Energy Intensity vs. Efficient energy use: Lessons of the Energy Efficiency Literature

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Abstract

The purpose of this paper is to provide lessons and selective review of the literature on energy intensity/productivity used to study energy efficiency. Energy intensity is an average measure of energy use and is sometimes confused with energy efficiency, which requires a marginal value index comparable with energy price to measure efficient energy use. Nevertheless, energy intensity has been widely used for measuring energy efficiency and a review of this literature shows the current position of research in this area and serves as the starting point for introducing an alternative marginal yardstick to measure efficient use of energy at the sectoral or national level in any country including Iran.

Keywords: Energy efficiency, energy intensity, efficient use of energy, energy productivity, marginal value index, microeconomics foundation.

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1. Introduction

There are substantial differences in the growth rate of energy use across countries. For the period 1970 to 1990 energy consumption increased on average by 1.3 percent in industrial countries, 2.4 percent in the former planned economies[2] and 4.5 percent in developing countries (Schipper and Sweeney, 1993). These numbers reflect the average energy intensity (energy per unit of GDP) or the reciprocal, productivity of energy use and do not measure economic efficiency[3] in energy use (World Bank, 1993).[4] Country level energy use depends on socio-economic and geographical circumstances such as comparative advantage in energy-intensive sectors, resource endowments, population levels, climate variation and energy policies. Nevertheless, energy policy makers can use this productivity information to predict how energy demand will change under different growth scenarios.

The data on measured energy intensities suggests that in developing countries energy growth rates increase more rapidly than growth in GDP with the opposite effect in developed countries. What is more, as countries develop there appears to be convergence[5] in energy productivity growth rates (Mulder and de Groot, 2003b, 2007; Miketa and Mulder, 2003, 2005; Miketa, 2001). However, convergence in energy consumption varies across countries and its economic determinants are not well understood. Nonetheless, the importance of relative growth rates in energy use and GDP as countries develop and convergence in energy use across countries overtime cannot be understood as it implies that growth in energy use will decrease as economic development advances and would improve the prospects for meeting the standards set out in the Kyoto Protocol.

The purpose of this paper is to present a selected review of the current methods, i.e. energy intensity/productivity in use in measuring energy efficiency. We will argue in the paper that such average measures are not proper measures of energy efficiency but nonetheless this is the level of the literature as it now stands. Section 2 will outline methods used to measure energy intensity/productivity, present a general econometric model used in energy intensity/productivity convergence across countries and a non-parametric procedure to decompose energy intensity for an individual countries by industrial sector. This is followed in Section 3 with a report of energy intensity/productivity for different countries of the world and some empirical evidence for energy productivity convergence across a sample of countries. Finally we will discuss energy intensity

[2] Eastern Europe and the Eastern block countries of the former Soviet Union.
[3] Economic energy efficiency requires a marginal measure of energy use.
[4] See also OECD/IEA, 1997 that employ energy use indicators to analyze the complex fabric of energy demand across industrialized countries at detailed sectoral levels. They point out that "energy intensity does not provide a measure of how efficient energy is used and how efficiency is improving; in fact using that ratio to compare countries is very misleading".
[5] The concept of productivity convergence has its roots in the traditional Solow-Swan neoclassical growth model (Solow, 1956; Swan, 1956) with its central notion of a transitional growth path toward a steady state. The model postulates convergence of income per capita driven by the assumption of diminishing returns to capital accumulation at the economy-wide level.

decomposition for some select countries. Section 4 presents a summary and research agenda for the future studies.

2. Methods

A common productivity index *(p)* used in measuring energy use is to define a ratio of aggregate income (*gdp*) (or, aggregate output *(q)*) to a quantity measure of total energy (*e*) consumed or $p = gdp/e$ or the inverse of this index defined as energy intensity or $i = e/gdp$. This average index is an aggregate measure of energy use and to the extent that GDP and energy use are measured differently across countries it is country specific. Nevertheless, this index has been widely used to measure energy use across different sectors within countries and for comparison of energy use across countries. In comparing countries it is common to define a representative or numeraire (*n*) country to which country (*j*) energy intensity is measured against. This index is defined as an energy intensity gap (*EIG*) and written as:

