Energy 36 (2011) 1143–1154

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Integrated energy strategy for the sustainable development of China

Linwei Ma, Pei Liu, Feng Fu, Zheng Li *, Weidou Ni

*State Key Laboratory of Power Systems, Department of Thermal Engineering, Tsinghua-BP Clean Energy Center, Tsinghua University, Beijing 100084, China*

ARTICLE INFO

*Article history:*
Received 11 May 2010
Received in revised form
18 November 2010
Accepted 20 November 2010
Available online 8 January 2011

*Keywords:*
Energy challenge
Energy strategy
Alternative energy
Energy savings
Sustainable development

ABSTRACT

We propose in this paper an integrated energy strategy based on a systems approach to address the energy challenges and energy dilemma in China. First, we give a review of existing approaches to energy planning and strategic management, followed by a discussion on the major relationships among energy, economical, environmental and societal systems. Next, we present a conceptual system model with alternative solutions and clarify corresponding concepts. Based on the results, we propose, summarize, and present strategic ideas as policy implications for China's decision makers. In conclusion, we determine that China should enhance strategic planning and regulation from a life cycle viewpoint of the whole society, prioritize energy saving, continuously improve incumbent energy, and rationally develop alternative energy.



## 1. Introduction

With a tremendous and ever-increasing energy demand, heavy environmental pollution, and increasing greenhouse gas (GHG) emissions, the development of China has attracted extensive attention both domestically and globally. Chinese and international scientists have recognized that an appropriate energy strategy is vital if China is to realize its national target of sustainable development. Previous researches set four objectives [1] for the sustainable development of the energy system in China. These are, to first, meet the power requirement to supply continuous economic growth; to ensure the security of China's energy supply; to guarantee the protection of public health and the environment; and, finally, to eliminate energy poverty. The major challenges to fulfilling these objectives are categorized into five groups [2–5] as follow:

1. *An immense and rapidly increasing energy demand*: During the period between 2000 and 2009, the total primary energy consumption (TPEC) of China increased from 0.97 billion tonnes oil equivalent (toe) to 2.17 billion toe, with an average annual growth rate of approximately 9.4%. Considering that the TPEC per capita of China is relatively low, there is still extensive room for further growth in energy demand. As reported by BP [6] and the World Bank [7], the TPEC per capita of China in 2008 was only 1.51 toe. Comparatively, the world average was 1.69 toe, the UK, Germany, Japan and France ranged from 3.45 to 4.16 toe, and the US had one of the highest at 7.56 toe. If China's TPEC per capita reaches the level of the UK, Germany, Japan and France, its total TPEC will more than double.
2. *A shortage of liquid fuel and high dependency on oil imports*: Between 2000 and 2008, the oil import dependency (OID) of China increased from 33.8% to 50.9% [8]. In 2009, China's OID reached 51.3% with net imports of 199 million tonnes (Mt) [9]. China's domestic conventional oil production is projected to peak at a level between 185 and 200 million tonnes per year (Mt/yr) before 2020 [10,11]. While the potential of unconventional oil remains uncertain, the gap between the oil supply and demand, driven mainly by growth of the transportation sector, will be satisfied primarily by oil imports, increasing OID and worries about energy security.
3. *Severe conventional pollution*: For China, the main source of air pollution remains the direct burning of coal. For metropolises, vehicle exhaust gas has become another important source [3,4]. Although emission standards have been improving, most of their impact is offset by the continuously growing energy demand. Moreover, rising concern about public health and environmental protection has also brought more serious constraints to energy safety and emissions control.
4. *Lack of clean energy in small cities and rural areas*: In rural China, especially northern China, the fraction of traditional biomass as a portion of total household energy consumption has been decreasing and gradually replaced by commercial energy, but commercial energy typically takes the form of the direct

* Corresponding author. Tel.: +86 10 62795735; fax: +86 10 62795736.
*E-mail address:* lz-dte@tsinghua.edu.cn (Z. Li).

0360-5442/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2010.11.035

burning of coal briquettes or powder, [12] which is heavily polluting. The supply of clean energy, such as electricity, gas, and liquid fuel, is still relatively small and should be increased.

5. *Vast and increasing GHG emissions*: The energy-related carbon dioxide ($CO_2$) emissions of China reached 6.1 billion tonnes (Gt) in 2007, overtaking the US (5.7 Gt in 2007) as the world's largest contributor to new added global $CO_2$ emissions [13]. In a business as usual scenario, the energy-related $CO_2$ emissions of China are predicted to peak at a level between 9 and 14 Gt around 2040 [14]. Following this scenario, China will face strong resistance on the international stage, where many are operating under the assumption that the concentration of $CO_2$ in the atmosphere must stabilize between 450 parts per million (ppm) and 550 ppm to avoid damaging global temperature increases. Stabilizing in this range requires that global energy-related $CO_2$ emissions must peak between 2020 and 2025 at a level of about 33 Gt, then decrease to a level between 25.7 and 32.9 Gt before 2030 [13].

