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Productivity changes of the renewable energy installed capacity: An empirical study relating to 31 European countries between 2002 and 2011

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Abstract

The objective of this study is to analyze productivity changes of renewable energy installed capacity in a sample of European countries from 2002 to 2011. Productivity changes reflect both technical efficiency change (how far the average country is from the best practice frontier) and technological change (shift in the best-practice frontier). This article analyses these two sources of productivity change using yearly data from the Electricity Industry in 31 European countries. A non-parametric approach is implemented to generate measurements of efficiency and technological changes. In particular, Data Envelopment Analysis and the Malmquist index total factor productivity are adopted to calculate technical efficiencies and split specific contributions to the global productivity change due into pure technical efficiency and technological changes. The results show that the total productivity of installed power generation capacity was unsteady from 2002 to 2011, and technological change contributed to the improvement of productivity. In particular, on average efficiency remained almost stable, while productivity grew at a rate of about 6%. Changes in productivity reflect to what extent main and auto electricity producers in the European countries have adopted technological change and were able to adapt to changes and availability of financial subsidies.

Keywords: Renewable energies; Electricity; Efficiency; Data Envelopment Analysis; Malmquist productivity index; Europe; Installed capacity; Hydro; Wind; Solar photovoltaic

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1. Introduction

According to the projections of the International Energy Outlook 2013, the world wide net electricity generation will rise by 2.2 percent per year on average from 2010 to 2040, with the strongest growth trend occurring in non-OECD countries, where electricity generation is estimated to increase by an average of 3.1 percent per year due to the rising standards of living that stimulates demand for home appliances and electronic devices, and commercial services. Vice versa, in the OECD countries that are characterized by a more mature infrastructure asset endowment and declining population growth, the projected increase in electricity generation is about 1.1 percent per year from 2010 to 2040 [1].

In the last two decades, some major developments have influenced the electricity generation industry all over the world: a) the governments of several industrialized countries have undertaken reforms in the electricity industry to introduce greater competition in domestic markets in order to increase consumer surplus by saving costs and improving management efficiency; b) in many developing countries new regulatory settings governing the generation and distribution have been implemented to attract foreign investments that would modernize and improve the technological infrastructure; c) as a consequence of the greater access to foreign investment, the infrastructure assets for the generation and distribution of electricity in a large amount of the developing regions of the world has been rapidly improved; d) as sustainable development has become a guiding principle for public policy in the attempt to reduce carbon dioxide emissions and mitigate climate change, a growing concern for the environment has induced governments to support the construction of power plants that generate clean energy from renewable sources (wind, geothermal, biomass, solar, photovoltaic and small hydropower plants); e) the awareness of the decreasing availability of fossil resources in the long term and the increase of the price of primary fuel sources has made the demand for more efficient and less costly energy generating technologies more pressing.

The mix of energy sources used to generate electricity has changed a great deal over the past two decades, and if on one hand coal has remained the dominant fuel, the use of oil for electricity generation has been slowing since the mid-1970s and the role of nuclear power in the world's electricity markets is projected to lessen, on the other hand generation from hydropower and other renewable energy sources is projected to grow more than 90% over the next 27 years [1]. The renewable energy industry has indeed become very important for the GDP of many countries, being a primary source of the electricity production all over the world providing nearly 20 percent of the world's power generation. It has been characterized by intensive innovation that has increased the electricity generation productivity and efficiency rates, and the European companies are currently among the world leaders in developing new technologies used in the renewable-energy source electricity industry [2]. In Europe, changes in the energy industry have been even more evident, and promoting the generation of electricity from renewable energy sources has become a high European Union priority since 2001 for a number of reasons, including the security and diversification of energy supply, environmental protection and social and economic cohesion [3]. In 2009 the European Union directed all 27 member states to increase their renewable energy share in the energy consumption to the target of 20% by the end of 2020 [4]. In 2010, approximately 25 percent of OECD Europe's total electricity supply came from renewable sources, and renewable energy is OECD Europe's fastest-growing source of electricity generation, estimated to increase at the annual average rate of 2.2 from 2010 to 2040. In the last two years, more than 70% of the new added electric capacity came from solar photovoltaic, wind, and hydroelectric power [1, 5]. Wind and solar photovoltaic power have achieved high levels of diffusion in countries like Denmark and Italy; respectively producing 30% of electricity with wind and 5.6% with solar power in 2012, while in 2011 Germany has doubled its solar photovoltaic generation capacity [1, 5, 6].

