Communication

China's natural gas: Resources, production and its impacts

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HIGHLIGHTS

- We show that available gas resources are overestimated by China's authorities.
- We forecast China's future gas production under different resource scenarios.
- This paper shows that China's gas production will not meet the soaring demand.
- The gap between supply and demand will continue to increase rapidly in future.
- China's gas security will meet a severe challenge because of this increasing gap.

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ABSTRACT

In order to achieve energy consumption targets, and subsequently reduce carbon emissions, China is working on energy strategies and policies aimed at actively increasing the consumption of natural gas—the lowest carbon energy of the fossil fuels, and to enhance the proportion of gas in total primary energy consumption. To do this, it is a necessary prerequisite that China must have access to adequate gas resources and production to meet demand. This paper shows that the availability of domestic gas resources are overestimated by China's authorities due to differences in classification and definitions of gas resources/reserves between China and those accepted internationally. Based on official gas resource figures, China's gas production remains low with respect to the projected demand, and will only be 164.6 bcm in 2020, far lower than the 375 bcm of forecast demand. The gap between gas production and demand will reach 210.4 bcm by 2020. Existing plans for the importation of gas and the development of unconventional gas will not close this gap in the next 10 years, and this situation will therefore present a severe challenge to China's gas security, achievement of targets in improving energy consumption structure and reducing carbon emissions.

1. Introduction

In China, high-carbon energy resources, such as coal and oil, dominate, and accounted for 88.07% (coal: 70.45%; oil: 17.62%) of Chinese primary energy consumption in 2010 (BP, 2011). Compared to these figures for high-carbon energy resources, the proportion of low-carbon energy resources, such as natural gas and non-fossil fuels, is only 11.93% (natural gas: 4.03%; non-fossil fuels: 7.89%). However, there is one important reason for us to believe that this structure of energy consumption will be unsustainable in future (Xue, 2008, 2009; Ju et al., 2010), and that is because China is facing tremendous pressure to reduce its carbon emissions due to the fact that it has become the largest carbon dioxide emitting country in the world (BP, 2011). On November 26, 2009, the State Council announced that China would endeavor to lower its carbon dioxide emissions per unit of GDP by 40–45% by 2020 relative to the 2005 level (World Resources Institute (WRI), 2009). Therefore, in order to fulfill its commitment to reduce carbon emissions, a reasonable choice for China is to change the structure of its energy resources and increase the quantities of low-carbon energy resources, enhancing their proportion in total energy consumption.

One of the best low-carbon energy resources is natural gas. According to the official “12th Five-Year Plan”, Chinese natural gas consumption will reach 260 billion cubic meters (bcm) in 2015, and its proportion of total energy consumption will be 8.3% (Qu, 2011). Consumption of natural gas was only 109 bcm in 2010 (BP, 2011), implying an annual growth rate of 18.99% in the next five years. After 2015, gas consumption will continue to rise and reach more than 350 bcm by 2020, with a proportion of over 10%...
of total energy consumed (Liu et al., 2010; Li, 2010, 2011). Therefore, we can expect the Chinese government to take a number of measures to increase natural gas consumption in the future.

However, one important factor seems to be ignored by Chinese policy makers, and that is whether or not there are adequate gas resources to support its ambitious goal for gas consumption. Currently, most Chinese scholars claim that Chinese domestic gas production will continue to rise rapidly. However, their analysis does not consider limitations on gas resources (Qiu and Fang, 2005, 2009; Li et al., 2009; Qiu et al., 2011). Even if there is a gap between gas production and demand, scholars accept that China can import adequate foreign gas resources to meet demand (Qiu et al., 2011). This extremely optimistic opinion of China’s gas supply may convey a misleading conclusion to Chinese policy makers, and furthermore, will result in flawed national natural gas strategies and policies. It is therefore very important that China carefully analyze its gas resources, so that a quantitative analysis on gas production potential can be achieved more accurately. This is the main purpose of this paper.

The structure of this paper is as follows. Section 2 reviews historical production and discovery of proved geological reserves of natural gas. Section 3 summarizes and discusses Chinese natural gas resources, and defines three analytic scenarios with different resources. Section 4 introduces the forecast models of discovery of proved gas geological reserves and production. In section 5, under different scenarios, we predict Chinese gas discovery and gas production by applying the models mentioned in Section 4. Then the forecast results are analyzed and discussed in Section 6. Section 7 summarizes the main lessons of this paper.

