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The energy footprint of human development

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THE ENERGY FOOTPRINT OF HUMAN DEVELOPMENT

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Abstract

In recent years special attention has been paid to the study of the relationship between energy use of a country and its level of development. While the interest of this research area is unquestionable, the indicators commonly chosen for study (Human Development Index (HDI) or GDP as measures of well-being and national energy consumption) are problematic. Thus, little attention has been paid to the fact that, in the current context of globalization, the energy consumption of a country is not a suitable indicator for measuring the total energy requirements associated with its level of development; the significant variable is the global energy consumed to produce the goods and services demanded by that country, i.e. its energy footprint. In this study, we compare the HDI of 40 countries with its energy consumption and its energy footprint. The results show that the energy footprint of developed countries is higher than its energy consumption (+13%); the opposite occurs in emerging economies (BRIIC, -16%), following a pattern that has been intensifying in the last decade. That is, the energy consumption underestimates the energy required to maintain a high level of development, since part of the energy consumption of less developed countries is devoted to sustain developed countries. Moreover, we find that in order to achieve a high level of development worldwide, global energy use shall increase by 40% from current levels (ceteris paribus)

Palabras clave: desarrollo humano, consumo de energía, huella energética.

Clasificación JEL. O13, Q40, Q56

Resumen

En los últimos años se ha prestado especial atención al estudio de la relación entre el uso de energía de un país y su nivel de desarrollo. Si bien no cabe duda del interés de este área de investigación, los indicadores habitualmente elegidos para su estudio (el IDH o el PIB como medidas del bienestar y el consumo nacional de energía) resultan problemáticos. Así, apenas se ha prestado atención al hecho de que, en el actual un contexto de globalización, el consumo de energía de un país no es un indicador adecuado para medir las necesidades energéticas asociadas a su nivel de desarrollo, pues la variable significativa es la energía consumida a escala global para producir los bienes y servicios que demanda ese país, es decir, su huella energética. En este estudio comparamos el IDH de 40 países con su consumo y huella energéticos utilizando la base de datos WIOD. Los resultados muestran que la energía embebida en la demanda final de los países desarrollados es superior a su consumo energético (+13%); lo contrario ocurre en las economías emergentes (BRIIC, -16%), siguiendo un patrón que se viene intensificando en la última década. Es decir, la variable consumo energético infravalora las necesidades energéticas para mantener un nivel de desarrollo alto, pues una parte del consumo de energía de los países menos desarrollados se dedica a sustentar a los desarrollados. Es más, para alcanzar in nivel de desarrollo alto a escala global se necesitaría, *ceteris paribus*, un 40% más de energía que la consumida actualmente.

1. Introduction

An adequate energy supply is a key prerequisite for economic and social development. Three major transitions in the development of energy systems led to greater quality in the types of energy in the last two centuries: from traditional fuels (wood, manure) to coal (steam power), from coal to oil (increased mobility), and finally, the use of electricity (light, computers) (Fouquet, 2010; Smil, 2010; WBGU, 2003). The United Nations General Assembly adopted in 1986 its “Declaration on the Right to Development” (UN, 1986), which established the right to development ‘as a universal and inalienable right and an integral part of fundamental human rights’, setting out a catalogue of objectives for ‘equality of opportunity for all in their access to basic resources, education, health services, food, housing, employment and the fair distribution of income’. Ultimately, energy, in its different forms, is essential to provide all the goods and services linked to the achievement of human development targets. The UN has recognized the role of energy for development and in September 2011, UN Secretary-General Ban Ki-moon launched the “Sustainable Energy for All” initiative, aiming at ensuring clean energy access for all.

In this context there are two key policy questions: i) how is the relation between energy use and human development? and ii) what is the minimum quantity of energy to achieve a certain level of development?

In relation to the first question, in recent year a number of studies have investigated the relationship between the energy use and human development (Alam et al., 1998; Cottrell, 2009; Dias et al., 2006; Martínez and Ebenhack, 2008; Mazur and Rosa, 1974; Olsen, 1992; Pasternak, 2000; Rosa, 1997; Smil, 2005; Steinberger and Roberts, 2010; Suárez, 1995; WBGU, 2003). Most studies have found strong correlations between energy and living standards at lower consumption levels (developing countries), and decoupling at higher levels (industrialized countries) (see Figure 1).[1] The human development decoupling at high consumption levels is referred to as a “plateau” by (Pasternak, 2000) or “saturation” by (Martínez and Ebenhack, 2008).

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[1] As early as 1974, (Mazur and Rosa, 1974) concluded their study of 55 countries by describing this pattern and stating that “so long as America's per capita energy consumption does not go below that of other developed nations, we can sustain a reduction in energy use without long-term deterioration of our [non-economic] indicators.”

