Energy efficiency in OECD Economics: does renewable energy matter?

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Abstract

The question being addressed is whether higher levels of energy efficiency are associated with a shift towards higher quality energy resources. The promotion of energy efficiency policies is considered an important objective by the International Energy Agency (IEA) and the Energy Information Administration (EIA). This paper estimates the level of energy efficiency associated with the energy mix across 28 OECD countries over the period 1975 to 2011. The empirical model uses stochastic frontier analysis and specifies demand as a function of economic variables, energy mix, population and location. Increases in the primary supply of renewable energy resources, resources of relatively higher quality, is found to be associated with more efficient energy consumption in OECD countries.

Key words: Energy demand, OECD countries, efficiency and frontier analysis, energy inefficiency, and energy mix.

JEL Classification: C51. D24. Q41. Q42

1. Introduction

Energy consumption is closely aligned with economic growth and it is the largest contributor to greenhouse gas emissions. In 2008, 83% of anthropogenic greenhouse gas emissions were associated with energy use (IEA 2010). Hence, improvements in energy efficiency yield a double dividend viz. contributing to growth and a reduction in greenhouse gas emissions (Shahiduzzaman & Alam, 2013). Energy intensity, defined as the ratio of energy use to GDP, is commonly used as an indicator for energy efficiency. It is well recognised that two issues arise from this definition. First, ideally differences in energy quality should be accounted for when deriving an estimate for the numerator especially when undertaking cross country studies. It is highly plausible that countries with similar estimates of energy use have quite different profiles of energy type. Second, GDP is a summary measure of economic activity. Again, countries with similar levels of GDP are likely to differ in terms of their economic structure. Therefore, in order to gain greater insights into energy efficiency, we must first recognise that aggregate energy consumption is composed of different types of energy of different quality where quality refers to the ability of a unit of energy to produce goods and services (Cleveland, 2014). For example, the quality of coal differs from the quality of geothermal energy.

These two issues are addressed by Wilson, Trieu, and Bowen (1994) who use factorization, a non-parametric method, to estimate trends in energy efficiency in Australia. Changes in fuel mix, away from petroleum toward gas and electricity, are shown to play an important role in improving energy end-use efficiency. The observation that improvements in energy efficiency occurred at a time when domestic oil prices suggests that relative energy prices are a key influence in observed gains in energy efficiency. However, attribution based on factorization are descriptive and do not establish causal linkages between variables of interest, such as the price of energy and economic structure, and end-use efficiency (Greening, Davis, Schipper, & Khrushch, 1997).

Ma and Stern (2008), observed a decline in commercial energy intensity in China, with few exceptions, over the period 1980-2002. They find that the influence of structural change on energy intensity increases with the level of sectoral disaggregation. Previous studies of China's energy intensity subsumed inter-fuel substitution into technological change. The distinction is significant because technological change implies a shift in isoquants whereas inter-fuel substitution is captured by movements along a given isoquant. Ma and Stern (2008), find that technology plays a dominant role while structural change plays a minor role in explaining the decline in China's energy intensity. Inter-fuel substitution was found to contribute little to changes in energy intensity.

Shahiduzzaman and Alam (2013), decompose energy intensity in Australia over the period 1978-2009 using the log mean divisia index approach. Energy efficiency was found to play a dominant, but variable, role in reducing energy intensity. The driving forces behind decreasing energy intensity include changes in efficiency and structure of the economy. Fuel mix was found to play a smaller role in reducing energy intensity.

Filippini & Hunt (2004, 2012) provide empirical estimates of the causal relationship between energy efficiency and explanatory variables, such as changes in economic structure, technology, and climate. Using a panel of 48 states in the US, Filippini and Hunt (2012) show that energy intensity is not a good predictor of energy efficiency. Thus, controlling for a range of economic and other factors is relevant when advising policy makers on the need to conserve energy and/or increase the efficient use of energy.

We summarise the above findings using the following framework that shows the relationship between energy demand, economic structure, fuel switching, and energy intensity.

