计公报). Beijing: Beijing Statistical Information Net.

Beijing Municipal Commission of City Administration and Environment. (2011). *Beijing Twelfth-Five Year Gas Development Plan* [Online]. Beijing: Beijing Government. [Accessed 10 Sep 2015].

BP (2015). BP Statistical Review of World Energy. London, UK: BP Distribution Services.

CEPY (2014). *China Electric Power Yearbook,* Beijing, China Electricity Press.

Chen, X. (2014). The Development of Chinese Gas Pricing: Drivers, Challenges and Implications for Demand, . *OIES working paper: NG 89.* Oxford Institute for Energy Studies.

Cornot-Gandolphe, S. (2015). China's Coal Market: Can Beijing Tame 'King Coal', . *OIES working paper*

Fridley, D. (2008). Natural Gas in China. *In:* STERN, J. (ed.) *Natural Gas in Asia: The Challenges of Growth in China, India, Japan and Korea.* Oxford: Oxford University Press.

Guan, D., Peters, G. P., Weber, C. L. & Hubacek, K. (2009). Journey to world top emitter: An analysis of the driving forces of China's recent CO2 emissions surge. *Geophysical Research Letters,* 36**,** L04709.

Guangdong Development and Reform Commission (2013) Guangdong Twelfth-Five Year Energy Development Plan, <http://www.gddpc.gov.cn/fzgggz/fzgh/zxgh/sewzx/201410/t20141027_264355.html>

Henderson, J. (2014). The Commercial and Political Logic for the Altai Pipeline. *Oxford Energy Comment, December 2014.* Oxford Institute for Energy Studies.

Hu, J., Kwok, G., Xuan, W., Williams, J. H. & Kahrl, F. (2013). Using natural gas generation to improve power system efficiency in China. *Energy Policy,* 60**,** 116-121.

IEA (2014). Medium-Term Gas Market Report 2014. Paris: IEA.

IEA (2015a). Medium-Term Gas Market Report 2015. Paris: IEA.

IEA (2015b). Natural Gas Information 2015. Paris: IEA.

Kahrl, F., Hu, J., Kwok, G. & Williams, J. H. (2013). Strategies for expanding natural gas-fired electricity generation in China: Economics and policy. *Energy Strategy Reviews,* 2**,** 182-189.

Li, R., Qu, H. & Zhu, J. (2014). Gas development faces uncertainties (我国天然气发展面临不确定因素). *China Petroleum and Chemical Industry Federation (中国石油和化学工业联合会),* 13.

Li, X. (2015). Driving Forces of China's Enegy and Emission Growths between 2007 and 2010: A Structural Decomposition Analysis. *OIES working paper series EV62.* Oxford Institute for Energy Studies.

Lin, X. & Polenske, K. R. (1995). Input–Output Anatomy of China's Energy Use Changes in the 1980s. *Economic Systems Research,* 7**,** 67-84.

Meng, Y. & Sun, H. (2014). Gas-for-Coal substitution in the Beijing-Tianjin-Hebei region（京津冀地区'煤改气'发展探讨）. *International Petroleum Economics (国际石油经济),* 11.

Ministry of Environment Protection. (2013). *The Implementation Regulations of the Air Pollution Prevention and Control Action Plan in Beijing-Tianjin-Hebei and Surrounding Regions (京津冀及周边地区落实大气污染防治行动计划实施细则)* [Online]. Beijing. Available: http://www.mep.gov.cn/gkml/hbb/bwj/201309/t20130918_260414.htm.

Ministry of Environmental Protection. (2015). *The statistics on major pollutat at regional level in the first half of 2015 (环境保护部发布 2015 年上半年各省、自治区、直辖市、主要污染物排放量数据公报)* [Online]. Beijing: Ministry of Environmental Protection. Available: http://www.mep.gov.cn/gkml/hbb/qt/201509/t20150906_309369.htm [Accessed 10 Sep 2015].

Ministry of Housing and Urban-Rural Development (2013). *China Urban-Rural Construction Statistical Yearbook 2012,* Beijing, China Planning Press.

National Bureau of Statistics (2013). *China Energy Statistical Yearbook 2012,* Beijing, China Statistics Press.

National Bureau of Statistics. (2014). *Statistical Communiqué of the People's Republic of China on the 2013 National Economic and Social Development* [Online]. Beijing. Available: http://www.stats.gov.cn/english/PressRelease/201402/t20140224_515103.html.

