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Renewable energy and macroeconomic efficiency of OECD and non-OECD economies

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Abstract

This article analyzes the effects of renewable energy on the technical efficiency of 45 economies during the 2001–2002 period through data envelopment analysis (DEA). In our DEA model, labor, capital stock, and energy consumption are the three inputs and real GDP is the single output. Increasing the use of renewable energy improves an economy's technical efficiency. Conversely, increasing the input of traditional energy decreases technical efficiency. Compared to non-OECD economies, OECD economies have higher technical efficiency and a higher share of geothermal, solar, tide, and wind fuels in renewable energy. However, non-OECD economies have a higher share of renewable energy in their total energy supply than OECD economies.

Keywords: Data envelopment analysis; Technical efficiency; Renewable energy

1. Introduction

In 2003 renewable energy accounted for 13.3% of the world's total primary energy supply, even though its supply grew insignificantly between 1990 and 2003 at a 1.8% annual rate. With the rapid growth of crude oil prices recently, more attention has been drawn to the further exploitation of renewable energy by academics and industries. While renewable energy technologies are non-competitive on purely financial grounds, their cost gap has narrowed significantly over the past two decades (Owen, 2004).

Because economies signing the Kyoto Protocol are CO_2-emission conscious, many of them will increase their renewable energy intensity. It is thus quite important to confirm if the increasing usage in renewable energy improves energy efficiency. Renewable energy systems are considered to be environmentally superior to traditional ones from the viewpoints of CO_2 mitigation and the effective utilization of resources. Many studies present that the substitution of conventional fossil fuels with biomass for energy production results both in a net reduction of greenhouse gas emissions and in the replacement of non-renewable energy sources (Schneider and McCarl, 2003; Dowaki and Mori, 2005; Caputo et al., 2005).

Domac et al. (2005) argue that bioenergy should help improve macroeconomic efficiency. They claim that in most economies, regional employment created and economic gains are probably the two most important issues regarding biomass use for energy production. From the macro-economic level, bioenergy production to replace fossil fuels contributes to all the important elements of economy or regional development: (1) The business expansion and new employment brought by renewable energy industries result in economic growth. (2) The import substitution of energy has direct and indirect effects on increasing an economy's GDP and trade balance. For energy importing states, biomass or any other local renewable energy use translates into important local economic and employment multipliers. Domac et al., also conclude that although these economic effects differ in kind and depend on the development of states, generally

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the increasing use of bioenergy relates to an improvement in regional productivity, enhanced competitiveness, as well as further investment in resources to accommodate the economic development.

Aside from the benefits of bioenergy, its impacts on living nature should not be neglected. Increasing usage of bioenergy may result in further land claims leading to deforestation. In some Asian economies such as China, India, Sri Lanka, Malaysia and Thailand (Bhattacharya et al., 2003), production of bioenergy means conversion of forests into tree plantation for electricity generation to a considerable extent. As the world population grows, higher demand for land growing crops to feed the growing population has lead to the 'food versus fuel' debate. Sustainable bioenergy use also requires ecosystem services of the nature to be maintained (Reijnders, 2006). Hence, those areas allocated to nature and biodiversity should not be eliminated.

Since energy efficiency improvement relies on total-factor productivity improvement (Boyd and Pang, 2000), the technical efficiency (TE) index is computed to analyze the energy efficiencies of economies. The TE index incorporates energy, labor, and capital stock as multiple inputs so as to produce the economic output of GDP. The traditional energy efficiency index is also calculated for comparison. We use the data envelopment analysis to find the technical efficiency of each economy. We test whether or not bioenergy or any other renewable energy contributes to technical efficiency improvement through a hierarchical regression and comparisons of multivariate means with empirical data from 2001–2002.

Domac et al. (2005) also argue that there is a huge difference between developing and developed economies with respect to the understanding and interpretation of bioenergy as a sector. In developing economies, bioenergy is a source of fuel for subsistence, which contributes to income particularly in off-harvest seasons. Many of the current practices are unsustainable: as a consequence of underdevelopment, bioenergy sometimes is associated with poor environment and health hazards. While in developed economies, bioenergy is actively promoted by governments due to its environmental benefits. The usage of bioenergy also potentially contributes to job creation, industrial competitiveness, and regional development. Domac et al. (2005) show the differences by giving a wage comparison among wood-energy workers of developing and developed economies. Wood-energy workers in developed economies earn wages equivalent to many other technically qualified workers and can have average lifestyle. However, wood-energy workers in developing economies earn wages below the average and are left in the lowest economic levels. They suggest approaches in order to modernize bioenergy systems in developing economies, which may lose some jobs but raise economic level.

We will test whether or not the energy profile of developed economies differs from that of developing economies.