ΔEnergy demand= ΔActivity + ΔStructure + ΔFuel Switching + ΔEnergy intensity

Where:

ΔEnergy demand is the change in energy demand

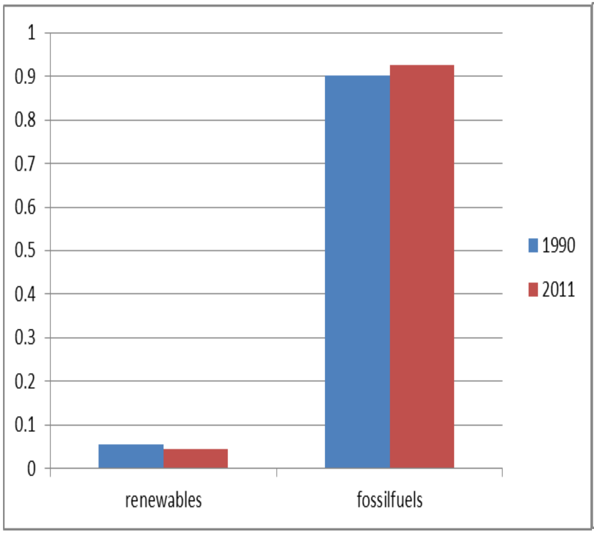
ΔActivity is the change in the level of production or the size of sector as measured by gross domestic product (GDP).

ΔStructure represents the change in economic structure; for example, shifting from an intensive energy industry to a less energy intensive industry.

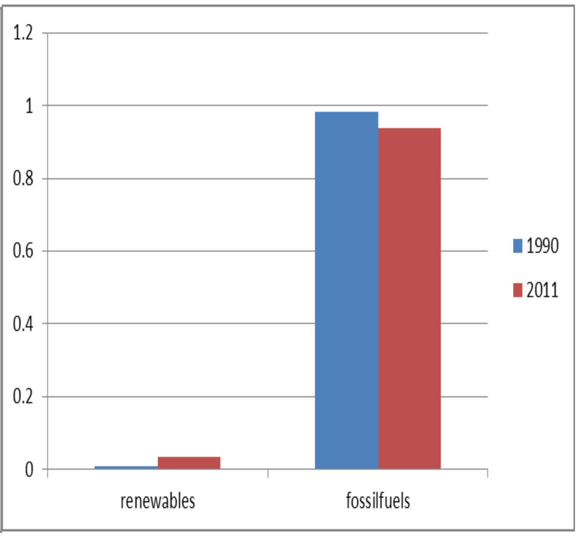
ΔFuel Switching or fuel mix refers to changes in the quantity of end use; switching from low to high energy quality, or vice versa; for example, switching from hydro (high energy quality) to coal (low energy quality).

ΔEnergy intensity is used as a measurement of energy efficiency.

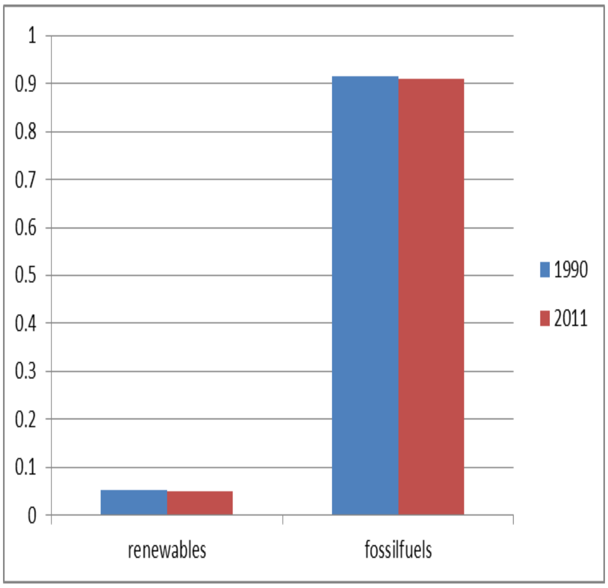
Obviously, the availability of usable energy resources; demand; and, the economic, environmental, and geopolitical context differ across countries (Armaroli & Balzani, 2011). The motivation for this paper comes from observing changes in the energy mix of countries over time. To illustrate, Figure 1 compares the share of renewable and fossil fuel sources of energy in 2011 with 1990 for Australia, New Zealand and the United States. In the case of New Zealand, the share of renewables increased over this period; by way of contrast, the share of renewables decreased in Australia and remained fairly constant in the United States. The question arising from these observations is whether higher levels of energy efficiency are associated with a shift towards higher quality energy resources.