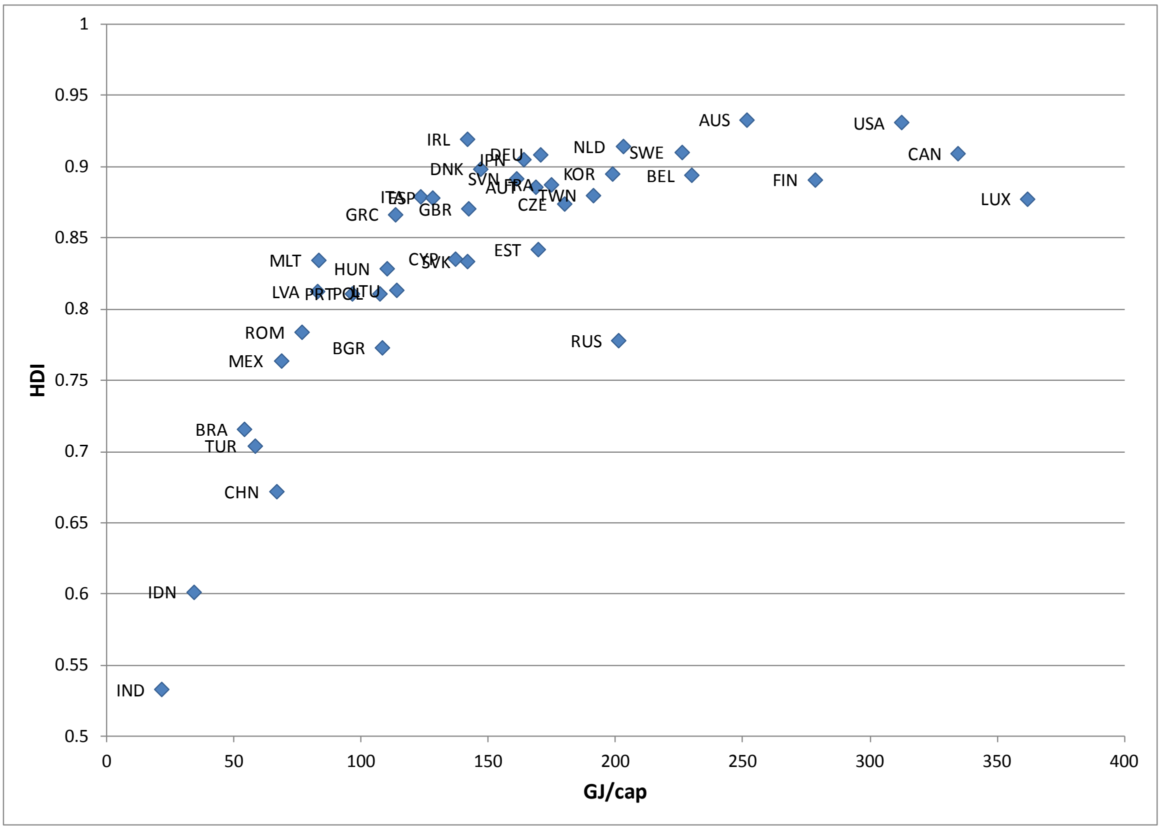

Figure 1: Human development index and energy use of selected countries, 2008

Source: own elaboration form data of the WIOD.

Regarding the second question, different studies have estimated these thresholds or minimum levels following different methodologies (see Table 1). The minimum per capita primary energy consumption (PCEC) in order to reach a high development is a normative issue and cannot be globally setdue to regional, historic and cultural differences. For example, the need for heating and the amount of energy used for this purpose depend on local climatic and building conditions which vary so much; also, in the majority of countries with a low electrification rate and a high proportion of traditional biomass use, indoor heating is rarely required. In individual cases, however, the energy requirement for heating may be very high. Similarly, although there is a minimum requirement for mobility because schools, medical facilities and markets that must be accessible for everyone under acceptable conditions, i it also variessubstantially because infrastructure and distances, for example, also vary widely, making impossible to convert the basic requirement for transport services into units of energy (WBGU, 2003). Moreover, basic needs vary not only with climate, region, period in time, age and sex, but also with personal outlook and expectations (Spreng, 2005).

In the light of these limitations, indirect, aggregated top-down methods are the most commonly used in order to obtain some rough estimates.[2] For example, (Martínez and Ebenhack, 2008) isolated the consumption patterns of certain nations[3] from the rest of the world in order to capture the primary trend. Through a simple screening method, they found that "no country has extremely low HDI with PCEC above 400 kgoe (16.7 GJ) and no country has an HDI above 0.7 with a PCEC below 800 kgoe (33.5 GJ)". They also concluded that, using the top five performers from the primary trend, energy-poor nations would require at least an additional 2500 kgoe (i.e. 120 GJ) to potentially achieve HDI values near 0.9.

