HOW CAN WE SUPPORT FUTURE ECONOMIC GROWTH? IS THERE A GLOBAL ENERGY DEMATERIALIZATION?

Marina Recalde[1 2 1]- Mariana Zilio[1 2] - Carina Guzowski[1 2]

[1] Instituto de Investigaciones Económicas y Sociales Del Sur (IIESS) (CONICET-UNS)

[2] Departamento de Economía, Universidad Nacional del Sur, 12 de Octubre y San Juan, piso 7, Bahía Blanca, Argentina.

Abstract

During the last decades, as a result of increasing concern about climate change consequences and depletion of the most important energy sources, the discussion of how to sustain the increasing energy demand has arisen. In this frame pursing a *decoupling* or *dematerialization* path seems to be the best solution. However, the possibility to extend the "successful" dematerialization experiences of developed economies to developing ones is at least doubtful. In this paper we study the historical evolution of energy intensity, energy consumption, CO_2 emissions and product generational dematerialization (PGD) for a sample of Latin American and Caribbean and OECD countries for the 1960-2009 period. No evidence for global long term dematerialization was found. Therefore, we stress the relevance of building new environmental friendly strategies to reduce human ecological impact.

Keywords: DECOUPLING; DEMATERIALIZATION; GLOBAL SUSTAINABILITY; REALLOCATION; ENERGY POLICY

[1] Corresponding autor: IIESS - UNS-CONICET, 12 de Octubre y San Juan piso 7, B8000CTX Bahía Blanca, Argentina. Tel: +54 0291 4595138; Fax: +54 0291 4595138
E-mail address: mrecalde@uns.edu.ar

1. Introduction

During the last decades, in a context of increasing concern about climate change consequences and depletion of the most important energy sources, the discussion of how to sustain the increasing energy demand has became highly relevant. The crucial point of this discussion is whether it will be possible to sustain global economic growth, not only in developed but especially in developing and underdeveloped regions, with the current worldwide supply of energy resources and a minimum of human environmental impact. There are different opinions in this matter.

According to the hypothesis of dematerialization, there is a reduction in material and energy consumption along the economic growth path, therefore the use of less energy and resources to produce the same economic output could represent a solution to the ecological compatibility of future economic growth (Ramos-Martin, 2005). From an environmental standpoint, for some economists this idea supports the hypothesis of the Environmental Kuznets Curve (EKC), which states the existence of an inverted-U shaped relationship between economic growth and environmental degradation, environmental degradation increases with economic activity up to a turning point after which income increases associate to higher environmental quality (Grossman and Krueger, 1991; Shafik and Bandopadhyay, 1992; Panayotou, 1993). If this hypothesis were correct, the best and probably the only solution to natural resources depletion and environmental problems will be growth and wait (Beckerman, 1992). Nonetheless, this hypothesis has been extensively criticized both because of its theoretical underpinnings and the empirical findings (Pargal and Wheeler, 1996; Harbaugh, Levinson and Wilson, 2002; Dasgupta et al, 2001; Stern, 2004; Ramos-Martin, 2005; Wagner, 2008).

When looking at the evolution of energy intensity in many developed countries, it is clear to see a decreasing trend. However, many authors argue that this drop has been highly due to a reallocation of energy intensive industries from developed to developing countries, within other policies, supporting the Haven Pollution Hypothesis (HPH) (Jenkins, 2003; Cole, 2004; Cole and Elliot, 2005; Wagner and Timmins, 2008). If this were the case developing regions, such as Latin American and Caribbean countries (LA&C), should try to reallocate their productions in order to replicate the successful cases. Nevertheless, if these countries do not have the real chance to reduce their energy intensity, both because of the role of energy in economic growth and because they cannot use the same policies (especially reallocation strategies), then other energy economic policies will be required.

In this frame, the core objective of this paper is to study the energy intensity decreasing trend in developed countries and their possible driven forces such as changes in energy mix, the rational use of energy policies, changes in the economy structure, and considering that production reallocation may have played a crucial role. The paper also seeks to discuss the real potential of these policies to reduce energy intensity in LA&C region. To this purpose, we use two different samples, one composed by a group of the Organisation for Economic Co-operation and Development countries (OCDE) and the other one by LA&C. We firstly analyze the aggregate and disaggregate energy intensity paths and Greenhouse Gases (GHG) emissions for each group. Then we introduce a measure of intergenerational dematerialization to study the decouple path of OECD countries and LA&C region potentialities to go throughout the same path. Finally, we present a discussion about the possibilities of global intergenerational dematerialization.