The adoption of lucrative financial subsidy schemes, i.e. feed-in tariffs, green certificate systems, tendering systems and tax incentives, together with a gradual decrease of prices of renewable technologies have led to a remarkable growth in renewable energy market. However, in the last two years the prolonged economic downturn, economic and policy-related uncertainties, ongoing tensions in international trade, have challenged some renewable energy industries and many governments planned to cut down financial incentives. Thus, evaluating the industry efficiency and to what extent investment in new electric generation capacity that exploits renewable resources is affecting the efficiency growth patterns in the European countries is a major concern.

This paper uses the Malmquist indexes to analyze productivity changes of renewable energy installed capacity in 31 European countries from 2002 to 2011. Productivity changes reflect both efficiency change (how far the average country is from the best practice frontier) and technological change (shift in the best-practice frontier). It proceeds as follows. Section 2 illustrates the method implemented to investigate productivity changes and describe the sample used in the study; Section 3 reports the results of the study; Section 4 summarizes the conclusion.

2. The empirical study setting

The efficiency study was conducted by implementing a non-parametric technique, the Malmquist total factor productivity index which uses Data Envelopment Analysis, a popular linear programming technique that evaluate the relative efficiencies of a set of homogeneous decision making units with multiple inputs and multiple outputs [7]. Since their introduction, non-parametric techniques have been largely used to measure efficiency in public utilities and, more specifically, the energy industries [8-17]. After conducting an in-depth literature survey, Zhou et al. [18] classified 100 studies that used this kind of techniques to calculate efficiency in the energy and environmental fields. In these studies, scholars adopted either a micro-perspective, aimed at measuring efficiency and comparing a set of companies or power generating plants [19-23] or a macro-perspective with the goal to assess and compare efficiency and productivity changes of different regions or countries [24-29]. However, no study was specifically focused on the assessment of efficiency changes in the sector of the electric power generation from renewable sources.

2. 1. The Malmquist Productivity Index (MPI)

This index is defined in terms of a distance function developed by Malmquist [30], and measures the change in total factor productivity of a decision making unit (DMU) between two time frames by calculating each DMU's relative distance rate to common technology. An output-based distance function is used as the output production is maximized with a given amount of inputs.

The Malmquist total productivity change index from year (t) to year (t+1) is calculated using the following formula [31]:

$$MPI_o\left(y_{t+1}, x_{t+1}, y_t, x_t\right) = \left[\frac{d_o^t\left(x_{t+1}, y_{t+1}\right)}{d_o^t\left(x_t, y_t\right)} \times \frac{d_o^{t+1}\left(x_{t+1}, y_{t+1}\right)}{d_o^{t+1}\left(x_t, y_t\right)}\right]^{\frac{1}{2}} \qquad (1)$$

Equation (1) can be rewritten as:

$$MPI_o\left(y_{t+1}, x_{t+1}, y_t, x_t\right) = \frac{d_o^{t+1}\left(x_{t+1}, y_{t+1}\right)}{d_o^t\left(x_t, y_t\right)} \times \left[\frac{d_o^t\left(x_{t+1}, y_{t+1}\right)}{d_o^{t+1}\left(x_{t+1}, y_{t+1}\right)} \times \frac{d_o^t\left(x_t, y_t\right)}{d_o^{t+1}\left(x_t, y_t\right)}\right]^{\frac{1}{2}} \qquad (2)$$

