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Evaluating efficiency of energy conservation measures in energy service companies in China

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ABSTRACT

Energy service companies (ESCOs) in China have been adopting various energy conservation measures, thus playing a significant role in mitigating carbon dioxide emissions. The efficiencies of such measures vary across China, yet a comprehensive decision-supporting tool that guides the selection of measures according to geographical characteristics is lacking. This study aims to develop an efficiency evaluation framework using data envelopment analysis (DEA) to guide the selection of the most efficient ESCO measures in different parts of China. Data from 1304 ESCO projects in six parts of Mainland China were examined using DEA to determine the efficiency of 15 energy-saving measures in the manufacturing and building sectors. The results indicate that reconstruction of industrial boiler furnaces is the most energy-efficient measure in the manufacturing sector, while energy management systems are the most efficient measure in the building sector. The variation in the statuses of economic development and the climate conditions of the six areas of China are the major factors for the differences in efficiency. A decision-making tool for guiding the selection of the ESCO measures with the most efficient technologies for specific regions and end-uses is developed to provide comprehensive information to both investors and the ESCOs.

1. Introduction

Climate change is one of the most significant and urgent global issues because of its broad environmental, economic, and social impacts. The interrelationship between climate change and the energy industry has been recognized by the Intergovernmental Panel on Climate Change (IPCC): the energy sector contributes significantly to climate change, while the adverse effects of climate change will disrupt various processes in the energy industry (World Energy Council and University of Cambridge, 2014). The high potential of energy saving through the implementation of energy-efficiency strategies has been recognized (World Energy Council and University of Cambridge, 2014). Policies on energy performance improvement are a vital tool in promoting efficient utilization of energy and reducing the impacts of climate change (Solangi et al., 2011). Numerous energy-efficiency policies have been announced and implemented worldwide; these include the National Energy Conservation Policy Act in the United States, the Energy Act 2011 in the United Kingdom, and the Energy Conservation Law in the People's Republic of China (World Energy Council, 2017). Transport, industry, and building sectors have been revealed to be the three main sectors covered by the mandatory energy-efficiency policies in numerous countries (Fig. 1), including China, presenting the huge potential for energy saving. The Paris Agreement, regarded as a milestone, recognized the importance of energy technology and innovation in meeting climate objectives. The implementation of mandatory policies and guidelines encouraged the development and application of numerous energy-saving technologies integrated with the application of renewable energy sources, such as photovoltaics (PV), combined heat and power systems, heat pumps, and motor system optimization (Tassou et al., 2011). Increasing numbers of energy-efficiency projects have been conducted, thus reducing energy consumption and GHG emissions considerably, leading to high financial savings (Painuly et al., 2003).

To encourage investment in energy-efficiency projects, the energy performance contracting (EPC) approach has been introduced in some countries through energy service companies (ESCOs) that help implement energy-saving strategies with zero initial investment by ESCO customers. ESCOs are companies that conduct energy-efficiency projects by providing a package of energy services (e.g., guaranteed energy savings, and associated design and installation services) for customers (Xu and Chan, 2013; Xu et al., 2015). The main drivers of the ESCO industry include technology, policy, and finance (Da-li, 2009; Goldman

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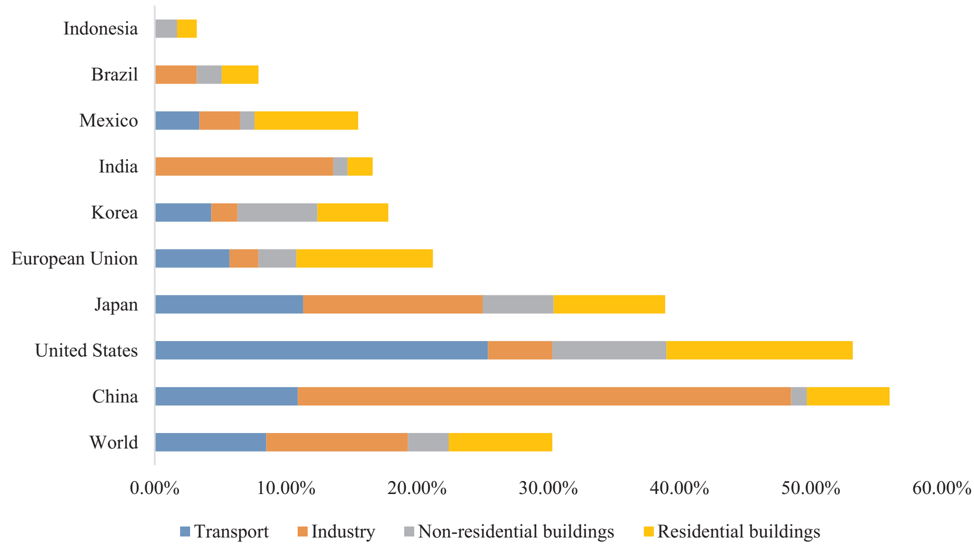

