The Scenario Analysis of Shale Gas Development in China
by applying natural gas pipeline optimization model

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Abstract

China has been estimated to have the largest shale resources in the world, while China has enormous unmet and pressing needs for a clean alternative fuel to substitute coal. Nonetheless, besides the uncertainty of economically producing shale gas, China faces the problem of transporting the gas efficiently overland with its limited pipeline network capacity and coverage. The aim of this study is to identify the potential bottlenecks in China’s gas transmission network, which could be one of the most critical constraints for shale gas development in the near future.

We examine this through formulating a gas pipeline optimization model, with optimistic, medium and conservative scenarios of domestic shale gas production on 2020. The model is aiming to minimize the gas demand that are unable to meet, by inputting parameters such as trunk pipelines capacity, gas supply and demand of each gas station which is the
node connecting the pipeline segments, and segments connectivity coefficient matrix of the network.

The results indicate that, more than half of the shale gas produced in Sichuan province and Chongqing municipal won’t be able to be transmitted out by pipeline under the optimistic production of shale gas, due to pipeline capacity and coverage limitation. Even under the conservative scenario, the existing and planned pipeline network is still not sufficient in meeting the growing natural gas demand by 2020. These suggest that, if shale gas could be produced in considerable scale, substantial pipeline expansion and new pipeline constructions should be in place as soon as possible to transmit the gas efficiently. If the pipeline constraints could be overcame, China will reduce 24% dependency on LNG import under the optimistic shale gas supply scenario in 2020.

1. Introduction

As an emerging unconventional energy, shale gas has been an economically viable step towards a cleaner energy future in U.S. China has been estimated to have potentially the largest shale resource in the world. (EIA, 2013) In addition, China’s natural gas demand is expected to grow robustly in the next decade for the following reasons. First of all, natural gas consumption takes only 4% of the total primary energy consumption by 2012 in China, which is far below the world average level 21%. (IEA, 2014) Secondly, the severe air pollution urges the country to substitute coal with clean alternative fuel. Thirdly, with the country’s great effort to develop wind farms and solar power, natural gas power plant would be essential to maintain the grid stability. Last but not least, fuel prices, growing urbanization and other factors make natural gas a practicable bridge towards cleaner energy future in China.

With quite limited conventional gas resources, to meet the growing gas demand and to improve energy security, China has set quite ambitious target of producing 60 to100 billion cu.m. of shale gas by 2020, which is almost equivalent to the country's total natural gas production in 2010. (NDRC, 2012) Nonetheless, in the central government’s “Energy Development Strategy 2014-2020” released in late 2014, the target has been shrinked to 30 billion cubic meter by 2020. The major constraints for shale gas development in China would be geological complexity, water scarcity, and the under-developed energy market.
The typically complex geologic structure of shale basins would challenge the rapid commercialization of shale gas. According to Energy Information Association (EIA)’s report, South China “Shale Corridor”, the Tarim Basin, the Junggar Basin and the Songliao Basin have better shale geology among the seven most prospective shale gas basins, the ratio of their share of the national risked recoverable shale gas resources is 76%, 19%, 3% and 1% respectively. However, the Sichuan basin, takes approximately 74% of South China “Shale Corridor” shale resources, its shale is consist of massive faults and folds, which creates instability and out-of-zone deviation while drilling horizontally nearby, accordingly raises the extrapolation cost. The Tarim Basin has relatively the deepest shale and quite remote location. Although the Junggar Basin and Songliao Basin has favorable continuous wet gas leads, they are dominated by lacustrine-deposited source rock shales, while all of the commercially extrapolated gas was from marine-deposited shales in U.S. All of this imposes further technical bottleneck is needed to be broken after learning U.S.’s experience. (EIA, 2013)