where the first term on the right side which has been denominated $\Delta TE_{t,t+1}$ measures the change in the output based technical efficiency between year (t) and year (t+1), while the second term in square brackets denominated $\Delta TK_{t,t+1}$ measures the technology change between year (t) and year (t+1):

$$\Delta TE_{t,t+1} = \frac{d_o^{t+1}\left(x_{t+1}, y_{t+1}\right)}{d_o^t\left(x_t, y_t\right)} \qquad (3)$$

$$\Delta TK_{t,t+1} = \left[\frac{d_o^t\left(x_{t+1}, y_{t+1}\right)}{d_o^{t+1}\left(x_{t+1}, y_{t+1}\right)} \times \frac{d_o^t\left(x_t, y_t\right)}{d_o^{t+1}\left(x_t, y_t\right)}\right]^{\frac{1}{2}} \qquad (4)$$

In particular, ΔTE evaluates the DMU efficiency change when this latter approximates to the production limit, while ΔTK evaluates the contribution to efficiency improvement due to the shift of the production limit. As a consequence, the multiplication of ΔTE and ΔTK yields the total factor productivity change. During the period between year (t) and year (t+1), if $MPI_o>1$ total factor productivity increases, while if $MPI_o<1$ total factor productivity decreases. Likewise, if ΔTE>1 the DMU technical efficiency increases from year (t) to year (t+1), while if ΔTE<1 the DMU technical efficiency diminishes from year (t) to year (t+1). The same conclusion is valid as to ΔTK. So, when ΔTK>1 technology progress contribute to increase total productivity [31].

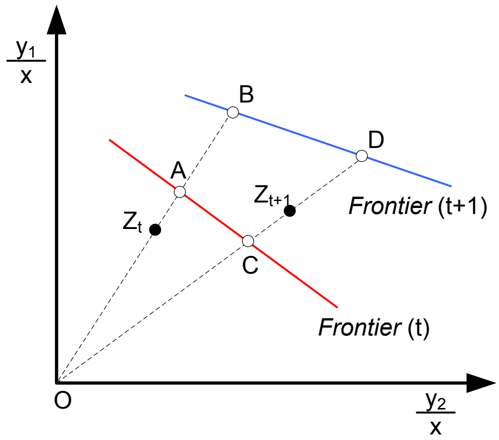

Fig. 1. The Malmquist productivity index.

Fig. 1 graphically illustrates how the Malmquist index measures efficiency changes. For simplicity, it is assumed that efficiencies of DMUs are measured using only one input and two outputs. Efficiency is measured at time t and time t+1. Under the assumption of convexity, the line segment that connects the (efficient) DMUs A and C is the efficiency frontier at time t of DMU Z (Z_t) which is inefficient. The efficient frontier defines the maximum amount of output that can be produced for a given combination of inputs. The ratio OZ_t/OA provides a relative measure of DMU Z efficiency. Z_t could become efficient and move to the efficient frontier at point A, by increasing its outputs or decreasing its input. Unit A is the closest "efficient peer" of Z at time t, and in fact it is the model unit for the inefficient unit Z_t. At time t+1, it is very likely that the input and output measurements of DMU Z will change, and the same will be for the other DMUs. As a consequence, at time t+1 DMU Z will change its position in the two-axes space and the (efficient) DMUs B and D will be on the efficient frontier of Z_{t+1}. Figure 1 clearly shows that the relative efficiency of Z has changed, and is now measured by the ratio OZ_{t+1}/OD. DMU Z lies always below the frontier line, but even though length of segment OZ_{t+1} is greater than length of segment OZ_t, Z_t is more efficient than Z_{t+1}, because of the shift of the efficient frontier.