Australia



New Zealand



US

Fig.1. share of energy resources

Approaches, such as index decomposition analysis (IDA) and frontier analyses (FA) have been proposed in order to overcome the problems associated with a use of energy intensity as an indicator of energy efficiency. The energy efficiency indicator as used in IDA is created according to a bottom-up approach (Boyd & Roop, 2004). On the other hand, FA provides an estimate of energy efficiency according to the distance between the actual demand of energy and the best practice frontier of energy use (Farrell, 1957). The parametric form of FA (SFA) is chosen in this paper because the non-parametric model of (FA) does not include statistical noise (Peng Zhou & Ang, 2008) and there is no algebraic form between output and inputs (M. Filippini and Hunt (2012), P Zhou, Ang, and Zhou (2012), and Hu and Wang (2006)).

To the best of our knowledge, this paper is the first study that includes the quality diversity of energy mix and energy efficiency using SFA. The objective of this paper is to provide empirical estimates of the impact of energy mix on the efficient consumption of energy resources in 28 OECD countries. This paper is organised as follows: Section 2 explains methodology. Section 3 describes data and empirical model. Section 4 presents the results. Finally, the summary and conclusions are provided in Section 5.

2. Methodological framework

This paper estimates energy efficiency according to the difference between productive efficient energy demand and actual demand rather than intensity. Productivity is defined as the ratio of output to inputs which is the inverse of energy intensity. In other words, this paper estimates efficient consumption of energy at the given level of productivity. Based on this, we test the hypothesis whether energy resources of different quality (energy mix) affect the efficient consumption of energy, under the assumption that all countries minimise their use of energy with respect to a given level of output. Stochastic frontier analysis (SFA) is denoted as follows:

$$y_{i,t} = f(X_{i,t};\beta).\exp\{v_{i,t} - u_{i,t}\} \quad i = 1,\ldots,N \quad t = 1,\ldots,T \qquad (1)$$

Where: y_{it} is observed final energy consumption by country i in year t; X_{it} is the $1\times$ K vector of explanatory variables which are associated with energy consumption of countries; β represents K × 1 vector of unknown parameters to be estimated. The error term has two components. The first component is stochastic v_{it} and assumed to have an independent and identical normal distribution with zero mean and constant variance, i.e. iid~ N (0, δ_v^2). The second component u_{it} is not stochastic and is assumed to be a one-sided normal distribution with the non-negative random variables, which represent technical inefficiency, i.e. $u_{it}{\sim}N^{+}(0,\delta_u^2)$.

Five models are commonly used in SFA; pooled, random effect, fixed effect, true random effect (TRE), and true fixed effect (TFE). Both TRE and TFE models include time-invariant group specific variables designed to capture heterogeneity and the time variant technical inefficiency term (u_{it}) (Greene 2005). Both TFE and TRE models are used in this paper and the pooled model (Aigner, Lovell, & Schmidt, 1977) is estimated for the purpose of comparison.

Unobserved heterogeneity bias, resulting from possible correlation between explanatory variables and the technical inefficiency term, is addressed by defining the technical inefficiency term u_{it} as a function of the explanatory variables (Mundlak, 1978).

$U_i = AX_i\pi + \tau_i$ (2) $AX_i = \frac{1}{T}\sum_{T=1}^{T} X_{it}$ (3) τ_i ~iid $(0,\delta_\sigma^2)$

Where: X_i represents the vector of the all explanatory variables of the demand function, AX_i is average vector of all explanatory variables, and the π is an unknown coefficient. When π=0 there is no correlation between the inefficient term and explanatory variables.

Equation (2) is readily incorporated into the equation (1) and the parameters in equation (1) are estimated using the maximum likelihood method. After estimating the productive efficient demand of energy, the level of energy inefficiency of countries is obtained according to the condition mean of efficiency term E (U_{it}| U_{it}+V_{it}) (Jondrow, Knox Lovell, Materov, & Schmidt, 1982). The level of energy inefficiency is expressed as:

$$EF_{it} = \frac{f(X_{it}.\beta).\exp(v_{it})}{y_{it}} = \exp(-\widehat{u_{it}}) \qquad (4)$$

Where $EF_{i,t} \in [0,1]$; a score of one indicating no inefficiency in energy consumption.

3. Data and empirical models

We use an unbalanced panel data set for 28 OECD countries between 1975 and 2011[3]. Data are drawn from the following sources: International Energy Agency (IEA) data on price, GDP, population, aggregated energy demand, and domestic primary supply of energy resources; World Bank data for value added of industry and service sectors; OECD for area size; and, climate dummy variables are based on the classification proposed by Kottek, Grieser, Beck, Rudolf, and Rubel (2006).

