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Technical note

Growth and renewable energy in Europe: Benchmarking with data envelopment analysis

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ABSTRACT

This paper conducts data envelopment analysis (DEA) for the purpose of calculating inefficiencies in the European countries' growth using as main inputs the variables typically used in the growth-energy literature nexus such as energy consumption, carbon emissions, employment and capital but also with a particular focus on renewable energy sources (RES) consumption. Since we have a panel data set, we also apply the Malmquist method to calculate total factor productivity and an analysis of peers. Mean overall efficiency has been calculated to be equal to 0.892, while mean pure technical efficiency is 0.569 and scale efficiency 1.798. Countries with remarkable renewable energy performance have medium to low efficiency, while renewable energy laggards are among the most technically efficient countries in Europe. Results from this paper are useful for monitoring and benchmarking purposes with respect to their 2020 renewable energy obligations stemming from 2009/28/ED Directive.

1. Introduction

Renewable energy sources (RES) are currently unevenly and insufficiently exploited in the European Union [1,2] with a small contribution of about 7.8–8% to the overall gross inland energy production [3]. In spite of the various European directives for the promotion of RES being the 2001/77/EC on electricity production from RES [4], the 2002/91/EC on energy performance of buildings [5], the 2003/30/EC on the promotion of biofuels and other bio-liquids [6] and the 2009/28/EC on the promotion of the use of energy from RES [7], which demanded that RES in final gross energy consumption in Europe being doubled from 6 to 12% and achieving 22% electricity production from RES by 2010; It also demanded a reduction in primary energy use by 20% and a reduction of greenhouse gases by 20% below the 1990 levels. Still however, no-long run relationship between RES consumption and growth has been confirmed, providing evidence for the neutrality hypothesis [2], namely evidence that no dependence of the two magnitudes exists or that RES do not play a significant role in European growth.

The vast majority of member states are confident they will reach their 2020 RES goals and 60% of them expect to exceed them, while Italy and Luxemburg plan to resort to co-operation mechanisms to achieve their goals [8] and smooth national discrepancies. By 2020, wind energy will represent 14.1% of the electricity consumption, hydropower 10.5%, biomass 6.5%, photovoltaic 2.35%, solar power 0.5%, geothermal energy 0.3% and ocean energy 0.15% [3]. The share of RES in heating and cooling will increase from 10.2% in 2005 to 21.3% in 2020. RES energy in transport would amount to 12.2% by 2020 [8]. There are also hopeful estimates that by 2050, RES electricity will provide 100% of the European power demand [9].

The relationship between energy and growth has been studied extensively in Refs. [10–17] and numerous other studies, while the relationship between growth and RES has been studied by fewer authors such as [1,18,19]. The growth – energy or RES nexus literature is typically concerned with the existence of long-run relationships and causality between growth, fuel energy or RES consumption, carbon emissions, employment and capital. This study is the first one that examines the relationship between growth and RES with the purpose of benchmarking, namely measuring technical efficiency of economies in producing growth and classifying them accordingly to peer groups, while at the same time measuring their total productivity.

DEA has been deployed in many managerial problems for benchmarking, because the latter is a necessary tool for apt

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management. In Refs. [1,2] it is reported that RES is unevenly and insufficiently exploited in Europe and as a result to that, RES do not contribute to European growth and a social marketing mix for their promotion is not all inclusive. A management hysteresis as regards RES deployment in Europe and the obligations countries have with respect to 2009/28/EC Directive is pinpointed in Ref. [20]. For a country to decide on a strategy regarding its RES capabilities and future and accelerate their deployment, it must know where it stands comparative to other countries with geographical, regulatory or other contextual environments.

Some member states resemble to others with respect to the barriers they face, because of similar financial, geographical, political or institutional surroundings. RES barriers in Europe are administrative (delays, lack of co-ordination between authorities, high costs of obtaining licenses, insufficient spatial planning, grid connection and access problems coupled with the obsolete existent infrastructure, which is necessary due to the intermittent nature of RES). There is still limited information and public awareness and lack of RES penetration in the building's sector and district heating and cooling. For a succinct report on the RES barriers in Europe, the interested reader should consult [21]. Overall, recognizing one's peers will help towards the consolidation of a unifying strategy or knowledge transfer through various mechanisms of co-operation.