In this example, MPI_o is calculated as follows:

$$MPI_o = \frac{\frac{OZ_{t+1}}{OD}}{\frac{OZ_t}{OA}} \times \left[\frac{\frac{OZ_{t+1}}{OC}}{\frac{OZ_{t+1}}{OD}} \times \frac{\frac{OZ_t}{OA}}{\frac{OZ_t}{OB}} \right]^{\frac{1}{2}} = \frac{\frac{OZ_{t+1}}{OD}}{\frac{OZ_t}{OA}} \times \left[\frac{OD}{OC} \times \frac{OB}{OA} \right]^{\frac{1}{2}} \tag{5}$$

MPI_o is calculated for each DMU by solving four linear programming (LP) problems to calculate the four component distance functions in Eq. (1).

2. 2. Sample, input and output variables

Sample includes 31 European countries, while the study covers a period of 10 years from

2002 to 2011. Data were collected from the Eurostat database. For every year of the temporal window, 3 inputs and 3 outputs were used to measure the country efficiency associated to the use of major renewable sources to generate electric power. In particular, the installed renewable energy capacity related to the generation of electric power from hydro, wind and solar photovoltaic sources were used as input measurements and the net amounts of electricity generated by plants using these sources were considered as outputs. Renewable sources like geothermal, municipal wastes, wood wastes, tide and wave were excluded from the study because of their more scanty diffusion in the sample. Table 1 presents data relative to the installed renewable electric power capacity in 2011. Total installed capacity was 382,270 Mw.

Fig. 2 shows changes in installed capacity of hydro, wind and solar photovoltaic energy sources over time. From 2002 to 2011 total capacity has increased by 63.5%, at an average rate of about 7%, thanks to the additive rather than substitutive effect of different renewable sources. However, the different energy sources did not experienced similar behaviors. The installed capacity of hydro power remained almost stable, while that of the wind and solar PV substantially increased. In particular, since 2002 there has been a constant and continuous growth of wind capacity, while solar PV installations showed a sharp growth only since 2007.

3. Results

The empirical results of the efficiency analysis are summarized in Figures 3-5. The analysis adopts a window-Malmquist index that uses a fixed period window as reference, by implementing the method proposed by Berg et al. [32]. Furthermore, an output orientation and constant returns to scale were used.

Fig. 3 shows graphs relative to the annual mean efficiency measurements for the sample as a whole. Technical efficiencies have been calculated with the current period as the reference set. For example, efficiency at year 2002 is the efficiency at year 2002 calculated using the input and output values in the same year (year 2002 as the reference set). Two different means have been calculated to obtain aggregated averaged efficiency measurements from single country-specific measurements. Data to plot the first graph were calculated using a simple arithmetic mean (s.a.m), while those ones for the second graph were calculated using a weighted arithmetic mean (w.a.m.) having weights equal to each country's share in total installed capacity summed across all countries in that specific year. This latter mean allows to weigh more those countries that have a larger installed electric power generating capacity from renewable sources. Both graphs in Fig. 3 show that the average efficiency diminishes from 2002 to 2011, but different behaviors emerge. Indeed, the w.a.m. efficiency graph is above the s.a.m. efficiency graph in the periods 2002-03 and 2004-06. Moreover, between 2009 and 2011, the w.a.m. efficiency graph remains above the s.a.m. efficiency graph and has an upward trend. This behavior of the w.a.m. efficiency indicates that, even in the presence of a reduction of efficiency, those countries equipped with a larger installed power capacity have a better (more efficient) utilization of their renewable energy plants, and between 2009 and 2011 have improved the utilization of their power generating facilities in comparison to countries equipped with a smaller power generating capacity.

Table 1. Installed renewable energy capacity (Mw) in 2011 (related to electric power generation only)