(Steinberger and Roberts, 2010) adopted a different approach, fitting historic data with a threshold function as a function of time, setting a set of constraints required to fulfil the definition of "high human development" by the UNDP: life expectancy of 70 years at birth, a GDP of 10,000 USD, a literacy rate of 80%, and an HDI of 0.8. The threshold functions were also extended into the future until 2030.

(WBGU, 2003) approximated a "guard rail" following a different approach, selecting a representative set of countries with a relatively high HDI (0.7-0.8) and low HPI (Human Poverty Index) (11-29). The arithmetic mean of these ten countries' annual per capita GDP was calculated (US$2,900 per person and year), which the WBGU considered to be the lower limit for a life in human dignity.[4] Therefore, a macroeconomic minimum energy requirement per person and year is derived from the primary energy consumption of the ten countries selected: 4,500 - 10,500kWh (16.2 - 37.8 GJ per person and year, with a mean of 7,500 kWh (27 GJ) per person and year.

Other authors have worked with the electricity as proxy to the energy consumption. For example, (Pasternak, 2000) found for the years 1980 and 1997 that no country with annual electricity consumption below 4,000 kWh (14.4 GJ) per person has an HDI of 0.9 or greater. Above 5,000 kWh per capita, no country has an HDI below 0.9. Furthermore, as electricity consumption increases above 4,000 kWh (17.1 GJ), no significant increase in HDI is observed. The observation that HDI correlates somewhat better with electricity than with primary energy may reflect the facts that electricity is high-quality energy that can be used with high efficiency at the point of application and that electricity requires substantial infrastructure to generate, transmit, and use. It

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[2] Bottom-up calculations rest on a number of assumptions regarding the type of energy consuming equipment (stove, light bulbs, etc.), their sizes, efficiencies and intensity of consumption. A couple of examples that follow this approach are (Goldemberg et al., 1985).

[3] mainly energy-exporting countries such from the Former Soviet Union and the Organization of the Petroleum Exporting Countries (OPEC), nations that are characterized by a set of differences from most of the world,

[4] Sixty countries with a total population of 2,200 million did not achieve this threshold in 1999. In 21 countries with a total population of 375 million, the indicator was actually lower than US$1,000.

may also reflect the likelihood that data for electricity are more accurate than for primary energy.

These different estimates are shown in Table 1. These studies follow two approaches: i) the “contemporary situation”: analyse the situation in a specific year and ii) the “potential future”: approach estimates how generalized efficiency improvements and fuel shifts policies would affect to the threshold (Goldemberg et al., 1985; Spreng, 2005; Steinberger and Roberts, 2010; WBGU, 2003).

Study	**Threshold**	**Well-being criteria**
Contemporary situation		
(Pasternak, 2000)	EC: 4,000 KWh (14.4 GJ)	HDI > 0.9
(Goldemberg, 2001)	PCEC: 42 GJ	“Acceptable standard of living”
(WBGU, 2003)	Average PCEC[1]: 35.4 GJ	0.7 < HDI < 0.8
(Martínez and Ebenhack, 2008)	16.7 GJ < PCEC < 33.5 GJ	“extremely low” < HDI < 0.7
	PCEC: 121.4 GJ	HDI > 0.9
(Steinberger and Roberts, 2010)	PCEC dynamic function: 60 GJ (2005)	HDI > 0.8
Potential future after generalized efficiency improvements and/or fuel shifts		
(Goldemberg et al., 1985)	PCEC: 1 KW (31.5 GJ)	Satisfaction of Basic Human Needs (BHN)
(WBGU, 2003)	Average PCEC[1]: 25.5 GJ (2020)	0.7 < HDI < 0.8
(Spreng, 2005)	PCEC: 2 KW (63 GJ)	Avoid dangerous climate change in a egalitarian emissions basis
(Steinberger and Roberts, 2010)	PCEC dynamic function: 50 GJ (2020)	HDI > 0.8

Table 1: Threshold HDI-PCEC/EC as estimated by different authors.

PCEC: annual per capita energy consumption. EC: annual per capita electricity consumption

[1] accounting for traditional energy consumption.