2. Historical production and proved geological reserves of natural gas

China’s natural gas industry has developed rapidly since 1949. One development is the increase in the annual production of natural gas from 0.01 bcm in 1949 to 96.76 bcm in 2010. The year 2004 proved to be a turning point for China because, until 2004, China had no pipeline network to transport natural gas, a barrier to the growth of domestic gas production. In 2004, the first West–East Gas Pipeline—connecting gas resources in the West with the market in the East, was completed and put into trial operation. Thereafter, China’s gas production rose rapidly with an average annual growth rate of 15.47% from 2004 to 2010 (Fig. 1).

The other major development for China’s gas industry is the substantial increase in the annual discovery of proved geological reserves. Fig. 1 shows that proved geological reserves of natural gas has grown rapidly since 1990, and especially since 2000, with an average annual increase of 543.38 bcm from 2000 to 2010. One important reason for this rapid development is that Chinese petroleum exploration has shifted from oil-dominance to oil–gas of equal importance (Dai et al., 2008). By the end of 2010, the cumulative proved that geological reserves of natural gas had reached 8.015 trillion cubic meters (Tcm).

3. China’s gas resource assessment

3.1. China’s official gas resource assessment

There are 5 major national oil and gas resource assessments in China since the “Reform and Opening-up” of 1978. From Table 1, we can observe that China’s known natural gas resources continue to increase, for example, prospective resources are 33 Tcm based on the first national oil and gas resource assessment (Zhou and Tang, 2004), however, according to the latest national oil and gas resource assessment, this has increased to 56 Tcm (Li et al., 2006). According to official reports, the reason for this apparent increase in gas resources is due to innovation in geological theory and progress in exploration technology. There were indeed many innovations and improvements to geological theory and exploration technologies during last decades, and we can see that data provided by the Chinese Academy of Engineering in 2004 (CAE) (2004) concurs with data provided by China’s national oil companies in 2000 (Li et al., 2004). After a year, the third national oil and gas resource assessment shows increase in all types of natural gas resources, especially for geological resources and recoverable resources. These increases, however, are hard to explain.

3.2. China’s scholars’ gas resource assessment

The results of the 3rd national oil and gas resource assessment have been widely used by many scholars and institutions (Li et al., 2009; Dai et al., 2008; Zhao et al., 2008; Higashi, 2009). However, in their articles and reports it is very hard to clearly identify accurate quantities of Chinese gas resources. The main reason is that the classifications and definitions of the petroleum resources/reserves used by Chinese authorities are different to those applied internationally (Zhang, 2009). For example, between the “Guidelines for

![Fig. 1. Historical annual discovery of proved geological reserves and production of Chinese natural gas.](image-url)
the evaluation of petroleum reserves and resources” published by SPE/WPC/AAPG (2001) and “Petroleum Resources Management System” published by SPE/AAPG/WPC/SPEE (2007), and this discrepancy is not clearly explained by the authors. So, when CNPC showed that proven reserves of China’s coalbed methane (CBM) were 134.3 bcm at the end of 2007 (Higashi, 2009), the proven reserves here actually refer to cumulative proved geological resources. And proven reserves applied by Zhao et al. (2008) actually refer to cumulative discovered recoverable reserves, including both cumulative production and remaining technically recoverable reserve. However, in “Petroleum Resources Management System”, proven reserves refer to remaining economically recoverable reserves. Therefore, it is very helpful and necessary for us to understand classifications and definitions of the petroleum resources/reserves applied by China’s official oil and gas resource assessment.

As we can see from Table 1, there are mainly three types of resources publicly reported. These are the Prospective resources, Geological resources and Recoverable resources. By comparing the different classifications and definitions, we find that Prospective resources, Geological resources and Recoverable resources in the 3rd national oil and gas resource assessment can be equated to Total Petroleum Initially-in-place (PIIP), Discovered Petroleum Initially-in-place (Discovered PIIP) and Ultimately Recoverable Resource (URR) respectively. However, the precise definitions of these terms are still different. From Table 2, it can be found that two main differences between Chinese definitions and SPE/AAPG/WPC/SPEE’s exist. One is that a time limit is not considered by China, which means that resources reported by the Chinese government may be discovered and available within 30 years, or 50 years, or may never be discovered (Zhu et al., 2003). However, a time limit is considered by others, for example, US Geological Survey (USGS) applied a time limit of 30 years (1995-2025) when estimating world Reserve Growth and Yet-to-find which are two important parts of URR (US Geological Survey (USGS), 2000).