Country	hydro	geothermal	wind	solar photovoltaic	municipal wastes	Wood/Wood Wastes/Other Solid Wastes	Tide, wave and ocean	Total renewable
Germany	11,562	7	29,071	25,039	1,486	2,148	0	69,313
Spain	18,540	0	21,547	4,332	224	563	0	45,206
Italy	21,737	728	6,918	12,773	742	421	0	43,319
France	25,332	2	6,691	2,760	910	324	240	36,259
Norway	28,640	0	0	0	0	0	0	28,640
Sweden	16,478	0	2,769	11	571	3,397	0	23,226
Turkey	17,137	114	1,729	0	0	10	0	18,990
Austria	13,211	1	1,080	317	459	2,394	0	17,462
Switzerland	13,866	0	0	149	360	0	0	14,375
United Kingdom	4,420	0	6,488	976	401	1,667	1	13,953
Portugal	5,551	25	4,256	170	76	478	0	10,556
Romania	6,483	0	988	1	0	26	0	7,498
Greece	3,224	0	1,640	612	0	0	0	5,476
Finland	3,156	0	199	7	0	1,910	0	5,272
Denmark	9	0	3,951	17	295	920	0	5,192
Belgium	1,426	0	1,069	1,391	240	701	0	4,827
Czech Republic	2,197	0	213	1,913	43	306	0	4,672
Poland	2,346	0	1,800	1	0	175	0	4,322
Netherlands	37	0	2,316	145	649	713	0	3,860
Bulgaria	3,108	0	541	154	0	0	0	3,803
Slovakia	2,523	0	3	188	5	171	0	2,890
Croatia	2,141	0	130	0	0	6	0	2,277
Ireland	529	0	1,631	0	0	5	0	2,165
Iceland	1,166	585	0	1	0	0	0	1,752
Latvia	1,576	0	36	0	0	5	0	1,617
Slovenia	1,253	0	0	57	0	33	0	1,343
Luxembourg	1,134	0	45	41	19	0	0	1,239
Lithuania	876	0	202	0	0	18	0	1,096
Hungary	55	0	331	4	38	436	0	864
TFYR Macedonia	556	0	0	2	0	0	0	558
Estonia	5	0	180	0	0	63	0	248
Sample (Mw)	210,274	1,462	95,824	51,061	6,518	16,890	241	382,270
Sample (%)	55%	0.38%	25.07%	13.36%	1.71%	4.42%	0.06%	100.00%

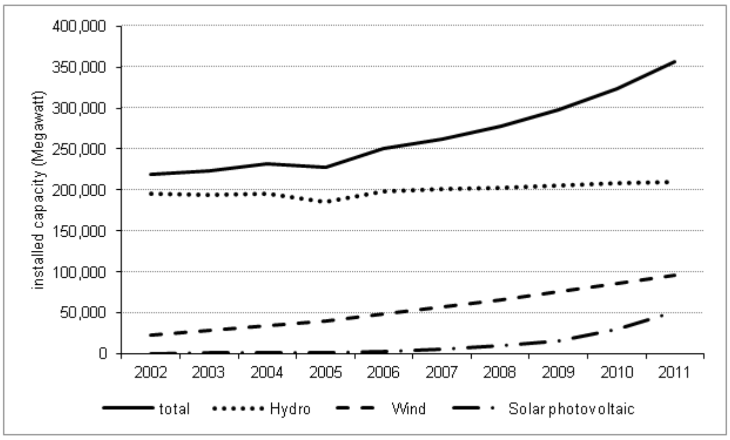

Fig. 2. Change of installed capacity.

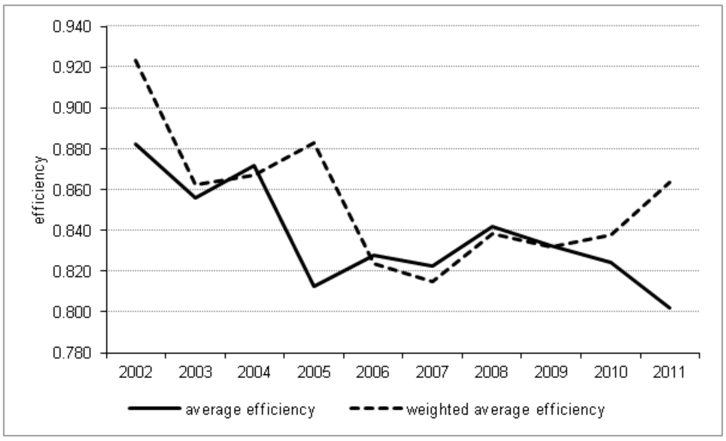

Fig. 3. Efficiency of renewable electric power generating capacity between 2002 and 2011.

