Renewable and Sustainable Energy Reviews 52 (2015) 1158–1171

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Clean energy use and total-factor efficiencies: An international comparison

Rui-Zhi Pang [a], Zhong-Qi Deng [b], Jin-li Hu [c,*]

[a] Institute of Industrial Economics of Nankai University, Tianjin, PR China
[b] Business School of Renmin University of China, Beijing, PR China
[c] Institute of Business and Management, National Chiao Tung University, Taipei, Taiwan

ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form
25 May 2015
Accepted 2 August 2015
Available online 25 August 2015

Keywords:
Clean energy
Directional distance function
Total-factor efficiencies
Environmental pressure

ABSTRACT

This paper analyzes the effect of clean energy use on total-factor efficiencies under the simultaneous consideration of economic output, energy conservation, and emission reduction. The empirical findings on 87 countries during 2004–2010 show that clean energy consumption significantly increases the total-factor emissions reduction efficiency (TFCE), slightly improves the total-factor economic output efficiency (TFYE), and significantly decreases the total-factor energy efficiency (TFEE), with the influence coefficients respectively 0.00292, 0.00029, and −0.00213. On balance, the comprehensive effect of clean energy consumption on total-factor technical efficiency (TFTE) is 0.00028. European countries have higher comprehensive efficiency in economic growth, energy conservation, and emissions reduction. International cooperation is needed to facilitate technology transfer and reduce the gap in efficiency.

Contents

* Correspondence to: Institute of Business and Management, National Chiao Tung University, 118, Sec. 1, Chung-Hsiao W. Rd, Taipei 100, Taiwan. Fax: +886223494922.
E-mail addresses: prz0525@nankai.edu.cn (R.-Z. Pang), zhongqideng@sina.com (Z.-Q. Deng), jinlihu@mail.nctu.edu.tw (J.-l. Hu).

http://dx.doi.org/10.1016/j.rser.2015.08.002
1364-0321/

1. Introduction

Energy resources are classified into three categories [1,2]: fossil fuels, renewable resources, and nuclear resources. The latter two categories are collectively referred to as clean energy sources (CES). Excessive use of fossil fuels, which are the main cause of carbon dioxide emissions, has accelerated global warming and environmental pollution in the last two decades [2–5]. As the growing demand for energy and the increasingly strengthening for environmental protection, popularization and application of clean energy, especially of renewable energy, has become an inevitable trend [6–9], e.g., the EU Directive 2001/77/EC (repealed by Directive 2009/28/EC from 1 January 2012) sets a target of 21% electricity generation from renewable energy sources in 2010, aims to make renewable energy account for 20% of its energy consumption by 2020. Mexico also has set the goal of generating 35% of its energy from renewable sources by 2024.

There is a large literature on the advantages of clean energy [2,10–18]. In this literature, Pao et al. suggested that developing clean energy is a viable solution for addressing energy security and climate change issues in MIST (Mexico, Indonesia, South Korea, and Turkey) [14]. Saidi and Fnaiech discussed the practices of renewable energy and energy efficiency in Tunisia [15], and Glorioso et al. researched about clean energy and its relation with sustainable development in the Mediterranean [16]. Pollin et al. estimated the economic benefits of investing in clean energy, proving that such investment could not only guide the U.S. out of high fossil fuel dependency, but also serve as a powerful engine of economic recovery and long-term economic development [17]. And Liu and Liang emphasized China's leadership in commercializing clean energy technology could ultimately help lower its costs and promote its commercialization globally [18].

