Approach for simulating natural gas consumption factor based on grey prediction method

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Abstract. The natural gas consumption has changed significantly in last ten years in China. This paper conducted a series of evaluations to analyze the China natural gas consumption. By analyzing the natural gas consumption sector, three important sectors, Industrial, Residential and Transport, are chosen as the study objectives. The main application of these three factors were discussed and different determinants for each sector were chosen. Correlation factor of each determinant was then calculated through grey coefficients analysis to investigate the relationship between determinants and natural gas consumption. We hope this evaluation can help to provide better policy plan of natural gas consumption in China.

1. Introduction
In China, the air pollution, mostly caused by the fossil energy, has received significant attentions from all over the world. Natural gas with lower carbon content and pollution potential is regard as a main substituted clean energy in China. According to China's 13th five-year plan, the annual natural gas primary consumption is supposed to increase with a growth rate of 19%, and the proportion of gas in energy consumption structure will rise to 10%-15% in 2020 from 5.6% in 2014, with the total volume up to 350 billion cubic meter [1]. Therefore, the analysis of natural gas consumption change and determinants are very important for energy policymakers for future energy sources planning.

A series of researches about natural gas consumption have been published in recent years. One of the widely used methods are the cointegration test and error correction model adopted by Wang and Lin [1] to study the relationships of explanatory factors and gas consumption. Income and price, urbanization and industrialization and climate are the chosen determinants. Logarithmic mean divisia index (LMDI) is another utilized method to decompose the China's final energy consumption into different influencing factors [2]. Residential energy efficiency, direct coal combustion, residential energy consumption are the focused strands to research the residential energy consumption influencing factors. In addition, some researchers used grey correlation analysis (GCA) and grey model (GM) to analyze the influencing factors and make prediction of energy consumption [3,4]. All of these three methods have their advantages and shortages.

This paper will discuss the natural gas sector consumption change and analysis the determinants for each sector. Since there are several determinants for each consumption sector, the GCA method will be used to rank these determinants for each sector. And, in order to make better energy plan for the policymakers, detailed suggestions will be made eventually.
2. China’s natural gas consumption sector and determinants

In China, natural gas consumption is mainly divided into 7 sectors according to the National Bureau of Statistics of China [1], which can be ranked as Industry, Residential, Transport, Commercial, Others, Construction and Agriculture based on their consumption volume. The total consumption volume in 2015 is almost 4 times more than volume in 2004, from 39.7 to 193.2 billion cubic meter, which indicates a huge increasing demand. In order to analysis the consumption sector change, the proportion of each sector is shown on Fig.1. Industrial is the main application of natural gas and it accounts for 62% of the total consumption and it was followed by Residential and Transport sector, accounting for 20% and 10% respectively. While the Construction, Commercial, Others and Agriculture sectors just account for 5% of the total natural gas consumption so we just focus on the biggest three sectors: Industry, Residential, and Transport.

![Figure 1. Proportion change of each consumption sector for China natural gas](image)

The whole Industry sector in China was from three subsector in Fig.2: manufacture, power and mine. The ratio for manufacture keeps 60% of the total Industry consumption, mainly for the usage as chemical material for methanol and hydrogen, and industry fuel (a replacement for coal and gasoline). While the mine subsector shows a decrease trends with the increasing proportion of power generation part. In 2015, the power generation subsector has increased to 28.6% of total Industry consumption and the mine subsector has decreased to 13.2%. Since natural gas is considered to be a replacement energy for coal and oil in recent year, the Industry natural gas consumption is related to industrialization, urbanization and economic development [5-7]. In this research, industrialization, urbanization and per-capita GDP were chosen as the determinants for Industry natural gas consumption.

Residential natural gas has increased from 3.23 billion cubic meter in 2005 to 36.0 billion cubic meter in 2015, with the annual growth rate of 18.8%. The natural gas is mostly used among cities and urbanization are proven to have a direct effect on Residential natural gas. Besides, economic growth is also an important part of Residential natural gas [8] and we selected the residential consuming level as the economic variable. And the Residential natural gas is also constrained by the regional mismatch between the gas supply and demand. The pipeline network construction is a best solution to promote the Residential natural gas consumption [9]. Therefore, with the blanket ban of coal and the construction of pipeline network, the Residential natural gas will keep increasing. Thus, the urbanization, residential consuming level and pipeline length are chosen as the determinants for Residential natural gas.

As the world’s largest natural gas vehicle fleet, the main part of Transport natural gas consumption is primarily applied for urban natural gas buses and taxis in China, in form of Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) [10]. The Transport consumption has increased from 0.88
billion cubic meter in 2005 to 2.32 billion cubic meter in 2015 and the proportion has keep around 12.3%.

Since the unitary natural gas application of Transport is vehicle, we will use natural gas vehicle quantity
and the GDP for the Transport sector as determinants.

3. Grey relation analysis

3.1. Methodology

Grey relation analysis (GCA) is a widely used system to deal with the incomplete information and it has
been used in many natural gas predictions. The GCA can be constructed according to the following
procedure.

