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Will economic development enhance the energy use efficiency and CO_2 emission control efficiency?

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ABSTRACT

This study employs data envelopment analysis approach to construct the meta-frontier global technical efficiency of energy use index and global technical efficiency of CO_2 emission control index to measure the energy use efficiency and CO_2 emission control efficiency at country level. Destruction of these efficiency indices into pure technical efficiency and scale efficiency sub-indices is to capture sources of inefficiency in relation to the development of an economy. The results indicate that for developed countries the enhancement of the pure technical efficiency in the energy use and the scale efficiency of CO_2 emission control are important tasks to pursue. On the contrary, developing countries have to seek the improvement of the pure technical efficiency of CO_2 emission control and scale efficiency of energy use.

1. Introduction

More and more scientific evidence verifies the causal relationship between the emission of greenhouse gases (GHG) and global warming. The United Nations Framework Convention on Climate Change (UNFCCC) ratified in 1992 Summit in Rio, Brazil, started tackling this emissions problem. At the third Conference of Parties in 1997, numerous countries committed to reduce CO_2 emissions by signing the Kyoto Protocol. The average emission level of the six greenhouse gases, including carbon dioxide (CO_2), must fall by 5.2%, relative to 1990 levels by 2012 (United Nations, 2007). Thus, minimising CO_2 emissions is an important challenge for many countries.

Fossil fuels have been the most important energy resource, generating rapid economic development for many developed countries. The higher the development of the economy, the more energy is required. This also indicates more GHG emissions are expected. Under such circumstances, maintaining the use of energy technology and/or complying with the emission reduction commitment will slow down or even sacrifice the development of the economy.

Currently, most of the 38 countries that ratified Kyoto Protocol to commit to reducing emissions are developed countries. The bounded emissions of GHG and CO_2 in particular will slow down the use of energy and development of the economy for these countries (United Nations, 2007). Other developing countries with high GHG emissions, however, are expected to be brought into future emission reduction commitments (Tonn, 2003).

To achieve the objectives of both economic development and a commitment to CO_2 emission reduction, policies designed to change the production structure through the change of energy use and control of CO_2 emission are foreseeable. Most research in this area uses decomposition approach to destruct the carbon intensity index into carbonization index and energy intensity to measure the amount of CO_2 emissions and the energy requirement for every domestic national product (GDP) created[2] (Kaya, 1990; Mielnik & Goldemberg, 1999; Zhang, 2000).

However, the decomposition of the carbon intensity index have been challenged for being too subjective, for not taking the production process into account and could not be applied to the cross units comparison (Dietz & Rosa, 1994; York, Rosa, & Dietz, 2005). Tyteca (1996), Yunos and Hawdon (1997), and Lozano and Gutiérrez (2008) have resolved these deficiencies using the efficiency measure index based on productive efficiency perspective. The focuses of these studies can be divided into two categories. One type is to analyse the energy use and its relationship with economic output, and the other type is to focus on the importance of control on CO_2 emission.

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[2] Kaya identity can be represented as $CO_2/GDP = (Energy/GDP) \times (CO_2/Energy)$ to measure the influences of energy intensity, i.e. *Energy*/*GDP*, and carbonization index, i.e. CO_2/*Energy*, on the carbon intensity, i.e. *Energy*/*GDP*.

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It can be concluded that the common framework for these two streams of literature is to utilise the theory of production to construct an efficiency index for relative efficiency comparisons among the country or firm decision-making units (DMU) and/or along the time trends. The difference between all these works is that some studies examine the efficiency comparison at the country level (e.g., Arcelus & Arocena, 2005; Barla & Perelman, 2005; Färe, Grosskopf, & Heranadez-Sancho, 2004; Hawdon, 2003; Hu & Kao, 2007; Kumar, 2006; Murillo-Zamorano, 2005; Zhou, Ang, & Poh, 2008), and others focus on the firm level (e.g., Coelli, Lauwers, & Huylenbroeck, 2007; Vaninsky, 2008; Wossink & Denaux, 2006).

In addition, the change in technology and institutions through the progress of economic development will have an impact on the consumption of energy and transformation of technology (Suri & Chapman, 1998). All these changes will further influence the efficient use of energy and efficient control of CO_2 emission. As a result, the development of the economy should have a certain linkage between the energy use efficiency and the CO_2 emission control efficiency. The existing efficiency analysis literature, however, has not investigated the interaction between the energy use efficiency, CO_2 emission control efficiency, and economic development in a theoretical or empirical aspect.