2. Data and descriptive statistics of renewable energy

According to the International Energy Agency statistics, renewable energy was the third largest contributor to global electricity production in the year 2003 (Fig. 1). It accounted for 17.6% of world generation, after coal (40.1%), and gas (19.4%), but ahead of nuclear (15.8%) and oil (6.9%). This is because the majority of renewable energy generated is consumed in the residential, commercial, and public service sectors (58.6%) (Fig. 2) as a consequence of widespread biomass use in the residential sector of developing economies. For example, biomass energy is one of the main sources for non-commercial energy use in China's rural areas, constituting 19.9% of China's total energy consumption in 2000 (Chang et al., 2003), while more than half of the renewable primary energy supply in OECD economies is used in the transformation sector to generate electricity. From a global point of view, only 21.3% of renewable energy is used on electricity plants.

The renewable energy indicators by an economy are collected from Renewables Information published by International Energy Agency (IEA) since 2002. The 1991 capital stocks in 1985 prices are obtained from Penn World Tables 5.6 (1998). The panel dataset of 45 economies from 2001–2002 is established for our analysis. Data on labor

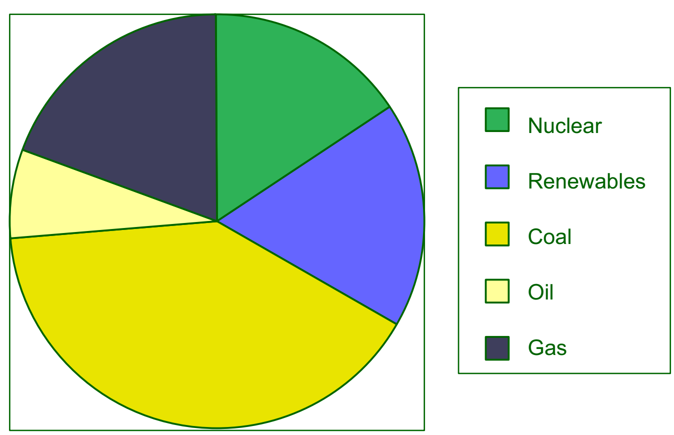

Fig. 1. Fuel shares in world electricity production in 2003.

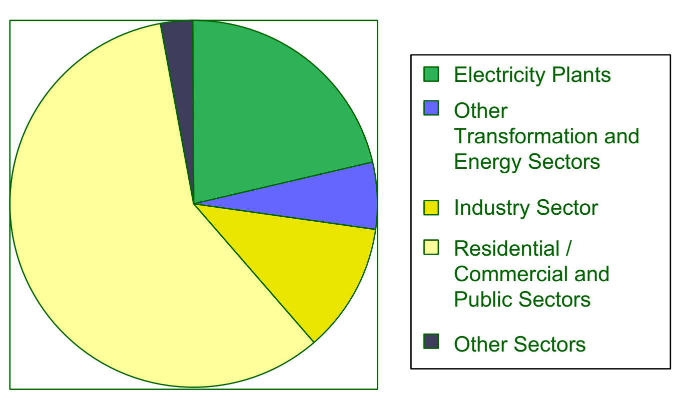

Fig. 2. World sectoral consumption of renewable energy in 2003.

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Table 1
Correlation matrix for inputs and the output (2001–2002)

	GDP	Labor	Capital	Energy
GDP	1.000			
Labor	0.313	1.000		
Capital	0.981	0.318	1.000	
Energy	0.977	0.369	0.927	1.000

employment, energy consumption and GDP are collected from the World Development Indicators database (World Bank, 2005). To the best of our knowledge, data of recent capital stock (after year 2000) are not available from any statistical yearbook or database. The capital stock is hence calculated by the following formula with the initial values obtained from Penn World Table and substituting into the formula with capital formation obtained from World Development Indicators database:

$$K_t = K_{t-1}(1-\delta) + I_t, \quad (1)$$

where K_t, the capital stock in the current year; K_{t-1}, the capital stock in the previous year; δ, depreciation rate of capital stock; I_t, capital formation in the current year.

The depreciation rate δ is set to be 6% according to the suggestions by many relevant studies such as Iyer et al. (2004). GDP and capital stock are transformed into constant 2000 US dollars by GDP deflators from the International Monetary Fund World Economic Outlook database (International Monetary Fund, 2005).

A correlation matrix is shown in Table 1, whereby positive correlations exist between these inputs and the output. The correlation between capital and GDP, energy and GDP, and energy and capital are particular strong (0.981, 0.977, and 0.927). These results confirm isotonicity of the three inputs and the one output in our data envelopment analysis (DEA) model.