$$EIG = \left(\frac{i_t^n - i_s^n}{i_s^n}\right) - \left(\frac{i_t^j - i_s^j}{i_s^j}\right) \quad (1)$$

for time periods t and s. If the growth in energy intensity for the j^{th} country relative to the numeraire declines this implies a reduction in energy intensity for the j^{th} country relative to the numeraire (e.g., see Markandya *et al.* 2004).[6] Calculations of energy use indices are of interest in themselves but the possibility of convergence in energy use across countries also has drawn considerable work. A number of papers in this area have followed Baumol[7] (1986) in modelling β-convergence in energy intensity (or, productivity). A good example of this technique is found in Markandya *et al.* (2004, 2006)[8], in a study of energy intensity/use changes in transition economies in terms of convergence relative to the EU average (the numeraire).

Markandya *et al.* set up a model using the Baumol framework where the growth in energy intensity for country *j* in period *t* is regressed on the growth in energy intensity of the EU relative to the energy intensity of the j^{th} country and the log difference in per capita income between the EU and the j^{th} country. The equation is written as:

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[6] Of course, a similar index for income gap could be defined by interchanging GDP for energy intensity.

[7] β-convergence is based on the regression of the growth in per-capita income for country *j* (y_{jt}) regressed on the log of the lagged value of per-capita income or $ln(y_{jt}/y_{jt-1}) = \alpha + \beta \ln y_{jt-1} + \varepsilon_{jt}$. β-convergence is identified with β statistically less than zero. Applications of this procedure applied to per-capita income are found in Abramovitz, 1986; Delong, 1988; Barro, 1991; Barro and Sala-i-Martin, 1992, 1995; Mankiw *et al*., 1992; Islam, 1995 and applied to labour and total factor productivity see, Dollar and Wolff, 1988; Baumol *et al.*, 1994; Ark and Crafts, 1996; Bernard and Jones, 1996a; Miller and Upadhyay, 2002; Islam, 2003.

[8] See also, Miketa and Mulder (2003, 2005); Mulder and de Groot (2003b, 2007).

$$\ln(\frac{i_{jt}}{i_{jt-1}}) = \delta_o + \alpha \ln(\frac{i_{EUt}}{i_{jt-1}}) + \beta \ln(gdp_{EUt} - gdp_{jt}) + \varepsilon_{jt} \qquad (2)$$

With estimation, α defines the rate at which actual energy intensity adjusts to desired energy intensity, in this case relative to the EU, and β measures for β-convergence in energy intensity as the GDP gap narrows between the EU and the j^{th} country. A statistically important positive β implies convergence in energy intensity of transition countries to the EU as economic development narrows the GDP gap. Markandya *et al.* show that $\beta/\alpha = \eta$ can be defined as the elasticity of adjustment or desired energy intensity with respect to the GDP gap. In other words, η refers to the rate at which the energy intensity gap adjusts for every percent change in the GDP gap.

Consistent estimation of the parameters in Equation (2) depends in a non-trivial manner on the assumption $E(\varepsilon_{jt} \mid X) = 0$, where X represents all right-hand-side variables. This assumption requires not only a mean error of zero but, more importantly, that X is correctly specified. Unobserved heterogeneity across countries or across industrial sectors within countries will violate this assumption. Panel data techniques have been used to address this issue but nevertheless results in this literature should be interpreted with respect to this crucial assumption.

An alternative non-parametric procedure[9] to explain changes in energy intensity relies on energy use and production output (q) by sector. This approach decomposes total energy intensity for country j by energy intensity in each sector, k weighted by the production share, s in each sector. The fundamental identity equation is;

$$i_{jt} = \sum_k \frac{e_{jt}^k}{q_{jt}^k} \cdot \frac{q_{jt}^k}{q_{jt}} = \sum_k i_{jt}^k \cdot s_{jt}^k \qquad (3)$$