To the best of the author's knowledge, DEA has never before been employed for benchmarking the RES performance at a European country level. A DEA study exists for North-African countries [22] on the achievements and perspectives of RES in the specific geographical region. No study has used DEA analysis to explore RES penetration in European countries. In Ref. [20] the aforementioned benchmarking, in a frontier analysis framework though, has been performed. DEA has been applied in the RES field but with the intention to measure the performance of specific RES technologies [23] or sectors and firms [24].

After this introduction, the rest of this paper is organized as follows: part 2 comprises the basic theory about data envelopment analysis, part 3 is concerned with the data description and results' presentation and last, part 4 is the conclusion.

2. Data envelopment analysis; some theory

DEA is the non-parametric mathematical programming approach to frontier estimation. The term was coined by Ref. [25]. The purpose of DEA is to construct a non-parametric envelopment frontier over the data points, such that all observed points lie on, or below the production frontier. For each decision making unit (DMU) which from this point on will be referred to as 'country', the efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs [26]. Ratio$_i$ = $\alpha' y_i/\beta' x_i$, $i = 1,\ldots N$, with y_i is the vector of M outputs and x_i is the vector of K inputs. The optimal weights are defined by the programming problem described in Equation (1):

Maximize wrt α, β: $\alpha' y_i/\beta' x_i$

Subject to

$$\begin{aligned} &\alpha' y_s/\beta' x_s \le 1,\ s = 1,\ \ldots N \\ &a_m \ge 0,\ m = 1,\ \ldots M \\ &\beta_k \ge 0,\ k = 1\ldots.K \end{aligned} \tag{1}$$

A score equal to one indicates an efficient country. Naturally, we want the outcome (GDP) as high as possible and the inputs as low as possible. Therefore, the ratio of the weighted output and the weighted input will be maximized.

DEA has two models; One developed by Ref. [25] assuming constant returns to scale and one developed by Ref. [27] assuming variable returns to scale. The first named CCR after its developers, estimates overall efficiency, while the second, named BCC decomposes overall efficiency into technical and scale efficiency. Pure technical efficiency has the effect of scale removed.

According to Ref. [28], the use of constant returns to scale specification, when not all countries are operating at the optimal scale (due to market imperfections and distortions), will result in measures of technical efficiency, which are confounded by scale efficiencies. Therefore, our programming problem for BCC is as follows:

Maximize wrt $\phi_i, \lambda : \phi_i$

Subject to

$$\begin{aligned} &\sum_s \lambda_s y_s - \phi_i y_i \ge 0 \\ &x_i - \sum \lambda_s x_s \ge 0 \\ &\lambda_s \ge 0 \end{aligned} \tag{2}$$

where y_i is the vector of M outputs and x_i is the vector of K inputs. The programming problem represented by Equation (2), defines the optimal weights. According to Equation (2), the efficiency of a country s is maximized subject to the restriction that the inefficiencies of all countries are less than or equal to 1 and that all weights are nonnegative.

Depending on the research focus, namely the output or input orientation, [29], provide evidence that in many instances, there are only minor differences in the efficiency scores provided by the two approaches. The input oriented approach (CCR model) is described by Equation (3), using duality:

Minimize wrt θ_i, λ: θ_i

Subject to

$$\begin{aligned} &\sum_s \lambda_s y_s - y_i \ge 0 \\ &\theta_i x_i - \sum \lambda_s x_s \ge 0 \\ &\lambda_s \ge 0 \end{aligned} \tag{3}$$

where θ_i is the input oriented technical efficiency score of country ***i***. It measures the extent to which each country can reduce inputs to obtain the same output. To apply the variable returns framework, I will also have to add to Equations (2) and (3) the following restriction:

$$\sum_s \lambda_s = 1 \tag{4}$$

2.1. The Malmquist index of total factor productivity

Output based Malmquist productivity change may be written as in Equation (5) [30]:

$$m_0(y_{t+1}, x_{t+1}, x_t) = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)} \times \frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)}\right]^{1/2} \tag{5}$$

This stands for the productivity of the production point (x_{t+1}, y_{t+1}) relative to the production point (x_t, y_t). Note that subscript 0 signifies output orientation. To calculate Equation (5), we need to calculate the four component distance functions, which involve the four following linear programming problems [31] shown by Equations (6)–(9).

$$\begin{aligned} &\left[d_0^t(x_t, y_t)\right]^{-1} = \max_{\phi,\lambda}\phi \\ &\text{s.t.} - \phi y_{it} + Y_t\lambda \ge 0 \\ &x_{it} - X_t\lambda \ge 0 \\ &\lambda \ge 0 \end{aligned} \tag{6}$$