To tackle each individual challenge described above, there exist many available or soon-to-be-available technical options. Issues of energy demand, security of oil supply, and energy poverty could be addressed by different means of coal conversion, for instance, clean coal combustion, coal to liquids, coal to gas, and others. Environment protection could be strengthened by more rigid emission standards and the development of renewable energy. Carbon dioxide emissions could be greatly reduced by the development of non-fossil fuels, such as nuclear power and renewable energy, and Carbon Capture and Sequestration (CCS) systems.

However, these challenges together compose an energy dilemma for China, that is, no single energy technology or combination of technologies exists that can address all these challenges whilst meeting all the objectives of sustainable development. For instance, a reduction of conventional air pollution and GHG emissions could be achieved by developing nuclear and renewable energy, but at a much higher energy cost. The development of CCS systems could realize near zero carbon emissions from the consumption of fossil fuels, but at the price of reduced energy efficiency and increased energy cost. The pressure of oil security could be released in the near-term future with the development of large-scale coal-derived synthetic fuels, but at the price of more GHG emissions, higher energy cost, and lower energy efficiency.

Fig. 1 illustrates the nature of China's energy dilemma [4]. In a scenario without coal to liquids (CTL) where non-fossil power (NFP) accounts for only 15% of the total power supply, OID could be as high as 75%. If China determines to reduce its OID by developing CTL, the decision would lead to higher fossil fuel consumption and $CO_2$ emissions. In a scenario with 30-percent-NFP, the total annual fossil fuel consumption rate would be 500 million tonnes coal equivalent (tce)[1] lower and $CO_2$ emissions would be 300 Mt lower than the 15-percent-NFP scenario. If China applies CCS in the 30-percent-NFP scenario, $CO_2$ emissions could be further reduced by about 400 Mt, but the total annual fossil fuel consumption rate would increase by about 250 million tce. A more detailed modeling of China's energy dilemma can be found in our recent study [15].

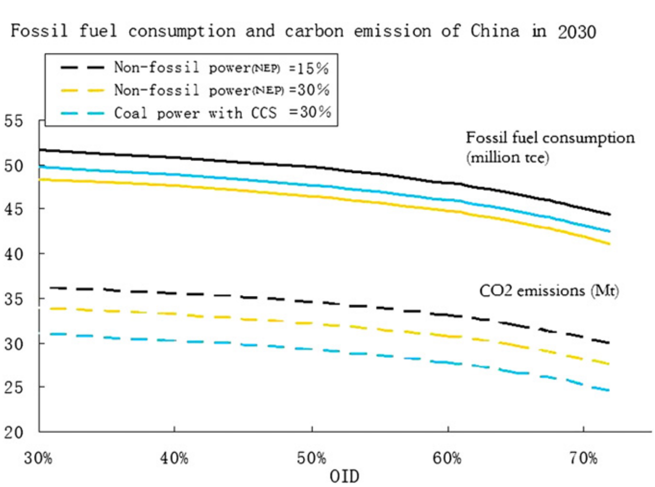


**Fig. 1.** An illustration of China's energy dilemma [4].

Due to the energy dilemma, the solution to the energy challenges should be based on how to systematically balance the multiple objectives of sustainable development, which are usually inconsistent or even in conflict with each other. This would be difficult to achieve if the only focus is 'energy', that is, the technical system composed of primary energy production, energy conversion, energy transportation, and energy utilization. Therefore, before radical innovation of energy technologies takes place, an integrated energy strategy considering the whole energy system – the related parts of the economy, environment, and society – should be proposed and applied to facilitate a smooth transition to a future, sustainable energy system.

Strategic solutions to China's energy problems them have been proposed from many angles, but many issues warrant further review. Some model-based studies greatly underestimated the energy demand growth rate and energy supply development in China, producing rather conservative conclusions [1,16,17]. Some approaches successfully address a typical energy problem, but they lack a systems-level viewpoint. These approaches include reviews of China's energy situation [18], energy diversification and energy safety [19], $CO_2$ emission control [20], low carbon economy [14,21], and updated model-based analysis [22]. At the same time, some argue that energy system models and corresponding methodologies originally developed for studying energy issues in developed countries should not be directly applied to developing countries, in particular China [23,24]. This is mostly because the specific energy-economy-environment-society system dynamics and complexities of developing countries are rather different from those of developed countries. For instance, energy issues in China are unique because of its enormous and geographically concentrated population, extensive infrastructure building, unbalanced market, changing life style, and reforming social institutions [25,26]. As a result, China should further study its own unique energy system to develop its own integrated energy strategy for sustainable development [27].

In our previous work, some of these issues have been addressed, including industrial development [28], energy for sustainable urban mobility [3,4], $CO_2$ emissions control [29], energy challenges and some strategic solutions [5], energy savings [30], alternative energy development [31], planning and design of energy systems [32–35], and methodologies of energy systems engineering [36–39]. In this paper, the aforementioned studies are integrated using a systems approach to provide an overall systematic view of China's energy issues and corresponding solutions. The key point of the systems approach is that a problem can be better understood under a systematic framework and from a life cycle viewpoint. Relationships are regarded as more important than a single component [40]. Qualitative analysis based on heuristic analyses is chosen rather than quantitative analyses based on existing

[1] The authors' previous work used tce as the energy unit instead of toe. Currently, tce is popularly used in China for energy measurement. 1 tce is approximately equal to 0.7 toe.