For comparative purposes the index is calculated by country and sector and it is the change in the index over time that is of particular interest. Note that in this literature a change in output share is defined as structural change. Decomposition for the change in energy intensity across countries can be based directly on Equation (3) by first taking the log and then differentiate with respect to time or:

$$d\ln i_{jt} = \sum_k (d\ln i_{jt}^k + d\ln s_{jt}^k) \qquad (4)$$

However, it has the disadvantage of being tedious to calculate, and parametric techniques have been developed to approximate Equation (4). The preferred decomposition relates the change in energy

[9] See, Cornillie and Fankhauser (2004); Zhang (2000); Sun (1998); Greening *et al*. (1997); Schipper *et al.* 1997; Ang and Lee (1994, 1996); Ang (1994, 1995).

intensity (Δi_j) to change in energy intensity summed over each sector Δi_j^k plus the change in output share for each sector (s_j^k) and written as:

$$\Delta i_j = \Delta i_j^k + \Delta s_j^k + r_j \quad (5)$$

There are two general parametric methods in the literature to transform Equation (4) into an expression like Equation (5), referred to as the Parametric Divisia Method 1 (PDM1) where

$$\begin{aligned} \Delta i_j^k &= \sum_k [i_s^k + \gamma^k (i_t^k - i_s^k)] \cdot \ln(i_t^k / i_s^k) \\ \Delta s_j^k &= \sum_k [i_s^k + \tau^k (i_t^k - i_s^k)] \cdot \ln(s_t^k / s_s^k) \end{aligned} \quad (6)$$

and the Parametric Divisia method 2 (PDM2) where

$$\begin{aligned} \Delta i_j^k &= \sum_k [s_s^k + \gamma^k (s_t^k - s_s^k)] \cdot (i_t^k - i_s^k) \\ \Delta s_j^k &= \sum_k [i_s^k + \tau^k (i_t^k - i_s^k)] \cdot (s_t^k - s_s^k) \end{aligned} \quad (7)$$

with $0 \leq \gamma^k, \tau^k \leq 1$.[10]

r_j is a residual resulting from the independent calculations of each component of Equation (5). Choosing interesting parameter values for γ^k and τ^k allows for different decompositions. Setting $\gamma^k, \tau^k = 0$ implies a Laspeyers type index where the decomposition is on structural and energy intensity change weighted by energy intensity in the initial year. Setting $\gamma^k, \tau^k = 1$ implies a Paasche type index where the decomposition is on structural and energy intensity change weighted by energy intensity in the final year. Other values of γ^k, τ^k are found in the literature (e.g., Greening *et al*., 1997; Liu *et al*., 1992; Boyd *et al*., 1988; Reitler *et al*., 1987).

The non-parametric model does not control for unobserved heterogeneity or for that matter observed heterogeneity across sectors. As such, variation in the energy index can result from unobserved and unexplained shocks. Nevertheless both the non-parametric and parametric approaches have been used widely in the literature and in the next section we present some examples of these results.[11]

[10] To achieve smallest variance some researchers prefer to log the last argument in each expression prior to measurement. For this reason, the average PDM1 has a smaller variance than the average PDM2 method.

[11] In addition, the energy policy design also has been pursued in the literature studying convergence or decomposition of energy intensity. There are studies underlying a descriptive methodology (e.g., Varone and Aebischer, 2001) that follow a design of policy instruments in energy efficiency improvement in developed and especially in former planned and developing countries, but it is based on average measure advocating a decline in energy use or a physical indicator of energy consumption.

3. Some Empirics

Markandya *et al.* (2004, 2006) report energy intensity levels and real per capita income for twelve transition countries[12] between 1992 and 2001. Table 1 summarizes by presenting the percentage change in energy intensity and GDP per capita for each country and for comparison also reports the corresponding EU average. Except for Slovenia and Turkey, the table shows for all countries a decrease in energy intensity over the period. For some countries (Poland, Estonia, Latvia, Lithuania and Slovak Republic) the decrease has been substantial but in all cases the decrease over this period has been greater relative to the decline in energy intensity for the EU average. Interestingly, Romania shows a negative change in GDP per-capita over this period but nonetheless energy intensity fell. On the other hand, Slovenia shows a substantial positive change in GDP per-capita but also a positive change in energy intensity. Finally, Turkey shows a moderate positive change in GDP corresponding to a substantial increase in energy intensity. One general result from the table is that for these countries and time period positive growth in GDP per-capita is negatively correlated with change in energy intensity.

