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December 2011

SEEDS 135
ISSN 1749-8384

School of Economics
University of Surrey

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# MEASURING ENERGY EFFICIENCY AND ITS CONTRIBUTION TOWARDS MEETING $CO_2$ TARGETS: ESTIMATES FOR 29 OECD COUNTRIES


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**ABSTRACT**

Using results for 29 OECD countries from the estimation of an extended version of the model advocated by Filippini and Hunt (2011a), actual energy consumption and CO2 emissions are compared to notional energy consumption and CO2 emissions if the countries were energy efficient. This shows the contribution that improvements in energy efficiency can make towards the reduction in CO2 emissions. It is found that in many countries efficiency improvements alone are not likely to be sufficient to bring about reductions in CO2 emissions required to meet ambitious obligations. However, this is not the case across all countries included in the investigation. Moreover, it is shown that some of the world's largest OECD emitters can make a significant contribution to CO2 reductions from becoming energy efficient. Therefore the negotiations of the new legally binding treaty agreed under the Durban Platform should promote emission reduction targets that incentivise national energy efficiency.



*JEL Classifications:* Q41; Q48; Q50; Q54.

*Key Words:* emissions; energy efficiency; Durban Platform

# Measuring energy efficiency and its contribution towards meeting $CO_2$ targets: estimates for 29 OECD countries [*]

Joanne Evans[#] Massimo Filippini[##] Lester C. Hunt[###]

## 1 Introduction

The Kyoto Protocol set an agenda in 1997 for GHG emission reductions (relative to the 1990 emission levels) in participating countries between 2008 and 2012. Despite emission reduction measures and strengthening political will internationally,[1] global $CO_2$ emissions reached their highest ever level in 2010[2] (IEA, 2010a) with an estimated 40% of global emissions coming from OECD countries. Unsurprisingly non-OECD countries, led by China and India, saw much stronger increases in emissions as their economic growth accelerated. However, on a per capita basis, OECD countries collectively emitted 10 tonnes, compared with 5.8 tonnes for China, and 1.5 tonnes in India (IEA, 2010a). This emissions profile is informative since international discussions in Copenhagen (2009) and Cancun (2010) focused

[*] **Acknowledgements**
We gratefully acknowledge the comments of participants at the 34th International IAEE Conference, Stockholm, Sweden, June 2011. The authors are, of course, responsible for all errors and omissions.

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[1] Although not legally binding countries representing over 80% of global emissions (114 parties agreed to 'take note of' the Accord) engaged with Copenhagen Accord (December 2009). The Accord does not commit countries to agree to a binding successor to the Kyoto Protocol; however, it does endorse the continuation of Kyoto like measures.

[2] After a dip in 2009 caused by the global financial crisis, emissions are estimated to have climbed to a record 30.6 Gigatonnes (Gt), a 5% jump from the previous record year in 2008, when levels reached 29.3 Gt. In terms of fuels, 44% of the estimated CO2 emissions in 2010 came from coal, 36% from oil, and 20% from natural gas. The top 10 $CO_2$ emitting countries in 2008 account for two thirds of the world $CO_2$ emissions (Top 10 total 19.1 Gt CO2, world total 29.4 Gt $CO_2$. In addition the combined share of electricity and heat generation (41% of global $CO_2$ emissions in 2008) and transport (22% of global $CO_2$ emissions in 2008) represented two thirds of global emissions in 2008 (IEA, 2010a, p. 11 Figure 4).

on countries contributing in line with "common but differentiated responsibilities and respective capabilities", Article 3 of the UNFCCC, (United Nations, 1992) to 2020 economy wide emissions reduction targets where developed countries should commit to emissions targets and countries party to Kyoto would strengthen their targets. Developing nations would 'implement mitigation actions' that are nationally appropriate to slow growth in emissions (UNFCCC, 2010). In 2011 in Durban, South Africa, the spirit of the negotiations changed and in conjunction with extending the life of the Kyoto Agreement by between five and eight years[3] to at least 2017, the so called Durban Platform deal (UNFCCC, 2011) commits the world to negotiating a new legally binding climate treaty by 2015 for implementation by 2020. The emissions levels specified in this new treaty would be legally binding on all nations including the US and China.

These commitments will require a mix of instruments to be employed; however improving energy efficiency has often been assumed to be one of the most cost-effective ways of reducing $CO_2$ emissions, increasing security of energy supply, and improving industry competitiveness. It is against this backdrop that the contribution of improvements in energy efficiency alone might make to national $CO_2$ emissions targets of 29 OECD countries is considered here. During the last 20 years, there has been considerable debate within energy policy about the possible contribution from an improvement in energy efficiency and on the effectiveness of ecological tax reforms in the alleviation of the greenhouse effect and in the decrease of the dependency on fossil fuels. Many of the national and international 'think tanks' and policy agencies[4] suggest a major role for improvements in energy conservation

[3] The final decision as to the exact term of the extension would be specified at the UNFCCC meeting in Qatar December 2012.

[4] Such as European Climate Change (Action) Programmes (ECCP) 2000 and 2005, IPCC (2007), IEA (2008), EC (2005, 2006a and 2006b) and European Roadmap 2050 EC (2011).

and efficiency. Indeed a report by the International Energy Agency (IEA, 2011) suggests that energy efficiency can play a major role in reducing a country's energy consumption and consequently its GHG emissions, further highlighting the importance of activities to support a country's energy efficiency policy. According to IEA (2011), since 1974, energy efficiency measures and programmes have contributed to limiting the growth of energy consumption in IEA member countries with savings as high as 63%, although the rate of energy efficiency progress has dropped since 1990. Consequently, IEA (2011) recommend that national energy policies should continue to include measures promoting energy efficiency[5].

Energy intensity is the typical indicator used to monitor energy efficiency at the country level and the IEA (2011) analysis is based on this simple traditional measure; defined as the ratio of energy consumption to GDP. However, according to an earlier report, IEA (2009), "Energy intensity is the amount of energy used per unit of activity. It is commonly calculated as the ratio of energy use to GDP. *Energy intensity is often taken as a proxy for energy efficiency, although this is not entirely accurate* since changes in energy intensity are a function of changes in several factors including the structure of the economy and energy efficiency" (*our emphasis*, p. 15). This highlights the weakness of this simple aggregate energy consumption to GDP ratio in that it does not measure the level of 'underlying energy efficiency' that characterizes an economy[6]; hence, it is difficult to make conclusions for energy policy based upon this simple measure.

[5] The IEA 25 energy efficiency policy measures recommended at G8 summits in 2007 (IEA 2007) and 2008 (IEA 2008) have been followed up with two audits (2009, 2011) to assess the progress made on energy efficiency improvements by national governments. These recommendations include measures for energy efficiency improvements in buildings, appliances and equipment, lighting, transport, industry and energy utilities as well as cross sectoral measures. Progress on energy efficiency has been noted (IEA, 2011).

[6] Energy Intensity can vary between countries for a whole range of reasons including the level of industrialisation, the mix of services and manufacturing, the climate, the level of energy efficiency of the appliance and capital stock and production processes and the organization of the production and consumption processes in space.

As IEA (2011) highlights, energy intensity has decreased in many countries. This decrease, sometimes justified on the ‘dematerialization’ of the economies of these countries (e.g. Medlock, 2004), has allowed GDP growth to be decoupled to a certain extent from the growth of energy demand, although there may be other explaining factors. Richmond and Kaufmann (2006), for example, argue that the inclusion of energy prices explains the evolution of energy intensity in most countries, so that the dematerialization hypothesis should be rejected when prices are considered. This view of the role of energy prices, which partly drive greater efficiency of processes and structural shifts, is supported by the recent work of Metcalf (2008) and Sue Wing (2008), although these papers come to different conclusions, with the former suggesting a major role for energy efficiency and the latter underscoring the role of structural shifts

In the energy economics literature some approaches have been proposed in order to overcome the problems related to the use of simple monetary based energy efficiency indicators like the energy-GDP ratio, such as Index Decomposition Analysis (IDA) and frontier analysis. IDA is basically a bottom-up framework that can be used to create economy-wide energy efficiency indicators.[7] Whereas frontier analysis is based on the estimation of a parametric, as well as a non-parametric, best practice production frontier for the use of energy where the level of energy efficiency is computed as the difference between the actual energy use and the predicted energy use.[8]

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[7]See Ang (2006) for a general discussion and application of this method.

[8] See Huntington (1994) for a discussion on the relation between energy efficiency and productive efficiency using the production theory framework. One of the first studies that made use of the frontier approach was Ferrier and Hirschberg (1992). More recent, in a developing strand of the literature, Filippini and Hunt (2011a) introduced, using the stochastic frontier model proposed by Aigner et. al. (1977), the idea of a frontier energy demand relationship (discussed below) as a way of estimating underlying aggregate energy efficiency for 29 OECD countries.

The next section introduces the empirical framework to estimate the energy efficiency for 29 OECD countries. In section 3 the energy efficiency estimates are used to calculate the contribution that improvements in energy efficiency alone might make to national $CO_2$ targets. Section 4 concludes.

**2. A panel 'frontier' whole economy aggregate energy demand function using parametric stochastic frontier analysis.**

Filippini and Hunt (2011a) use a parametric frontier approach to estimate an energy demand frontier function in an attempt to isolate 'underlying energy efficiency'. This is done by explicitly controlling for income and price effects, country specific effects, climate effects and a common Underling Energy Demand Trend (the UEDT), capturing 'exogenous' technical progress and other exogenous factors. Hence, it allows for the impact of 'endogenous' technical progress through the price effect and 'exogenous' technical progress (and other factors) through the UEDT.

