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Energy technology roadmap for ethylene industry in China

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HIGHLIGHTS

- A three-level technology selection is constructed for ethylene industry.
- A National Energy Technology model is established for China's ethylene industry.
- The impacts of production structure change and advanced technologies are evaluated.
- Technology roadmap for achieving the target of current policies are obtained.
- A more sustainable development pathway is proposed for China's ethylene industry.

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ABSTRACT

Ethylene production increases rapidly in recent years in China, which promotes the growth of energy consumption and CO_2 emissions. Ethylene industry is a technology-intensive industry, for which steam cracking, coal to olefins and methanol to olefins are three main production ways. In view of energy-efficient and low-carbon technology selection, this study aims to find a suitable roadmap to achieve the targets under current policies for China's ethylene industry by utilizing National Energy Technology model. With this roadmap, we find that the policy goal for steam cracking could be achieved and the energy consumption and CO_2 emissions of producing one-ton ethylene could decrease effectively. Specifically, for producing per ton ethylene, energy consumption could be reduced by 16.8% and 17.1% in 2030 compared to 2015 for steam cracking and coal to olefins respectively, and the values of CO_2 emissions are 18.1% and 14.8%. In addition, this study makes a discussion about how to achieve a more sustainable development for ethylene industry in China and it is found that both of energy consumption and CO_2 emissions could be reduced by about 20% in 2030 compared to the reference scenario. It is proposed that structure of feedstock in steam cracking could be optimized with more light materials and ethylene producing ways need to be planned well. Especially, environmental effect of coal to olefins should be taken into consideration in its process of development. Steam cracking with ethane and methanol to olefins with imported methanol could be encouraged as they can reduce energy consumption and CO_2 emission directly.

1. Introduction

Ethylene is a versatile chemical material and is generally considered as the building block of the chemical industry together with propylene and aromatics [1,2]. With demand growing steadily, China's capacity of ethylene has ranked second in the world. From 2005 to 2016, the yield of ethylene increases at a rate of 8.1% annually to 17.81 million tons in China (Fig. 1a) [3]. Ethylene equivalent, which also consider the demand for ethylene's downstream products like polyethylene, ethylene glycol and so on, is always considered as the real demand of ethylene, while its self-sufficiency[1] is under 50% in long term. It is predicted that quantity of ethylene equivalent would keep increasing at a rate of 3.6% annually during year 2016–2020 [4]. This would promote the yield of ethylene to increase at a rate of 11.5% annually during the 13th Five-Year Plan to 30 million tons in year 2020 [5]. China plans to construct seven petrochemical industrial bases during

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[1] Self-sufficiency refers to the ratio of yield to total demand.

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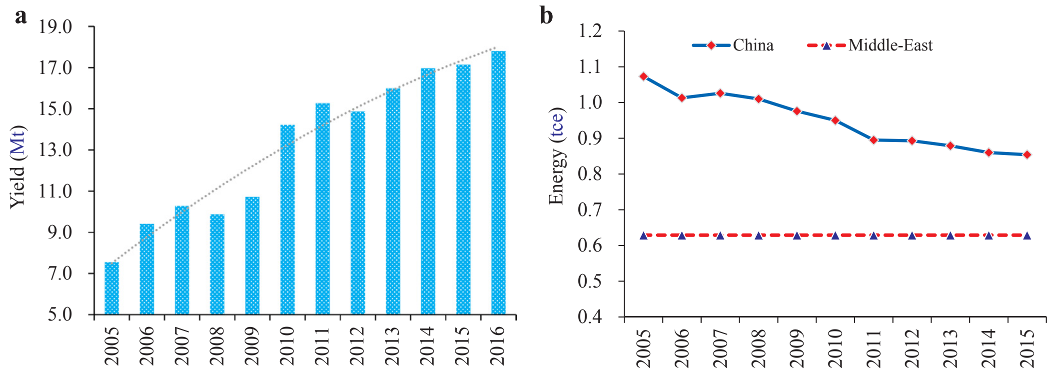

(a) Ethylene yield of China

(b) Average energy consumption per ton ethylene (steam cracking)

Fig. 1. Ethylene yield of China and average energy consumption per ton ethylene (steam cracking) in China and in Middle-East.