Table 1: Energy Intensity and GDP per capita: Transition Countries, 1992-2001

Country	Energy intensity% change	GDP per capita% change
Bulgaria	-18.0	20.1
Croatia	-14.2	49.7
Czech Republic	-19.3	19.1
Estonia	-37.4	28.4
Hungary	-22.8	32.9
Latvia	-37.1	25.2
Lithuania	-34.0	8.5
Poland	-38.9	50.7
Romania	-16.5	-5.4
Slovak Republic	-30.6	45.5
Slovenia	0.3	35.4
Turkey	9.9	4.7
Average EU	-12.4	26.8

Source: Markandya *et al.* 2004.

[12] Bulgaria, Croatia, Czech, Estonia, Hungry, Latvia, Lithuania, Poland, Romania, Slovak Republic, Slovenia and Turkey.

Hannesson (2002) examined the relationship between GDP and energy use in 16 of the most populous countries in the latter half of the 20th century. Table 2 reports the level of energy intensity for each country for the period 1950-1997. These countries can be categorized on a rich/poor basis with distinctly different development levels of energy intensity. In the rich countries energy intensity has generally fallen since 1950, especially after 1970. This is certainly true for France, US and particularly UK. In Japan and Italy, we see an increase in energy intensity up to 1970; perhaps representing rapid growth and industrialisation. Most, but not all, of the poor countries represented in Table 2 experienced increasing energy intensity after 1950. This is true for Mexico, Brazil, Turkey, Philippines, India, Islamic Republic of Iran and Thailand. For some periods, energy intensity decreased in some poor countries, notably Nigeria, Egypt and Indonesia, possibly associated with wide swings in economic development. China is exceptional; energy intensity has fallen since 1960 but the level of the energy intensity index is still remarkably high. Garbaccio *et al*. (1999) argue that the fall in energy intensity in China is mainly due to technological progress. Obviously, the level of economic development, energy abundance, energy policies and population has been important factors in explanation of energy intensity evolution within and across these countries over time.

Table 2: Energy Intensity for Select Countries 1950-1997

Tonnes of oil equivalent/US $ million (1990 prices)*

	1950	1960	1970	1980	1990	1997
Japan	163(384)	166(393)	176 (416)	155	133	135
USA	462(834)	457 (826)	464(838)	377	320	303
France	242(473)	217(425)	212(415)	188	171	171
Italy	71(152)	110(235)	163(349)	152	143	139
UK	446(809)	393(714)	323(587)	260	219	198
Mexico	228(244)	302(256)	300(254)	369	413	406
Brazil	147(154)	172(180)	169(178)	171	177	201
Turkey	161(174)	140(151)	196(212)	240	273	295
IR Iran	-	124(97)	254(199)	443	700	776
Thailand	44(25)	122(68)	218(122)	302	343	453
Egypt	740(335)	814(368)	499(226)	653	500	590
Philippines	218(112)	248(127)	359(184)	340	392	500
Indonesia	-	470(203)	381(165)	406	560	482
Nigeria	176(60)	148(50)	161(54)	323	487	305
India	443(163)	501(185)	472(174)	566	616	633
China	-	4,509(1,148)	2,396(610)	2,393	1,613	1,039

* The numbers in parentheses are in tonnes of coal equivalent, with GDP measured at Purchasing Power Parity (PPP).

Source: Hannesson, 2002.

Hannesson compared the growth rate of GDP and energy consumption over five sub-periods. The first two periods cover the era of low energy prices, 1950-60 and 1960-74, the third and fourth periods cover the era of high energy prices, 1974-80 and 1980-87, and the last period, 1987-97, has been characterized by variable, but lower energy prices than in 1974-85. Hannesson concludes that energy consumption has, in most cases, grown more rapidly than GDP in poor countries, while the opposite is true for rich countries. But the growth rate of energy use relative to the growth rate of GDP was markedly reduced in some countries by the high oil price of 1974-85.

