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The use of natural gas pipeline network with different energy carriers

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ABSTRACT

This paper discusses the economic and environmental aspects of utilizing the existing natural gas pipeline network in the UK with different energy carriers. A model has been developed to analyze the potential integration of hydrogen and biogas within the current natural gas network. By considering different energy carriers into the model under different scenarios, the cost and environmental performance vary. It has been concluded that hydrogen is less expensive than biogas and makes significant contribution to CO_2 emission reduction. Particularly, the injection of hydrogen generated from wind power is the most sustainable pathway, with a 45.13% reduction in CO_2 emission and a £0.2 M/d reduction in total cost.

1. Introduction

Electricity generation from renewable resources, such as wind and solar provide an efficient approach following the strict limitation on carbon footprint. According to the Eurostat data, the ratio of electricity generated from renewable resources to the gross electricity production had increased from 3.50% to 10.80% in the UK between 2004 and 2012 [1].

Compared to conventional power plants, the amount of electricity produced via renewable sources are not adjustable. When there is shortage of renewable electricity, the supply needs to be supplemented by other type of sources. Power-to-gas could be one of the technologies to be used in the future. It converts electricity surplus produced from renewable resources to hydrogen with electrolysis, and then injects the hydrogen generated to the existing natural gas pipeline network [2]. It represents the bridge between power, gas and transport networks with potential for new energy storage options [3]. Besides the full use of excess renewable electricity and the provision of energy storage capacity, power-to-gas also facilitates the revolution of energy system and the gradual realization of sustainable gas [4,5].

Currently, there are mainly two ways of supplying sustainable gas. One is to insert a suitable concentration of hydrogen produced by renewable electricity to natural gas, and the other is to supplement natural gas with biogas [6]. The idea of utilizing hydrogen generated by electrolysis is not new, but the combination of renewable power generations with the existing natural gas has not been yet fully understood. The rapid growth in installed wind power capacity made the concept of injecting hydrogen into existing natural gas pipelines of high interest to the research community. This includes the recent agreements on 'Power-to-Gas' initiatives [7].

Similarly, biogas has also been injected to the existing natural gas network in many European countries. Biogas generated from organic matter is considered a renewable energy that can partly substitute natural gas. With certain upgrading technology, biogas is upgraded to methane that reaches the quality standard of transmission. Biogas plants are mostly constructed at areas with available feedstock resources, while the consumption of biogas is related to demand [8]. No matter hydrogen or biogas, the main purpose of sustainable gas injection is to facilitate adequate energy supply and minimizing the environmental impacts raised by them.

This study analyzes the use of natural gas pipeline network with different energy carriers in the UK. A techno-economic analysis is conducted to compare hydrogen and biogas injection into the existing natural gas pipeline network.

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2. Overview of the current UK natural gas network

2.1. UK natural gas network

A supply chain is a network involved in providing a good or service from producer to consumer. The supply chain of natural gas starts from gas supply through gas pipeline network to end-users. Currently, UK gas supply sources are mainly from offshore production and import through pipelines or liquefied natural gas (LNG). The gas pipeline network consists of all infrastructures needed for natural gas transportation from the reception terminals to use. Boilers and cooking stoves are the main residential use of natural gas. The development of UK natural gas network progressed in two major periods. First, 1960s–1980s, the nationalization and centralization of power-national transmission system was built to allow the switch of the entire country from town gas to natural gas. Second, 1980s to the present, privatization and market liberalization-the privatization of gas transmission network and the appearance of eight regional distribution network companies [9].

2.2. UK gas supply

In the UK, there are mainly three gas supply sources. A large amount of gas comes from offshore gas fields in the North and Irish seas. Gas is also imported through pipelines from Netherlands, Belgium and Norway. In the meantime, LNG imports are playing an increasingly important role as a gas supply source nowadays as well as in the future. As is shown in Fig. 1, in 2012, 45.5% of gas supply is from United Kingdom Continental Shelf (UKCS), 39.4% is imported from European countries, and the rest is LNG imports. 97% imported LNG of it is from Qatar.

The historic UK gas supply is shown in Fig. 2. The gas supply was dominated by flows from the UKCS in the mid-1990s to the mid-2000s. Then since the year 2004, the decline in UKCS production diverted the UK into a net gas importer for the first time [10]. Piped gas is imported from other European countries to supplement domestic production. LNG is also considered an alternative source, due to its flexibility of transportation. Thus, the transition of supply structure leads to an increase in gas reception points.