Variables

With energy consumption as the dependent variable we use the price of energy, GDP, population, area size, industrial value added shares, service value added shares, climate, and underlying energy demand trend (UEDT) for capturing the exogenous effect of technical progress and other exogenous effect, such as changes in consumer tastes and changes in the social norms are considered as controlling variables. The endogenous impact of technical progress is captured through price. Importantly, we control for quality, accessibility, and types of energy. UETD demonstrates technical progress. It could be argued that even if innovative technologies are available, counties do not install technologies at the same rate. It assumed that different technology rates across countries arises because of different behaviour which is captured by the inefficiency term (M. Filippini & Hunt, 2012).

As the impact of different energy mix on productive efficient demand is of primary importance in this paper, the primary supply of different energy resources include: coal, crude oil, gas, Geothermal, hydro, oil products (oil products includes naphtha, white spirit and SBP, lubricants, bitumen, paraffin waxes, and petroleum coke), renewable municipal (Renewable municipal waste consists of products that are combusted directly to produce heat and/or power and comprises wastes produced by households, industry, hospital, and tertiary sector at are collected by local authorities for incineration at specific installations. (IEA, 2008)), solar photovoltaics, solar thermal, solid biomass, and wind. Total primary supply is defined as sum of primary supply from coal, crude oil, gas, geothermal, hydro, oil products, renewable municipal, solar photovoltaics, solar thermal, solid biomass, wind, peat, heat, tide, wave, and ocean sources.

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[3] Australia, Austria, Belgium, Canada, Czechoslovakia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak, Spain, Sweden, Switzerland, Turkey, UK, and USA.

Table 1

Variable measurement

Variables	Measurement
Final energy consumption	Million tonnes oil equivalent (Mtoe).
Domestic primary supply	Kilo tonnes (Kt).
Consumer Price Index (CPI)	Real energy prices (2010-100) PPP.
Annual GDP per Capita	Billions 2005 USD using PPPS.
Value added of industry	Percentage of GDP.
Value added of services	Percentage of GDP.
Climate classification[4]	A, tropical weather; B, dry weather; C, mild mid-latitude weather; and E, polar one
Area size	Squared kilometres.
Population	All persons annually.

Table 2

Descriptive statistics for key variables

Variables	Mean	Std. Dev.	Min	max
Final energy consumption	115645.8	257909.3	2213.68	1581622
Wind	159.3443	744.9712	0	12113.79
Solar thermal	62.14103	217.3382	0	1972.536
Solar photovoltaics	18.78575	128.7051	0	2408
Hydro	2362.474	5702.136	0	32681.12
Geothermal	586.5168	1980.844	0	15650.9
Renewable municipal	193.6357	569.7636	0	4095.181
Coal	36549.27	87132.98	54.431	558411.6
Crude	70574.77	153356.4	0	921892.6
Gas	34590.38	90010.42	0	594784
Oil products	-1297.893	13468.56	-115557	56174.32
Price	60.84787	28.06941	0	131.5
Industrial value added	31.6771	6.144834	12.93014	61.59483
Service value added	64.21803	8.992673	31.60943	86.77441
GDP	99.6929	36.4326	23.10094	251.7267
Population	3.82e+07	5.35e+07	358950	3.14e+08

Area size	1250403	2766057	2586	9984670

Empirical model

The empirical model is described by equation 5 and estimated in natural log form:

$$d_{i,t} = \beta + \beta^{p} P_{i,t} + \beta^{shi} SHI_{i,t} + \beta^{she} SHE_{i,t} + \beta^{gdp} GDP_{i,j} + \beta^{rpop} Rpop_{i,t} + \beta^{em} EM_{i,t} + \beta^{t} D_{t} + \beta^{c} D_{c} + v_{i,t} + u_{i,t} \quad (5)$$

where:

i = 1,...,28 denotes country; t = 1,...,36 denotes year.