The other difference is that estimations of Chinese recoverable resources do not consider commercial conditions, meaning that some Chinese recoverable resources may not be available for production when the resource price is low.

Based on the above two reasons, it can be seen that the results of China’s official oil and gas resource assessment are over-estimated. Furthermore, there are a number of other terms for which it is even harder to find a match. For example, in China, Geological Resources can be further subdivided into two categories: Proved geological resources and Unproved geological resources. Proved geological resources are the geological reserves estimated with a high level of confidence, which is very important in China, not only because it is the only type of resources that are counted by China’s authorities and reported to the public every year, but also because it is used to calculate a very important and widely-used parameter—resource-proved rate (Resource-proved rate = Cumulative proved geological resources/Geological resources). However, there is no any internationally similar type of resource definition.

Facing this situation, many Chinese scholars call for Chinese standards to conform with international standards (Zhang and Zhang, 1994; Zhang, 1997; Chen, 2009). In order to understand the actual resources, scholars estimate Chinese gas resources individually, and their results are shown in Table 3. From Table 3, we can see that quantities of geological resources are estimated between 13 Tcm and 21.66 Tcm, with an average quantity of 16.92 Tcm; quantities of recoverable resources are estimated between 6.737 Tcm and 13.32 Tcm, with an average quantity of 10.19 Tcm. When compared with official results for gas resource assessment, the resource quantities estimated by Chinese scholars’ are apparently much lower.

3.3. Resources scenarios in this article

In this article, three resource scenarios (shown in Table 4) are defined. In the high scenario, we use the results of the 3rd
national oil and gas resource assessment. This result has been shown to be questionable and a probable overestimation, however, it is still very useful and helpful for us to describe a maximum possible production curve. For the low scenario, results from Chinese scholarly research on gas resource assessment are applied, providing a minimum possible production curve. We note that the results from the CAE (2004) agree with the China’s national oil companies’ result in 2000 (Li et al., 2004), giving a maximum possible production curve. For the low scenario, results shown to be questionable and a probable overestimation, how-

In Table 4, the use of geological resources instead of prospective resources may be queried. The main reason for using this particular measure is that geological resources are of more practical significance than prospective resources, and there is a close relationship between geological resources and recoverable resources. The geological resource is multiplied by a recovery factor and results in an estimated recoverable resource (Liu et al., 2009a).

Geological resources in Table 4 will be used to forecast future annual discovery of proved geological reserves, and recoverable resources will be used to predict future annual production of natural gas.

4. Methodology and data

4.1. Forecasting model

In 1949, Hubbert (1949) proposed that the production of fossil fuels in a given region over time would follow a roughly bell-shaped curve, and subsequently he proposed the logistic model (i.e. Hubbert model) to forecast reserves and the rate of production. Due to his successful prediction that oil production in US would peak in 1969–1971 (Hubbert, 1956), the Hubbert model has become the most widely known forecasting model and has been used comprehensively. In China, Weng (1984) has also claimed that the total resources available were limited for non-renewable fossil fuels, and first advanced the eponymous Weng model to forecast reserves and the rate of production of oil and gas. Then Chen (1996) developed a theoretical derivation of the Weng model establishing the Generalized Weng model. Currently, the Generalized Weng model is the most commonly used model in China.

Compared with the Hubbert model, the shape of Generalized Weng curve is not necessarily symmetrical. The actual historical oil and gas production curve is generally asymmetrical (Laherrere, 2000). The Generalized Weng curve also produces a flatter peak, indicating a longer peak plateau, a better fit with the reality of China’s oil and gas field exploitation (Zhu et al., 2008; Wang et al., 2011). Based on these reasons, the Generalized Weng model is used to forecast the future annual proved geological reserves and future gas production.

The Generalized Weng model can be described as follows when it is used to forecast future annual proved geological reserves:

\[ n_D(t) = a t^b e^{-(t/c)} \]  \hspace{1cm} (1)

\[ N_{RD} = ac^{b+1} \Gamma(b+1) \]  \hspace{1cm} (2)

where \( n_D(t) \) is proved geological reserves at time \( t \), bcm/a; \( N_{RD} \) is geological resources, bcm; \( a, b \) and \( c \) are simply statistical parameters; \( \Gamma(b+1) \) is the gamma function, when \( b \) is a positive, \( \Gamma(b+1) = b! \).