Currently, natural gas is delivered to nine terminals around the UK by importers and producers. Among them, Bacton and St. Fergus are two of the largest import terminals, while Kent, Teesside and Milford Haven are built for LNG import. After the gas reach the beach terminals around the country, it needs several treatments to guarantee the quality of gas entering pipeline system.

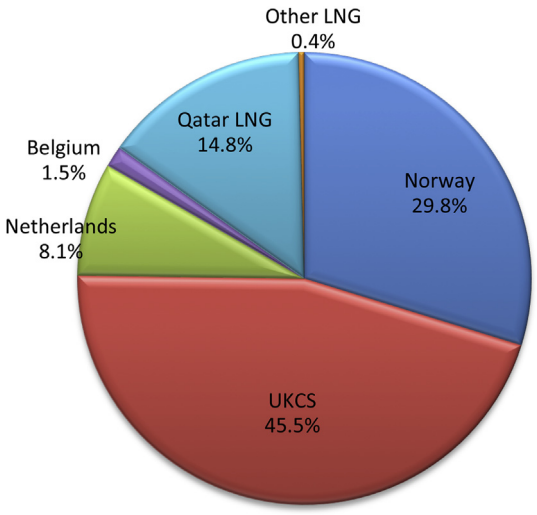

Fig. 1. UK gas supply sources 2012. (Source: DECC Stats, 2012).

2.3. UK natural gas pipeline network

From the terminals, natural gas enters the country through gas pipeline network which contains transmission, distribution mains and service pipelines. Having met the quality standard, gas firstly enters the National Transmission System (NTS) presented in Fig. 3. Transmission pipeline infrastructures in the UK are solely owned and operated by National Grid. NTS is a high pressure pipeline system, including reception terminals, pipelines, compressor stations and offtakes. NTS consists of more than 7660 km long steel pipeline with diameter from 63 mm to 1200 mm, operating at a maximum pressure of 85 bar. Along the pipeline, 23 compressor stations are placed to maintain the high-pressure flow of gas [10].

In order to balance daily and seasonal fluctuations in demand, maintain stable pressure of transmission network, gas storage facilities were constructed. Generally, LNG storage facilities are overground and natural gas storage facilities are underground. LNG occupies far less space than gas, so the storage capacity of LNG is larger than gas. The Rough project operated by the Centrica Storage is the largest storage facility, accounting for 72% of the overall storage capacity in the UK [10]. Besides the existing storage projects, two more projects are also under construction since 2014.

The NTS provides natural gas to UK end users with more than 175 offtake points. Gas is supplied through these offtake points to large industries, power stations and Local Distribution Zones (LDZ). The distribution network in the UK is called Local Transmission System (LTS), contains twelve Local Distribution Zones within eight regional distribution networks. These eights are not owned all by National Grid, they are managed by the companies shown in Fig. 4 [11].

Gas leaves NTS at the offtakes must meet a minimum pressure level, which is usually 25 bar. It is then delivered through decreasing pressure levels and finally received by the end users. The overall length of distribution network is 267,750 km, with diameter from 300 mm to 600 mm [12]. Most of the lower-pressure distribution pipelines built in the recent 30 years are polyethylene pipelines, however older pipelines are made of steel and iron. Currently, National Grid is embarking an iron gas pipeline replacement programme. Once complete, all low pressure iron distribution pipelines will be replaced by polyethylene, a plastic material which is flexible and less vulnerable to corrosion. Distribution service pipelines are smaller than distribution main pipelines, linking the distribution mains network with buildings. Although service pipelines are narrower and shorter, they represent the largest amount of pipelines as nearly 23 million in the UK. The size of local pipe connecting to the gas meter ranges from 20 mm to 180 mm.

2.4. End user

By the year 2011, there were 23 million natural gas customers in the UK [13]. According to the Department of Energy and Climate Change (DECC) statistics in 2013, the UK gas consumption is 2.6Tcf. Natural gas consumption presented in Fig. 5 is mainly used for power station, energy, industry, residential and service sectors. Cookers and boilers are the main end users of the largest gas consumption sector, the residential sector. If hydrogen is injected into natural gas network, there will be some adjustments in