3. Macroeconomic technical efficiency

Energy, labor, and capital stock are key inputs to produce the economic output—GDP (Hu and Kao, 2007; Hu and Wang, 2006). It is desirable for an economy to increase its GDP and to decrease its inputs in order to maximize production efficiency. We use DEA to construct an efficiency frontier for each of the 45 economies in each year. The macroeconomic technical efficiency is measured in each economy for how far apart they are from their efficiency frontier in that year. DEA is a mathematical programming technique to measure the efficiency frontier and assess the efficiencies of decision-making units (in this study, each individual economy is the decision-making unit). Further details of the DEA method are demonstrated in Coelli's (1996) article and other relevant literature. We employ the constant returns to scale model proposed by Charnes et al. (1978) to estimate the technical efficiency (TE) scores of these 45 economies in years 2001 and 2002, respectively.

An index of partial-factor energy efficiency (PFEE) computing the efficiency ratio by dividing GDP by energy inputs is calculated for comparison. Table 2 shows the 2001–2002 TE and PFEE scores. Denmark, Ireland, Japan, Luxembourg, and the United Kingdom are found to have the optimal efficiency for both 2001 and 2002. Although Denmark, Ireland, Japan, Luxembourg, and the United Kingdom are on the frontier in our analysis, this does not mean that the five economies have the best energy technology levels. The fact that these five economies constitute the efficiency frontier simply means that their inputs and output level are operating at the optimal level.

Table 2
2001–2002 TE and PFEE scores for 45 economies

Economy	2001		2002	
	TE	PFEE	TE	PFEE
Argentina	0.871	3.663	0.814	3.372
Australia	0.719	2.240	0.713	2.186
Austria	0.769	3.500	0.757	3.525
Belgium	0.794	2.940	0.780	2.949
Bolivia	0.573	2.462	0.616	2.416
Canada	0.765	1.514	0.776	1.534
Chile	0.715	1.971	0.737	1.944
Colombia	0.506	2.416	0.525	2.419
Denmark	1.000	4.936	1.000	5.014
Dominican Republic	0.757	3.191	0.776	2.911
Ecuador	0.419	2.068	0.408	2.034
Finland	0.738	1.568	0.739	1.555
France	0.816	3.378	0.805	3.439
Germany	0.769	3.733	0.764	3.788
Greece	0.704	2.619	0.717	2.601
Guatemala	0.984	4.726	0.961	4.656
Honduras	0.490	1.814	0.507	1.720
Hong Kong, China	0.903	4.458	0.887	4.446
Iceland	0.924	1.195	0.895	1.138
India	0.582	1.284	0.612	1.257
Ireland	1.000	4.808	1.000	4.928
Italy	0.798	3.938	0.775	3.882
Japan	1.000	4.939	1.000	4.830
Kenya	0.789	2.946	0.818	2.837
Luxembourg	1.000	3.527	1.000	3.562
Mexico	0.747	3.557	0.731	3.498
Morocco	0.810	2.634	0.808	2.596
Netherlands	0.800	3.773	0.775	3.770
New Zealand	0.652	1.632	0.682	1.617
Norway	0.903	1.528	0.903	1.606
Panama	0.615	3.010	0.610	3.024
Peru	0.611	2.915	0.635	2.884
Philippines	0.657	1.997	0.692	2.197
Poland	0.608	1.731	0.630	1.775
Portugal	0.646	2.711	0.640	2.621
Spain	0.654	2.875	0.659	2.854
Sweden	0.846	1.822	0.854	1.876
Switzerland	0.940	4.603	0.952	4.631
Syrian Arab Republic	0.383	1.156	0.413	1.133
Thailand	0.422	1.359	0.459	1.318
Turkey	0.601	1.934	0.660	1.960
United Kingdom	1.000	4.415	1.000	4.490
United States	0.983	2.840	0.970	2.856
Venezuela	0.581	1.887	0.551	1.771
Zambia	0.690	0.628	0.710	0.587

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4. Second stage statistical analysis

In order to verify the argument that the use of bioenergy or any other renewable energy contributes to efficiency improvement, we identify the relationship between renewable energy and efficiency by the following two analyses:

Analyses A (Hierarchical regression):

$$\textit{Model 1}: \textit{Technical efficiency} = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5;$$

$$\textit{Model 2}: \textit{Technical efficiency} = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + a_7X_7;$$

where the samples in this analysis are 45 economies across the world; X_1, GDP; X_2, labor force; X_3, capital stock; X_4, traditional energy (total primary energy supply−renewable energy); X_5, renewable energy; X_6, share of hydro fuel in renewable energy; X_7, share of geothermal, solar, tide and wind (GSTW) fuel in renewable energy.

We use the three variables of GDP, labor force and capital stock as controlling variables in this model. The input of energy is broken down into traditional energy and renewable energy in Model 1. By the definition of IEA, renewable energy is divided into the three categories of: (1) hydro fuel; (2) geothermal, solar, tide and wind fuel; and (3) combustible renewable energy and waste. The three categories of energy are all very different in nature and cost (Owen, 2004). For Model 2, renewable energy is broken down into the share of hydro fuel in renewable energy, the share of geothermal, solar, tide and wind fuel in renewable energy, and the share of combustible renewable energy and waste in renewable energy. Since shares of: (1) hydro fuels; (2) geothermal, solar, tide and wind fuels; and (3) combustible and waste fuels in renewable energy add up to 100%, we omit the last one in the regression to avoid multicollinearity.