Water scarcity would be one of the most considerable constraints for shale gas development in China. Based on experience in the United States, hydraulic fracturing a single well require between 7 million and 23 million liters of water. Drilling and fracturing thousands of wells in the same area, which is the pathway to make it profitable, will rapidly drawing local fresh water. Nevertheless, over 60 percent of China’s shale resources are in areas of high to extremely high baseline water stress or arid conditions, indicating more competition among users and greater depletion of water resources. Tarim Basin is subject to the highest baseline water stress or aridest conditions, while 40% areas of Sichuan Basin, along with a few other basins in southern China, having relatively low water stress. (Reig, 2014)

The technical problem, water scarcity and other constraints create considerable uncertainty for shale gas development in China. Even though these issues could be overcome, another problem China is facing is transporting the gas efficiently from the gas field to the consumers. The major gas and oil field, largely overlapping with the shale gas basins, are located in western and northern China. In contrast, the highly populated and urbanized regions are dominated in southern and eastern China. Although China have constructed trunk pipelines across the land, comparing with U.S., the capacity and coverage of trunk pipeline network is still quite limited, due to the little share natural gas took in the energy structure historically. In the national thirteenth-five year plan, the central government have published policy to encourage natural gas demand growth to substitute coal consumption future increase. Gas shortage, which is already exist in the eastern China, is expected to be broadened. However, if the shale gas could develop
optimistically, whether the trunk pipelines have enough capacity to transmit it would be essential question for development and utilization of shale gas. (Pan J. 2011)

In China, most segments of the oil and gas industry are dominated by three major national oil companies (NOCs): China National Petroleum Corporation (CNPC), Sinopec, and China National Offshore Oil Corporation (CNOOC). The trunk pipelines are entirely controlled by CNPC and Sinopec. (Tian L. 2014) The transparency of the pipelines information, such as the utilization rate was quite low. The previous research was not quantified enough to answer the pipeline capacity question.

This study is aiming to identify the potential bottlenecks in China’s gas transmission network, as well as to examine the shale gas development affecting particular supply locations and demand centers, by formulated a gas pipeline optimization model. The input for the model would be optimistic, medium and conservative scenarios of shale gas supply on 2020, along with capacity and connectivity parameters of each pipeline segment, gas supply and demand quantity of each gas station, which are the nodes connecting the pipeline segments. The function is to minimize the total demand that are unable to meet. As output, we could examine the utilization of each pipeline, as well as the gas shortage extent of each gas station, for the three shale gas supply scenarios respectively.

2. Shale Gas Production Scenarios

China's shale gas development is still in the initial stage, test wells have been drilled, and demonstration zones have been established in Sichuan Basin, Ordus Basin, Soliao Basin and South China Corridor. Initial drilling confirms China’s shale gas potential, but scaling it to make rapid commercialization is still quite risked for most of the basins in short term for the reasons mentioned in the introduction session.

Southwestern quadrant of Sichuan Basin have been identified as China’s most prospective shale gas play, taking 56% of the national technical recoverable shale gas resources. It has relatively favorable geology, abundant water resources, existing pipelines, and access to major urban markets. (EIA, 2013) Thus, for short term, considerable volumes of shale gas will be all produced from the Sichuan Basin. The three scenarios of shale gas production are listed in Table 1.
Table 1. The Conservative, Medium and Optimistic Scenarios of Shale Gas Production in China by 2020

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Shale Gas Production by 2020 (billion cu.m.)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Conservative Scenario</td>
<td>6.5</td>
<td>Shale gas production Target for 2015 (Energy Development Strategy 2014-2020)</td>
</tr>
<tr>
<td>The Medium Scenario</td>
<td>25.0</td>
<td>IEA’s Projection (World Energy Outlook, 2014)</td>
</tr>
<tr>
<td>The Optimistic Scenario</td>
<td>60.0</td>
<td>The Twelfth-Five Year Plan target for 2020 Shale Gas Development Planning (2011-2015)</td>
</tr>
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3. Methodology and Data Sources

2.1 The optimization model

In the proposed model, the objective is to minimize the demand shortage of all the gas stations on an annual basis, which is limited by the pipeline capacity and supply quantity.