$d_{i,t}$ = aggregate energy demand

$P_{i,t}$ = energy consumer price index

$SHI_{i,t}$ = industrial sector value added

$SHE_{i,t}$ = service sector value added

$GDP_{i,t}$ = gross domestic product

$Rpop_{i,t}$ = population density

$EM_{i,t}$ = energy mix, ratio of primary supply of different energy resources to total primary supply

D_{t} = time dummy variables[5]

D_{c} = climate categorical variables

$v_{i,t}$ = non-random component of error term

$u_{i,t}$ = stochastic component of error term

After performing the Wu-Hausman test, the True Fixed Effect model (TFE) is chosen. As mentioned previously, V_{it} is assumed to follow the normal distribution (in both models; Pooled and TFE). However, in the TFE model, due to the uniform correlation between dependent and

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[5] As estimating prise and income elasticises are not the purpose of this paper, this paper does not use Structural Time Series model (STSM) to show UEDT (Dimitropoulos, Hunt, & Judge, 2005).

independent variables, the distribution of U_{it} is assumed to be exponential (in the Pooled model, the distribution is half-normal, as usual).

Since, service value added and industrial value added are expressed as a percentage of GDP, the Spearman's test was applied to find whether there is a correlation among GDP, service value added, and industrial value added. Correlation between GDP and industrial value added was not significant. However, the correlation between service value added and GDP was significant and service value added was dropped from the model. There is no correlation between price and final energy consumption, and between price and primary energy supply.

The level of energy efficiency according to the condition mean of efficiency term E $(U_{it} | U_{it} + V_{it})$ (Jondrow et al., 1982) is expressed as:

$$EF_{it} = \frac{D^{\wedge}{}_{it}}{D_{it}} = e\ (-\widehat{u_{it}}) \qquad (7)$$

$D^{\wedge}{}_{it}$= the frontier demand of energy (optimal).

D_{it}= the actual demand of the energy in the county (i) at the year (t).

4. Results

Results are presented in Table 3. Because of the correlation between service value added and GDP, service value added is dropped out of energy demand equation. The pooled model does not converge without service value added. The TFE model converges. As can be seen from the second column of Table 3 (TFE without lags), most of the energy variables are significant, with expected signs, except renewable municipal. With the exception of price, industrial value added, GDP, and the ratio of population to area, are strongly significant with expected signs. All of the time dummy coefficients are significant and positive. Some climate dummy variables are significant with the expected sign. Lambda, the ratio of the variance to the inefficiency term to the variance of stochastic term, illustrates the relative contribution of efficiency (U_{it}) and stochastic (V_{it}) parts of the error term. Lambda is significant with the expected sign.

Taking advantage of Spearman's test that shows no correlation among price and primary energy supply and final energy consumption, both models are estimated with lagged price as an instrument variable. The third and fourth columns of Table 3 show the results. The pooled model results show that with the exception of wind and solar photovoltaics, all energy variables are significant with expected sign. While the industrial value added and the ratio of population into the area size are strongly significant with the expected sign, the GDP and lagged price are not significant. All dummy variables in both two series are significant. Technical inefficiency (U_{it}) is not significant, the coefficient of lambda is also not significant. TFE model is also estimated with lagged price and as can be seen in Table 3, most of energy variables are significant (wind, solar thermal, and biomass). Industrial value added and population density are significant with the expected sign, but GDP and lagged price are not. Dummy variables in both series are significant with expected sign.

Log-likelihood and AIC indicators are utilised to choose the best model. Since there is a uniform correlation between depended variables and independent variables, the positive log-likelihood is acceptable. Moreover, the positive log-likelihood should be accompanied with a negative AIC. Consequently, the true fixed effect model without instrument variable (TFE model without lags), which has the best log-likelihood and AIC, is chosen to predict the energy inefficiency.

The positive energy coefficients in the chosen model illustrate whenever the primary supply of each energy resources in countries increases over the period, final energy consumption increases (except renewable municipal). Also, the results show that with a 1% increase in the industrial value added and the ratio of population into the area size of countries, the final energy consumption of countries rises by 0.03% and 0.005% respectively. The negative coefficient for GDP demonstrates that 1% growth in GDP causes a 0.001% decrease in final energy consumption. Since the impact of industrial sector is captured by the industrial value added variable and there is not service value added to capture the effect of service sector (due to the correlation among GDP, service value added, and industrial value added), GDP demonstrates the effect of service sector. Hence, the coefficient of GDP is expected to be negative. The lambda coefficient is 4.12 which shows that the contribution of one-sided error component is relatively high. Therefore the effect of inefficiency term is significantly high and positive.