Results of Model 1 show that renewable energy does not significantly affect technical efficiency in the year 2001, but does affect technical efficiency in 2002. If we break down renewable energy into different categories of energy in Model 2, a significant positive relationship exists between renewable energy and technical efficiency. The behaviors of all the variables are quite consistent in 2001 and 2002. For Model 1, the variables of GDP, capital stock, and traditional energy are significant in both 2001 and 2002. For Model 2, the variables of GDP, labor force, capital stock, traditional energy, renewable energy, and hydro fuel share in renewable energy are significant in both 2001 and 2002 (Table 3).

In Model 2 the coefficients of renewable energy are significant in years 2001 (0.009) and 2002 (0.008) and the t-statistics are 2.150 for 2001 and 2.438 for 2002. Thus, the prediction that increasing the share of renewable energy among total energy supply improves technical efficiency is confirmed by Model 2. It is worth noting that increasing the input of traditional energy decreases technical efficiency. For an economy to improve its technical efficiency, it is important not to increase the total input of energy. By substituting traditional energy with renewable energy, technical efficiency can be improved. This result is consistent even if we revise Model 2 to omit GSTW share in renewable energy instead of combustible renewable energy and waste share in renewable energy so as to avoid multicollinearity (see Table 4).

It is argued that in every respect, there is a huge difference in the understanding and interpretation of bioenergy as a sector between developing and developed economies (Domac et al., 2005). Here, we use the term

Table 3
Regression results of all 45 economies in 2001–2002

Coefficients (t-statistics)	2001		2002	
	Model 1	Model 2	Model 1	Model 2
Constant	0.738	0.776	0.741	0.776
	(29.013***)	(20.070***)	(31.635***)	(22.414***)
GDP	9.370×10^{-13}	9.340×10^{-13}	9.360×10^{-13}	9.540×10^{-13}
	(3.100***)	(3.118***)	(3.335***)	(3.560***)
Labor force	-1.400×10^{-9}	-3.000×10^{-9}	-1.500×10^{-9}	-2.800×10^{-9}
	(−0.884)	(−1.688*)	(−1.028)	(−1.831*)
Capital stock	-2.500×10^{-13}	-2.400×10^{-13}	-2.400×10^{-13}	-2.400×10^{-13}
	(−2.524**)	(−2.448**)	(−2.793***)	(−2.890***)
Traditional energy	−0.002	−0.003	−0.002	−0.003
	(−3.146***)	(−3.448***)	(−3.512***)	(−3.82***)
Renewables	0.005	0.009	0.006	0.008
	(1.403)	(2.150**)	(1.662*)	(2.438**)
Hydro fuel share in renewable energy		−0.002		−0.002
		(−1.847*)		(−1.999**)
GSTW share in renewable energy		0.001		0.002
		(0.963)		(1.264)

Note: * represents significance at the 10% level; ** represents significance at the 5% level; *** represents significance at the 1% level.

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Table 4
Results of Model 2 when omitting the variable of share of GSTW fuels in renewable energy in 2001–2002

Coefficients (*t*-statistics)	2001 Model 2A	2002 Model 2A
Constant	0.900	0.942
	(9.382***)	(7.694***)
GDP	9.150×10^{-13}	9.540×10^{-13}
	(3.084***)	(3.561***)
Labor force	-3.000×10^{-9}	-2.800×10^{-9}
	(−1.674*)	(−1.832*)
Capital stock	-2.300×10^{-13}	-2.400×10^{-13}
	(−2.422*)	(−2.891***)
Traditional energy	−0.003	−0.003
	(−3.401***)	(−3.883***)
Renewables	0.008	0.008
	(2.134**)	(2.440**)
Hydro fuel share in renewable energy	−0.003	−0.003
	(−2.358**)	(−2.304**)
Combustible renewables and waste share in renewable energy	−0.001	−0.002
	(−1.234)	(−1.270)

Note: * represents significance at the 10% level; ** represents significance at the 5% level; *** represents significance at the 1% level.

environment to describe factors which could influence the efficiency of an economy, where such factors are not traditional inputs and are assumed to be not under the control of a government in the short run. We use the method proposed by Charnes et al. (1981). We divide the samples into OECD (developed) economies and non-OECD (developing) economies and solve DEAs for each sub-group. The OECD members are considered more developed than other economies in the world, and so we use the status of membership in OECD as a proxy variable for being a developed economy. We use the new technical efficiency when comparing only OECD economies to verify Model 1 and Model 2. The results of the OECD relevant TE are shown in Table 5.