As stated above their aim, and the aim here, is to analyze economy wide energy efficiency; hence, the estimated model introduced below is for aggregate energy consumption for the whole economy. Economy wide aggregate energy demand is derived from the demand for energy services including heat, illumination, cooked food, hot water, transport services and manufacturing processes. A combination of energy and capital (such as household appliances, cars, machinery, etc.) is required to produce the desired services. The demand for energy is therefore influenced by the level of efficiency of the equipment and, generally, of the production process. Of course, in reality, apart from the technological and economic factors, there are a range of exogenous institutional and regulatory factors that are important in explaining the level of energy consumption. Hence, it is important that the UEDT is specified in such a way that it is 'non-linear' and could increase and/or decrease over the estimation period as advocated by Hunt et al. (2003a, b). Therefore, given a panel data set is used this is achieved by time dummies as proposed by Griffin and Schulman (2005) and Adeyemi and Hunt (2007).[9]

In order to try to tease out these different influences, a general energy demand relationship found in the standard energy demand modelling literature, relating energy consumption to economic activity and the real energy price, is utilized for the estimation of an aggregate energy demand function for a panel of OECD countries. Moreover, in order to control for other important factors that vary across countries and hence can affect a country's energy demand, some variables related to climate, size, and structure of the economy are introduced in to the model. Thus after controlling for income, price, climate effects, technical progress and other exogenous factors, as well as effects due to difference in area size and in the structure of the economy the 'underlying energy efficiency' for each country is isolated.[10] This is defined with respect to a benchmark, e.g. a best practice economy in the use of energy by estimating a 'common energy demand' function across countries, with homogenous income and price elasticities, and responses to other factors, plus a homogenous UEDT. This is important given the need to isolate the different underlying energy efficiency across the countries.[11] Consequently, once these effects are adequately controlled for, it allows for the

[9] It is worth noting that Kumbhakar and Lovell (2000) highlight that the use of a large number of time dummies in a parametric frontier framework can create estimation problems. Thus although not done here, Filippini and Hunt (2011a and 2011b) do also consider a time trend for the specification of the UEDT, but there is no discernable difference in the efficiency rankings.

[10] Note, previous studies by Buck and Young (2007) and Boyd (2008) did not base their estimation on an energy demand function, in that they did not consider the energy price as an explanatory variable; hence omitting this important control variable.

[11] The UEDT includes exogenous technical progress and it could be argued that even though technologies are available to each country they are not necessarily installed at the same rate; however, it is assumed that this

estimation of the underlying energy efficiency for each country showing i) how efficiency has changed over the estimation period and ii) the differences in efficiency across the panel of countries.

In the case of an aggregate energy demand function the frontier gives the minimum level of energy necessary for an economy to produce any given level of goods and services. The distance from the frontier measures the level of energy consumption above the baseline demand, that is, the level of energy inefficiency. Energy efficiency measures the ability of a country to minimize the energy consumption given a level of GDP.[12]

## 2.1 An aggregate frontier energy demand model

Given the discussion above, it is assumed that there exists an aggregate energy demand relationship for a panel of OECD countries, as follows:

$$E_{it} = E\ (P_{it}, Y_{it}, POP_{it}, DCOLD_i, DARID_i, A_i, ISH_{it}, SSH_{it}, D_t, EF_{it}) \quad (1)$$

where $E_{it}$ is aggregate energy consumption, $Y_{it}$ is GDP, $P_{it}$ is the real price of energy, $DCOLD_i$ is a cold climate dummy, $DARID_i$ is a hot climate dummy , $POP_{it}$ is population, $A_i$ is the area size, $ISH_{it}$ is the share of value added of the industrial sector and $SSH_{it}$ is the share of value added for the service sector all for country $i$ in year $t$.[13] In contrast to the model estimated by Filippini and Hunt (2011a), Equation (1) includes an extra dummy variable for extreme high temperatures (DARID). $D_t$ is a variable representing the UEDT that captures the common impact of important unmeasured exogenous factors that influence all countries. Finally, $EF_{it}$ is the unobserved level of 'underlying energy efficiency' of an economy. This

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results from different behaviour across countries and reflects 'inefficiency' across countries; hence, it is captured by the different (in)efficiency terms for all countries.

[12] See Filipini and Hunt (2011b) for further discussion of the meaning of 'energy efficiency'.

[13] Unfortunately, it is not possible to get more sectoral disaggregated data (e.g. data on energy intensive sectors) on a consistent basis for all 29 countries for all the years.

could incorporate a number of factors that will differ across countries, including different government regulations as well as different social behaviours, norms, lifestyles and values. Hence, a low level of underlying energy efficiency implies an inefficient use of energy (i.e. ‘waste energy’), so that in this situation, awareness for energy conservation could be increased in order to reach the ‘optimal’ energy demand function. Nevertheless, from an empirical perspective, when using OECD aggregate energy data, the aggregate level of energy efficiency of the capital equipment and of the production processes is not observed directly. Therefore, this underlying energy efficiency indicator needs to be estimated. Consequently, in order to estimate this economy-wide level of underlying energy efficiency ($EF_{it}$) and identify the best practice economy in term of energy utilization, the stochastic frontier function approach introduced by Aigner et al. (1977) is used.[14]

### *2.2 Econometric specification*

This frontier approach allows the possibility to identify if a country is, or is not, on the frontier. Moreover, if a country is not on the frontier, the distance from the frontier measures the level of energy consumption above the baseline demand, e.g. the level of energy inefficiency. The approach used here is therefore based on the assumption that the level of economy-wide energy efficiency can be approximated by a one-sided non-negative term, so that a panel log-log functional form of Equation (1) adopting the stochastic frontier function approach proposed by Aigner et al. (1977) can be specified as follows:

$$e_{it} = \alpha + \alpha^{y} y_{it} + \alpha^{p} p_{it} + \alpha^{pop} pop_{it} + \delta_t D_t + \alpha^{C} DCOLD_i + \alpha^{R} DARID_i + \alpha^{a} a_i + \alpha^{I} ISH_{it} \alpha^{S} SSH_{it} + v_{it} + u_{it} \qquad (2)$$

[14] The frontier function approach suggested by Aigner et al. (1977) was developed within the neoclassical production theory and the main goal of this literature has been to estimate production and cost frontier in order to identify the level of productive inefficiency (allocative and technical inefficiency). In this study, the neoclassical production theory is discarded and instead the concept of a stochastic frontier within the empirical approach traditionally used in the estimation of economy wide energy demand function is employed. Of course, behind the concept of underlying energy inefficiency developed here, there is still a ‘production process’.

where $e_{it}$ is the natural logarithm of aggregate energy consumption ($E_{it}$), $y_{it}$ is the natural logarithm of GDP ($Y_{it}$), $p_{it}$ is the natural logarithm of the real price of energy ($P_{it}$), $pop_{it}$ is the natural logarithm of population ($POP_{it}$), $DCOLD_i$ is a cold climate dummy variable, $DARID_i$ is a hot climate dummy, $a_i$ is the natural logarithm of the area size of a country ($A_i$), $ISH_{it}$ is the share of value added of the industrial sector, and $SSH_{it}$ is the share of value added for the service sector. The time variable $D_t$ is a series of time dummy variables.

Furthermore, the error term in Equation (2) is composed of two independent parts. The first part, $v_{it}$, is a symmetric disturbance capturing the effect of noise and as usual is assumed to be normally distributed. The second part, $u_{it}$, which represents the underlying energy level of efficiency $EF_{it}$ in equation (1) is interpreted as an indicator of the inefficient use of energy, e.g. the 'waste energy'.[15] It is a one sided non-negative random disturbance term that can vary over time, assumed to follow a half-normal distribution.[16] An improvement in the energy efficiency of the equipment or on the use of energy through a new production process will increase the level of energy efficiency of a country. The impact of technological, organizational, and social innovation in the production and consumption of energy services on the energy demand is therefore captured in several ways: the time dummy variables, the indicator of energy efficiency and through the price effect. In summary, this is a slightly modified version of Equation (2) in Filippini and Hunt (2011a) which is estimated in order to estimate underlying energy efficiency for each country in the sample.

[15] The energy demand function estimated in this paper can be considered an input demand function derived through a cost minimizing process from an aggregate production function. Of course, theoretically the demand for energy might also depend on the price of other inputs, but in line with previous energy demand studies, data limitations make it impossible to include these variables. For this reason this equation is specified, similar to the general energy demand literature, in a relatively *ad hoc* way with an indirect reference to production theory.

[16] It could be argued that this is a strong assumption for *EF*, but it does allow the 'identification' of the efficiency for each country separately.

## 2.3 Data

The study is based on an unbalanced panel data set for a sample of 29 OECD countries ($i$ =1, . .. , 29)[17] over the period 1978 to 2008 ($t$=1978–2008) taken from the International Energy Agency database (IEA, 2010b),"World Energy Statistics and Balances of OECD Countries" and from the general OECD database "Country Profile Statistics" available at www.oecd.org. *E* is each country's aggregate energy consumption in thousand tonnes of oil equivalent (ktoe), *Y* is each country's GDP in billion US2000$PPP, *P* is each country's index of real energy prices (2000=100), and *POP* is each country's population in millions. The climate dummy variable, *DCOLD* and *DARID*, indicate whether a country belongs to those characterized by a cold respectively a hot climate (according to the Köppen-Geiger climate classification[18]) and *A* is the area size of a country is measured in squared kilometres. Finally, the value added of the industrial and service sectors is measured as percentage of GDP (*ISH* and *SSH*). Descriptive statistics of the key variables are presented in Table 1.

**Table 1: Descriptive statistics**

| Variable Description | Name | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Energy consumption (toe) | **E** | 117472 | 260780 | 2214 | 1581622 |
| GDP (1000 US2000$PPP) | **Y** | 832.26 | 1571.90 | 8.56 | 11693.2 |
| Population in Millions. | **POP** | 38.40 | 53.52 | 0.36 | 301.75 |
| Real Price of energy (2000=100) | **P** | 89.08 | 15.89 | 12.63 | 149.33 |
| Area size in km$^2$ | **A** | 1241662 | 2755333 | 2590 | 9984670 |
| Share of industrial sector in % of GDP | **ISH** | 31.20 | 5.35 | 15.40 | 46.20 |
| Share of service sector in % of GDP | **SSH** | 64.25 | 6.81 | 45.40 | 84.30 |
| Climate Dummy | **DCOLD** | 0.30 | 0.46 | 0 | 1 |
| Arid Country Dummy | **DARID** | 0.30 | 0.46 | 0 | 1 |

[17] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the UK, and the US. For some countries, data on for some of the explanatory variables are not available for the whole sample period; for this reason the data set is unbalanced.