Now consider the numbers in parentheses in Table 2. These numbers are the level of energy intensity for each country when GDP and energy units change to purchasing power parity (PPP) and tonnes of coal equivalent, respectively. The level of energy intensity in the rich countries (Japan, US, France, Italy, UK) dramatically increases, and at the same time, the level of energy intensity in the poor nations (Thailand, IR Iran, Egypt, Nigeria, India, China) substantially decreases; this shows volatility of the average measure to changes in energy and GDP units/contents and can be misleading about real energy consumption and energy efficiency within and across countries.[13]

Miketa and Mulder (2003, 2005) extend the convergence analysis of energy productivity using a database of country specific sectoral energy-productivity data covering the period between 1971 and 1995. The data is collected for 56 countries[14] and of these 24 are characterized as industrialized or developed countries and 32 are characterized as less industrialized or developing countries. The first group consists of OECD countries of North America, the Pacific and Western Europe while the second includes mostly non-OECD countries. The paper builds energy productivity indices defined over 10 manufacturing industries:[15] food and tobacco (FOD), textiles and leather (TEX), wood and wood products (WOD), paper, pulp and printing (PAP), chemicals (CHE), non-metallic minerals (NMM), iron and steel (IAS), non-ferrous metals (NFM), machinery (MAC) and transport equipment (TRM). Table 3 reports both average energy productivity indices and growth rates in energy productivity. Column two shows energy productivity for each sector averaged over all countries. The purpose of these calculations is to show the variability of energy productivity across sectors and it is substantial from an index of 251 for transport equipment to 12 for non-metallic minerals. Of course we would expect variation in energy productivity by sector, but the purpose is to show that sectoral changes in energy productivity can have a substantial impact on country level aggregate productivity; referred to

13 Goldemberg (1996) discusses the variability of energy intensity particularly in developing countries. Sun (2003) explains the role of statistical scopes in energy intensity trend change for 7 developing countries whether we use Total Primary Energy Supply (TPES) before or after (biomass included in TPES) 1998 in the IEA database.

14 See also similar study by Mulder and de Groot (2003b, 2007) at a detailed sectoral level for 14 OECD countries.

15 Classified according to the International Standard Industry Classification (ISIC).

in the literature as structural change.[16] This indicates that energy productivity/intensity at country level can be misleading or biased about a real energy consumption pattern due to potential impacting factors like structural change, energy mix, technology, etc.

Table 3: Average Energy Productivity by Industrial Sector

Industrial Sectors[a)]	Average Energy Productivity all countries	Average Growth Energy Productivity 24 Developed	Average Growth Energy Productivity 32 Developing
CHE	36	1.20	-0.84
FOD	108	1.22	-0.95
IAS	21	2.69	1.54
MAC	221	0.27	3.68
NFM	26	2.26	1.70
NMM	12	0.39	0.48
PAP	49	1.46	1.38
TEX	110	0.07	0.83
TRM	251	0.98	-3.96
WOD	165	1.07	-0.67

a) Industrial Sectors: CHE, chemicals; FOD, food and tobacco; IAS, iron and steel; MAC, Machinery; NFM, non-ferrous metals; NMM, non-metallic minerals; PAP, paper, pulp and printing; TEX, textiles and leather; TRM, transport equipment; WOD, wood and wood products.
Source: Miketa and Mulder (2003, 2005).

The third and forth columns of Table 3 report the average growth in energy productivity by sector averaged for the period 1975-1990 for developed and developing countries, respectively. The highest growth rates of energy productivity are to be found in energy-intensive sectors both for developed and developing countries. In particular, the energy-intensive sectors iron and steel, non-ferrous metals and paper experienced rapid energy productivity growth in both regions. An important exception is the energy-intensive sector, non-metallic minerals, which experienced rather slow energy-productivity growth in both regions. In the sectors, chemicals, food, transport and wood the table records only modest energy productivity growth for the developed region and negative growth in the developing countries.[17]

[16] See, Mulder and de Groot, 2003a; Unander *et al*., 1999, Garbaccio *et al*., 1999; Greening *et al*., 1997; Eichhammer and Mannsbart, 1997; Howarth *et al*., 1991. For instance, Garbaccio *et al*. (1999) concluded that the fall in energy intensity in China is mainly due to technological progress, while structural change associated with economic growth had the opposite effect(see energy intensity levels in China in Table 2).