The relevance of this study for LA&C, and other developing regions, is twofold. In the first place, as energy is the material base of the economy (Georgesçu-Roegen, 1971; Podololinsky, 1883; in Ramos Martin, 2005; Stern, 2004; Cleveland, 2003; Beaudreau, 2005; Stern and Cleveland, 2004), sufficient energy supply will be required to sustain the economic growth of these regions. In the second place, in a context of increasing relevance of the discussion about climate change, its costs and responsibilities, the way in which future energy requirements will be supply becomes crucial. According to the IPCC scenarios in 2035 and 2050, developing countries will be the most energy consumer countries, as they will grow at a highest rate than developed ones (IPCC, 2011). Therefore, these countries will have to make harder efforts to reduce their energy consumption. If reallocation were not a feasible option for LA&C, then imitating “the successful decoupling strategy” of developed regions will not be an easy task and it will be necessary to find other environmental and energy policies to sustain our common future.

2. Theoretical underpinnings: the dematerialization theory

In the last decades the issue of dematerialization has gained a lot of attention in both theoretical and empirical economic literature. Usually, dematerialization refers to the phenomenon of de-linking income and the use of nature, a reduction in the use of energy and materials both in absolute or relative terms (a reduction in energy or material intensity) (Cleveland and Ruth, 1999). If this argument were true, then it would be possible to decouple energy and material consumption from economic growth.

The relevance of the concept of dematerialization has recently increased in the frame of environmental concern, as well as the discussion about the potential and actual impact of economic growth and development process over the natural environment. For some authors and policymakers, dematerialization may contribute to ease conflicts between the economy and the environment (Wieringa et al., 1992). Contrarily, other authors argue that the optimism on dematerialization process, as well as predictions on future decoupling, has been overvalued since developed countries seem to be in a re-materialization phase, and their previous de-materialization process may have been due to a reallocation of pollutant and energy (material) intensive industries (Ramos Martin, 2005).

There are different definitions of the concept of dematerialization. While some of these definitions emphasize energy or material consumption, others stress the role of pollution and waste production. One of the most common applications of the dematerialization concept is the approach of the intensity of use. This hypothesis was firstly stated by Malenbaum (1978) and states that income is the main factor explaining material and energy consumption (Ramos Martin, 2005). This hypothesis supports the theory of the Environmental Kuznets Curve (EKC)[2], which states the existence of an inverted-U shaped relationship between economic growth and environmental degradation. In this frame, environmental degradation increases with economic activity up to a *turning point*, after which income increases are associated to higher environmental quality (Panayotou, 1993). Then, there is an income level after which a de-linking process between economic growth and consumption can be expected. If the EKC hypothesis were truth, then developed countries may be in a decoupling stage, as their have reached the threshold of income and consumption per capita, while developing ones may still be materializing, as they are in a growth path which requires increasing amounts of energy and material consumption. The policy relevance of this argument is straightforward: the solution to natural resources depletion and environmental problems would be *growth and wait* (Recalde and Ramos Martin, 2012).

There are different arguments supporting the EKC hypothesis. In particular, the EKC is supported by three main arguments: *scale* effects, *composition* effects and *technology* effects (Grossman and Krueger, 1991). In the first place, the scale effect refers to the environmental degradation required for sustaining the growth path; the more the economic activity, the more waste, pollutant emissions and environmental damage. In the second place, the composition effect reflects the "natural" change in the economic structure in its development path, increasing the share of less environmentally damaging activities. The transition from rural to industrial activities produces higher environmental degradation. Nevertheless, after this industrial phase there is a shift to an economy based on services, clearly less polluting than industrial activity. Finally the technology effect states that it would be expected that a wealthy

[2] For a complete review on the theoretical and empirical literature of the EKC see: Zilio (2011).

nation can afford more R&D investments, replacing dirty technologies by cleaner ones. Both the composition effect and the technology effect explain the decoupling (U-inverted shape) after the income threshold.

In this frame, there are several ways to pursue dematerialization: for instance a transition to a service economy, investment in high-technological processes, or re-using recycled or recovered waste materials. If the intensity of use argument were correct, then these policies, highly related to economic growth processes, would lead to reductions in environmental pressure. The phase to a *dematerialized economy* would be a “natural consequence” of the economies.