As such, this study employ the data envelopment analysis approach (DEA) to construct the global technical efficiency (TE) of energy use index (denoted as EU_{TE}) and global technical efficiency of CO_2 emission control index (denoted as CEC_{TE}) to measure the energy use efficiency and CO_2 emission control efficiency at the DMU of country level. Furthermore, in order to capture the sources and factors of inefficiencies of energy use and CO_2 emission control and to understand how these factors change in relation to the development of an economy, this study further deconstructs the index of EU_{TE} into pure technical efficiency (PTE) of energy use (denoted as EU_{PTE}) and scale efficiency (SE) of energy use (denoted as EU_{SE}) to capture the DMU's management performance and production scale's influence on energy use efficiency. Similarly, deconstruction of the index of CEC_{TE} into pure technical efficiency of CO_2 emission control (denoted as CEC_{PTE}) and scale efficiency of CO_2 emission control (denoted as CEC_{SE}) is employed to measure how those factors affect the CO_2 emission control efficiency and to identify their relations with the economic development.

In sum, there are three purposes to this study. Our first goal is to construct the possible interrelationship among economic development, energy use efficiency, and CO_2 emission control efficiency. Secondly, we estimate the EU_{TE}, EU_{PTE}, EU_{SE} and explore their relationship with economic development. Similarly, we perform this analysis for the CO_2 emission control efficiency. Finally, we identify the relationships among global technical efficiency, pure technical efficiency, scale efficiency, and economic development both for energy use and CO_2 emission control.

In order to conduct the empirical analyses, we utilise data from The Climate Analysis Indicator Tool (CAIT) (World Resource Institute, 2008), United Nations Statistics Division (2008) and the World Development Indicators (WDI) from the World Bank (2008). The selection of countries and the corresponding years follows the rules of representation, completeness, and consistency for analysing the issues of global change (Levett, 1998). The empirical analyses hereafter use 57 countries in total, including all the countries on the Kyoto Protocol, during the years of 1990 through 2005.

2. The correlations among economic development, energy use efficiency, and CO_2 emission control efficiency

Utilisation of fossil energy is the main power for a society's economy. It is also the major source of GHG, primarily CO_2. It is expected that every country will have a different responsibility for the reduction of GHG in general or CO_2 in particular (United Nations, 2007). Decreasing the use of fossil energy could be necessary to reduce emissions worldwide. However, it is essential to achieve the ideal emission reduction goals without sacrificing economic development.

From input–output production structure, energy can be treated as one of important factor in the development of economy. The development of the economy is a desired outcome in this process, but the emission of CO_2 is not. Within the production structure, the commitment to reduce emissions and the desire for persistent economic development implies that there are two goals existing for each DMU at country level in the use of energy. The first goal is to generate more output from a lower input of energy, i.e. increases for the energy use efficiency. The second goal is to decline CO_2 emissions generated from fossil energy, i.e. increases for the CO_2 emission control efficiency. Both policy goals described above are summarised in Fig. 1 below.

To achieve both policy goals, it is necessary to control the factors that influence the energy use efficiency and CO_2 emission control efficiency. These factors mainly fall into three categories. The first category is the pressure from the general public while the economy is reaching a certain stage of development. Relatively rigorous environmental regulations are required. That is, fewer environmentally harmful types of energies would be in demand (Suri & Chapman, 1998; Vaninsky, 2008). The second category of these factors is the improvement in efficiency from new technologies. The same amount of production output can be produced from less energy, or the same amount of energy can generate less CO_2 (Mielnik & Goldemberg, 1999; Richmond & Kaufmann, 2006). The third category relates to the change of the industrial structure that decreases the high demand of energy. This could be a change from a manufacturing sector to a service sector. High economic values are not necessarily accompanied by high levels of CO_2; instead, the composition effect of changing sectors is created (Grossman & Krueger, 1995).

Economic development makes possible the opportunity to increase the energy use efficiency and CO_2 emission control

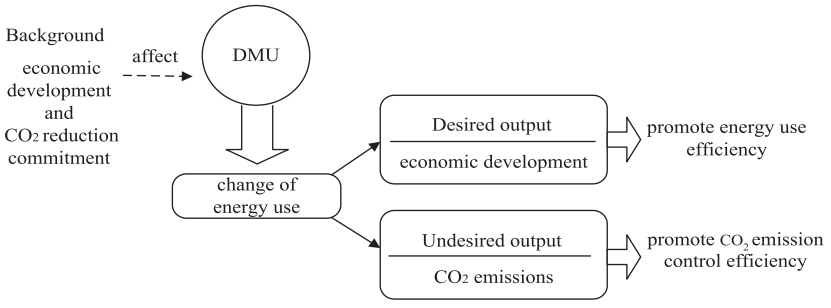

Fig. 1. Policy goals of considering both sides in economic development and CO_2 missions reduction commitment.