When the Generalized Weng model is used to forecast future gas production, it can be described as follows:

\[ Q(t) = a t^b e^{-(t/c)} \]  \hspace{1cm} (3)

\[ N_{RP} = ac^{b+1} \Gamma(b+1) \]  \hspace{1cm} (4)

where \( Q(t) \) is gas production at time \( t \), bcm/a; \( N_{RP} \) is recoverable resources (i.e. URR), bcm; other parameters are described above.

Table 3
Chinese gas resources estimated by Chinese scholars.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Forecast time</th>
<th>Type of resource</th>
<th>Reference</th>
<th>Results (Tcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wan (1997)</td>
<td>1997</td>
<td>Recoverable</td>
<td>Sustainable development strategy of China’s oil and gas resource</td>
<td>7–10</td>
</tr>
<tr>
<td>Wang (Zhang, 2002)</td>
<td>1997</td>
<td>Recoverable</td>
<td>Oil and natural gas in China</td>
<td>10.5</td>
</tr>
<tr>
<td>Ma (1999)</td>
<td>1998</td>
<td>Geological</td>
<td>Development prospects of China’s natural gas industry</td>
<td>13.02</td>
</tr>
<tr>
<td>Kang (2000)</td>
<td>2000</td>
<td>Recoverable</td>
<td>Prospect analysis on Chinese oil and gas exploration and resources</td>
<td>11</td>
</tr>
<tr>
<td>Qiu and Xu (2000)</td>
<td>2000</td>
<td>Recoverable</td>
<td>Prospect for China’s oil and gas exploration</td>
<td>10</td>
</tr>
<tr>
<td>Dai et al. (2001)</td>
<td>2001</td>
<td>Recoverable</td>
<td>Estimation of natural gas resources and reserves in China: with concerning to reserves for West-East gas pipeline project</td>
<td>13.32</td>
</tr>
<tr>
<td>Average</td>
<td>–</td>
<td>Geological</td>
<td>Recoverable</td>
<td>16.92</td>
</tr>
</tbody>
</table>

Table 4
Different resources scenarios used in this article.

<table>
<thead>
<tr>
<th>Resources scenarios</th>
<th>Low scenario</th>
<th>Middle scenario</th>
<th>High scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological resources (Tcm)</td>
<td>16.92</td>
<td>22</td>
<td>35</td>
</tr>
<tr>
<td>Recoverable resources (Tcm)</td>
<td>10.19</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Recovery factor</td>
<td>60.2%</td>
<td>59.1%</td>
<td>62.9%</td>
</tr>
</tbody>
</table>
Chen (1996) presents the equation-solving process. Taking the production equations as an example, the equation solving process is shown as follows:

By changing Eq. (3), we get:

\[ \frac{Q(t)}{B} = a e^{-(t/C)} \]  

(5)

By taking logarithms on both sides of Eq. (5), this gives:

\[ \ln \frac{Q(t)}{B} = \ln a + \left( -\frac{1}{C} \right) t \]  

(6)

Then, provided \( A = \ln a \), \( B = -1/C \), Eq. (6) can be rewritten as:

\[ \ln \frac{Q(t)}{B} = A + Bt \]  

(7)

In order to solve Eq. (7), the value of parameter \( b \) should be given first, and then the value of \( A \) and \( B \) can be obtained through linear regression. The next step is to obtain the value of \( a \) and \( c \), and finally, we can forecast \( Q(t) \) and \( N_{RP} \) by substituting \( a, b \) and \( c \) into Eqs. (3) and (4).

However, there are always some differences between the forecasted \( N_{RP} \) calculated by Eq. (4) and the actual \( N_{RP} \) given by Chinese official or scholars’ gas resource assessment. The reason is that the value of parameter \( b \) is not calculated by Eqs. (3) and (4), but predetermined. In order to overcome this limitation, the goal seeking method is used to obtain an optimal value for \( b \) (by letting calculated \( N_{RP} \) be equal to actual \( N_{RP} \)). Then the best value of parameter \( a \) and \( c \) can be obtained. Based on these parameters, a more satisfactory production profile can be acquired using Eq. (3).