Fig. 1. Share of energy consumption covered by mandatory energy efficiency policies (Source: Energy Efficiency Market Report 2016).

et al., 2005; Lee et al., 2003; Vine, 2005). EPC is a market-oriented approach in which the ESCOs implement energy efficiency measures and are paid from the financial savings made by the customers through the adoption of measures. Besides the avoidance of initial investment, another advantage of the EPC approach is that energy efficiency improvements in multiple aspects can be achieved simultaneously through the application of numerous energy-saving skills in one comprehensive and complex project, thus enhancing the flexibility and savings of the projects (Bates, 2010; Xu et al., 2011; Zheng et al., 2018). Multi-dimensional skills are essential for ESCOs to become successful in accommodating various end uses (Vine et al., 1999). ESCO technologies have advanced over the years, from partial replacement to complex improvement (Lee et al., 2003). The integrated application of energy conservation technologies (referred to as energy conservation measures in this research study) is the core competitiveness of an ESCO.

China, as the world's main energy consumer, has been improving its energy efficiency and has become the world's energy-efficiency heavyweight over the last few decades. Although the global economy is becoming less energy-intensive, the progress needs to be accelerated for the world's energy system to become sustainable (IEA, 2016). Since 2015, the Chinese government has launched its 13th Five-year Plan, with an investment of USD 270 billion, aiming to save approximately 560 Mtoe annually by 2020 (IEA, 2016). The savings will come from two shifts in economic structure: (i) from industry to services and (ii) from heavy manufacturing to light manufacturing. Since EPC was introduced into China in 1996, the Chinese government has been advocating its development (Table 1). With policy support, EPC developed rapidly, with investment increasing from 0.85 billion Chinese Yuan (CNY) in 2003 to 103.96 billion CNY in 2015 and output increasing from 1.77 billion CNY in 2003 to 312.73 billion CNY in 2015. However, the lack of appropriate mechanisms for guiding financial investment in such projects has been identified as an important barrier to promoting energy efficiency (Hannon and Bolton, 2015; Lee et al., 2003). A decision-making tool for guiding the selection of the ESCO measures, with technologies for specific regions and end-uses that save the maximum amount of energy for a given investment, is demanded to provide comprehensive information to investors and the ESCOs.

Although each ESCO project may adopt different energy-saving measures, they each serve the same purpose of achieving the highest level of energy savings and profits (outputs) with the least investment and shortest contract period (inputs). The efficiency of the energy-saving measures in ESCO projects can be measured by the input-output relationship (Blomberg et al., 2012; Guo et al., 2011). Determination of weights on the inputs and outputs with different units of measurement was compulsory in previous multifactor studies, which has led to subjectivity in the evaluation. This research suggests the use of Data Envelopment Analysis (DEA), which can assess the relative efficiency of the decision-making units (DMUs), based on their performance in different criteria, without the need for assigning subjective weightings. The DEA approach has been adapted for benchmarking the environmental and economic performance of different activities, such as transportation, wastewater treatment, farming, and regional eco-efficiency (Kuosmanen and Kortelainen, 2005; Lorenzo-Toja et al., 2015; Picazo-Tadeo et al., 2011; Rybaczewska-Błażejowska and Masternak-Janus, 2018). The DMUs should have the same function and require the same types of inputs and outputs, yet the inputs and outputs could be measured in different units, such as amounts of emissions and monetary values. Such characteristics give DEA the advantage and flexibility for wide application in different fields. Thus, DEA is identified as a suitable tool for evaluating the relative performance of different ESCO measures regarding investment costs, contract periods, energy savings, and profits.

This study aims to evaluate the efficiency of energy conservation measures in different regions of China. The aim can be achieved by the following three main steps: (i) sorting the common energy conservation measures provided by ESCOs; (ii) benchmarking the ESCO measures by determining the relative efficiency of each measure applied in the manufacturing and building industries; and (iii) developing a DEA framework to guide decision-making in the selection of the energy conservation measures provided by the ESCOs in different regions and, thus, optimize the efficiency of the investments in energy saving. The DEA framework will be demonstrated across China.

2. Related studies and data description

2.1. Related studies

The successfulness of ESCO projects is often evaluated by the amount of energy saved, which can be reflected by the financial profits achieved (Vine et al., 1999). Scholars agree that the efficiency of technologies differs (Nassiri and Singh, 2009a; Sarıca and Or, 2007; Wang et al., 2013). For a client who wants to adopt an ESCO project for energy-efficiency improvement, it is crucial to choose the most efficient energy-saving measure, which reduces energy consumption by more with least investment.

Previous studies have attempted to evaluate the efficiency of the