The assumptions made in the formulation of the model are as follows:

1) The natural gas flow in the pipelines are all from China domestic produced gas, imported gas through cross-border pipelines and gasification from LNG terminals along the coastline of China.

2) The gas demand of each gas station is based on population proportion of the provincial gas demand. Details will be explained in the data sector. No gas export considered in the model.

3) The pipelines connecting the same origin station and the same destination station have been combined, and the capacity will be the sum of their capacity. Only the trunk pipelines transmitting gas across provinces are selected in the model, the reduced and combined pipeline network has 191 segments.
4) The gas stations have been combined and reduced to the 118 main stations connecting the pipeline segments. The gas supply and demand quantity of the reduced station is merged as well. The stations that have been reduced are merged to the main stations that have the shortest distance from it within the same province.

5) The produced or imported gas will enter the pipeline through the main gas station that has the shortest distance from the source within the same province. The demanded gas will be transmitted or transported from the main station which has the shortest distance from it within the same province.

6) Each the station could be either supplier or demand.

7) The loss of gas through the transmission process is not considered in the model.

8) The gas could be transmitted in both directions in the pipeline.

9) The operating gas pipelines in 2020 are the operating, under construction and planned ones recorded in the national and provincial twelfth-five year plan.

After combining the pipelines, the trunk pipeline network in the model has 191 segments. The gas stations have been merged into 118 major stations, each of the stations has gas supply and gas demand value, the allocation method and data sources will be described in the data sector.

Suppliers $i = 1,2,...118$
Demand $j= 1,2,...118$
Pipelines $k = 1,2,...191$

**Decision variables:**

$x_{ij}$: Quantity of gas transmitted from supplier $i$ to demand $j$.

$y_k$: Quantity of gas transmitted in pipeline $k$ in the year.

In this study, $x_{ij}$ is the decision variable to trace the origin and destination of each volumes of transmitted gas; $y_k$ is the key variable to identify how much capacity of each pipeline have been utilized.
The objective function of the optimization model is listed as below

$$\min \sum_{j=1}^{m} ep_j$$

Where $ep_j$ is the quantity of demand that can’t be met in the station $j$.

Gas Transmission Constraints:

Constraint (1) establishes the total quantity of gas being transmitted from station $i$ should not exceed the supply quantity of $i$, where $x_{ij}$ is the quantity of gas transmitted from supplier $i$ to demand $j$, $a_i$ is the maximum supply quantity of supplier $I$.

$$0 \leq \sum_{j=1}^{m} x_{ij} \leq a_i$$ (1)

Constraint(2) describes the equation to calculate $ep_j$, the gas shortage of station $j$. $b_j$ is the gas demand of station $j$, $\sum_{i=1}^{n} x_{ij}$ indicating the sum of the gas being transmitted to the station $j$.

$$\sum_{i=1}^{n} x_{ij} = b_j - ep_j$$ (2)

Constraint (3) establishes how much gas has been transmitted in pipeline $k$ in the year, where $\delta_{ijk}$ is the connectivity coefficient of the pipelines, in other words, the topology of the network. If the shortest pathway of gas transmission between supplier $i$ and demand $j$ passes through pipeline $k$, $\delta$ equals to 1, otherwise it is 0.

$$y_k = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \delta_{ijk}$$ (3)

Constraint (4) limits the quantity of gas transmitted in pipeline $k$ to be less than the designed pipeline capacity, where $P_k$ is the transmission capacity of pipeline $k$.

$$0 \leq y_k \leq P_k$$ (4)

Constraint (5) defines the gas transmitted to station $j$ should not more than its demand.

$$ep_j \geq o$$ (5)
2.2 Data Sources

The gas supply information is consist of i) large scale domestic production of conventional natural gas, coal bed methane, coal to gas and shale gas; ii) gas import through pipelines from Turkmenistan, Kazakhstan, Uzbekistan, Burma and Russia, iii) import LNG terminals capacity. The gas pipeline capacity data along with the gas supply data was firstly collected from the “Atlas of the Chinese Natural Gas Pipeline”, and then examined based on the national and related provincial twelfth-five year plan.