All these studies focus on comparing the HDI with the energy used by each country. However, trade makes it possible to increase countries development level by benefiting from consuming goods and services produced abroad and without the need of using energy to produce them. For example, let be the case of a country A that in order to maintain a certain level of development consumes 10,000 car/year that are produced by a company located in A using 1,000 toe. Now, suppose that country A’s car manufacturer shifts its activity to a second country B, but continues selling all its production in country A. In such a case, country A would still consume 10,000 car/year and, ceteris paribus, its development level would remain constant. However, country A’s energy consumption would have dropped by 1,000 toe (which would also be the increase in country B’s energy consumption). In other words, thanks to international trade, country A´s could maintain its development level while reducing its energy consumption, since part of the energy requirements to satisfy its consumptions has been shifted to country B and therefore is computed as country B's energy consumption. Thus, the energy use would give biased information on the energy requirements to support a level of development, since it does not consider the energy embedded in international trade.

In the current context of the global economy, it can be argued that in order to give a more accurate picture the relation between energy and development one should account for the global energy requirements to support a specific level of development regardless the country in which the energy was actually consumed. This indicator is commonly referred as the energy footprint and reflects the global energy embedded in the domestic final demand (private consumption, public consumption and investment) of a country and links with the some hot research topics such as the environmental footprints (Arto et al., 2012a; Hoekstra and Wiedmann, 2014), the environmental consequences of international trade (Lenzen et al., 2012) and the share of responsibility for environmental degradation between consumers and producers.

In this context, the main objective of this paper is to revisit the questions of the relation between energy and development, and the minimum quantity of energy to get a certain level of development, but using the energy footprint as a measure of the energy requirements. We will also compare these results with the ones derived from the traditional approach which analyses the relation between development and national energy use.

The remaining of the paper is structure as follows: section 2 shows the methodology that will be used for the calculation of the energy footprint of a set of 40 countries for the period 1995 – 2008, section 3 presents the main results, and sections 3 discusses the results.

2. Methodology

Multi-regional input-output (MRIO) analysis is accepted as the method for the calculation of environmental footprints of nations. This method has been used for the study of different environmental topics (Arto et al., 2012; Hoekstra and Wiedmann, 2014; Lenzen et al., 2012; Steen-Olsen et al., 2012; Wang et al., 2011; Weinzettel et al., 2013; Wiedmann et al., 2013). However, the studies estimating the world energy footprint of nations[5] are scarce. (Chen and Chen, 2011, 2013) focus in the energy embodied in global trade flows using the GTAP database for the years 2004 and 2007 respectively, however as pointed by

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[5] Some studies have also calculated the energy footprint of single countries: (Machado et al., 2001) for Brazil for the year 1995, (Liu et al., 2010) for China between 1992-2005 and (Tang et al., 2013) for UK for the period 1980-2010), and

these authors, the GTAP database shows some shortcomings for this type of analysis.

To some extent, the lack of studies in this area could be related to the absence of global MRIO databases extended with energy accounts able to assess the energy embedded in the flow of goods and services worldwide. In our case we will use the recently published World Input-Output Database (WIOD) (Dietzenbacher et al., 2013). This database comprises a time series of harmonized supply, use, and symmetric IO tables. It also includes data on international trade and satellite accounts related to environmental and socio-economic indicators. The WIOD comprises information from 1995 to 2009, for 35 industries, 59 products and 41 countries: the 27 member states of the European Union (EU-27), 13 non-EU countries (Australia, Brazil, Canada, China, India, Indonesia, Japan, South Korea, Mexico, Russia, Turkey, and the United States of America (USA)), and the Rest of the World (RoW) as an aggregated region.

The MRIO used for the calculation of the energy footprints is described for the case of three regions with n sectors, but it can be applied to any number of regions and sectors. In this study, the model was applied to 41 regions (40 countries plus the rest of the world as an aggregate region), 35 industries and 5 final demand categories.

The starting point of the model is the MRIO table at basic prices. This table describes the flows of goods and services from all sectors to all intermediate and final users, explicitly distinguishing the countries of origin and destination for each flow.

We can distinguish three main components in the MRIO table:

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11} & \mathbf{Z}^{12} & \mathbf{Z}^{12} \\ \mathbf{Z}^{21} & \mathbf{Z}^{22} & \mathbf{Z}^{23} \\ \mathbf{Z}^{31} & \mathbf{Z}^{32} & \mathbf{Z}^{33} \end{bmatrix}, \ \mathbf{f} = \begin{bmatrix} \mathbf{f}^{1} \\ \mathbf{f}^{2} \\ \mathbf{f}^{3} \end{bmatrix} = \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \mathbf{f}^{13} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \mathbf{f}^{23} \\ \mathbf{f}^{31} + \mathbf{f}^{32} + \mathbf{f}^{33} \end{bmatrix}, \ \mathbf{x} = \begin{bmatrix} \mathbf{x}^{1} \\ \mathbf{x}^{2} \\ \mathbf{x}^{3} \end{bmatrix},$$

where $\mathbf{Z}^{rs}$ is the intermediate matrix with sectoral deliveries from country r to country s; $\mathbf{f}^{rs}$ is the column vector of country s final demand (including household consumption, government consumption, and investment) for goods produced by country r; and $\mathbf{x}^{r}$ is the vector column vector of gross output for country r.