Nevertheless, these arguments deal with many criticisms. For instance, Jevons (1990), suggested that economy-wide rebound effects are very important and that energy plays a key role in driving productivity improvements and economic growth then, instead of reducing energy consumption, technological progress will increase energy demand (Recalde and Ramos Martin, 2012). According to this argument, rather than reducing environmental impact, production efficiency may increase ecological pressure. The energy/material saving technological progress may have the contrary effect of increasing energy/material demand. The “new availability of further energy resources” (as a consequence of more efficient production activities) may lead to increases in already existing products and services as well as the production of new ones, instead of a reduction of total consumption of resources. Therefore, as stated in the Jevon´s Paradox, efficiency gains will increase ecosystems stress.

The empirical estimation of the EKC, which is highly related to the intensity of use and dematerialization hypothesis, also faces several detractors. Some of these have been addressed by Stern et al (1996), who insist that the usefulness of the results of the EKC estimations is limited to descriptive statistics. Firstly, the empirical relationship between environmental quality and economic performance is subject to several technical concerns, grouped by Stern (2004) into heteroskedasticity problems (Schmalensee et al, 1998), simultaneity (Holtz-Eakin and Selden, 1995; Dinda and Coondoo, 2006), omitted variables bias (Stern and Common, 2001) and temporal and cointegration concerns (Perman and Stern, 1999; Perman and Stern, 2003; Wagner, 2008; Romero-Ávila, 2008). Secondly, international trade has played a crucial role in the reduction of energy intensities of developed countries: when importing raw materials from a one country the counterpart may be exporting environmental impact, the same applies for the imports of those energy intensive goods. Thirdly, the authors insist that there are some data problems, particularly the quality of information and the coverage of time series, which should be carefully taken into account as they can be the origin of non reliable results.

It is also important to mention the role of the shift in energy mix, particularly in the case of developed countries in the trend of energy intensities, and consequently in the verification of the EKC hypothesis and the limits that such shift will face in the future and when globally extended. Cleveland (2003) and Stern (2004) highlight that inter fuels substitutions played a crucial role in the reduction of energy intensity and environmental pressure around the world. Furthermore, some authors (Kaufmann, 1992; Cleveland et al., 1984) insist that substitution within primary energy sources leads to reductions on final energy consumption, due to the use of more efficient energy fuels, instead of as a result of changes in energy patterns (Zilio and Recalde, 2011).

As stated by Ramos Martin (2005) the use of "intensive variables" to measure the dematerialization process has also been criticized. The key point in this respect is whether the historical evolution of an aggregate relative indicator, such as the intensity of use of energy, is good enough to represent the historical evolution of an absolute indicator for the environmental pressure or not.

Besides, the criticism is extended to the fact of projecting future evolution or perspectives of decoupling energy (and matter) consumption from economic growth based on the past evolution of the series. The extrapolation of current and past behaviours into the future is highly criticized in ecological economics (as well as in other approaches of economic theory except for mainstream). To some extent this falls into the discussion about the feasibility of the ergodic axiom or the economic theory, according to which all future events are actuarially certain, then the future can be accurately forecasted from an analysis of existing data. If the world and future events are recognized to be uncertain (nonergodic), as for instance it is in the framework of postkeynesian analysis, then no predictions can be made. This is even more important for environmental phenomenon, as some future environmental problems and their relative consequences are currently completely unknown. Furthermore, uncertainty about evolution could have especially serious implications in case of environmental problems, due to its irreversibility characteristic.

Finally, even when it has been empirically tested for some countries or regions, it is impossible for the EKC to be verified for the whole world. As it was briefly mentioned previously, an important source of explanation of the EKC could be the shift of energy and material intensive economic activities from developed countries to developing ones. This is in the frame of the HPH, according to the HPH the differences in environmental regulations between developed and developing countries may be compounding this general shift away from manufacturing in the developed world and causing developing countries to specialize in the most pollution intensive manufacturing sectors (Cole, 2004).

3. Empirical analysis

3.1. Data

In order to discuss the dematerialization hypothesis we use data for the 1960-2009 period for OECD and LA&C countries[3]. The former is composed by a group of 31 High income OECD counties that according to the World Bank Database are those in which 2010 GNI per capita was 12,276 US dollars or more. The latter, is composed by all 41 countries of the Latin American & Caribbean Region. The complete list of countries is available in tables A1 and A2 of

[3] Due to restrictions in the data availability the analysis for the LA&C region is only defined for the 1971-2009 period.

the annex. In order to avoid data problems arising from the use of different sources of information, for both samples we use information from the World Bank Database[4].