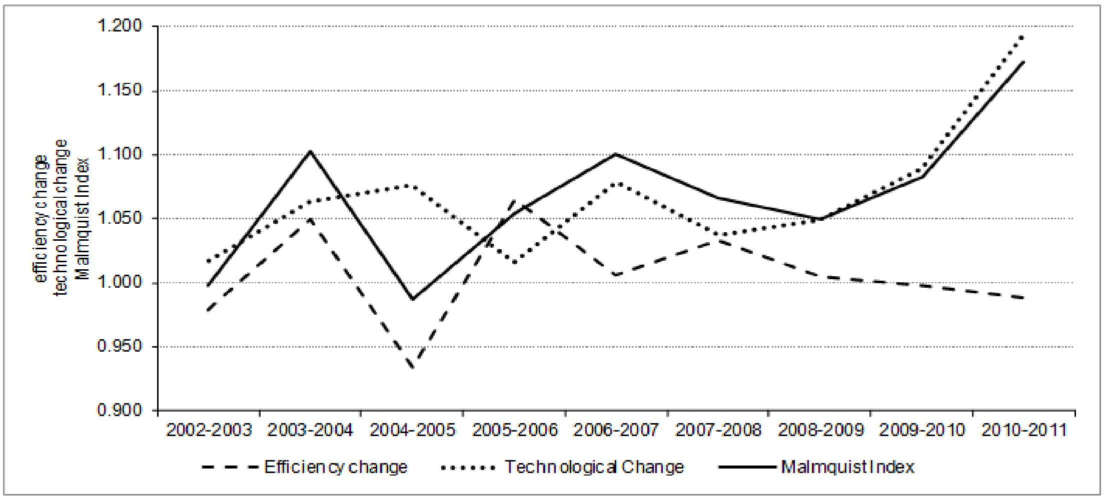

Fig. 4. Efficiency change, Technological change and Malmquist Productivity Index between 2002 and 2011 (average values calculated as simple arithmetic means).