The relation between $\mathbf{x}$, $\mathbf{Z}$ and $\mathbf{f}$ is defined by the accounting equation $\mathbf{x} = \mathbf{Zi} + \mathbf{f}$, where $\mathbf{i}$ is the column summation vector consisting of ones.

Further, the global MRIO table is extended with: a vector $\mathbf{s}^r$ with element s_i^r indicating the (national) energy use by sector *i* in country *r*; the scalar h^r which gives the direct energy use of households in country *r*. We define

$$\mathbf{s} = \begin{bmatrix} \mathbf{s^1} \\ \mathbf{s^2} \\ \mathbf{s^3} \end{bmatrix} \mathbf{h} = \begin{bmatrix} h^1 \\ h^2 \\ h^3 \end{bmatrix}$$

Accordingly, the energy use of country I can be expressed as:

$$e^r = \left(\mathbf{s^r}\right)'\mathbf{i} + h^r$$

It is important to highlight that, in order to avoid double-counting, we will use the concept of "net" energy use[6]. Thus, the energy use by each sector will represent the volume of energy it dissipates. For example, in the electricity sector we will compute as energy use the difference between the primary energy used in the transformation process (coal, gas, nuclear, etc.) and the electricity produced; the later will be computed as energy use of the sector that consume the electricity (e.g. iron, households, etc.),

The input coefficient matrix for the whole system is defined as $\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1}$, where $(\hat{\mathbf{x}})$ is a diagonal matrix with the values of vector $\mathbf{x}$ long its diagonal and zero elsewhere. Thus, the accounting equation can now be written as the standard input-output model: $\mathbf{x} = \mathbf{Ax} + \mathbf{f}$ .The last, is the basic equation of the standard input-output model. For an arbitrary final demand final demand vector $\mathbf{f}$, the solution to the model is given by $\mathbf{x} = \mathbf{Lf}$, where $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{\mathbf{-1}}$ is the Leontief inverse.

The energy coefficients vector, $\mathbf{c} = (\hat{\mathbf{x}})^{-1}\mathbf{s}$, gives the amount of energy per unit of output. Hence, the amount of energy required for the production of goods in order to satisfy total final demand $\mathbf{f}$ is given by

$$\mathbf{s} = \hat{\mathbf{c}}\mathbf{x} = \hat{\mathbf{c}}\mathbf{Lf} \qquad [1]$$

We can write [1] in its partitioned form as:

$$\begin{bmatrix} \mathbf{s}^1 \\ \mathbf{s}^2 \\ \mathbf{s}^3 \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{c}}^1 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{c}}^2 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \hat{\mathbf{c}}^3 \end{bmatrix} \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{12} & \mathbf{L}^{13} \\ \mathbf{L}^{21} & \mathbf{L}^{22} & \mathbf{L}^{23} \\ \mathbf{L}^{31} & \mathbf{L}^{32} & \mathbf{L}^{33} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{11} + \mathbf{f}^{12} + \mathbf{f}^{13} \\ \mathbf{f}^{21} + \mathbf{f}^{22} + \mathbf{f}^{23} \\ \mathbf{f}^{31} + \mathbf{f}^{32} + \mathbf{f}^{33} \end{bmatrix} \qquad [2]$$

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[6] The WIOD include information on gross energy use and emission relevant energy use. In order to avoid double counting we proceed to transform the gross energy use into net energy use.

From [2] we can calculate the energy embodied in the exports $eexp^{\mathbf{1}}$ and imports $eimp^{\mathbf{1}}$ the energy trade balance $etb^{\mathbf{1}}$, and the energy footprint $efp^{\mathbf{1}}$ of region 1:

$$eexp^{1} = \mathbf{c}^{1}\mathbf{L}^{11}\left(\mathbf{f}^{12} + \mathbf{f}^{13}\right) + \mathbf{c}^{1}\mathbf{L}^{12}\mathbf{f}^{2} + \mathbf{c}^{1}\mathbf{L}^{13}\mathbf{f}^{3} \qquad [3]$$

$$\begin{aligned} eimp^{\mathbf{1}} = & \left(\mathbf{c}^{2}\mathbf{L}^{21} + \mathbf{c}^{3}\mathbf{L}^{31}\right)\mathbf{f}^{11} + \left(\mathbf{c}^{1}\mathbf{L}^{12} + \mathbf{c}^{2}\mathbf{L}^{22} + \mathbf{c}^{3}\mathbf{L}^{32}\right)\mathbf{f}^{21} \\ & + \left(\mathbf{c}^{1}\mathbf{L}^{13} + \mathbf{c}^{2}\mathbf{L}^{23} + \mathbf{c}^{3}\mathbf{L}^{33}\right)\mathbf{f}^{31} \end{aligned} \qquad [4]$$