For the first descriptive stage of the study we have used three different series. Firstly, as a proxy for Primary Energy Consumption we use Energy use as indicator, measured in kilotons of oil equivalent (ktoe), refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. Secondly, carbon dioxide emissions (CO_2) are those arising from the burning of fossil fuels and the manufacture of cement. Finally, energy intensity is defined as energy use per unit of output, measured in ktoe/US dollars. In the second phase of the study a dematerialization index will be conveniently defined.

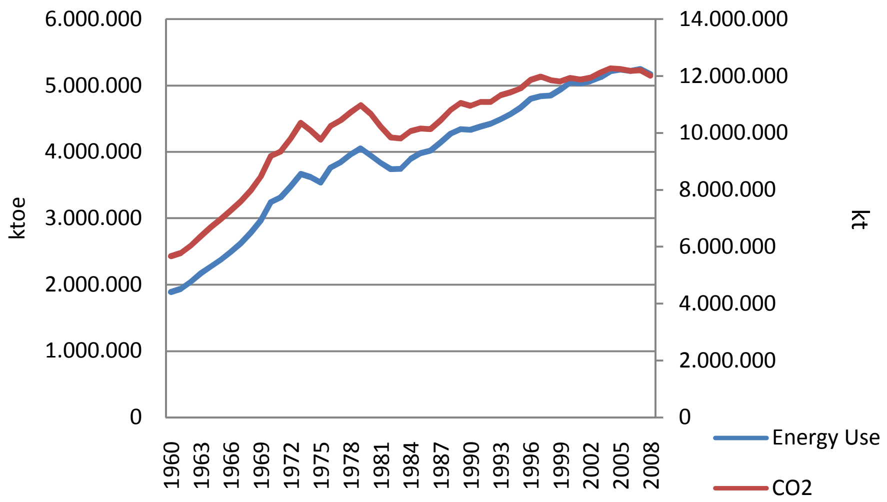
3.2. The descriptive analysis

Figures 1 and 2 show the evolution of energy use and CO_2 emissions in the regions of LA&C and OECD. At first sight in both cases energy consumption and CO_2 emissions share a trend through the time series. This is even clearer for OECD countries than for LA&C, as both series seem to display a clear co-move in the first case. The high relation can be associated to the different composition of the energy mix and the use of less environmentally friendly energy sources. In 2009, 81% out of Total Primary Energy Sources (TPES) in OECD came from hydrocarbons with coal and peat accounting for nearly 20% and renewable sources (hydro, geothermal, solar, wind, biofuels and waste) representing 7,72%. Contrarily, in the same year 69% of TPES in LA&C region were represented by hydrocarbons, 3% of which were coal and peat, and 30% renewable sources. Moreover, it is worth noting that LA&C has a marginal role as an emitter country, as it shares of 5,1% of worldwide CO_2 emissions from burning fossil fuels and cement manufacture. However, CO_2 emissions from use land changes are particularly high in that region and its considering could raise its share up to 9% (WRI, 2010).

[4] Available at: http://databank.worldbank.org

One of the main differences between both regions is the different behaviour of the energy use series. Even though energy use followed a positive trend in both of them, while it showed a positive annual rate of growth for every period in Latin America, this was not the case for OECD. As is clear from figure 2, energy use in OECD countries reduced in two sub-periods of the sample: during both oil crisis. After the first oil crises, when oil prices increased more than 350 per cent between 1973 and 1974, following ever since a high positive trend, energy use in OECD countries fell 1.30 and 2.25 % in 1974 and 1975 respectively. However, the impact of the 1979 energy crisis over energy consumption was even more pronounced. The average price of crude oil rose from 14.02 US dollars per barrel in 1978 to 36.83 US dollars in 1980[5]. As a result developed economies, most of which were net energy importers, reduced their energy consumption. In the case of OECD region, this reduction accounted for 7.84 % between 1978 and 1982, when energy use recovered its positive trend. To this respect, Geller *et al* (2006) argue that industrialized nations became more energy efficient since 1973, because they adopted several policies to improve energy efficiency in all sectors of their economies in the wake of the 1970s oil crises.