Denmark, Ireland, Japan, Luxembourg, and the United Kingdom are found to have optimal efficiency for both years 2001 and 2002 when comparing with OECD economies only. The values of PFEE do not vary when the reference group changes.

Analysis B (hierarchical regression):

$$\text{Model 1: Technical efficiency when comparing with OECD countries only} = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5;$$

$$\text{Model 2: Technical efficiency when comparing with OECD countries only} = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + a_7X_7.$$

The samples for study B1 are 26 OECD economies (all developed economies) while the samples for study B2 are 19 non-OECD economies (developing economies).

Table 5
2001–2002 TE scores for 26 OECD economies

Economy	2001 TE	2002 TE
Australia	0.719	0.713
Austria	0.769	0.757
Belgium	0.794	0.780
Canada	0.765	0.776
Denmark	1.000	1.000
Finland	0.738	0.739
France	0.816	0.805
Germany	0.769	0.764
Greece	0.704	0.717
Iceland	0.924	0.895
Ireland	1.000	1.000
Italy	0.798	0.775
Japan	1.000	1.000
Luxembourg	1.000	1.000
Mexico	0.747	0.731
Netherlands	0.800	0.775
New Zealand	0.652	0.682
Norway	0.903	0.903
Poland	0.608	0.630
Portugal	0.646	0.640
Spain	0.654	0.659
Sweden	0.846	0.854
Switzerland	0.940	0.952
Turkey	0.601	0.660
United Kingdom	1.000	1.000
United States	0.983	0.970

Our results (Table 6) show that there is no significant relationship between renewable energy and technology efficiency when comparing all the developed economies together. We solve DEA for the non-OECD group, too. The resulting TE scores by non-OECD economies in 2001–2002 are shown in Table 7.

Our results show (Table 8) that there is no significant relationship between renewable energy and technology efficiency when comparing all the developing economies together.

We assess the differences in the two sub-groups by comparisons of multivariate means. The comparisons of multivariate means pertains to our situation in which a particular treatment is administered to two groups of subjects (in our case, the OECD and non-OECD economies). In the comparisons of multivariate means, the question of equality of mean vectors for the OECD group and non-OECD group is divided into several specific possibilities. Notations $\mu_{\text{OECD},1}, \ldots,$ and $\mu_{\text{OECD},13}$ represent the average values of GDP, labor force, capital stock, electricity generation, TE, PFEE, total primary energy supply, traditional energy, renewable energy, share of renewable energy in total energy, hydro fuel share in renewable energy, GSTW fuel share in renewable energy, and combustible energy and waste share in renewable energy for OECD economies, respectively. Notations $\mu_{\text{non-OECD},1}, \ldots, \mu_{\text{non-OECD},13}$ show, respectively, the average values of GDP, labor force, capital stock, electricity

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Table 6
Regression results for twenty-six OECD economies in 2001–2002

Coefficients (*t*-statistics)	2001		2002	
	Model 1	Model 2	Model 1	Model 2
Constant	0.834	0.828	0.826	0.805
	(27.981***)	(17.048***)	(29.236***)	(18.651***)
GDP	7.120×10^{-13}	7.300×10^{-13}	7.270×10^{-13}	7.330×10^{-13}
	(3.007***)	(2.911***)	(3.274***)	(3.056***)
Labor force	-4.300×10^{-9}	-4.400×10^{-9}	-3.300×10^{-9}	-3.200×10^{-9}
	(−1.650)	(−1.573)	(−1.392)	(−1.270)
Capital stock	-1.900×10^{-13}	-1.900×10^{-13}	-1.800×10^{-13}	-1.900×10^{-13}
	(−2.391**)	(−2.347**)	(−2.647**)	(−2.574**)
Traditional energy	−0.002	−0.002	−0.001	−0.002
	(−2.376**)	(−2.200**)	(−2.741**)	(−2.354**)
Renewables	0.001	0.001	0.001	0.001
	(0.246)	(0.298)	(0.464)	(0.172)
Hydro fuel share in renewable energy		−0.0001		0.0004
		(−0.109)		(0.357)
GSTW share in renewable energy		0.001		0.001
		(0.641)		(0.761)

Note: * represents significance at the 10% level; ** represents significance at the 5% level; *** represents significance at the 1% level.