$$etb^{1} = eexp^{\mathbf{1}} - eimp^{\mathbf{1}} \qquad [5]$$

$$e^{1} = \mathbf{cLg}^{\mathbf{1}} + h^{\mathbf{1}} \qquad [6]$$

where $h^{\mathbf{1}}$ is the energy used directly by households, and $\mathbf{g}^{\mathbf{1}}$ is a column vector that represents the domestic final demand of country 1:

$$\mathbf{g}^{\mathbf{1}} = \begin{bmatrix} \mathbf{f}^{11} \\ \mathbf{f}^{21} \\ \mathbf{f}^{31} \end{bmatrix}$$

3. Results

Figure 1 shows the relation between the Human Development Index (HDI) and the two energy indicators analysed in this study: the per capita energy use (EU) and the per capita energy footprint (EF) for the year 2008.

Focusing on the relation between HDI and EF (red line in Figure 1) we find a positive correlation between HDI and EF: $r_{HDI,EF}$ = 0.80. This relation is especially strong at the lower levels of development, for instance below a HDI of 0.85, the correlation coefficient between HDI and EF is $r_{HDI<0.85,EF}$ = 0.83, while for a HDI over 0.85 the correlation between the two variables decreases to $r_{HDI>0.85,EF}$ = 0.41, which indicates the presence of a saturation point. In terms of EU (dotted line in Figure 1) we, the interpretation of the results is similar but the correlation coefficients are lower: $r_{HDI,EU}$ = 0.72, $r_{HDI<0.85,EU}$ = 0.72 and $r_{HDI>0.85,EU}$ = 0.37.

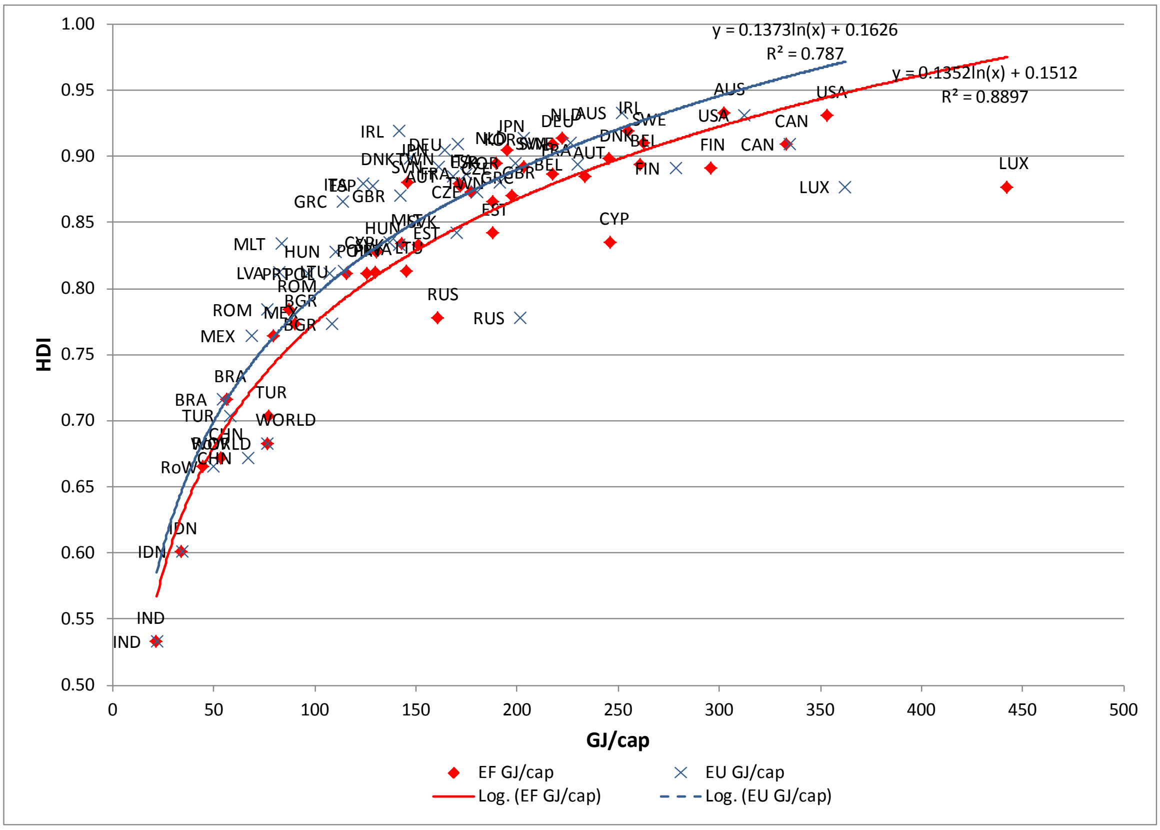

Figure 2: Human development index, energy use and energy footprint

Source: own elaboration form data of the WIOD.