[17] The point is that comparison of energy productivity across energy-intensive and -extensive sectors can result in the conclusion that energy-intensive sectors are less energy efficient than the energy-extensive ones. If we adopt a marginal value measure of energy use, we can show that an energy-extensive sector can economically be more energy efficient than an energy-intensive sector.

The obvious result of Table 3 is the clear disadvantage in energy productivity growth rates for developing countries[18]. In general, the root cause of this disadvantage can be found in weak energy market fundamentals. In many developing countries, energy prices are subsidized and do not cover marginal cost of supply. What is more, the subsidy often varies across alternative energy sources. The World Bank (1990) reported on electricity tariffs in sixty developing countries and found that average tariffs for nearly 80 percent of the utilities did not cover long-run marginal cost of supply. Distorted price signals alter the economic incentives facing energy consumers resulting in excess energy consumption relative to the market price, inefficient investment decisions in technology and price differentials among alternative fuels that cause inefficient substitution in production.

For developing countries it is often found that the industrial and commercial sectors are dominated by a relatively few large monopoly and protected state enterprises. Protected both from market discipline and the need for efficiency, energy consumption per unit of output exceeds that found in developed countries. But the problem is more overwhelming than just monopoly elements, many developing countries are characterized by weak public institutions, absence of trained manpower, lack of an adequate legal framework and financial accountability, uncertain and variable policy frameworks and a command and control decision making process that increases the likelihood of corruption (World Bank, 1993). In addition, the cost of adopting more energy-efficient systems, procedures and technologies tend to be higher in developing countries because of a lack of intermediaries to reduce the costs of information, financing and management assistance.

Markandya *et al*, (2004, 2006) is an example of parametric estimation of energy intensity convergence[19] based on Equation (2). Their model is augmented with numerous control variables and is estimated for twelve transition economies relative to the EU average. The assumption of per capita income convergence between transition countries and the EU average is supported. Overall, the convergence rate within the EU and transition countries is estimated to be about 1.7% per year during the period 1992-2002. Table 4 shows estimates for α - the rate at which actual energy intensity adjusts to desired energy intensity relative to the EU, for β - the rate of convergence in the energy intensity as the per-capita GDP gap narrows between the EU and the j^{th} country and for η - the elasticity of desired energy intensity with respect to the per-capita GDP gap. Table 4 shows that the statistical results measured for this group of countries are mixed with many parameters statistically

[18] Ezcurra (2007) also applied a non-parametric approach to examine the spatial distribution of energy intensities in 98 countries over the period 1971-2001.
[19] Similarly, Miketa and Mulder (2003, 2005) used a parametric estimation of energy productivity convergence at sectoral level across 56 countries; using a similar procedure, Mulder and de Groot (2003b, 2007) also provided a comparison of energy and labour productivity convergence at a detailed sectoral level for 14 OECD countries.

unimportant. Estimates of α in column one are statistically significant at 5 or 10% level for all countries except Slovenia and show that, on average a decrease of 1% in the ratio (i_{EUt}/i_{jt-1}) (desired energy intensity) leads to a decline in the actual energy intensity growth rate of 0.63% (Bulgaria), 0.78% (Croatia), 0.84% (Czech), 0.87% (Estonia), 1.24% (Hungry), 0.80% (Latvia), 0.78% (Lithuania), 0.99% (Poland), 0.91%(Romania), 0.98% (Slovak Republic), 0.07% (Slovenia) and 0.57% (Turkey).