Table 7
TE scores for nineteen non-OECD economies in 2001–2002

Economy	2001 TE	2002 TE
Argentina	1.000	1.000
Bolivia	0.608	0.653
Chile	0.816	0.896
Colombia	0.565	0.607
Dominican Republic	0.830	0.875
Ecuador	0.449	0.446
Guatemala	1.000	1.000
Honduras	0.521	0.538
Hong Kong, China	1.000	1.000
India	0.617	0.648
Kenya	0.837	0.866
Morocco	0.859	0.856
Panama	0.689	0.729
Peru	0.680	0.732
Philippines	0.696	0.733
Syrian Arab Republic	0.426	0.474
Thailand	0.466	0.523
Venezuela	0.667	0.676
Zambia	0.732	0.752

generation, TE, PFEE, total primary energy supply, traditional energy, renewable energy, share of renewable energy in total energy, hydro fuel share in renewable energy, GSTW fuel share in renewable energy, and combustible energy and waste share in renewable energy for non-OECD economies. We construct the profiles for the OECD group and non-OECD group for 2001 and 2002 separately. We formulate the question of equality in the following hypothesis.

Hypothesis 1. The OECD profile is parallel to the non-OECD profile. The statistical forms of Hypothesis 1 are as the following equations:

$$
\begin{aligned}
H_{01}: \quad & \mu_{\text{OECD},2} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},2} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},3} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},3} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},4} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},4} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},5} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},5} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},6} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},6} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},7} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},7} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},8} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},8} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},9} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},9} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},10} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},10} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},11} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},11} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},12} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},12} - \mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},13} - \mu_{\text{OECD},1} = \mu_{\text{non-OECD},13} - \mu_{\text{non-OECD},1}.
\end{aligned}
$$

If Hypothesis 1 is accepted, then the expected values of the 13 indicators do not vary from the OECD group to the non-OECD group.

Hypothesis 2. The expected values of the means of the 13 indicators are equal for the OECD group and non-OECD group.

The statistical form of Hypothesis 2 is

$$
\begin{aligned}
H_{02}: \quad & (\mu_{\text{OECD},1} + \cdots + \mu_{\text{OECD},13})/13\\
& = (\mu_{\text{non-OECD},1} + \cdots + \mu_{\text{non-OECD},13})/13.
\end{aligned}
$$

Hypothesis 3. The OECD profile is coincident with the non-OECD profile. The statistical forms of Hypothesis 3 are as follows:

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Table 8
Regression results for nineteen non-OECD economies in 2001–2002

Coefficients (*t*-statistics)	2001		2002	
	Model 1	Model 2	Model 1	Model 2
Constant	0.682	0.772	0.708	0.792
	(14.024***)	(14.845***)	(15.447***)	(14.947***)
GDP	4.930×10^{-12}	5.040×10^{-12}	5.790×10^{-12}	6.160×10^{-12}
	(3.558***)	4.376***)	(3.286***)	(3.994***)
Labor force	-9.800×10^{-10}	-6.200×10^{-9}	-4.700×10^{-9}	-6.900×10^{-9}
	(−0.166)	(−1.179)	(−0.692)	(−1.142)
Capital stock	-1.400×10^{-12}	-1.900×10^{-12}	-1.900×10^{-12}	-2.400×10^{-12}
	(−1.588)	(−2.342**)	(−1.911*)	(−2.609**)
Traditional energy	−0.006	−0.001	−0.002	0.002
	(−1.129)	(−0.108)	(−0.589)	(0.368)
Renewables	0.008	0.013	0.011	0.012
	(0.662)	(1.213)	(0.857)	(0.945)
Hydro fuels share in renewable energy		−0.003		−0.003
		(−2.665**)		(−2.326**)
GSTW share in renewable energy		−0.003		−0.003
		(−1.158)		(−1.063)

Note: * represents significance at the 10% level; ** represents significance at the 5% level; *** represents significance at the 1% level.

$$
\begin{aligned}
H_{03}:\quad & \mu_{\text{OECD},1}=\mu_{\text{non-OECD},1},\\
& \mu_{\text{OECD},2}=\mu_{\text{non-OECD},2},\\
& \mu_{\text{OECD},3}=\mu_{\text{non-OECD},3},\\
& \mu_{\text{OECD},4}=\mu_{\text{non-OECD},4},\\
& \mu_{\text{OECD},5}=\mu_{\text{non-OECD},5},\\
& \mu_{\text{OECD},6}=\mu_{\text{non-OECD},6},\\
& \mu_{\text{OECD},7}=\mu_{\text{non-OECD},7},\\
& \mu_{\text{OECD},8}=\mu_{\text{non-OECD},8},\\
& \mu_{\text{OECD},9}=\mu_{\text{non-OECD},9},\\
& \mu_{\text{OECD},10}=\mu_{\text{non-OECD},10},\\
& \mu_{\text{OECD},11}=\mu_{\text{non-OECD},11},\\
& \mu_{\text{OECD},12}=\mu_{\text{non-OECD},12},\\
& \mu_{\text{OECD},13}=\mu_{\text{non-OECD},13}.
\end{aligned}
$$

The results of the comparisons of multivariate means are shown in Tables 9 and 10.