[18] See for a discussion of this classification Peel et al. (2007).

### 2.4 *Panel data efficiency estimation*

Greene (2005a and 2005b) suggests that the original SFA model (Aigner, et al., 1977) is extended by adding a fixed or random individual effect in the model[19] and such models produce efficiency estimates that do not include the persistent inefficiencies that might remain more or less constant over time. In fact, the time-invariant, country-specific energy inefficiency is captured by the individual random or fixed effects. Therefore, to the extent that there are certain sources of energy inefficiency that result in time-invariant excess energy consumption, the estimates of these models could provide relatively high and imprecise levels of energy efficiency. Of course, one advantage of the approaches proposed by Greene (2005a and 2005b) with respect to the original approach proposed by Aigner et al. (1977) is the reduction of the potential so-called 'unobserved variables bias'; e.g. a situation where correlation between observables and unobservables could bias some coefficients of the explanatory variables. However, by introducing several explanatory variables such as the climate, the area size, population and some variables on the structure of the economy it is possible to reduce this problem. Given this the 'pooled' model based on Aigner et al. (1977) is used for the estimation of Equation (2) utilising the half-normal distribution for the efficiency term. [20]

The country's efficiency is therefore estimated using the conditional mean of the efficiency term $E[\langle u_{it} \,|u_{it} \,+ v_{it}\rangle]$, proposed by Jondrow et al. (1982).[21] The level of energy efficiency can be expressed in the following way:

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[19] For a successful application of these models in network industries, see Farsi, et al. (2005) and Farsi, et al. (2006).

[20] See Filippini and Hunt (2011b) for a discussion and presentation of some alternative estimates such as the true random effects model proposed by Greene (2005b).

[21] See also Kumbhakar and Lovell (2000) and Battese and Coelli (1992).

$$EF_{it} = \frac{E_{it}^F}{E_{it}} = \exp(-\widehat{u_{it}}) \quad (3)$$

where $E_{it}$ is the observed energy consumption and $E_{it}^F$ is the frontier or minimum demand of the $i^{th}$ country in time *t*. An energy efficiency score of one indicates a country on the frontier (100% efficient); while non-frontier countries, e.g. countries characterized by a level of energy efficiency lower than 100%, receive scores below one. This therefore gives the measure of underlying energy efficiency estimated below.[22]

Given the discussion above, the a pooled frontier energy demand model Equation (2) is estimated followed by utilising Equation (3) to estimate the efficiency scores for each country for each year. The discussion of the results is given in the next sub-section.

### *2.5 Estimation Results*

The estimation results for the frontier energy demand model, Equation (2), are given in Table 2.[23] This shows that the estimated coefficients and *lambda* have the expected signs and are statistically significant.[24]

For the variables in logarithmic form, the estimated coefficients can be directly interpreted as elasticities. The estimated income and own price elasticities are about 0.8 and –0.25 respectively; values are not out of line with previous estimates. The estimated population elasticity is about 0.1 and the estimated area elasticity is about 0.07. The estimated coefficients for the climate variables, DCOLD and DARID, are 0.08 and -0.31 respectively.

[22] This is in contrast to the alternative indicator of energy inefficiency given by the exponential of $u_{it}$. In this case, a value of 0.2 indicates a level of energy inefficiency of 20%.

[23] To note, that in comparison to Filippini and Hunt (2011a), in this study the data set that contains information for an extra year and the model specification includes an extra explanatory variable for the climate.

[24] Lambda ($\boldsymbol{\lambda}$) gives information on the relative contribution of $u_{it}$ and $v_{it}$ on the decomposed error term $e_{it}$ and shows that in this case, the one-sided error component is relatively large.

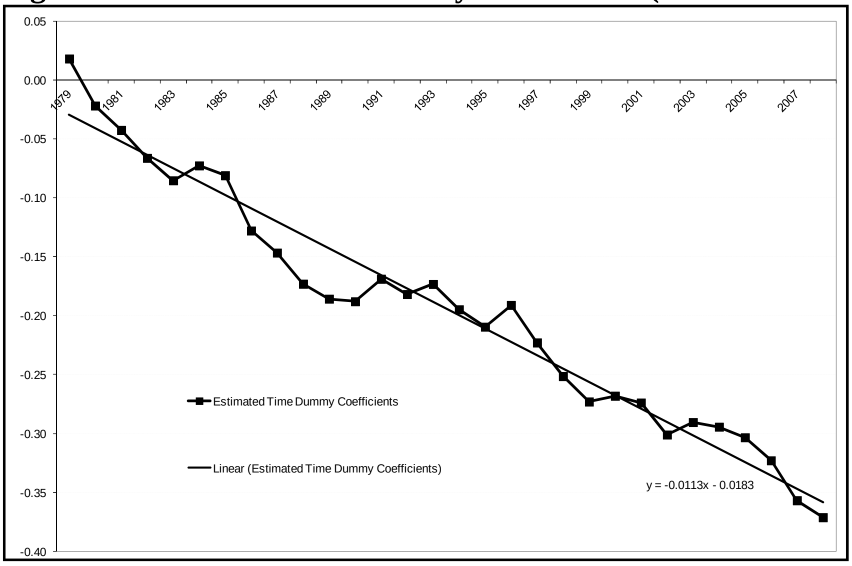
These coefficients indicate that as expected climate has an important influence on a country's energy demand. Further, the impact of hot temperatures is larger than the impact of cold temperatures. Similarly, larger shares of a country's industrial and service sectors will also increase energy consumption. Moreover, the time dummies, as a group, are significant and, as expected, the overall trend in their coefficients is negative as shown in Figure 1; however, they do not fall continually over the estimation period, reflecting the 'non-linear' impact of technical progress and other exogenous variables.

**Table 2: Estimated Frontier Energy Demand Frontier for 29 Countries (1978 - 2008)**

| **Coefficient** | **Estimate** **(t-values in parentheses)** |
|---|---|
| Constant ($\alpha$) | 1.835<br>(3.11) |
| $\alpha^y$ | 0.807<br>(27.46) |
| $\alpha^p$ | -0.245<br>(-5.97) |
| $\alpha^{pop}$ | 0.109<br>(4.03) |
| $\alpha^a$ | 0.074<br>(12.70) |
| $\alpha^C$ | 0.083<br>(4.16) |
| $\alpha^R$ | -0.311<br>(-16.07) |
| $\alpha^I$ | 0.028<br>(8.78) |
| $\alpha^S$ | 0.028<br>(8.46) |
| Time dummies | Yes |
| Lamda (λ) | 0.723<br>(7.79) |

**Note:** An unbalanced panel was used for estimation given for some variables the data were not available for every year.

**Figure 1: Estimated Time Dummy Coefficients (relative to 1978)**




### *2.6 Underlying Energy Efficiency Estimates*

Figure 2 illustrates the rankings by ordering according the estimated efficiency. These show that over the whole of the estimation period the most efficient country was Switzerland followed by Denmark. At the other end of the spectrum the two countries found to be the relatively least efficient over the whole period were Luxembourg and the USA.[25] It should be noted that, although presented individually for each country, the estimated efficiencies of each country should not be taken as the precise position of each country given the stochastic technique used in estimation. However, they do give a good relative indication of a country's change in efficiency over time and a country's relative position vis-à-vis other countries.

Focussing on the 2003-2007 period, Table 3 compares the estimated underlying energy efficiency with energy intensity. This shows that Luxembourg, Japan, Canada, and Korea are estimated to be the four least efficient countries, with Switzerland, Ireland, the UK and

[25] However, one of the reasons for the estimated poor performance of Luxembourg could be the presence of 'tank tourism', which is not captured in the aggregate model.

Denmark estimated to be the four most efficient countries.[26] However Table 3 also shows that Ireland, Switzerland Greece and the UK are the least energy intensity whereas Canada, Finland, the Slovak Republic and the Czech Republic are the most energy intensive, with the countries re-ordered from the least energy intensive to the most energy intensive. Thus although there would appear to be a generally negative relationship between the rankings of the estimated underlying energy efficiency and energy intensity there is not a one to one correspondence. For example, for the period 2003-2007 according to the energy intensity measure Italy, Turkey, Japan and are ranked 6th, 7th and 10th respectively whereas they are estimated to be 18th, 19th and 28th respectively according to the estimated energy efficiency measure; thus for these countries the simple energy intensity ratio would appear to overestimate their relative efficiency position. On the other hand, according to the simple energy intensity ratio Sweden, New Zealand, Poland and the Slovak Republic are ranked 18th, 20th, 21st and 27th respectively whereas they are estimated to be 6th, 9th, 11th and 15th respectively according to the estimated energy efficiency measure; thus for these countries the simple energy intensity ratio would appear to underestimate their relative efficiency position. This relationship between the two measures is further illustrated in Figure 3.[27]

The discussion above illustrates the importance of attempting to adequately define and model 'energy efficiency' rather than just relying on the simple energy to GDP ratio – energy intensity. Furthermore, the estimated levels of efficiency give an indication of the possible savings in energy consumption that countries could make if they were all efficient. This is further analysed, along with the potential $CO_2$ savings in the next section.

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[26] However, it should be noted that, given the unbalanced panel used in estimation, the figures for Switzerland are over a much shorter period.

[27] We are grateful to Dermot Gately who suggested presenting the results in this way.