Table 4: Convergence in Energy Intensity

Country	α [a)]	β [b)]	η [c)]
Bulgaria	0.63*(0.16)	0.82*(0.28)	1.29*(0.37)
Croatia	0.78*(0.18)	1.87*(0.45)	2.42*(0.72)
Czech Republic	0.84*(0.23)	0.87*(0.22)	1.04*(0.32)
Estonia	0.87*(0.23)	0.20(0.58)	0.23(0.70)
Hungary	1.24*(0.46)	1.04*(0.48)	0.84(0.59)
Latvia	0.80*(0.32)	0.68(0.87)	0.85(1.36)
Lithuania	0.78*(0.34)	0.77**(0.48)	0.99(0.93)
Poland	0.99*(0.20)	0.23(0.51)	0.23(0.54)
Romania	0.91*(0.21)	1.11*(0.28)	1.22*(0.37)
Slovak Republic	0.98*(0.09)	1.44*(0.40)	1.47*(0.41)
Slovenia	0.07(0.17)	1.80*(0.50)	24.16(56.14)
Turkey	0.57**(0.40)	1.39*(0.31)	2.43**(1.60)

a) α defines the rate at which the actual energy intensity growth adjusts to converge with the desired energy intensity growth rate, relative to the EU average.
b) β measures for $\beta-$convergence in the energy intensity of the j^{th} country as the per capita GDP gap narrows between the EU average and the j^{th} country.
c) η measures the rate at which the gap in energy intensity adjusts for every change in per capita GDP gap between the EU average and the j^{th} country.
* Statistically significant at the 5% level.
** Statistically significant at the 10% level
Source: Markandya *et al.* 2006.

An alternative interpretation of $\hat{\alpha}$ is that 50% of the full adjustment to a new equilibrium value occurs in (ln0.5/ln (1-$\hat{\alpha}$)) of a year.[20] Thus 50% of the adjustment occurs in 0.7 of a year (Bulgaria), 0.46 of a year (Croatia), 0.38 of a year (Czech), 0.34 of a year (Estonia), 0.43 of a year (Latvia), 0.46

[20] Greene, W.H. (2000), "*Econometric Analysis,*" 4th Edition, Prentice Hall, USA.

of a year (Lithuania), 0.15 of a year (Poland), 0.29 of a year (Romania), 0.18 of a year (Slovak), 9.55 of a year (Slovenia) and 0.82 of a year (Turkey).

The second column of Table 4 report β estimates that are all statistically significant at the 5 or 10% level except Estonia, Latvia and Poland. The estimates indicate that on average a 1% decrease in the per-capita GDP gap between the EU and the j^{th} transition country leads to a decline in the energy intensity growth rate of Bulgaria by 0.82%, Croatia by 1.87%, Czech by 0.87%, Estonia by 0.20%, Hungry by 1.04%, Latvia by 0.68%, Lithuania by 0.77%, Poland by 0.23%, Romania by 1.11%, Slovak Republic by 1.44%, Slovenia by1.80% and Turkey by 1.39%.

The third column of Table 4 shows the estimates of η. In the case of Bulgaria, on average, a 1% decrease in per-capita GDP gap relative to the EU leads to a decrease in the energy intensity gap of 1.29%, and so on for other countries. A value of 1.0 indicates that the energy intensity gap closes as fast as the per-capita GDP gap. A value of less (greater) than 1.0 implies that the energy intensity gap closes more slowly (quicker) compared to the per-capita GDP gap. Only Bulgaria, Croatia, Czech, Romania, Slovak and Turkey are statistically significant at 5 or 10% level. Hence, the $\hat{\eta}$ values in Table 4 suggest that Turkey has the most rapid closure of the energy intensity gap; followed by Croatia, Slovak Republic, Bulgaria, Romania and Czech. A statistically insignificant value of η (Estonia) could be interpreted as saying that energy intensity convergence is not related to per-capita GDP convergence.

In general, the results for the study are mixed and certainly lack robustness to the theory. However the authors do argue that the results are important overall and show differences in the rate of convergence across countries. They state that in general a 1% decrease in per capita income gap between the EU and transition economies leads to a 7% decrease in the energy intensity gap and they forecast that by 2020 many transition economies will have converged to EU levels. But, they also found that between 2000 and 2020 energy demand in many countries will increase in spite of the major decline in energy intensity.