According to Table 9, the interaction effect of indicators × groups is not significant (p-value = 0.279), and Hypothesis 1 is supported. The result of the significant between-subjects effect (p-value = 0.059) shows that the overall OECD profile has significant differences from the non-OECD profile in 2001, and hence Hypothesis 2 is rejected. There are significant differences in the indicators of GDP, capital stock, energy consumption, TE, renewable energy share in total energy, and GSTW fuel share in renewable energy between the OECD profile and non-OECD profile, and Hypothesis 3 is rejected.

The empirical results in 2002 (Table 10) are very similar to those in 2001 (Table 9). The interaction effect of indicators × groups is not significant (p-value = 0.275), and Hypothesis 1 is supported. The result of the significant between-subjects effect (p-value = 0.060) shows that the overall OECD profile has significant differences from non-OECD profile in 2002, and hence Hypothesis 2 is rejected. There are significant differences in the indicators of GDP, capital stock, TE, PFEE, renewable energy share in total energy, and GSTW fuel share in renewable energy between the OECD profile and non-OECD profile. Hypothesis 3 is rejected. We demonstrate the mean differences in the two groups in Table 11.

To sum up, the average values of GDP and capital stock are higher in OECD economies than in non-OECD economies. Technical efficiency is higher in OECD economies than in non-OECD economies. The share of renewable energy in total energy supply is higher in developing economies than in OECD economies due to the widespread biomass use in the residential sector of developing economies as explained previously. The share of GSTW fuel in renewable energy is higher in OECD economies than in non-OECD economies.

Because the share of renewables in total energy supply and the composition of renewables are very different in OECD and non-OECD economies, the argument that renewable energy is very different in developed and developing economies is hence confirmed.

5. Discussions and concluding remarks

We use the DEA method to estimate the technical efficiency for the 45 economies in the years 2001 and 2002. Increasing the share of renewable energy among total energy supply will significantly improve technical efficiency. It is worth noting that increasing the input of traditional energy decreases technical efficiency. For an economy to improve its technical efficiency, it is important not to increase the total input of energy. By substituting traditional energy with renewable energy, an economy's

Table 9
Mean difference test of OECD and non-OECD economies in the year 2001

Manova test criteria and exact F statistics for the hypothesis of no indicators × group effect		
Statistics	*F* value	*P*-value
Wilks' Lambda	1.330	0.279
Dependent variable: GDP		
Source of differences	*F*-statistic	*P*-value
Model	3.49	0.069*
Dependent variable: labor force		
Source of differences	*F*-statistic	*P*-value
Model	0.430	0.515
Dependent variable: capital stock		
Source of differences	*F*-statistic	*P*-value
Model	3.980	0.053**
Dependent variable: energy consumption		
Source of differences	*F*-statistic	*P*-value
Model	2.780	0.103*
Dependent variable: TE		
Source of differences	*F*-statistic	*P*-value
Model	13.060	0.001***
Dependent variable: PFEE		
Source of differences	*F*-statistic	*P*-value
Model	2.640	0.112
Dependent variable: total primary energy supply		
Source of differences	*F*-statistic	*P*-value
Model	1.940	0.171
Dependent variable: traditional energy		
Source of differences	*F*-statistic	*P*-value
Model	2.310	0.136
Dependent variable: renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	0.210	0.651
Dependent variable: renewable energy share in total energy		
Source of differences	*F*-statistic	*P*-value
Model	7.87	0.008***
Dependent variable: hydro fuel share in renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	0.240	0.628
Dependent variable: GSTW fuel share in renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	4.520	0.039**
Dependent variable: combustible energy and waste share in renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	0.880	0.355
Tests of hypotheses for between subjects effects		
Source	*F*-statistic	*P*-value
Group	3.750	0.059*

Note: * represents significance at the 10% level; ** represents significance at the 5% level; *** represents significance at the 1% level.

Table 10
Mean difference test of OECD and non-OECD economies in the year 2002

Manova test criteria and exact F statistics for the hypothesis of no Indicators × Group effect		
Statistics	*F* value	*P*-value
Wilks' Lambda	1.340	0.275
Dependent variable: GDP		
Source of differences	*F*-statistic	*P*-value
Model	3.47	0.069*
Dependent variable: labor force		
Source of differences	*F*-statistic	*P*-value
Model	0.450	0.507
Dependent variable: capital stock		
Source of differences	*F*-statistic	*P*-value
Model	3.970	0.053**
Dependent variable: energy consumption		
Source of differences	*F*-statistic	*P*-value
Model	2.740	0.105
Dependent variable: TE		
Source of differences	*F*-statistic	*P*-value
Model	13.01	0.001***
Dependent variable: PFEE		
Source of differences	*F*-statistic	*P*-value
Model	3.310	0.076*
Dependent variable: total primary energy supply		
Source of differences	*F*-statistic	*P*-value
Model	1.900	0.175
Dependent variable: traditional energy		
Source of differences	*F*-statistic	*P*-value
Model	2.27	0.140
Dependent variable: renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	0.200	0.660
Dependent variable: renewable energy share in total energy		
Source of differences	*F*-statistic	*P*-value
Model	7.230	0.010***
Dependent variable: hydro fuel share in renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	0.004	0.851
Dependent variable: GSTW fuel share in renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	4.890	0.032**
Dependent variable: combustible energy and waste share in renewable energy		
Source of differences	*F*-statistic	*P*-value
Model	1.820	0.184
Tests of hypotheses for between subjects effects		
Source	*F*-statistic	*P*-value
Group	3.74	0.060*