**Figure 2: Estimated Average Underlying Energy Efficiency (1978 - 2008)**

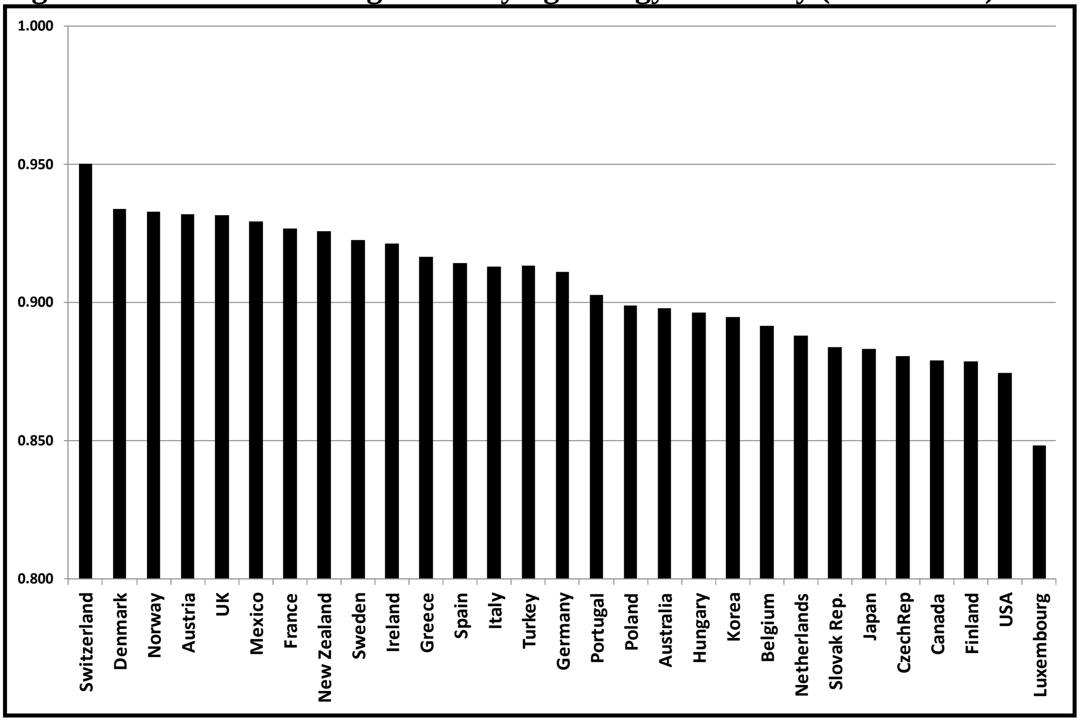



**Figure 3: Energy Efficiency and Energy Intensity 2003 – 2007**

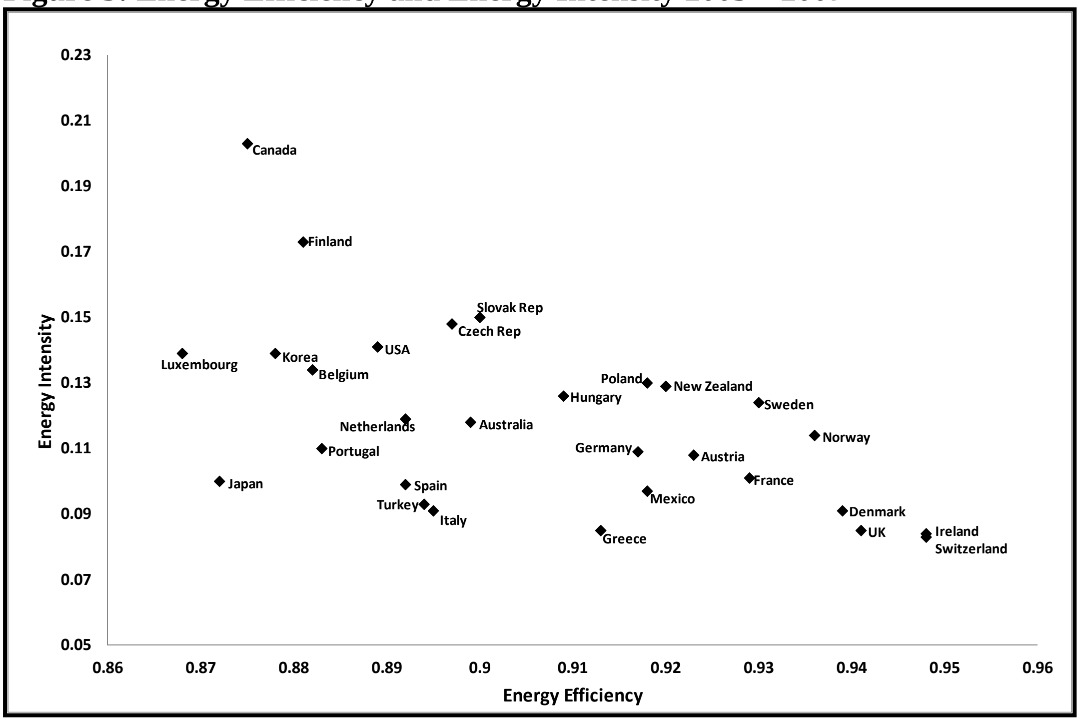


**Table 3: Comparison of the Rankings for Average Estimated Underlying Energy Efficiency and Energy Intensity (2003-2007)**

| | ***Estimated Underlying Energy Efficiency ($\overline{EF_i}$)*** | | ***Energy Intensity (Energy GDP ratio, toe per 1000 US2000$PPP)*** | |
|---|---|---|---|---|
| | ***Level*** | ***Rank*** | ***Level*** | ***Rank*** |
| **Australia** | 0.899 | 16 | 0.118 | 16 |
| **Austria** | 0.923 | 8 | 0.108 | 12 |
| **Belgium** | 0.882 | 24 | 0.134 | 22 |
| **Canada** | 0.875 | 27 | 0.203 | 29 |
| **Czech Rep** | 0.897 | 17 | 0.148 | 26 |
| **Denmark** | 0.939 | 4 | 0.091 | 5 |
| **Finland** | 0.881 | 25 | 0.173 | 28 |
| **France** | 0.929 | 7 | 0.101 | 11 |
| **Germany** | 0.917 | 12 | 0.109 | 13 |
| **Greece** | 0.914 | 13 | 0.085 | 3 |
| **Hungary** | 0.909 | 14 | 0.126 | 19 |
| **Ireland** | 0.948 | 2 | 0.083 | 1 |
| **Italy** | 0.895 | 18 | 0.091 | 6 |
| **Japan** | 0.872 | 28 | 0.100 | 10 |
| **Korea** | 0.878 | 26 | 0.139 | 23 |
| **Luxembourg** | 0.868 | 29 | 0.139 | 23 |
| **Mexico** | 0.918 | 10 | 0.097 | 8 |
| **Netherlands** | 0.892 | 20 | 0.119 | 17 |
| **New Zealand** | 0.920 | 9 | 0.129 | 20 |
| **Norway** | 0.936 | 5 | 0.114 | 15 |
| **Poland** | 0.918 | 11 | 0.130 | 21 |
| **Portugal** | 0.883 | 23 | 0.110 | 14 |
| **Slovak Rep.** | 0.900 | 15 | 0.150 | 27 |
| **Spain** | 0.892 | 21 | 0.099 | 9 |
| **Sweden** | 0.930 | 6 | 0.124 | 18 |
| **Switzerland** | 0.948 | 1 | 0.084 | 2 |
| **Turkey** | 0.894 | 19 | 0.093 | 7 |
| **UK** | 0.941 | 3 | 0.085 | 3 |
| **USA** | 0.889 | 22 | 0.141 | 25 |

**Note:** A rank of 29 for underlying energy efficiency represents the least efficient country by this measure, whereas a rank of 1 represents the most efficient country. A rank of 29 for energy intensity represents the most energy intensity country whereas a rank of 1 represents the least energy intensive country.

## 3. The contribution of Energy Efficiency to $CO_2$ Targets

The results presented in the previous section reveal an interesting result in that four out of the six OECD countries in the world's top 10 carbon emitters, are found to be in the bottom half of the estimated energy efficiency rankings over the 2003 to 2007 period with Japan at 28$^{th}$, Canada at 27$^{th}$, Korea at 26$^{th}$ and the USA at 22$^{nd}$ (see Table 3 and Figure 3); whereas the UK is 3$^{rd}$ and Germany 12$^{th}$. This suggests that there is some scope for $CO_2$ savings from more energy efficient behaviour. Therefore, the efficiency measures calculated in Section 3 are employed to determine the contribution of energy efficiency alone to the reduction of $CO_2$ emissions by the OECD countries so as to contribute towards national Kyoto targets. The next sub-section sets out how this is achieved.

### *3.1 Method for Calculating $CO_2$ Savings*

In order to determine the impact of improvements in energy efficiency of each country on their respective emissions a $CO_2$ coefficient is constructed which, when multiplied by the level of energy demand assuming the country is efficient, gives an estimate of the emissions that might be saved if each country was on the efficient frontier. Therefore, $\lambda_i$, the average $CO_2$ coefficient for country $i$ over the period 2003 to 2007, is calculated as follows:

$$\lambda_i = \frac{\overline{CO2}_i}{\bar{E}_i} \tag{4}$$

where $\overline{CO2}_i$ represents average $CO_2$ emissions for country $i$ over the period 2003 to 2007 and $\bar{E}_i$ average energy consumption for country $i$ over the period 2003 to 2007.

The notional energy consumption for each country $i$ that would be consumed if it were operating efficiently ($\bar{E}_i^*$) is therefore estimated by:

$$\bar{E}_i^* = \bar{E}_i \times \overline{EF}_i \tag{5}$$

where $\overline{EF_i}$ is the average level of energy efficiency for country $i$ over the period 2003 to 2007 estimated in Section 3 above (see Table 5). This is then used to estimate the amount of notional $CO_2$ for each country $i$ that would be consumed if it were operating efficiently ($\overline{CO2}_i^*$) given by:

$$\overline{CO2}_i^* = \lambda_i * \bar{E}_i^* \quad (6)$$

Thus the average potential savings of energy and $CO_2$ for each country if it were being energy efficient are given by:

$$Esav_i = \bar{E}_i - \bar{E}_i^* \quad (7)$$

and

$$CO2sav_i = \overline{CO2}_i - \overline{CO2}_i^* \quad (8)$$

respectively.