Table 3

Estimated coefficient (t-value in parentheses)

Variables	**TFE (without lags)**	**TFE (with two lags)**	**Pooled (with two lags)**
Wind	4.249** (2.90)	0.94 (0.42)	-3.823 (-0.85)
Solar thermal	34.16*** (4.58)	5.71 (0.63)	119.8*** (6013)
Solar photovoltaics	-13.56 (-1.72)	-23.22* (-2.52)	-12.75 (-0.43)
Hydro	-0.182 (-1.66)	-5.59*** (-19.69)	3.418*** (5036)
Geothermal	3.235*** (15.77)	-1.52*** (-5.13)	8.474*** (7.83)
Biomass	0.252 (.)	-10.16 (0)	7.257*** (5.79)
Coal	0.105 (1.14)	-4.65*** (-25.74)	2.566*** (4.66)
Crude oil	0.270***	-4.87***	3.071***

	(4.19)	(-36.56)	(5.20)
Gas	0.706***	-4.14***	3.354***
	(7.08)	(-25.68)	(5.34)
Oil products	0.502***	-4.51***	4.059***
	(6.44)	(-30.3)	(6.38)
Renewable municipal	-7.648***	-14.3***	119.8***
	(-4.81)	(-6.3)	(6.13)
GDP	-0.00166***	-0.0006	0.00237
	(-3.35)	(-0.74)	(1.67)
Industrial value added	0.0379***	0.045***	0.0407***
	(13.03)	(11.1)	(8.40)
Price	0.000168		
	(0.28)		
Lagged price		-0.0001	0.00108
		(-0.37)	(1.04)
RPOP	0.00502***	0.006***	0.00202***
	(4.50)	(6.17)	(4.02)
Lambda	4.128***	5.42***	
	(0.01)	(0.01)	
Log-likelihood	815.52	486.39	
AIC	-1473.04	-814.78	

Note: ***, **, and * coefficient are significantly different from zero at the 99%, 95%, and 90% confidence level respectively.

Figure 1 shows the mean of energy inefficiency of countries. According to the bar chart, the highest energy inefficiency is belong to Korea and the lowest one is belong to the Greece.

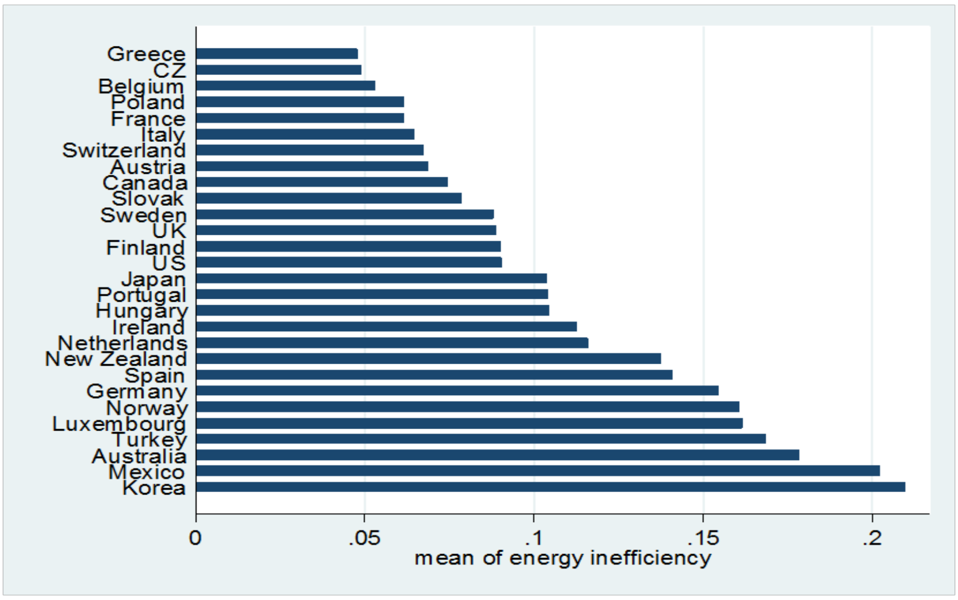


Fig.2. Mean of energy inefficiency

Table 4 shows the ranking of energy efficiency for OECD countries with considering energy resources, also it shows the other ranking of energy efficiency for OECD countries which is given by Filippini and Hunt (2013).