However, up to now clean energy sources are utilized still at very low levels [18–20]. According to the report of the International Energy Agency (IEA), 2011 global energy use was evaluated at 12.7 billion tons of oil, with fossil fuels, renewable resources, and nuclear energy accounting for 81.5%, 9.8%, and 8.7%, respectively [21]. Now that clean energy has so many advantages [10–18], why not use it totally? Because resource allocation should aim to maximize outputs based on the least amount of resources (input factors), i.e. maximizing input–output efficiency (or total-factor productivity) [22–24], rather than single economic growth or environmental protection. Questions thus come up: Can clean energy development enhance a country's total-factor efficiency (productivity)? Developing clean energy may be helpful for environment protection [2,25], but the issue of high cost and the difficulty in storage remain unresolved [26,27], so developing clean energy maybe decrease productivity, especially in less developed countries. In addition, can clean energy use reduce total energy consumption? Sbia et al. inferred that clean energy has a positive impact on energy consumption in United Arab Emirates [28], but this conclusion is not well-recognized [5,27].

Earlier studies reflected energy efficiency by energy intensity (energy consumption per unit of GDP) in different countries [16,29], labor efficiency by labor productivity [30–32], and emissions reduction efficiency by CO_2 emissions per unit of GDP or per unit of capital [33,34]. However, two problems exist: First, energy alone cannot produce any output [20], and neither can capital nor labor. Therefore, a more scientific way is to compare the total-factor efficiency when analyzing efficiencies, i.e., by considering capital, labor, energy consumption, economic output, environmental impact, and other factors at the same time. Second, energy intensity, labor productivity or other like indicators cannot reflect the comprehensive effect on economic growth, energy conservation, and emission reduction. As the growth hypothesis holds, restrictions on the use of energy may adversely affect economic growth, while increases in energy may contribute to economic growth [35–37], thus the economic, social and environmental impact of energy structure must be considered at the same time [20,38,39], which is so-called total-factor framework in this paper.

Under the total-factor framework, we accordingly consider both clean energy use and its environmental and economic impact, which involves the problem of multi-input variables and multi-output variables. This method is often used to describe the relationships between socioeconomic variables, but multivariate analysis frequently reduces data dimensionality [40], which can be difficult to interpret by both the analyst and the intended audience [41]. At present, to deal with such a problem in economics, the most popular and most scientific approach is data envelopment analysis (DEA)—a nonparametric approach used to estimate the efficiency of DMUs (decision making units) in order to support the performance evaluation of production systems [42]. There are a great number of studies in the literature measuring energy efficiency or environmental efficiency with the DEA method, such as Domazlicky and Weber, Hu and Kao, and Chiu et al. [43–45]. Ever since Charnes, Cooper, and Rhodes established this method in 1978 [46], DEA has been further developed for more than 30 years, and a variety of derivative DEA methods has also appeared. Among them, directional distance function (DDF) has expanded the DEA model from single factor-oriented to multi-factors mixed-oriented. However, DDF has not completely solved the problem of orientation (or direction) of DEA [47], and so we shall look to solve the problem of orientation in this paper.

In order to evaluate whether an enterprise, a province, or an industry (referred to as a decision making unit, DMU) is efficient, economists usually hold that an enterprise is efficient if it makes production activities on its production frontier (envelopment line of the feasible region) [24,48], because it maximizes outputs under the given inputs, or minimizes inputs under the given outputs. Therefore, the core of the efficiency evaluation is to compare the distance from the DMU location to its frontier [46–49], such that the farther the distance, the more inefficient the DMU is [50]. DEA (or DDF) is also based on this idea, but the actual inputs and outputs are often multidimensional, such that the frontier is generally a "hyper-plane" and the distance in DEA (or DDF) is a "dot to plane" distance, rather than a "dot to dot" distance. In order to calculate the distance we have to find a benchmark. This direction from DMU location to the benchmark is the direction of DDF, which is yet countless [51]. In particular, a DMU can get to the production frontier by increasing outputs (upwards) or get to frontier by reducing inputs (leftwards) [42]. From the perspective of a social planner, the movement direction should not be restricted, as long as the DMU makes production activities on the frontier. Based on method innovation, the rest of the paper will measure various total-factor efficiencies, and analyze the effect of clean energy use on these efficiencies.