Furthermore, for each of the OECD nations who are party to the Kyoto Agreement, the implications of consuming energy efficiently on achieving their emissions targets are considered comparing the Kyoto target level of $CO_2$ emissions (which varies between countries for the period) with the actual level of $CO_2$ emissions and the estimated level of notional $CO_2$ emissions that would have been produced had the annual aggregate energy consumption been efficient.

### *3.2 Additional Data and Estimated Potential Energy $CO_2$ Savings*

The average energy consumption and the average energy efficiency estimates for each country over the period 2003-2007 obtained in Section 3 are used along with each country's $CO_2$ emissions obtained from Fuel Consumption (Sectoral Approach Mt of $CO_2$) [28] for 29

[28] $CO_2$ emissions in the IEA database are measured in two different ways: the Sectoral Approach and the Reference Approach. The $CO_2$ Reference Approach data contains total $CO_2$ emissions from fuel combustion; it is based on the supply of energy in a country and as a result includes fugitive emissions from energy

OECD countries between 2003 and 2007 are from the IEA (2010c) database. The results from the above calculations are presented in Table 4. Although presented individually the estimated $CO_2$ emissions reduction of each country should not be taken as the precise value given the stochastic technique used in estimation of the level of efficiency. However, they do give a good approximation of the potential direction of a country's change in efficiency and $CO_2$ emissions over time. Unsurprisingly the countries with the relatively lower energy efficiency rankings are, broadly, amongst those which stand to make the most potential $CO_2$ savings were they to operate on their efficient energy demand frontiers as seen in Figures 4 and 5.

It can be seen in Figure 4 that Korea, Germany, Canada, Japan and USA, who are among the top 10 world emitters, are amongst those countries with the largest estimated potential to consume less energy if they operated efficiently. That said the 10 counties shown in Figure 4 to have the estimated least potential to reduce energy consumption (Luxembourg, Ireland, Denmark, New Zealand, Switzerland, Slovak Rep., Norway, Hungary, Greece, and Austria) would collectively reduce their energy consumption by just under 28 Mtoe, being more than the potential savings for Canada of about 25 Mtoe. Furthermore, as Figure 5 illustrates the 10 counties with the least estimated potential for $CO_2$ savings individually (Luxembourg, Switzerland, Ireland, Norway, New Zealand, Denmark, Sweden, Slovak Rep., Hungary, and Austria) has an estimated potential to save less than 6 Mt of $CO_2$ emissions; however, added together their saved $CO_2$ emissions would be about 32 Mt. This is similar to the estimated

transformation and for this reason is likely to overestimate national $CO_2$ emissions. The difference between the Sectoral Approach and the Reference Approach includes statistical differences, product transfers, transformation losses and distribution losses (IEA, 2010c, p. 8). The Sectoral Approach contains total $CO_2$ emissions from fuel combustion including emissions only when the fuel is actually combusted (IEA, 2009, p. 3). Consequently, the Sectoral Approach data is used here since by definition this measure provides the most accurate measure of emissions. Nevertheless, there is no discernable difference between the results generated using each of the two measures.

potential savings for the UK and Mexico, suggesting that the relatively small emitters and the savings that they can make if operating efficiently should not be ignored.

**Table 4: Estimated Potential Emissions and Energy savings if Energy Efficient (2003 – 2007)**

| Country $i$ | Average Energy Cons. (ktoe) $\bar{E}_i$ | Average $CO_2$ Emissions Mt $\overline{CO2}_i$ | $CO_2$ Co-efficient (kt/toe) $\lambda_i$ | Estimated Notional Energy Cons. (ktoe) $\bar{E}_i^*$ | Estimated Notional $CO_2$ Emissions Mt $\overline{CO2}_i^*$ | Estimated Potential Energy Savings (ktoe) $Esav_i$ | Estimated Potential $CO_2$ Savings Mt $CO2sav_i$ |
|---|---|---|---|---|---|---|---|
| Australia | 73537 | 380.54 | 0.005175 | 66089.46 | 342.00 | 7448 | 38.54 |
| Austria | 27016 | 72.57 | 0.002686 | 24930.11 | 66.97 | 2086 | 5.60 |
| Belgium | 41157 | 112.83 | 0.002742 | 36285.68 | 99.48 | 4871 | 13.35 |
| Canada | 200696 | 556.62 | 0.002773 | 175622.7 | 487.08 | 25073 | 69.54 |
| CzechRep | 27405 | 120.97 | 0.004414 | 24570.67 | 108.46 | 2834 | 12.51 |
| Denmark | 14884 | 52.71 | 0.003541 | 13982.41 | 49.52 | 901 | 3.19 |
| Finland | 26380 | 65.23 | 0.002473 | 23234.23 | 57.46 | 3146 | 7.78 |
| France | 167871 | 382.51 | 0.002279 | 155888 | 355.20 | 11983 | 27.30 |
| Germany | 241188 | 824.25 | 0.003417 | 221208 | 755.97 | 19980 | 68.28 |
| Greece | 20985 | 94.76 | 0.004515 | 19169 | 86.56 | 1816 | 8.20 |
| Hungary | 19107 | 55.95 | 0.002928 | 17361 | 50.84 | 1746 | 5.11 |
| Ireland | 11821 | 43.05 | 0.003642 | 11200 | 40.79 | 621 | 2.26 |
| Italy | 139417 | 452.23 | 0.003244 | 124746 | 404.65 | 14671 | 47.59 |
| Japan | 344870 | 1218.76 | 0.003534 | 300806 | 1063.05 | 44063 | 155.72 |
| Korea | 141005 | 470.31 | 0.003335 | 123791 | 412.89 | 17214 | 57.42 |
| Luxembourg | 3902 | 10.77 | 0.002761 | 3385 | 9.35 | 516 | 1.43 |
| Mexico | 106175 | 386.60 | 0.003641 | 97495 | 355 | 8679 | 31.60 |
| Netherlands | 59766 | 181.37 | 0.003035 | 53309 | 161.78 | 6456 | 19.59 |
| New Zealand | 12420 | 33.02 | 0.002659 | 11427. | 30.38 | 993 | 2.64 |
| Norway | 20478 | 37.28 | 0.001820 | 19158 | 34.88 | 1320 | 2.40 |
| Poland | 62001 | 297.53 | 0.004799 | 56902 | 273.06 | 5099 | 24.47 |
| Portugal | 20126 | 58.40 | 0.002902 | 17772 | 51.57 | 2354 | 6.83 |
| Slovak Rep. | 11461 | 37.62 | 0.003282 | 10310 | 33.84 | 1150 | 3.78 |
| Spain | 100119 | 330.64 | 0.003302 | 89260 | 294.78 | 10858 | 35.86 |
| Sweden | 34568 | 50.64 | 0.001465 | 32135 | 47.07 | 2432 | 3.56 |
| Switzerland | 20634 | 43.57 | 0.002112 | 19566 | 41.32 | 1067 | 2.25 |
| Turkey | 67634 | 226.08 | 0.003343 | 60456 | 202.09 | 7177 | 23.99 |
| UK | 147331 | 530.83 | 0.003603 | 13866 | 499.61 | 8666 | 31.22 |
| USA | 1568233 | 5731.59 | 0.003655 | 1393429 | 5092.71 | 174804 | 638.88 |