13th Five-Year Plan, which would increase 7.2 million tons of ethylene capacity[2]. Steam cracking, coal to olefins[3] via methanol (CTO), methanol to olefins directly (MTO) and catalytic pyrolysis process (CPP) are four ways to produce ethylene in China. Among which, steam cracking is the most important way which always accounts for more than 80% of the total yield, followed by CTO and MTO, which are two alternative ways but with part of production process similar. While the capacity of CPP only accounts for nearly 2% in 2015.

Energy consumption of ethylene production accounts for more than 15%[4] (including as fuel and material) in thousands of chemical products currently, which indicates that it is one of the biggest energy consumers in chemical industry. There is no doubt that the rapid growth of production would increase the total amount of energy consumption and carbon emission in China's ethylene industry. As a response to energy saving and carbon emissions reduction, great efforts have been made by developing more efficient technologies and improving the structure of feedstock. For steam cracking, energy consumption per ton ethylene has decreased from 1.07 tons of coal equivalent (tce) to 0.85 tce from year 2005 to 2015, while the value in Middle-East is 0.629 tce (Fig. 1b) [6]. The substantial difference between China and Middle-East lies in cracking material structure, which is naphtha-oriented in China while ethane-oriented in Middle-East. Meanwhile, upgrading and demonstration of several CTO projects are carried out to help reduce dependence on foreign oil. While in terms of energy saving and carbon emission, CTO might not be an appropriate way to produce ethylene, whose energy consumption and emissions are far more than steam cracking [7]. According to the national plan, ethylene production by CTO and MTO would account for more than 20% until 2020 while it is 12% in 2015 [4,5]. It can be foreseen that energy consumption and carbon emission would increase sharply and it would face great pressure for energy saving and emission reduction in the ethylene industry.

Currently, the government has introduced a series of policies to stimulate the energy saving and emission reduction in chemical industry (e.g. Petrochemical and Chemical Industry Development Plan (2016–2020) and Modern Coal Chemical Industry "13th Five-Year" Development Guide), mainly related to the chemical production structure adjustment, industrial transition and upgradation, green development and breakthrough & innovation in key technologies. Several goals have been proposed in these policies, especially, energy consumption for producing per ton ethylene with steam cracking should decrease by 3.19%[5] in 2020 compared to 2015. But in terms of the influence of existing policies on energy consumption and emissions in ethylene industry and how to achieve the proposed policy targets, it is unknown.

Consequently, this study attempts to answer two questions: (1) What's the technology roadmap to reach the goal in ethylene industry under the current national energy-saving and emission-reduction policies in China and what's the policy impacts? (2) How to achieve more sustainable development for ethylene industry in China? Considering the energy consumption and emissions for ethylene production strongly depend on the production technology, and meanwhile, the cost is the main factor influencing companies' decisions on technology deployment, this study develops a National Energy Technology (NET) model which targets each industrial process and incorporates the potential energy-saving technologies with a goal of total cost minimization under the constraint of national policy and industry development plan. Based on the sub-model NET-Chemical model, a roadmap of energy technology development in the ethylene industry are obtained to support the decision making of policy makers or enterprises for the technology deployment plan in future. Furthermore, we define a sustainable developing scenario (SDS) in this study, which can answer the potential emission reduction in the ethylene industry in China and how to achieve more sustainable development.

The following is organized as this: Section 2 is literature review. The process of ethylene production with different ways are introduced in Section 3. The NET model and NET-Chemical model, framework of technology selection, data and scenario setting are explained in Section 4. Section 5 presents the results of this study. Conclusions and policy implications are drawn in Sections 6 and 7.

2. Literature review

As an important consumer of energy consumption and emitter of greenhouse gas (GHG), industrial sectors have been a focus in terms of energy saving and emission reduction, which appeals a large number of studies. They are mostly on the sectors of iron and steel, cement and power [8,9]. While for chemical sector, as a consequence of its complex production process and data availability, less studies have been found. Especially, some studies point that data availability in chemical industry is poor and it needs to be improved [10,11].

As chemical industry is huge and complex, many studies have been carried out targeting some key chemical products which consume energy and emit CO_2 mostly and they are combined to represent the

[2] Data source: http://www.mlr.gov.cn/xwdt/jrxw/201409/t20140916_1329862.htmb

[3] Olefins include ethylene, propylene and so on. Especially, ethylene and propylene are the two most important products in olefins.

[4] It is calculated by the authors according to literatures [4,6,24,26,31–33,36], some reports and Anychem.com which has a database of coal chemical industry (http://coalchem.anychem.com/project).

[5] As a difference in statistical calibre, here the target refers to the decline ratio of energy consumption.