For each natural gas consumption sector, the consumption volume and related factors will be
generated as sequence $X(0)$ with $n+1$ numbers of terms first. With the year interval segments, $X(0)$ will
be listed as:

$$X_i^{(0)} = \left[ X_i^{(0)}(0), X_i^{(0)}(1), X_i^{(0)}(2), \ldots, X_i^{(0)}(n) \right]$$ (1)

$X_i^{(0)}(0)$ is the reference sequence and $X_i^{(0)}(1), X_i^{(0)}(2), \ldots, X_i^{(0)}(n)$ is the compared
observations. As the origins of observations are different or measured by different units, normalization
of the observations are required. So for each compared observation $X(1)(k)$ includes $n$ attributes and is
represented as

$$X_i^{(1)} = \left[ X_i^{(1)}(1), X_i^{(1)}(2), \ldots, X_i^{(1)}(n) \right]$$ (2)

Where

$$X_i^{(1)}(k) = \frac{\max X_i^{(0)}(k) - X_i^{(0)}(k)}{\max X_i^{(0)}(k) - \min X_i^{(0)}(k)}$$ \quad k=1,2,3,\ldots,n$$ (3)

After normalization is done, GVA is computed through the following relation.

$$\xi_j(k) = \frac{\min_i \min_k [X_i^{(0)}(k) - X_i^{(1)}(k)] + \rho \max_i \max_k [X_i^{(0)}(k) - X_i^{(1)}(k)]}{[X_i^{(0)}(k) - X_i^{(1)}(k)] + \rho \max_i \max_k [X_i^{(0)}(k) - X_i^{(1)}(k)]}$$ (4)

Where $\rho \in (0,1)$ is a distinguishing coefficient and $\rho$ is usually set to be 0.5.

Finally, the average correlation coefficient and the grey correlation degree are computed by Eq. (5),
the quantitative analysis could evaluate on development relations between different parameters and their
influence.

$$r_j = \frac{1}{N} \sum_{k=1}^{K} \xi_j(k)$$ (5)
3.2. Result
All the determinants were calculated following the steps in Section 3.1 and the correlation coefficient ($r_i$) were listed on Table 1 according to their ranking.

| Sector      | Determinants          | Correlation coefficient |
|-------------|-----------------------|-------------------------|
| Industrial  | Per-capita GDP        | 0.944                   |
|             | Urbanization          | 0.894                   |
|             | Industrialization     | 0.497                   |
|             | Urbanization          | 0.899                   |
| Residential | Resident consuming level | 0.828               |
|             | Pipeline length       | 0.778                   |
| Transportation | GDP of transportation | 0.744               |
|             | Natural gas vehicle   | 0.717                   |

For *Industrial* sector, the natural gas consumption is closely related to the per-capita GDP and urbanization with $r_i$ of 0.944 and 0.894, while industrialization has the $r_i$ of 0.497, meaning a relatively low correlation with natural gas consumption. This is mainly because the *Industrial* natural gas is applied for manufacture, power and mine. And increasing of urbanization and per-capita will induce more natural gas consumption by power generation and manufacture. And the industrialization in China has reached a stable level, contributing less to the natural gas consumption [13].

In *Residential* sector, urbanization and resident consuming level play important roles in *Residential* sector. The natural gas pipeline also shows a correlation with $r_i$ of 0.778, which means the increasing pipeline length will increase the natural gas consumption. This also proved that the construction of pipeline network in China is an effective method to transport the natural gas to residents and solve the mismatch of natural gas production and consumption.

While in *Transport* sector, the data for natural gas vehicle is limited and we introduce the GDP of transportation to investigate the determinants. The natural gas vehicle and the GDP of transportation have $r_i$ of 0.744 and 0.717, showing a strong correlation.

4. Conclusion and suggestion
In this paper, we discussed the China natural gas consumption change, especially in three important sectors, *Industrial*, *Residential* and *Transport*. *Industrial* sector has shown a decreasing proportion with the increasing proportion of *Residential* and *Transport*. The main determinants for each sector was analyzed through GCA. Per-capita GDP, urbanization, per-capita consume level, pipeline and natural gas vehicle are the main determinants for these sector. The promotion of these determinants will increase sector consumption and decrease CO$_2$ emissions per unit of GDP eventually.

Although China natural gas consumption has increased, there is still a big difference between the world and China. The world average proportions of *Industrial*, *Residential* and *Transport* sector are 35%, 35% and 4% respectively. While in China, thesethree sector accounts for 63.9%, 18.6% and 12.3% respectively. Since GDP and urbanization in China will keep a stable rate in the future, the *Industrial* sector consumption will keep stable in next few years. More attentions should paid to the big difference of *Residential* sector between China and the world average. With the blanket ban of coal in cities, the great demand in *Residential* sector has resulted huge heating severance in most parts of China. Since the pipeline network has been proven to be an effective method to promote the natural gas in *Residential* sector, more investments should be paid to the pipeline construction.
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