To transfer the topology of trunk pipeline network into the connectivity coefficient matrix $\delta_{ijk}$, we firstly digitized the pipeline map in ArcGIS based on the national map from the “Atlas of the Chinese Natural Gas Pipeline”, the next step is to merge the overlapping pipelines and reduce the gas station as keeping only the stations that are locating as the network nodes. The ArcGIS network analyst module helps in identifying the shortest routes connecting each pair of origin and destination. The coefficient $\delta_{ijk}$ is then collated according to it.

The gas demand for each of the gas stations is decentralized from the provincial natural gas demand, which is extrapolated from the historical provincial natural gas demand and the national planned natural gas consumption growth rate till 2020. (Bureau (2014) To decentralize the provincial level data to the stations, we used the spatial data of 2010 population census on county level with GIS maps. Since each county in ArcGIS is represented by a polygon with embodied population information, the population attributed to each gas station is calculated by adding the population of all the counties which have the nearest distance from the county polygon geometry center to the station point. The gas demand is extrapolated by the population proportion of each station multiplied by their extrapolated provincial gas consumption by 2020.

4. Results

With the existing and planned trunk pipeline network, there is approximately 9% of the total demand unable to meet in all the three scenarios. Even in the conservative scenario, 62 out of 191 trunk pipelines in the model have been 100% utilized.
Figure 1. China gas pipeline projected transmission 2020
Conservative Scenario of shale gas supply

Figure 2. China gas pipeline projected transmission 2020
Optimistic Scenario of shale gas supply
Figure 1 and Figure 2 shows the result for southern China. The pie charts representing supply stations, i) the light blue area indicating gas trapped in the supply stations without enough pipeline capacity to transmit it out; ii) the dark blue area is the gas being transmitted out from the supplier; iii) the yellow area is the gas consumed in the place. The yellow single points are the demand stations, indicating the demand have been met with the gas transmitted from suppliers, while the red single points are the demand gaps of the specified station. For all the points, as well as the pie charts, the bigger in size indicating the larger quantity of gas demand or supply. The pipelines are shown as lines, the pipeline utilization ratio has been separated into five extents, represented by different colors demonstrated in the legend.

To compare the conservative scenario and optimistic scenario of shale gas supply, there are significantly more pipelines turned to red, which indicating almost fully utilization of the pipeline, and it is congregating along the way from Sichuan basin towards Shanghai. In addition, it is obvious that more and larger light blue areas appearing in the optimistic scenario, especially in the Sichuan basin. It indicates massive shale gas trapped in the Sichuan province and Chongqing Municipal. To quantify it from the model returned xij matrix, there are 52% (31.2 billion cu.m.) of optimistic supplied shale gas being left over in the basin due to pipeline capacity and coverage limitation.

5. Conclusion

Based on the gas pipeline optimization model, the rapid growing gas demand will not be met due to pipeline capacity and coverage limitation. It implicates that even without shale gas development, the existing and planned trunk pipeline network is still not sufficient to transmit the gas efficiently from the gas field, LNG terminals and import pipeline gas sources to the consumers.

If there is optimistic production of shale gas, more than half of the shale gas produced in Sichuan province and Chongqing municipal won’t be able to be transmitted out by pipeline, while there is gas shortage in Beijing, Shanghai, Jiangsu, Anhui and Henan. As long as the technical bottleneck would be broken in Sichuan basin, not only new pipelines should be constructed to connect it from the gas filed to the trunk pipeline, but also substantial trunk pipeline expansion (especially in the pathway from Sichuan to Shanghai, and the segments connecting it with the North-west phase one pipeline) should be in place as soon as possible to transmit the gas efficiently, or otherwise it could be a critical constraint for shale gas development in the region.
If the pipeline constraints could be overcame, the gas demand gap in China could be filled, and China will be able to improve its energy security by reducing 24% dependency on LNG import under the optimistic shale gas supply scenario in 2020.

References