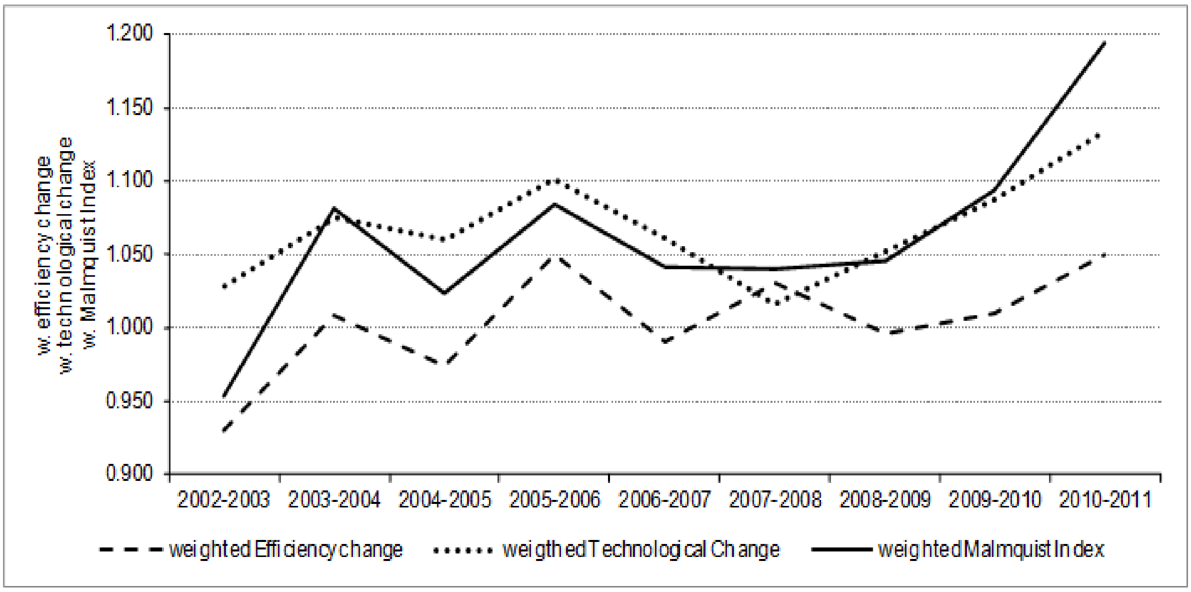

Fig. 5. Efficiency change, Technological change and Malmquist Productivity Index between 2002 and 2011 (average values calculated as weighted arithmetic means).

Figs. 4 and 5 report a set of graphs that illustrate how the Malmquist Productivity Index, and the efficiency and technology changes evolve over time. As before, the simple and weighted arithmetic means were used to generate averaged efficiency measurements to plot in each chart. The two set of graphs in Figs. 4 and 5 show different tendencies. In both charts, the variables under examination are showing an irregular behavior with a number of fluctuations that are more ample when the influence of the size of installed capacity is not incorporated in the measurement of mean (Fig. 4). Figures relative to the technological change component of the Malmquist Index are always greater than 1, thus having a positive effect on the total productivity rate of the electric power generating installed facilities. Technological change played an important role to balance the decreasing efficiency between 2002 and 2005, and its weight was particularly critical for those countries with smaller power generating capacity. On average efficiency remained almost stable, while productivity grew at a rate of about 6%.

In Fig. 4, between 2005 and 2009 the Malmquist productivity graph is above the technological change graph. However, between 2004 and 2007 the technological change contributes to improve productivity of the installed power generating facilities, balancing the diminishing efficiency. The slow growth of technological progress is unable to balance the abrupt decline of technical efficiency change. From 2007 to 2009 there is a mild productivity worsening caused by a negative influence of the technological component until 2008 and a reduced efficiency from 2008 to 2009. Since 2009 the productivity of the power generating facilities is experiencing a sharp and continuous upward trend, mostly induced by technological improvement that is well balancing a prolonged reduction of efficiency.

In Fig. 5, after an initial fluctuation, between 2006 and 2009 productivity remained stable suffering from the declining rate of technological change but benefiting by an increasing efficiency change until 2007, and later affected by the inverted trends of these variables. In the last two periods of the analysis, there was a sharp productivity growth induced by technological change and efficiency improvement. The behavior of this graph is further emphasizing how countries having a large installed power generating capacity and countries having a small installed capacity experienced different productivity change trajectories from 2002 to 2011.

4. Conclusion

The objective of this study was to analyze productivity changes of renewable energy installed capacity in a sample of 31 European countries from 2002 to 2011 and overcome a gap of the literature lacking in studies specifically focused on the overall assessment of efficiency changes in the industry of the electric power generation from renewable sources. Data Envelopment Analysis (DEA) and Malmquist indexes were adopted to implement the performance study. Particularly, DEA measured the technical efficiency of a country installed capacity at a specific time, while the Malmquist Indexes measured productivity changes over time of the country electric power capacity, providing insights to understand the nature of changes.

Unexpectedly, from 2001 to 2011, the average productivity growth from one year to the next was close to 6%, only. Figures also show that the total productivity of installed power generation capacity was characterized by several fluctuations from 2002 to 2011, and technological change largely contributed to this improvement, while technical efficiency remained almost stable. Productivity change paths differed between countries. In particular, countries having a larger installed electric generating power capacity experienced a sharp productivity growth induced by technological change and technical efficiency improvement, with a better utilization of power generating facilities.

A major challenge to increase productivity is thus investment to develop network infrastructure capacities necessary to cope with the increasing share of electricity generated from renewable sources, capable to smooth out production variability, dynamically balancing electricity demand and supply, and to allow better grid interconnections for improving reaction times as to electric power demand.

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