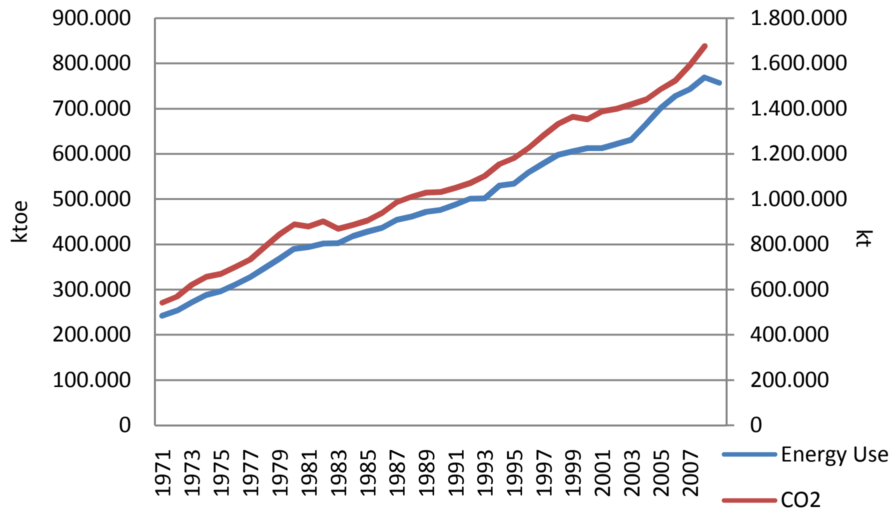
Figure I: Energy Use and CO_2 emissions evolution in OCDE. 1960-2008



Source: Own elaboration based on World Bank Database

[5] Information on crude oil prices from BP Statistical Review of World Energy, available at: http://www.bp.com/statisticalreview

Figure II: Energy Use and CO_2 emissions evolution in LA&C. 1970-2008

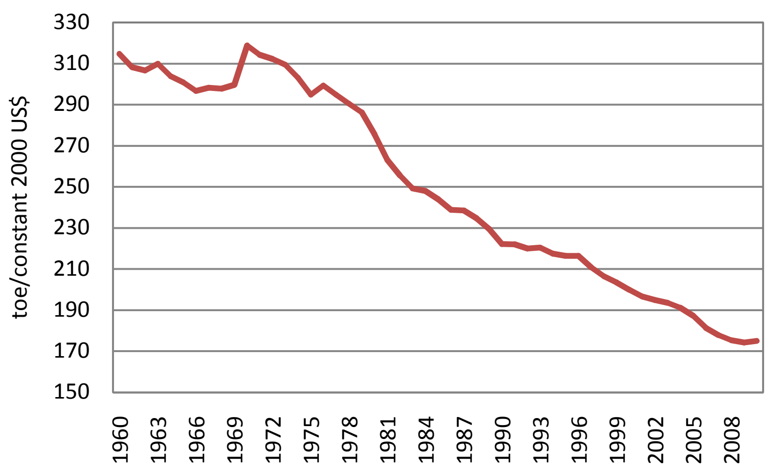


Source: Own elaboration based on World Bank Database

Contrary to the case of energy use, the pattern of energy intensities of both regions has been very different. For OECD countries, there is a clear decreasing trend from the beginnings of the seventies. The driving forces of this trend have been highly studied and discussed by different authors. On the one hand there is the idea that energy policies and increases in energy efficiency has reduced energy consumption by GDP, as the Geller´s et al (2006) argument. On the other hand, some authors stress the impact of the delocalization of energy intensive and polluting industries from European Union and United States to underdeveloped and developing regions (Bear, 2005; Gerefy, 2001; Gereffy et al, 2008). In contrast to this case, figure 4 shows the erratic evolution of the energy intensity in LA&C region with a clear increase between 1979 and 1991. Recalde and Ramos Martin (2012) argue that this increase can be partially explained as an accounting artifact during the regional financial crisis at the beginning of the 1980s, often known as the *lost decade*. The deterioration in the terms of trade during this period resulted in recessions, reduction in imports, unemployment, inflation and a reduction in the purchasing power mainly for the middle classes. Then the main reason for the increase in energy intensity may have been the contraction of economic activity, and the devaluation of local currency against the US dollar. Subsequently, the slight decrease in energy intensity may have been due to stronger currencies and economic recuperation after the financial crises rather than to successful reductions in energy consumption.