Note: * represents significance at the 10% level; ** represents significance at the 5% level; *** represents significance at the 1% level.

technical efficiency can be significantly improved. Thus, the hypothesis that renewable energy improves technical efficiency is confirmed if we take into account the effect of different categories of renewable energy.

We also verify the hypothesis that the use of renewable energy is very different in developed economies and developing economies. We use the status of OECD and non-OECD economies as a proxy variable for developed and developing economies respectively. We then compare the mean differences of OECD and non-OECD economies and find that there are significant differences in some variables.

The TE is higher in OECD economies than in non-OECD economies. The share of renewable energy in total energy supply is higher in non-OECD (developing) economies than in OECD (developed) economies. If we neglect the controlling variables for TE, then these two results combined may lead to the incorrect conclusion that the OECD economies with lower renewable energy share have higher technical efficiency, and thus renewable energy has a negative effect on technical efficiency. It is vital to recognize that technical efficiency is significantly affected by the inputs and output. It is necessary to evaluate the effect of renewable energy on technical efficiency from

Table 11
Average values of the 13 indicators for OECD economies and non-OECD economies in 2001–2002

	Year 2001		Year 2002	
	OECD economies	Non-OECD economies	OECD economies	Non-OECD economies
GDP (constant 2000 US$)	967639057846	84768701158	981005049346	84895533526
Labor force (persons)	20033098	33947209	20202573	34662794
Capital stock (constant 2000 US$)	1886676663516	202958029195	1975932871821	207682070554
Electricity consumption (kwh)	305479519530	44343433249	309690527806	46085834079
TE	0.814	0.650	0.815	0.660
PFEE	3.010	2.452	3.019	2.396
Total primary energy supply (Mtoe)	194.335	48.653	194.481	49.495
Traditional energy (Mtoe)	182.800	32.405	182.885	33.295
Renewable energy (Mtoe)	11.535	16.247	11.596	16.200
Renewable energy share in total energy (%)	13.482	30.669	13.615	30.449
Hydro fuel share in renewable energy (%)	30.219	26.426	28.677	27.226
GSTW fuel share in renewable energy (%)	12.638	2.874	12.669	2.774
Combustible energy and waste share in renewable energy (%)	57.142	65.442	58.654	70.000

economies of similar conditions. Therefore, we need to evaluate the effect of renewable energy on technical efficiency by controlling the variables of inputs and output. When the variables of inputs and output are treated as controlling variables in our hierarchical analysis, the results show that renewable energy has a positive effect on the technical efficiency. The share of geothermal, solar, tide, and wind fuel in renewable energy is higher in OECD economies than in non-OECD economies. The differences of renewable energy existing between developed and developing economies are thus confirmed.

The technical efficiency being significantly higher in OECD economies than in non-OECD economies may also explain why renewable energy does not have a significant effect on technical efficiency when we do the regressions separately for the OECD group and non-OECD group. The reason is that when we separate the two groups, each group becomes more homogeneous in technical efficiency, and the effect of renewable energy on technical efficiency becomes less obvious since the dependent variables are similar within the same group.

Having confirmed that increasing the use of renewables can significantly improve an economy's technical efficiency, we suggest that governments should adopt comprehensive strategies to promote the use of renewable energy. The European Parliament and Council Directive 2001/77/EC requires its member states to set the national target that the electricity produced from renewables should account for 7% in the overall electricity production by 2010. Individual state could set up a feasible objective for itself, for example, Lithuanian establishes the objective for renewables to account for 12% in its fuel mix by 2010 (Katinas and Markevicius, 2006). Governments should adopt institutional measures such as sponsoring the research on enhancing renewables utilization and legislative measures such as enforcing replacement of traditional fuels by renewables. Subsidies also provide economic incentives for enterprises and households to use renewables.

Renewables Information (IEA, 2003, 2004) has been published by IEA since 2002. The time series analysis should be more robust for the long-term effect of renewable energy when more annual data are available. As shown in most relevant productivity studies, the availability of information for capital stock limits the number of research objects in our study. In addition, the reasons why the share of hydro fuel energy in renewable energy reduces technical efficiency need further clarification.

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