Table 4
Average Energy Efficiency Scores and Rankings

Country	**Efficiency-Rank(with energy resources)**	**Efficiency-Rank(without energy resources)***
Australia	26	2
Austria	8	9
Belgium	3	16
Canada	9	3
CZ	2	18
Finland	13	8
France	5	3
Germany	22	20
Greece	1	22
Hungary	17	12
Ireland	18	24
Italy	6	9
Japan	15	11
Korea	28	29
Luxembourg	24	19
Mexico	27	21
Netherlands	19	5
New Zealand	20	25
Norway	23	6
Poland	4	26
Portugal	16	28
Slovak	10	12
Spain	21	27
Sweden	11	14
Switzerland	7	1
Turkey	25	22
UK	12	7
US	14	16

* Source: (M. Filippini & Hunt, 2011)

Energy inefficiency

According to Table 4, Australia, Belgium, Norway, and Poland are four countries whose rankings change significantly after considering energy resources. Hence, this part describes their energy inefficiency according to their energy mix graph.

Australia

As it can be seen, crude oil was the main source of energy until 1987, due to a dramatic fall, from 1987, coal replaced crude oil as a main source of energy. Natural gas is another energy resource which has a sharp increase over the estimated period. Primary supply of oil products is increasing between 1975 and 2011. Furthermore, there are two main renewable energy resources in Australia; biomass and hydro. The primary supply from biomass and hydro decreased over the period. The amount of other renewable energy resources is negligible compared to fossil fuels. The primary supply of fossil fuels is shown to increase in contrast to the primary supply of renewable energy resources which decrease over time. As a result, energy inefficiency in Australia is increasing.

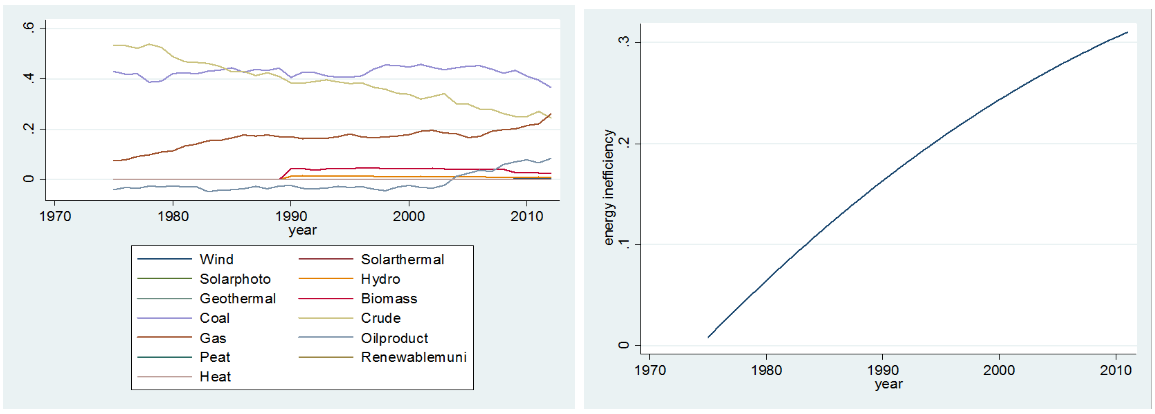


Fig. 3. Energy types and energy inefficiency of Germany

New Zealand

The main source of energy in New Zealand is crude oil. The primary supply of crude oil decreased from 1975 to 1985, increased through 1989 and has remained relatively constant through 2011. Natural gas primary supply increased between 1975 and 1989, then it decreased. The primary supply of coal has a gradual decline during the estimated period. The primary supply of oil products also has slowly fallen from 1975 to 2011. Furthermore, the primary supply of renewable energy resources is high, especially geothermal. Primary supply of geothermal increased sharply from 1990 to 2011. According to the energy mix graph of New Zealand, the primary supply of fossil fuels is decreasing and the primary supply of all renewable energy resources is increasing. Thus, although energy inefficiency of New Zealand increased from 1975 to 2002, this rise is with a decreasing slope, and falling from 2002.