**Figure 4: Estimated Potential Energy Savings for the 29 OECD countries (2003 – 2007)**

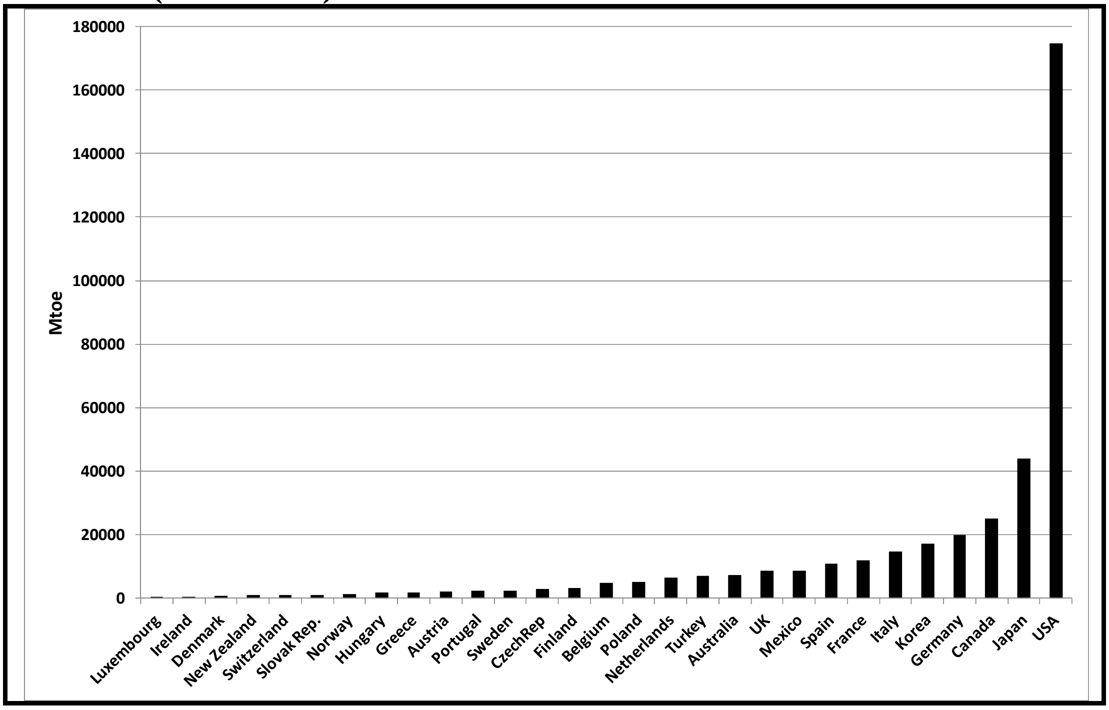
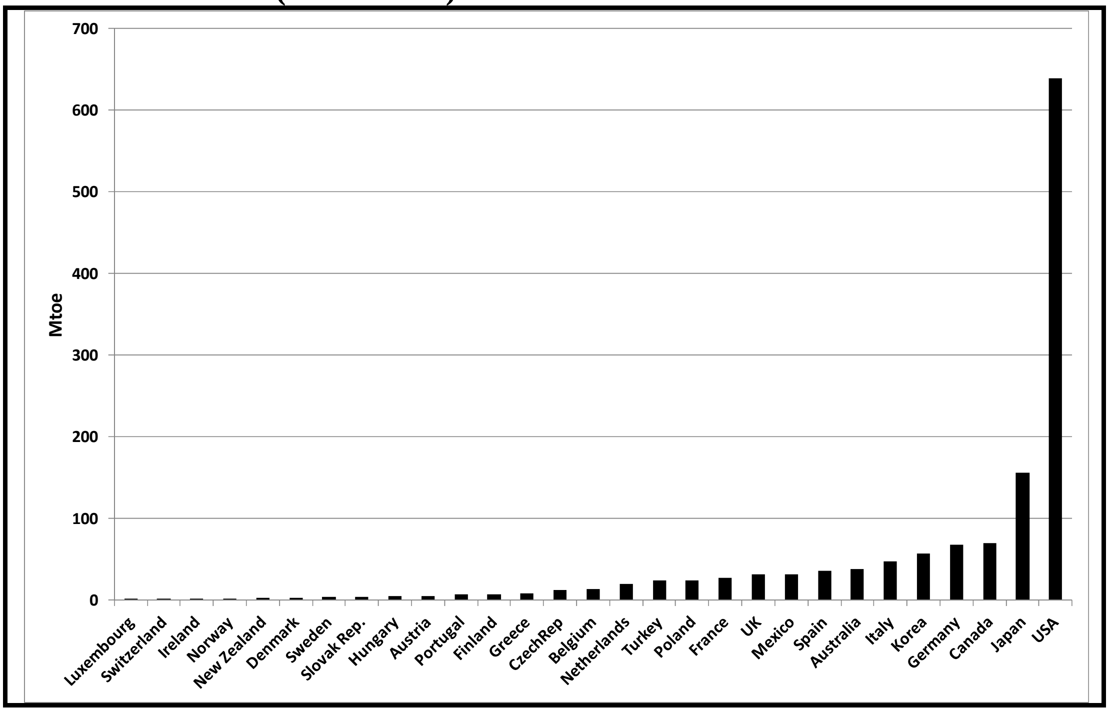



**Figure 5 Estimated Potential CO2 Savings if Energy Efficient for the 29 OECD countries (2003 – 2007)**



### *3.3 Comparison with Kyoto Targets*

When comparing the emissions savings of each country had it been operating efficiently with the Kyoto emissions targets that parties to the agreement have agreed to for the 2008 – 2012 first phase of the Kyoto obligations illustrated in Table 5, it can be seen that in most instances improvements in efficiency alone are not sufficient to contribute fully to eliminating the gap between the emissions and the emissions targets (based on 1990 emissions levels). This implies that energy efficiency improvements in conjunction with changes in the fuel mix are necessary to facilitate many countries in this analysis to achieve their emissions targets under the Kyoto Agreement. As many were emitting above the level of the Kyoto targets and even assuming efficiency would still have done so.

There are however a number of EU member countries in the group of OECD countries including the Czech Republic, Hungary, Poland, Slovak Republic and Germany who were all emitting below the Kyoto target during the period.[29] This is of particular interest in the case of Germany given its total level of emissions and suggests that rather than employing a flat EU reduction target of a reduction of 8% on 1990 emission levels, these countries could have been challenged by a higher emissions reduction target. An initiative encouraged by the Copenhagen Accord (2009) and the UNFCCC meeting in Cancun (2010), although it delivered little improvement on a possible compromise. On emission reductions the text of the Cancun document says countries could either cut emissions by a specified percentage or simply implement their chosen target without regard to how ambitious it is.[30] The thinking at Cancun was along the lines of forming regional arrangements, where similar economies via

[29] Assuming Poland was to have a target consistent with the other EU target of a reduction of 1990 by 8%, in which case it too would be polluting less than this target.

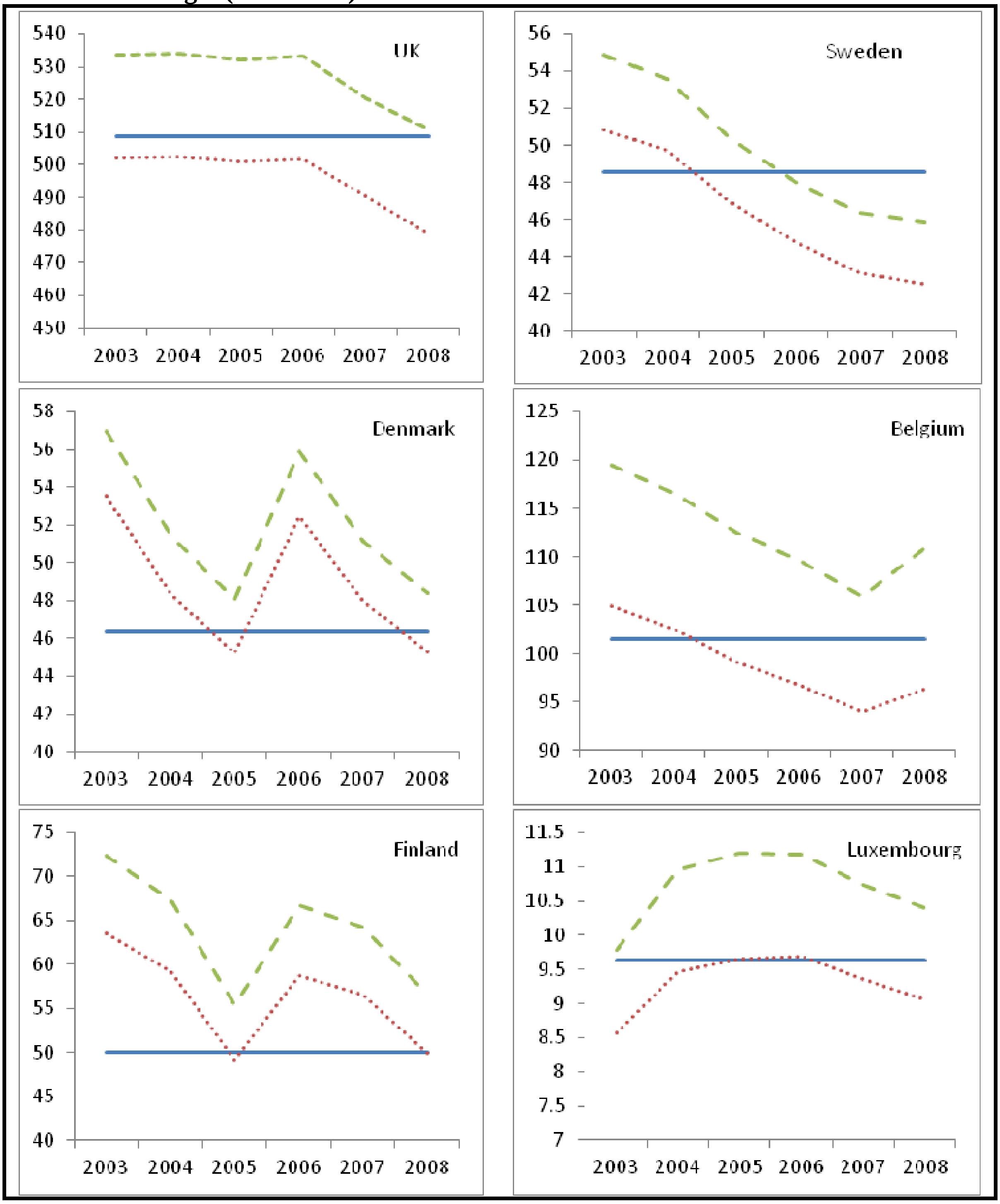
[30] The first week of talks was dominated by tension following Japan's unwillingness to accept the continuation of the Kyoto protocol. A position condemned by developing countries and Britain alike. However, there is underlying concern in many quarters that the protocol covers less than a third of global emissions. Britain, for one, will not allow the protocol to continue unless China signs an agreement to cut emissions.

‘coalitions of the willing’ established binding agreements to cover the spectrum of climate problems limiting their own emissions, helping others to limit theirs and promoting low carbon development. The results suggest that regional agreements, like the 8% reduction offered by many of the EU countries under the Kyoto Protocol will not necessarily be as challenging for all regional members and indeed some with the appropriate incentive could make further significant reductions in their emissions.