Al-Fattah and Startzman (1999) pointed out that there are usually several cycles in the historical gas production curve, so the multicyclic model should be established to forecast gas production. Based on this, Feng et al. (2010) have established the multicyclic Generalized Weng model to forecast gas production, which can be described as follows:

\[ Q(t) = \sum_{i=1}^{k} Q(t)_i = \sum_{i=1}^{k} \left[ \frac{N_{RP}}{b+1} \left( b+1 \right) e^{-(t/C)} \right]_i \]  

(8)

where \( k \) is the total number of production cycles.

4.2. Data sources


5. Forecast results

5.1. Future annual proved geological reserves

Discovery of annual proved geological reserves is shown in Fig. 2 and Table 5. From Fig. 2 and Table 5, it can be seen that the annual discovery of proved geological reserves will peak in the years ahead. Even in the high scenario, the discovery of annual proved geological reserves will peak in 2019 with a peak discovery of 970.94 bcm. The corresponding resource-proved rate is 43.38%, which means that discovery of proved geological reserves will reach its peak and decline before 50% of geological resources are proved.

5.2. Future gas production

Fig. 3 and Table 6 show forecast results for China’s future gas production. It can be seen that China’s gas production will reach its peak between 2027 and 2043, and peak production will range from 157.35 bcm to 217.91 bcm. Furthermore, the ratio of cumulative gas production to \( N_{RP} \) at peak time shows that gas production will peak before half of recoverable resources (about 32%) have been extracted. This conclusion has also been evidenced by Sorrell et al. (2010).

6. Gas demand, import outlook and discussion

In order to understand why China’s limited gas resources and gas production will have a serious negative impact on achieving targets to improve the energy consumption structure and reduce carbon emissions, two important factors—China’s gas demand and gas imports should also be assessed.

Fig. 2. Forecasting China’s annual discovery of proved gas geological reserves based on different \( N_{RP} \).
6.1. Soaring China’s gas demand

After entering the 21st century, China’s gas consumption continued to grow rapidly, especially after 2002, with an average annual growth rate of 16.7% for 2002–2010 (BP, 2011). Many scholars and institutions are forecasting that China’s future gas demand will rise rapidly (Zhang, 2009; Xu and Wang, 2010; Li et al., 2011; International Energy Agency (IEA), 2008, 2009, 2010; Energy Information Administration (EIA), 2010; National Development and Reform Commission (NDRC), 2009; Ma and Li, 2010), however, when compared with the China’s official targets, it is obvious that most of these forecasts have greatly underestimated China’s future gas demand (Fig. 4). As we have discussed in Section 1, in order to improve Chinese energy consumption structure, China plans to increase its gas consumption to 260 bcm by 2015 according to its official “12th Five-Year Plan” (Qu, 2011). Furthermore, to achieve its carbon emission reduction target, some studies have also shown that China’s gas demand will have to reach 350–400 bcm in 2020, an average value of 375 bcm (Liu et al., 2010; Li, 2010, 2011), with a forecast of more than 400 bcm from Ma and Li (2010). This soaring demand will create huge pressure on China’s gas supply.

6.2. Increasing gap between domestic gas production and gas demand

Facing soaring gas demand, one important energy strategy being implemented by the Chinese government currently is to increase upstream investment in gas resources and to expand gas production capacity. As a result, Chinese gas production, as is shown in Fig. 1, is rising rapidly, with an average annual growth rate of 14.3% between 2002 and 2010. However, domestic gas production still cannot meet demand, resulting in China beginning to import LNG in 2006. Thereafter, China’s gas imports rise rapidly, and total net gas imports reach 12.55 bcm by 2010 with a degree of external dependence of 11.73% (Ministry of Commerce of China (MC), 2011). As we have shown, China’s gas demand will continue to increase, reaching 375 bcm by 2020, however, even in the high resource scenario, domestic gas production in 2020 is only 164.6 bcm, meaning that the gap between domestic gas production and gas demand will reach 210.4 bcm by 2020 with a degree of external dependence of 56.11%. This increasing gap between domestic demand and supply will present a huge challenge to China’s gas supply security.

6.3. Existing import plans will not meet this discrepancy

In order to close this gap, China has signed many long-term LNG sales and purchase agreements (SPAs) and pipeline gas import contracts with Kazakhstan, Turkmenistan, Burma, Indonesia, Malaysia, Iran, Australia and Russia (Higashi, 2009). Qiu and Fang (2009) have predicted that China’s LNG imports from the Middle East, Australia and Indonesia and pipeline gas imports from Turkmenistan and Russia will reach 40 million tons (about 54 bcm) and 60 bcm respectively by 2020. Based on their forecast, total gas imports will reach 114 bcm by 2020, however, imports in 2010 are only 12.55 bcm, implying an annual growth rate of net gas imports of 24.69% required to achieve the import targets outlined in the current import plan. However, these existing import plans still cannot close the predicted gap. Even in the high resource scenario, China still needs to import an additional 96.4 bcm of gas resources (210.4–114) (Fig. 5).