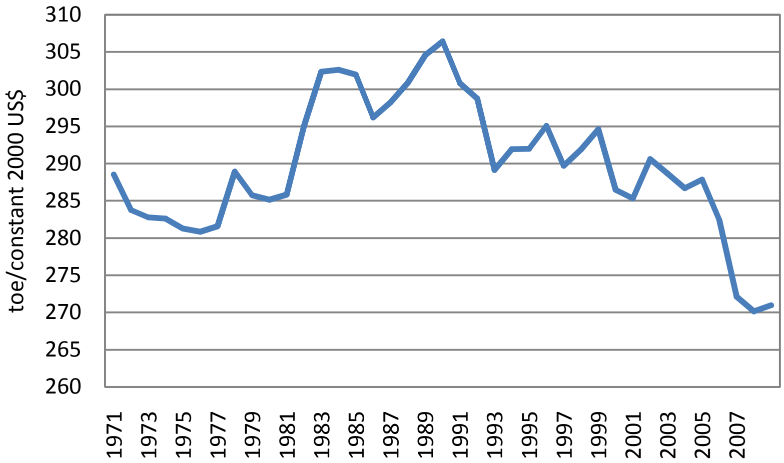
It is very important to remark that increasing energy consumption and decreasing energy intensity in the OECD, and increasing energy consumption and erratic evolution in LA&C may be more related to the evolution of the GDP than to energy policies. While in the first case GDP has increased systematically, in the latter it has evolved erratically, with the consequences on energy intensity paths. This is inevitably related to the development stage of each group of economies and their institutions. The economic instability of developing countries has avoided them to reduce their energy consumption per unit of GDP. Furthermore, it is clear that regarding their developing characteristics, if the countries of this region are to pursue a developed condition, then their energy requirements will increase implying increasing energy intensities.

Figure III: Energy Intensity in OCDE. 1960-2008



Source: Own elaboration based on World Bank Database

Figure IV: Energy Intensity in LA&C. 1970-2008

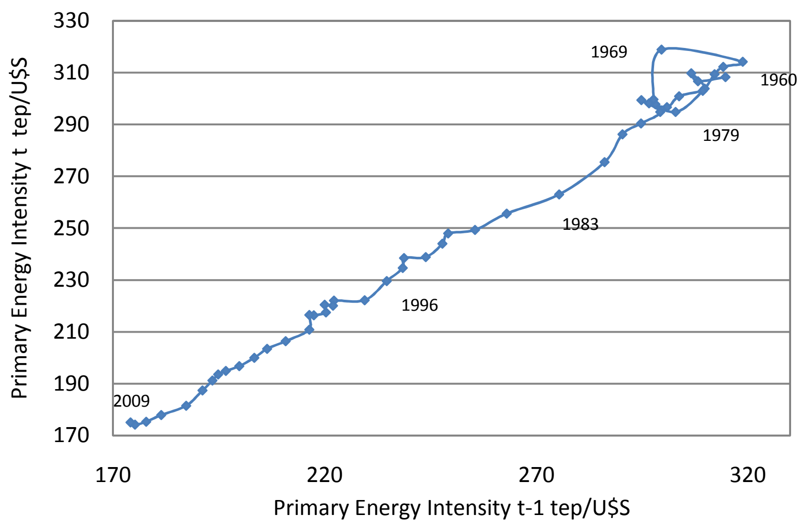


Source: Own elaboration based on World Bank Database

It is clear from the analysis that even when energy intensities may be decreasing after some threshold total energy use, as well as total CO_2 emissions, display a positive trend. In this sense, a relative indicator showing a de-linking process is only indicative of weak dematerialization, while the strong or absolute dematerialization would be clear if there were a decrease in the total consumption of energy in the regions. The latter would also be indicative of a reduction of total environmental pressure of the economies or, in terms of some ecological economists, a change in the energy metabolism of the system (Ramos Martin, 2005). Indeed, as seen in figures 1 and 2, environmental impact of both groups of economies measured by CO_2 emissions has increased along the period, even in the case of OECD countries in which a reduction of energy intensity is observed from the early seventies.