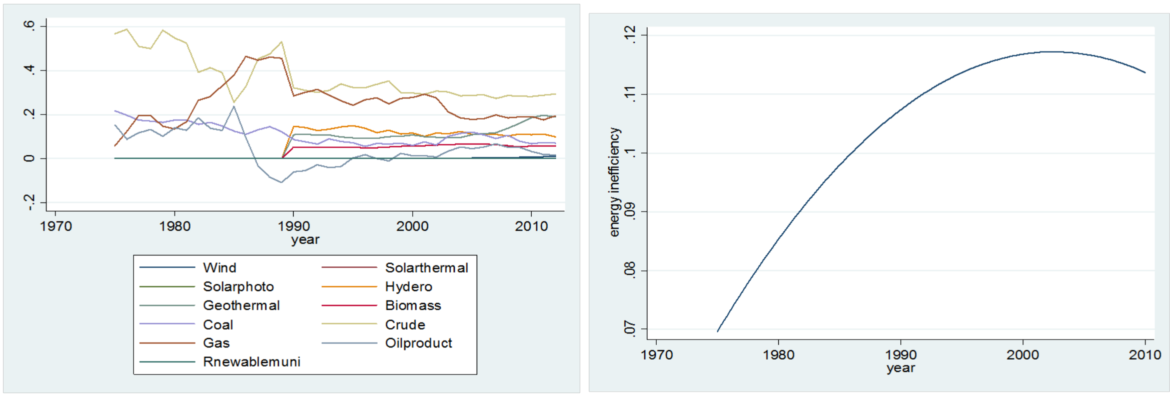
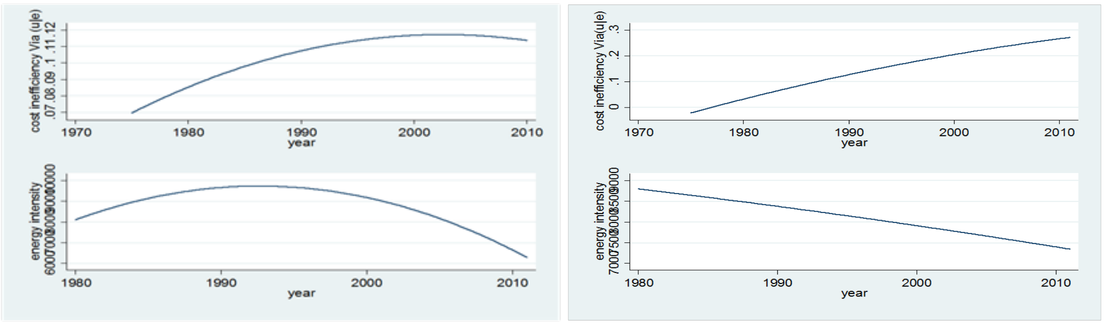


Fig. 4. Energy types and energy inefficiency of New Zealand

Energy intensity and energy inefficiency

We now turn to a comparison of energy intensity and energy inefficiency. First, we note that Spearman's rank correlation coefficient implies that energy intensity and energy inefficiency are independent. Energy intensity and energy inefficiency graphs of Australia and New Zealand are drawn for purpose of comparison.



New Zealand

Australia

Fig. 5. Energy inefficiency and energy intensity

The comparison illustrates that energy intensity cannot be a reliable indicator for energy efficiency[6].

5. Summary and Conclusion

Building on M. Filippini and Hunt (2012), and also considering the direct and indirect impact of quality diversity of energy resources on energy demand, this paper shows that energy resources with the high quality affects energy efficiency. The estimated energy efficiency illustrates, in the majorityof OECD countries (except: Italy, Finland, and Sweden) increasing in primary supply of renewable energy resources (energy with the high quality) or decreasing in primary supply of

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[6] Merely in some countries, such as Slovak, Portugal, Germany, and Canada, the energy intensity graph is similar to the energy inefficiency one (appendix).

fossil fuel energy resources (energy with the low quality) can increase the efficiency in energy consumption. In particular comparisons of energy inefficiency and energy intensity emphasise the unreliability of energy intensity indicator because only 4 countries (Slovak, Portugal, Germany, and Canada) out of 28 have some degree of similarity between their energy intensity and energy inefficiency. Therefore, shifting toward the renewable energy resources, as the primary supply of energy, can increase the energy efficiency.

At the first glance, consumption of fossil fuels, in most countries, seems to be cheaper than renewable energy resources. However, reliance on fossil fuels energy resources is accompanied with some issues; such as, environmental externalities (greenhouse emissions) and energy security. In addition, based on the IEA report in 2013, the amount of subsidies worldwide for consuming fossil fuels was $548 billion in 2013 which is over four-times the value of subsidies to renewable energy resources (IEA, 2013). Thus, with considering environmental externalities, energy security, and fossil fuel subsidy as costs of fossil fuels consumption, shifting toward consumption of renewable energy resources is justifiable.

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