National Bureau of Statistics. (2015). *Statistical Communiqué of the People's Republic of China on the 2014 National Economic and Social Development* [Online]. Beijing. Available: http://www.stats.gov.cn/english/PressRelease/201502/t20150228_687439.html.

NDRC (2012). Twelfth-Five Year Natural Gas Development Plan Beijing: National Development and Reform Commission.

NDRC. (2014a). *CNPC Shaan-Jing Phase IV has been approved (中石油陕京四线获国家核准批复)* [Online]. Beijing: NDRC. Available: http://www.sdpc.gov.cn/fzgggz/jjyx/gjyx/sh/201408/t20140826_623499.html [Accessed 10 Sep 2015].

NDRC. (2014b). *Shandong Gas Peaking Demand in Winter Working Summary (山东省天然气迎峰度冬情况)* [Online]. National Development and Reform Commission. Available: http://yxj.ndrc.gov.cn/zttp/trqyfddzl/2013ntrqyfdd/201404/t20140425_608862.html [Accessed 11 Sep 2015].

NDRC. (2015). *Shandong Gas Peaking Demand in Winter Working Summary (山东省天然气迎峰度冬情况)* [Online]. National Development and Reform Commission. Available: http://yxj.ndrc.gov.cn/dfyx/dfyq/201504/t20150430_690161.html [Accessed 11 Sep 2015].

Ou, X., Zhang, X. & Chang, S. (2010). Alternative fuel buses currently in use in China: Life-cycle fossil energy use, GHG emissions and policy recommendations. *Energy Policy,* 38**,** 406-418.

Paik, K. W. (2015). Sino-Russia Gas and Oil Cooperation: Entering into a New Era of Strategic Partnership. *OIES Working Paper: WPM 59.* Oxford Institute for Energy Studies.

Paltsev, S. & Zhang, D. (2015). Natural gas pricing reform in China: Getting closer to a market system? *Energy Policy,* 86**,** 43-56.

Pang, M. L. (2015). *A Summary of China Natural Gas Import in 2014 (2014 年中国天然气进口大盘点)* [Online]. Available: http://www.wusuobuneng.com/archives/16453 [Accessed 3 September 2015].

Shaanxi Statistical Yearbook (2014)

Shan, Y. 2014. The barriers of gas-fired power generation in Guangdong and policy implications (广东省天然气发电面临的问题及政策建议）. *China Power Enterprise Management (中国电力企业管理)*, 7.

Shandong Government 2013. Shandong Air Pollution Mitigation Plan (2013 - 2020) (山东大气污染防治计划 2013 - 2020）. Jinan, Shandong.

Shandong Government 2014. Shandong Energy Saving and Low Carbon Development Action Plan (2014 – 2015) (山东省 2014 - 2015 年节能减排低碳发展行动实施方案的通知). Jinan, Shandong.

Sichuan Statistical Yearbook (2014)

State Council (2014). Energy Development Strategy Action Plan (2014 - 2020) 能源发展规划行动计划（2014 – 2020）. Beijing.

TIAX (2007). Full Fuel Cycle Assessment: Well-to-Wheels Energy Inputs, Emissions and Water Impacts. California, US: California Energy Commission.

Wang, H., Fang, H., Yu, X. & Wang, K. (2015). Development of natural gas vehicles in China: An assessment of enabling factors and barriers. *Energy Policy,* 85**,** 80-93.

Wang, T. & Lin, B. (2014). China's natural gas consumption and subsidies—From a sector perspective. *Energy Policy,* 65**,** 541-551.

World Bank and Development Research Center (2013). China 2030: Building A Modern, Harmonious, and Creative Society. Washington DC: The World Bank.

Yeh, S. (2007). An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles. *Energy Policy,* 35**,** 5865-5875.

Yi, F. (2015). *Fossil-fuel power generation has about 170 GW of surplus capacity (我国火电存在近 1.7 亿千瓦限制装机）*[Online]. Available: http://www.china5e.com/news/news-914793-1.html [Accessed 10 Sep 2015].

Yin, X., Chen, W., Eom, J., Clarke, L. E., Kim, S. H., Patel, P. L., Yu, S. & Kyle, G. P. (2015). China's transportation energy consumption and CO2 emissions from a global perspective. *Energy Policy,* 82**,** 233-248.