Anyhow, the relation between the HDI and EF or EU is not unique and we can find many different pairs of development and energy. Thus, in order to facilitate the interpretation of these results we have split the countries according to their HDI. We consider as “developed” countries those countries whose HDI is over the threshold of 0.8, while countries with a HDI below 0.8 will be labeled as “developing” countries.

Following this taxonomy, in the year 2008, 31 out of 41 regions analysed belong to the “developed” group of countries. The population-weighted average HDI of these countries is 0.900, the EF is 247 GJ/cap and the EU is 212. In other words, the energy requirements to achieve a certain level of development are higher when measured in terms of footprint than when measured in terms of energy use. This can also be confirmed at the country level. Within this group, 15 countries show an EF over 200 GJ/cap, 9 between 150-200, in 9 between 115-150, and in 5 countries the EF is below 115. In 27 out of these 31 developed countries the EF is higher than the EU (red cells in 5th column of Table 2). For instance, Ireland, which ranks 3rd in the list of developed countries, shows an EF that exceeds its EU by 80%.

The top ten countries in terms of HDI are Australia (HDI: 0.934; EF: 302 GJ/cap; EU: 252 GJ/cap), the USA (0.931; 353; 313), Ireland (0.919; 255; 142), the Netherlands (0.914; 222; 203), Sweden (0.910; 263; 226), Canada (0.909; 333; 335), Germany (0.909; 217; 170), Japan (0.905; 195; 164), Denmark (0.898; 245; 147) and Korea (0.895; 190; 199). These countries show high levels of development with quite different requirements of levels, in terms of EF all of them are above 190 GJ/cap, while in terms of EU the lowest bound is 140 GJ/cap.

Another interesting result from this list of developed countries is the identification of the regions that are able to have a HDI over 0.8 with the lowest energy requirements. In this regards, Poland (HDI: 0.811; EF: 116 GJ/cap), Portugal (0.811; 126) and Latvia (0.812; 130 GJ/cap), show the lowest EF, while Latvia (0.812; 83 GJ/cap), Malta (0.834;84), Portugal (0.811; 96) show the lowest EU.

On the opposite side, nine countries representing 49% of global population and 34% of the EU show a HDI below 0.8 (i.e. developing countries), with a population-weighted average of 0.633 and an EF of 47 GJ/cap and an EU of 53 GJ/cap. These countries are Romania (HDI: 0.784; 87 GJ/cap; EU: 77 GJ/cap), Russia (0.778; 160; 201), Bulgaria (0.773; 90; 108), Mexico (0.764; 79; 69), Brazil (0.716; 56; 54), Turkey (0.704; 77; 58), China (0.672; 53; 67), Indonesia (0.601; 34; 34) and India (0.533; 22; 22). In la these countries, except Russia, both the EF and the EU are below 110 GJ/cap. The aggregate region of the RoW has a HDI of 0.665 and an EF and EU of 50 GJ/cap and covers 36% of world's population.

In the case of developing economies, we can observe that the number of regions with an EF higher than the EU I lower than in the case of developed economies. China stands out in this list, with a EF 20% lower than the EU.

Table 2: Human development index, energy use and energy footprint, 2008

	Developed			
	HDI	EF GJ/cap	EU GJ/cap	EF/EU
AUS	0.933	302	252	20%
USA	0.931	353	313	13%
IRL	0.919	255	142	80%
NLD	0.914	222	203	9%
SWE	0.91	263	226	16%

	Developing			
	HDI	EF GJ/cap	EU GJ/cap	EF/EU
ROM	0.784	87	77	13%
RUS	0.778	160	201	-20%
BGR	0.773	90	108	-17%
MEX	0.764	79	69	16%
BRA	0.71	56	54	4%

	0			
CAN	0.909	333	335	-1%
DEU	0.909	217	170	28%
JPN	0.905	195	164	19%
DNK	0.898	245	147	67%
KOR	0.895	190	199	-5%
BEL	0.894	261	230	13%
SVN	0.892	203	161	26%
FIN	0.891	296	279	6%
FRA	0.887	218	175	25%
AUT	0.885	233	169	39%
TWN	0.880	146	191	-24%
ITA	0.879	171	124	39%
ESP	0.878	172	128	34%
LUX	0.877	442	362	22%
CZE	0.873	177	180	-2%
GBR	0.870	197	142	39%
GRC	0.866	188	114	65%
EST	0.842	188	170	10%
CYP	0.835	246	137	79%
MLT	0.834	143	84	71%
SVK	0.833	151	142	7%
HUN	0.828	130	110	18%
LTU	0.813	145	114	27%
LVA	0.812	130	83	57%
POL	0.811	116	108	8%
PRT	0.811	126	96	31%
	6			
TUR	0.704	77	58	33%
WORLD	0.683	77	77	0%
CHN	0.672	53	67	-20%
RoW	0.665	45	50	-10%
IDN	0.601	34	34	-1%
IND	0.533	22	22	-1%

Source: own elaboration form data of the WIOD.