**Table 5: Comparison of potential $CO_2$ savings with Kyoto Targets**

| **Country** $i$ | **Average $CO_2$ Emissions (Mt)** $CO2_i$ | **Notional $CO_2$ Emissions (Mt)** $CO2_i^*$ | **Potential $CO_2$ Savings (Mt)** $CO2sav_i$ | **Kyoto Target as % of 1990 emissions %** | **Emission Target based on 1990 emissions and Kyoto obligations (Mt)** |
|---|---|---|---|---|---|
| Australia | 380.54 | 342.00 | 38.54 | 8 | 280.59 |
| Austria | 72.57 | 66.97 | 5.60 | -8 | 52.04 |
| Belgium | 112.83 | 99.48 | 13.35 | -8 | 101.47 |
| Canada | 556.62 | 487.08 | 69.54 | -6 | 406.29 |
| CzechRep | 120.97 | 108.46 | 12.51 | -8 | 142.68 |
| Denmark | 52.71 | 49.52 | 3.19 | -8 | 46.35 |
| Finland | 65.23 | 57.46 | 7.78 | -8 | 50.05 |
| France | 382.51 | 355.20 | 27.30 | -8 | 323.94 |
| Germany | 824.25 | 755.97 | 68.28 | -8 | 874.39 |
| Greece | 94.76 | 86.56 | 8.20 | -8 | 64.52 |
| Hungary | 55.95 | 50.84 | 5.11 | -6 | 64.40 |
| Ireland | 43.05 | 40.79 | 2.26 | -8 | 28.18 |
| Italy | 452.23 | 404.65 | 47.59 | -8 | 365.97 |
| Japan | 1218.76 | 1063.05 | 155.72 | -6 | 1007.14 |
| Korea | 470.31 | 412.89 | 57.42 | n/a | n/a |
| Luxembourg | 10.77 | 9.35 | 1.43 | -8 | 9.63 |
| Mexico | 386.60 | 355.00 | 31.60 | n/a | n/a |
| Netherlands | 181.37 | 161.78 | 19.59 | -8 | 144.06 |
| New Zealand | 33.02 | 30.38 | 2.64 | 0 | 21.37 |
| Norway | 37.28 | 34.88 | 2.40 | 1 | 28.73 |
| Poland | 297.53 | 273.06 | 24.47 | n/a | n/a |
| Portugal | 58.40 | 51.57 | 6.83 | -8 | 36.14 |
| Slovak Rep. | 37.62 | 33.84 | 3.78 | -8 | 52.19 |
| Spain | 330.64 | 294.78 | 35.86 | -8 | 189.38 |
| Sweden | 50.64 | 47.07 | 3.56 | -8 | 48.53 |
| Switzerland | 43.57 | 41.32 | 2.25 | -8 | 37.45 |
| Turkey | 226.08 | 202.09 | 23.99 | n/a | n/a |
| UK | 530.83 | 499.61 | 31.22 | -8 | 508.73 |
| USA | 5731.59 | 5092.71 | 638.88 | -7 | 4522.86 |

**Figure 6: OECD Countries where energy efficiency makes a difference to attaining Target (2003-2007)**



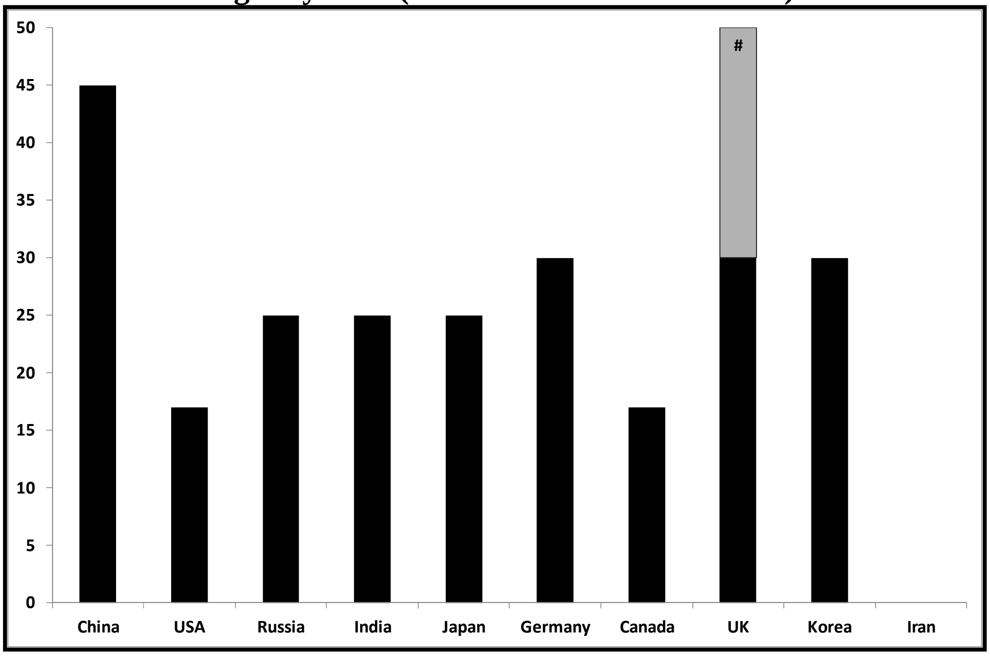

**Note**: Solid line represents emission target based on 1990 figures
Dashed line represents actual $CO_2$ emissions
Dotted line represents the estimated efficient level of $CO_2$ emissions

In each of the 6 countries in Figure 6 energy efficiency improvements alone would have taken each country below their emissions for at least some of the period. In the case of

Denmark and Finland energy efficiency alone would have led to the attainment of the target in 2005 and 2008, in Belgium energy efficiency improvements alone would have taken is below its environmental target from 2004 on and in Sweden it would have meant achieving target about a year (to 18 months) ahead of when the target emission barrier was broken. In Luxembourg there are relatively small levels of emissions but nevertheless for the entire sample period energy efficiency alone would have meant that emissions targets were met. This is also the case for the UK; however the magnitude of emissions level is significantly larger than Luxembourg and indeed approximately ten times larger than Sweden, Denmark and Finland. The UK could have produced $CO_2$ emissions below its Kyoto targets for the entire period had it been operating on the efficient frontier this is significant for one of the world's top 10 $CO_2$ emitters.

The remaining countries in the sample are those who are still exceeding their emissions target (in some cases quite significantly). This pattern of emissions is of concern given the undertaking of many of these nations at Cancun to seek to strengthen their existing targets. The Australians commitment to only increase emissions by 8% from 1990 levels are still way above this 'generous' target and efficiency measures alone will not be enough. The USA target of a reduction of 7% and Canada 6% of 1990 emissions levels are not close to being met and both countries have committed to targets of 17% reduction of 2005 emissions levels by 2020. Energy efficiency improvements will assist but alone will not be sufficient to attain such ambitious targets. Japan and Korea have committed to $CO_2$ reduction targets of 25% and 30% respectively by 2020 (UNFCCC, 2010). Germany along with other EU member states have committed to a 30% reduction in emissions from 1990 levels by 2020 and the UK in its $4^{th}$ Green Budget of May 2011 (as shown in Figure 7) has committed to a 50% reduction in $CO_2$ emissions from 1990 levels.

**Figure 7: National Commitments under Copenhagen Accord Emission Reduction Pledges by 2020 (% of 1990 emissions levels*)**




**Source:** UNFCCC (2010)

**Note:** * USA and Canada base year is 2005

# The grey extension for the UK commitment represents the additional 20% committed by the UK in its fourth Green Budget in May 2011 (HM Government, 2011).[31]

When considering the national benefits of improvements in energy efficiency, with the notable exceptions the benefits nationally appear modest and in the short term are possibly outweighed by the costs of doing so. However the sum of the energy that would have been saved on average over the period if all the 29 OECD countries had operated on their efficient frontiers is 24.8% of the USA's actual average energy consumption for the same period. That is, if all 29 OECD countries operated on the efficient energy demand frontier this would have saved average annual energy consumption equivalent to 24.8% of USA average annual energy consumption. This saving in average annual energy consumption of the 29 OECD countries would allow for a reduction in $CO_2$ emissions equivalent to just over 12% of USA

[31] This budget covers the five years from 2023 - 2027 and commits the UK to a 50% reduction of $CO_2$ emissions on 1990 emissions levels by 2025 (with a 34% emissions reduction by 2020). On this basis, emissions reductions by 2050 are targeted at 80% of 1990 levels. The carbon budgets sets out emissions targets for the UK as required under the Climate Change Act 2008.

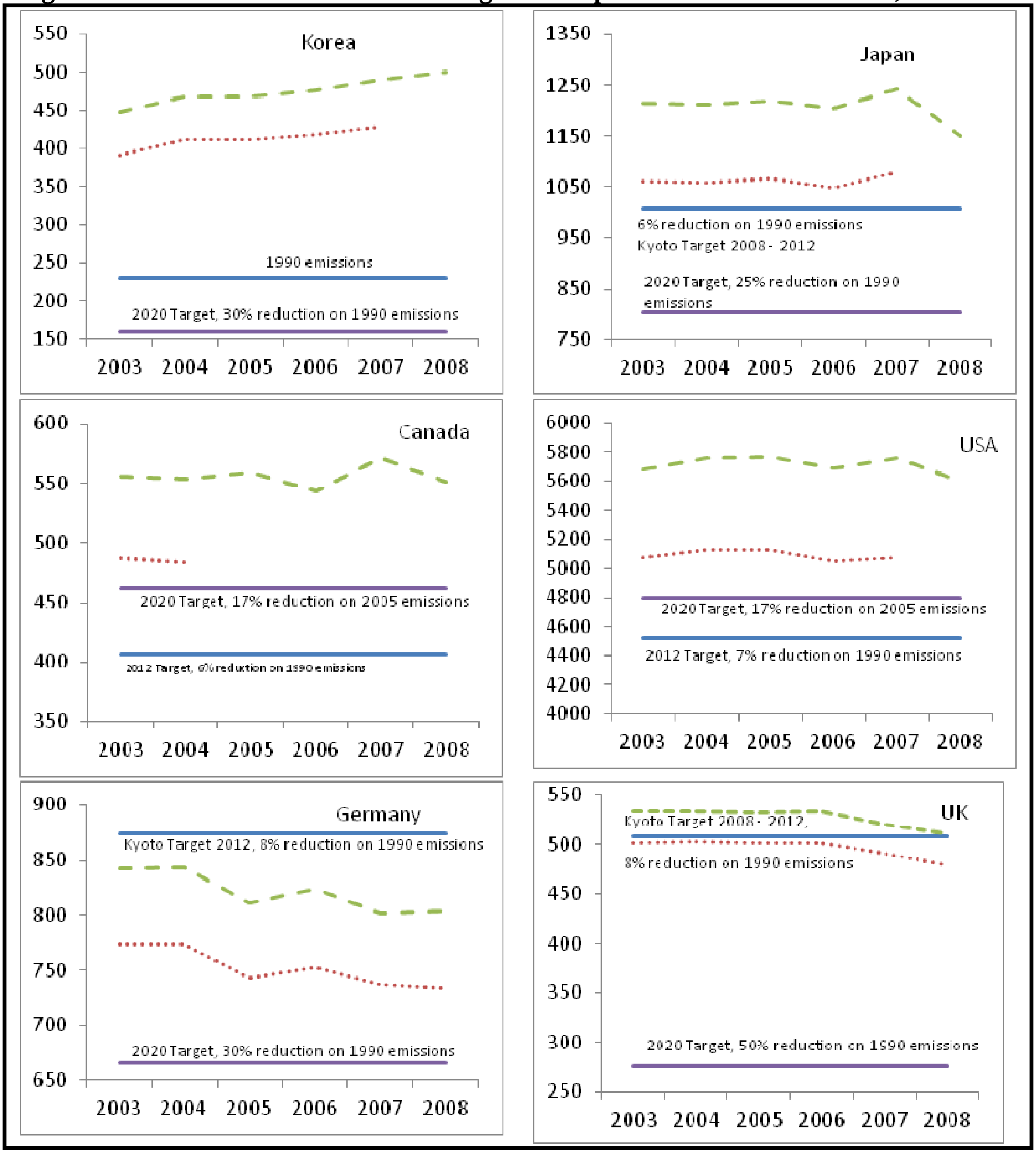
$CO_2$ emissions for the period 2003 – 2007 and about 5½% of the total average $CO_2$ emissions over the same period for the 29 OECD countries included in this study.