Cornillie and Fankhauser (2004) make an application of the non-parametric decomposition as defined by Equations (5), (6) and (7).[21] They apply the decomposition to 22 developing countries[22] in

[21] See the original paper for details on the specification of the decomposition equation.
[22] The countries included Albania, Bulgaria, FYR Macedonia, Romania, Croatia, Czech Republic, Hungary, Poland, Slovak Republic, Slovenia, Estonia, Latvia, Lithuania, Belarus, Moldova, Russia, Ukraine, Armenia, Azerbaijan, Kazakhstan, the Kyrgyz Republic and Uzbekistan.

transition to market economies for the period 1992-1998. Energy intensity values for transition countries, which historically have been high compared to industrialized economies, have decreased since the beginning of transition. The decomposition literature recognizes four factors driving evolution of energy intensity in transition countries: energy intensity in the industrial sector (IND), energy intensity in the rest of the economy (ROE), energy intensity in transportation (TRA) and structural change (STR).

The results of their decomposition show different patterns in the evolution of energy intensity over the last decade. Overall energy intensity changes have been caused either by sectoral changes or individual country shocks. The authors suggest three distinct patterns of energy intensity changes in the data. For the first group (Hungry, Latvia and Slovenia) energy intensity of industry decreased sharply compared to the overall economy. The second group (Poland, Romania and Slovak Republic) energy intensity of industry remained stable over the period but the rest of the economy improved significantly. These countries tend to be characterized by large share of heavy industry in GDP and governments have been reluctant to restructure these sectors. The final group of countries, Common-wealth Independent countries of the former Soviet Union (CIS), showed a marked increase in energy intensity over the period. In theses countries, the transition process was delayed or mismanaged. The pattern across countries with respect to the remaining decomposition factors is more uniform. Structural change was beneficial in most countries but its contribution to changes in overall energy intensity was generally modest. The energy intensity of the transport sector also remained more or less constant through the period.

The point is that energy intensity decomposition is a physical breakdown of the average indicator in terms of energy and output changes across sectors within and cross-countries and does not reflect real energy use pattern in terms of socio-economic impacting factors, since it is not derived from an explicit theory-based equation being capable of a parametric-decomposition.[23] The problem is that energy intensity (productivity) data and its decomposition are widely applied to study energy efficiency growth pattern within and across-nations.[24]

[23] Sue and Eckaus (2004) used a KLEM dataset to decompose long-run changes in aggregate energy intensity of 35 U.S. industries by shifts in structural change and individual industries' energy intensity. They modelled energy intensity variation in terms of variable input prices, capital composition and technology. However, they modeled the average ratio of energy intensity and do not account for economic efficiency of energy use.

[24] Cornillie and Fankhauser (2004) argue that the "difference in energy intensity between OECD countries and transition countries is sometimes seen as an indictor of the latter region's energy inefficiency. Strictly speaking, this is not correct, and differences in energy intensity should not be confused with differences in energy efficiency. Energy use depends on socio-economic and environmental circumstances-such as comparative advantages for energy-intensive activity, resource endowment, population density and climate--and energy efficiency is a measure of how resourcefully energy is used under these conditions (and given prices). The comparison of energy intensity data does not crrect for different circumstances. It picks up differences in both efficiency and socio-economic conditions." (p.284)

4. Conclusion and Recommendations for Future Studies

The purpose of this brief literature review was to emphasize that the focus of the energy literature is on intensity/productivity measures of energy use. These measures have been applied widely both for energy efficiency analysis at the sectoral level, and within and across countries. However they fall short of being a measure of economic efficiency in energy use or are not able to measure efficient use of energy. The reason for this is that the productivity indices described here are void of price and economic theory argues that allocative efficiency relates productivity value to price. In other words, if we are interested in an economic measure of energy efficiency we must develop a marginal value measure and study how energy use is related to the price of energy. The overall focus of this review is to propose a marginal value indictor to measure the economic efficiency and efficient use of energy. We do propose this in the three following recommendations where the first we suggest to use a marginal value measure of energy use in relation to the price of energy as a measure of energy efficiency. This suggestion can use the theory of duality in a profit maximizing framework to describe in detail the methodology of using the marginal value measure of energy in measuring efficiency of energy use. The second suggestion can be an application of the marginal value indictor for measuring energy efficiency of different industrial sectors of a country including Iran and provide decomposition of the energy marginal value measure for select industrial sectors. The final suggestion can develop an extension of convergence analysis in area of energy efficiency using the energy marginal value measure for select industrial sectors in a country.

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