6.4. Unconventional gas cannot close this gap

It may be claimed that China still has plenty of unconventional natural gas resources to exploit, and that unconventional gas production will fill the predicted gap of 96.4 bcm between gas supply (domestic conventional gas production + LNG imports + Pipeline gas imports) and gas demand. In the long run, perhaps,
it is possible, however, when considering the next 10 years we should question expectations of unconventional gas production for the following reasons.

First, unconventional gas resources reported by China’s authorities are extremely huge, however, little of them has been proved, meaning that few unconventional gas resources are currently producing. Taking CBM as an example, it is considered to have the biggest potential for extraction in China in the short to medium term. According to official reports, geological resources of CBM are 36.81 Tcm (Liu et al., 2009b), even bigger than conventional gas resource numbers of 35 Tcm. However, of these geological resources, the cumulative proved geological reserves were only 0.3 Tcm by the end of 2010 (Yang et al., 2011), meaning that only 0.815% (Calculated by 0.3/36.81) of these geological resources are proved (i.e. Resource-proved rate is 0.815%). Furthermore, according to the statistics of the China National Administration of Coal Geology (CNACG), the recovery factor of China’s CBM range from 8.9% to 74.5%, with an average value of 35% (China National Administration of Coal Geology (CNACG), 2008), leaving a recoverable reserves currently extracted at only 0.105 Tcm (0.3 x 35%).

Second, exploration and development of unconventional gas requires huge investment. However, China’s gas price is controlled by the government and has been maintained at artificially low levels for many years (Zhao, 2011; Dong et al., 2010). As a result of huge investment and low gas price, China has good unconventional gas prospects but few commercial projects. Currently, only a few CBM projects are commercial, and production is very low; the production for 2007 is only 0.38 bcm (Higashi, 2009).

Third, even if there are adequate funds to invest in the next decade, unconventional gas production will still have difficulty making up the gap of 96.4 bcm outlined above. US Energy Information Administration (EIA) has forecast that China’s total unconventional gas production will only be 0.32 trillion cubic feet (about 8.5 bcm) by 2020, according to its “International Energy Outlook 2010 (IEO2010)” (EIA, 2010), increasing to 1.4 trillion cubic feet (about 39.2 bcm) in its IEO2011 (EIA, 2011) without...
any explanation. Nevertheless, compared to the predicted short fall of 96.4 bcm, it is still not enough.

7. Conclusions

In this paper, we analyze and summarize several important points:

1. In order to improve its energy consumption structure and to achieve its carbon emission reduction target for 2020, China has decided to actively pursue domestic development, and use, of natural gas. As a result, its gas demand is to increase rapidly in the future and reach 260 bcm by 2015 and 375 bcm by 2020. This growth rate greatly exceeds most forecasts by scholars.

2. It is reasonable to believe that the available gas resources are overestimated by China's authorities, and future gas production may also be lower than official expectations. In fact, based on our analysis, even in the high resources scenario, production is only 134.41 bcm by 2015 and 164.60 bcm by 2020.

3. The gap between domestic production and demand will expand rapidly. Even in the high resources scenario, the gap will reach 210.4 bcm by 2020 with a degree of external dependence of 56.11%. However, the gap in 2010 is only 12.55 bcm with a degree of external dependence of 11.73%. This increasing gap between supply and demand will present a huge challenge to China's gas supply security.

4. Existing importation plans and development of unconventional gas will not close the gap in the next 10 years. According to existing import plans, gas imports will continue to rise rapidly in the future and reach 114 bcm by 2020; however, it is still far lower than 210.4 bcm required. Furthermore, even if there is development in China's unconventional gas, production may only be 39.2 bcm, clearly not enough to make up the gap.

In summary, China's gas security faces a severe challenge because limited gas resources cannot meet soaring demand. As a result, China may not be able to achieve its targets for improving its energy consumption structure and reducing its carbon emissions under the current energy strategy and energy policy. Therefore, future Chinese governments must reconsider and adjust their existing energy strategy and energy policy.

Acknowledgments

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