4. Discussion

The relation between energy and human development shows a clear positive correlation with a saturation point, and regardless of the energy indicators used for the analysis (the EU or the EF). However, the energy requirements associated to a high level of development (i.e. HDI>0.8) are higher when measured in terms of EF that in term of EU. The reason for these results is closely related to the processes of specialization and globalization. In the latest decades, developed countries have specialized in economic activities with high value added, while reducing their share of energy intensive sectors and manufacturing industries. At the same time, some emerging economies like China, India and Brazil have experienced a process of rapid industrialization, increasing their share in global economy and are exporting enormous volumes of manufactured products to developed countries. This shift of economic activities between countries has also consequences in terms of energy use. Thus, developed countries can reduced their energy use and at the same time increase/maintain their welfare, and this is done at the expense of a higher energy use in emerging economies and thanks to international trade. In this sense, the utilization of the EU as indicator to assess the links between energy and development would results on an underestimation of the energy requirements to obtain high levels of development, since it does not take into account the energy embedded in international trade. Similarly, it would overestimate the energy required at lower levels of development. Thus, the use of the energy footprint would be a better option for this type of studies. This claim would be also valid for other research topics like the (in)equality in the use of energy resources worldwide or the responsibility for the growth in energy global consumption.

This argument is reinforced by many recent studies providing evidence on the environmental consequences of the growth in international trade. International trade is modifying the balances in a way where most developed countries have increased their resource use from a consumption-based perspective (resource footprint) faster than from their territorial perspective (Arto et al., 2012; Hoekstra and Wiedmann, 2014). These studies have focused into assessing different footprints: land (Steen-Olsen et al., 2012; Weinzettel et al., 2013), water (Hoekstra and Mekonnen, 2012), materials (Wang et al., 2011; Wiedmann et al., 2013), and associated impacts, for example in terms of biodiversity (Lenzen et al., 2012). Also, some studies have performed the comprehensive analysis of different footprints for a set of countries, such as (Arto et al., 2012). Specially, the increasing net CO2 emission transfers via international trade from developing to developed countries in the last decades is currently being a topic of intensive research, due to its strong implications in terms of climate policy efficacy: (Arto and Dietzenbacher, 2014; Davis and Caldeira, 2010; Peters et al., 2011). Since CO2 emissions from the burning of fossil fuels are the primary cause of global warming (65% of total GHG emissions in 2010 (IPCC, 2014)), it seems evident that these net emissions transfers are ultimately driven by an unbalance between the energy territorially-used and the energy footprint.

The estimation of the of the energy requirements is also an issue of policy relevant especially when regarding the issue of the minimum energy requirements to get a specific level of development. In terms of EU, the developed country (i.e. HDI>0.8) with the lowest energy requirements is Latvia, with 83 GJ/cap. Let be the case of a hypothetical scenario in which this EU is extrapolated to all the 6,740 million people in the world in order to get a HDI greater than 0.8 worldwide. In such a case the global energy requirements would be equal to 564 Exa Joules (EJ), which is 6% over the global energy use in the year 2008 (532 EJ). In consequence, the issue of the minimum energy requirements for reach an universal level of development could be interpreted as a mere question of inequality in the distribution of resources, since there are almost enough resources to supply those 564 EJ.

However, as pointed before this figures do not take into account that part of the energy requirements of Latvia are embedded in their imports and are not accounted in their EU. Thus, if instead of using the EU as a benchmark we use the EF, we would take Poland as the developed country with the lowest EF (116 GJ/cap). Now, the extrapolation of the Polish EF to the whole planet would result on a global energy requirement of 789 EJ, which exceed by 40% the energy consumption of 2008. Hence, when we introduce the concept of EF, the problem of global development crashes into the wall of resource availability.

Our analysis has some limitations derived from the geographical coverage of the database. This is clearly a limitation for the case of developing economies, since only nine developing countries are represented in our database, however, this does not invalidate the arguments derived from the analysis of the developed economies, as the 31 developed economies we have analysed represent 72% of the countries with an HDI over 0.8

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