### *3.4 Beyond Kyoto*

At UNFCCC meetings in Copenhagen (2009) and again in Cancun (2010) measures for action beyond Kyoto started to take shape. A new round of more ambitious commitments has been sort from countries party to the Kyoto agreement and those that operated outside the agreement. The commitments of the top emitters are presented in Figure 8.

For the majority of the 29 OECD countries analysed improvements in efficiency of energy consumption alone were not sufficient to meet emissions targets. Of the top 10 emitters, the US, Japan, Canada and South Korea were over target, Germany under target and the UK is over target but energy efficiency would have put the UK under target. Therefore championing energy efficiency policies alone will be unlikely to yield the target results. Indeed the common target across the EU of a reduction of 8% on 1990 emission levels appears to have been relatively easily attainable for the likes of a number of EU countries including Germany, but not others. There are the six notable exceptions (as shown in Figure 6) where improvements in efficiency of energy consumption alone were, and are likely to be, the difference between meeting the emissions target and not. In the UK, the results suggest that without any adjustment to the fuel mix employed, but with only increases in the efficiency of energy consumption the Kyoto targets should be within reach.

**Figure 8: 2020 Emission Reduction Targets of Top 10 OECD emitters 2007, 2010**




**Note**: Solid lines represents emission targets
Dashed line represents actual $CO_2$ emissions
Dotted line represents the estimated efficient level of $CO_2$ emissions

As national governments face up to their environmental obligations and consider the most appropriate measures to take beyond Kyoto (2008 – 2012)[32], they has been guided by the text

[32] They must consider the relative roles of improvements in efficiency of energy consumption as one means of reducing energy consumption or the alternative options of reducing carbon emitted per unit of energy by the fuel mix employed so as to be able to maintain and grow economic output.

of the Cancun documentation (December 2010) which suggested that countries could either cut emissions by a specified percentage or simply implement their chosen target without regard as to how ambitious it might be nationally. The formation of regional arrangements via ‘coalitions of the willing’ was the suggested way forward. It was on this basis that the 2020 emissions targets set out in Figure 8 were made. In all instances it would seem that energy efficiency measures alone will be insufficient to meet $CO_2$ emissions targets and a mix of policy initiatives as suggested by the IEA (2008) is necessary to achieve the targets set out.

It might have been expected that the negotiations at the UNFCCC meetings in Durban, South Africa in December 2011 would continue towards voluntary national climate commitments in line with the Bali Action Plan and the agreements made in Copenhagen and Cancun. However, the Durban Platform raises the stakes by refocusing countries on the negotiation of a legally binding agreement to be in place by 2020 (UNFCCC, 2011). To this end the EU has promised to register existing emissions pledges under the extended protocol[33] as have a number of other countries.[34] In conjunction with these measures progress was also made towards establishing a Green Climate Fund to help developing countries meet their emissions reduction commitments.

[33] The European Commission’s Roadmap of March 2011 sets out a pathway to reach the EU’s objective of cutting greenhouse gas emissions by 80-95% of 1990 levels by 2050. In conjunction with the Roadmap a European Energy Efficiency Plan has also been set out (EC, 2011). The Roadmap suggests that the most cost effective way of achieving the 2050 target, requires a 25% emissions cut by 2020 (5 % higher than current European targets) via domestic measures because by 2050 it is predicted that international credits for offsetting emissions will be less available. The Efficiency Plan is a set of proposed measures aimed at creating benefits for households and businesses through lowered emissions targets of 20% improvement in energy efficiency go some way to meeting the reduction targets set out by the Roadmap. The impact of the Energy Efficiency Plan will be reviewed in 2013 and legally binding targets introduced if insufficient progress has been made towards the Roadmap targets.

[34] Brazil, South Africa, China and the US have indicated that they would accept binding commitments under a new treaty. India is holding to the position of the original 1992 Framework Convention on Climate Change, which stated that countries have “common but differentiated responsibilities”. Canada, however, has been unable to meet its Kyoto commitments, and announced on 12 December 2011 that it would formally withdraw from the protocol (UNFCCC, 2011).

## 4. Conclusions

The details of the proposed new treaty envisioned under the Durban Platform are to be determined over the coming years. The contribution of energy efficiency to emissions reductions targets found here suggests that the terms of the treaty need to be carefully negotiated so as to ensure that national governments are given the appropriate incentives to ensure not only that national emissions target are ambitious but that energy efficiency improvements make the optimal contribution towards such emissions reduction targets.

This paper attempts to estimate a panel 'frontier' whole economy aggregate energy demand function for 29 countries over the period 1978 to 2006 using parametric stochastic frontier analysis (SFA). Consequently, unlike standard energy demand econometric estimation, the energy efficiency of each country is also modelled and it is argued that this represents a measure of the underlying efficiency for each country over time, as well as the relative efficiency across the 29 OECD countries.[35] This shows that energy intensity is not necessarily a good indicator of energy efficiency, whereas by controlling for a range of economic and other factors, the measure of energy efficiency obtained via this approach is. This is particularly relevant in a world dominated by environmental concerns with the subsequent need to conserve energy and/or use it as efficiently as possible. Moreover, the results show that although for a number of countries the change in energy intensity over time might give a reasonable indication of efficiency improvements; this is not always the case. Therefore, unless this analysis is undertaken, it is not possible to know whether the energy intensity of a country is a good proxy for energy efficiency or not. Hence, it is argued that this analysis should be undertaken to avoid potentially misleading advice to policy makers.

[35] It should be noted that the estimated underlying energy efficiency and associated potential $CO_2$ savings for each country should not be taken as precise values given the stochastic technique used for the estimation. However, they do give a good approximation of each country's direction of change in efficiency and $CO_2$ emissions over time.

As national governments face up to their environmental obligations and participate in the negotiation of the new legally binding treaty to replace the Kyoto Agreement beyond 2020 they must ensure that the legally binding emission reduction targets are nationally challenging, requiring energy efficiency improvement as well as other measures to meet the target. The results presented here suggest that due in part to different levels of energy efficiency that common targets amongst neighbours will significantly challenge some countries, whilst being easily met (and in some cases exceeded) by others. For the majority of the 29 OECD countries analysed improvements in efficiency of energy consumption alone were not sufficient to meet emissions targets. Therefore, whilst important, championing energy efficiency policies alone will be unlikely to yield the target results.[36]

As shown, the common 8% emissions reduction target on 1990 emission levels applicable to many of the EU member states appears to have been relatively easily attainable for a number of EU countries including Germany, but not for others. There are however, six countries within our sample, where improvements in efficiency of energy consumption alone could have made the difference between meeting the emissions target and not. Further, for the UK, it suggests that increases in the efficiency of energy consumption alone should be enough to meet the Kyoto targets, even without any adjustment to the fuel mix employed. Therefore a uniform reduction target; of the same fixed percentage of a given year's $CO_2$ emissions for all countries is not likely to produce the most efficient outcome, indeed for some countries the

[36] This is consistent with the IEA findings that while energy efficiency is still important in limiting increases in energy use in IEA countries the rate of energy efficiency improvement since 1990 has been slower than previously and will need to speed up to make a more significant contribution; this is possible with energy efficiency measures improvements in buildings, industry and transport but government action is necessary in conjunction with the market mechanism for the deployment of energy efficiency technologies. IEA (2008) Energy Technology Perspectives 2008. In 2008 the IEA presented a list of high priority energy efficiency policy recommendations.

target set on this basis will be too ambitious (and not realistically attainable) while for others not challenging enough to incentivise the drive for optimal energy efficiency.

Instead the legally binding requirements of the treaty could usefully include national emissions reduction targets which are determined in two parts. The first part of the target should be calculated on the basis of desirable national energy efficiency improvements, which could be specified in the treaty. That is, the first part of the target should determine the emissions reductions possible when each nation is energy efficient. Beyond this, the second part of the target could require emissions reductions via additional measures and might indeed be set as a flat rate reduction target or on a sliding scale (to accommodate developing countries). Such a measure would ensure that each nation had a challenging emissions reduction target and the incentive to improve both energy efficiency and undertake other measures to reduce $CO_2$ emissions. Our results suggest that measure to improve energy efficiency alone have been and therefore are likely to continue to be insufficient to meet $CO_2$ emissions targets and therefore a mix of policy initiatives will be required to achieve the emissions reductions levels necessary.

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