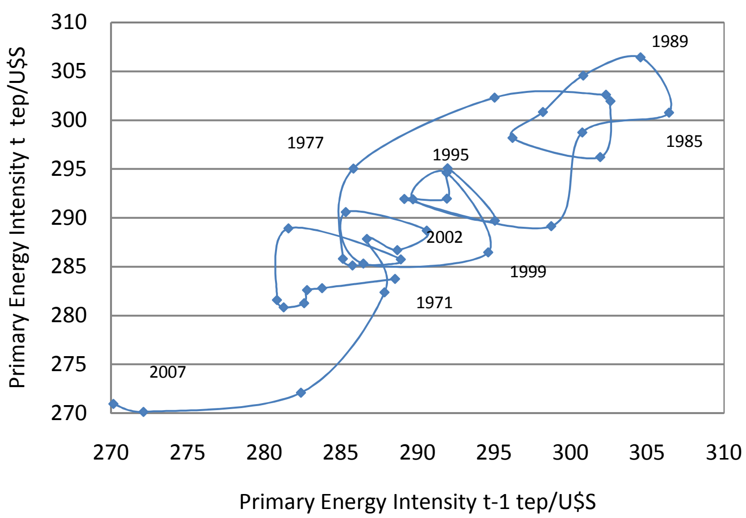
Finally, following Ramos Martin (2005) and Recalde and Ramos Martin (2012) we use a phase diagram of energy intensity with the purpose of studying the continuity of the historical energy intensity trends. This is a methodology which plots energy intensity of the year *t* and that of the year *t - 1* to check the continuity of a particular trend or the existence of alternate phases of increased and decreased energy intensity around certain *attractor points*. Our results are in concordance with the previous results of the analysis of energy intensities. The OECD graph has a left decreasing trend without attractor points except for the seventies and continuity in the historical reduction in energy intensity, while LA&C region is characterized by three attractor points during the seventies, eighties and nineties. Once again, in this last case the erratic evolution of GDP and institutions may be the answer of the energy intensity irregular behaviour.

Figure V: Phase diagram for OECD. 1976-2008



Source: Own elaboration based on World Bank Database

Figure VI: Phase diagram for LA&C. 1970-2008



Source: Own elaboration based on World Bank Database

3.3. Energy Intensity and Product Generational Dematerialization: a comparison

3.3.1. Methodology

As mentioned in section 2 the issue of dematerialization has recently gained a lot of relevance. From an empirical standpoint, most of the studies have been developed in the frame of the EKC, through the study of the evolution of the throughput of matter or energy (Suri and Chapman, 1998; Agras and Chapman, 1999; Stern and Cleveland, 2004; Richmond and Kaufmann, 2006; Luzzati and Orsini, 2009; Zilio and Recalde, 2011).

Besides, another group of studies have been performed with other methodologies, with the purpose of verifying the dematerialization hypothesis (Bernardini and Galli, 1993; Sun and Meristo, 1999; Sun, 2003). The majority of these dematerialization analysis, mostly performed with relative indicators usually fail to appreciate the role of important variables in the environmental pressure. As stated by Ramos Martin (2005), a reduction in consumption per unit of output does not necessarily imply a reduction in absolute terms and, according to the author, the trend of the environmental impact is determined by the different rates at which the consumption per unit of output is reduced compared to the growth of production of output per capita. Furthermore, Ziolkowska y Ziolkowski (2011) insist that the majority of dematerialization methodologies do not inform about the reduction of materials (or energy) used in the economy compared to population. The role of population gathers anytime the intergenerational and dynamics of the environmental concern is recognized. It is clear that the dematerialization/materialization process may be different attending at the dynamics of population growth of different regions, particularly important for developing countries considering their high rate of growth[6].

Besides, from the point of view of this paper, these studies fail to perform a complete and aggregate long range analysis to discuss the real potential of a global decoupling from a dynamic perspective. What is more, from a sustainability standpoint, it is the intergenerational

[6] In the case of the two samples under study, population growth differs between 1.1 and 0.6 % between 2000 and 2010 for LA&C and OCDE countries respectively (World Bank, 2012)

dematerialization trend, not for isolated countries or regions but for the world as a whole, complemented with the study of the trend of absolute environmental pressure indicators, the most important thing to analyze.

Therefore, with the purpose of pursuing a global dynamic dematerialization analysis, we follow Ziolkowska y Ziolkowski (2011) and use the product generational dematerialization (PGD) indicator for energy use to complement the statistical information presented in section 3.2, and to discuss the dematerialization approaches.

As defined by the authors the PGD is the difference between population and consumption dynamics in different time periods.

$$PGD = \left(\frac{P_t}{P_{t-1}}\right) * 100 - \left(\frac{E_t}{E_{t-1}}\right) * 100$$

Where:

PGD: Product generational dematerialization

P_t: Population in time t

P_{t-1}: Population in time t-1

E_t: Energy Use (consumption) in time t

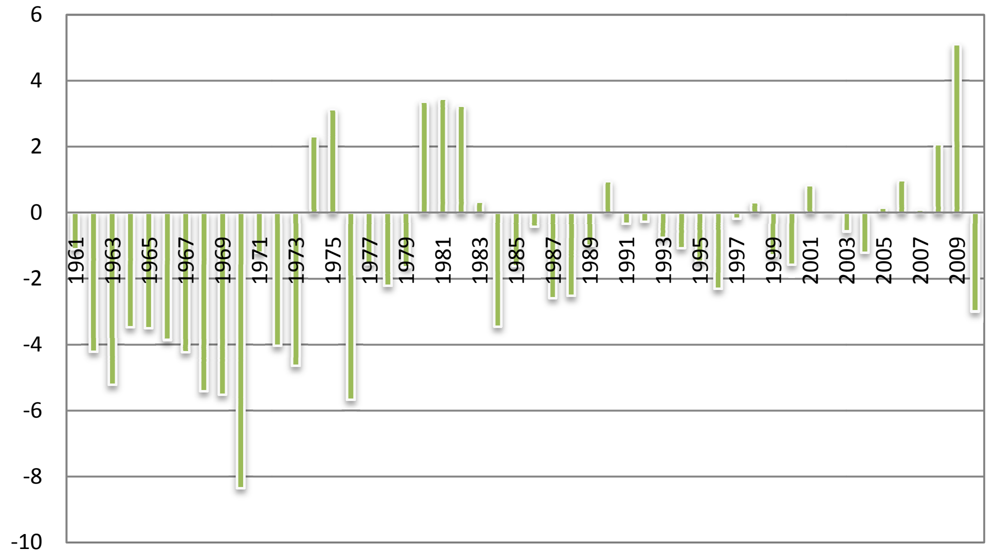
E_{t-1}: Energy Use (consumption) in time t-1

3.3.2. Results

Figures 7-9 present the results of the PGD for OECD, LA&C and the global economy. The results denote that neither OECD nor LA&C region attempt to pursue a product generational dematerialization, except for some periods. The same situation applies for global economy.

According to figure 7 OECD has only had three long-term dematerialization periods: 1974-1975, 1979-1983, and 2005-2009. During these years the PGD was positive, indicating that the rate of growth of energy use per capita was lower than in the rest of the years.

Figure VII: PGD indicator for energy use in the OECD economies in 1961-2010



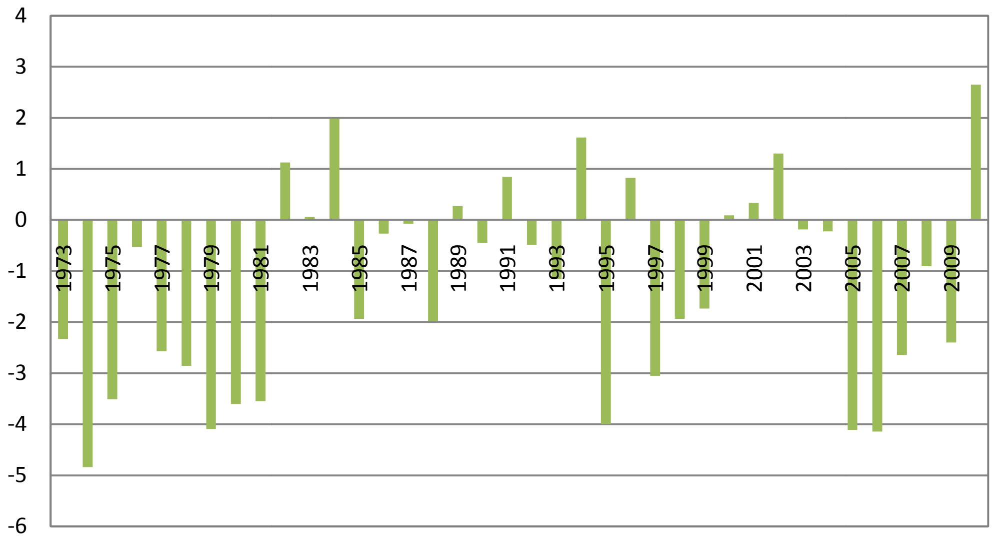
Source: Authors own elaboration

As it has been tracked in section 2 according the different authors, and as explained by the HPH, one of the main explanations (and also critics) for those empirical results supporting dematerialization and decoupling theories comes from the international trade of “dirty” goods and services, as well as the reallocation of energy and matter intensive industries. If this argument were true, it would be highly probably to find opposite patterns of materialization/dematerialization between different regions of the world and therefore global sustainability, from a wide perspective, would not be possible.

Figure 8 shows the results of PGD for LA&C region. This developing region does not seem to be pursing an intergenerational dematerialization, as energy use has grown at a higher rate than population. The materialization of this region is even more pronounced during the seventies and from mid twenties on.

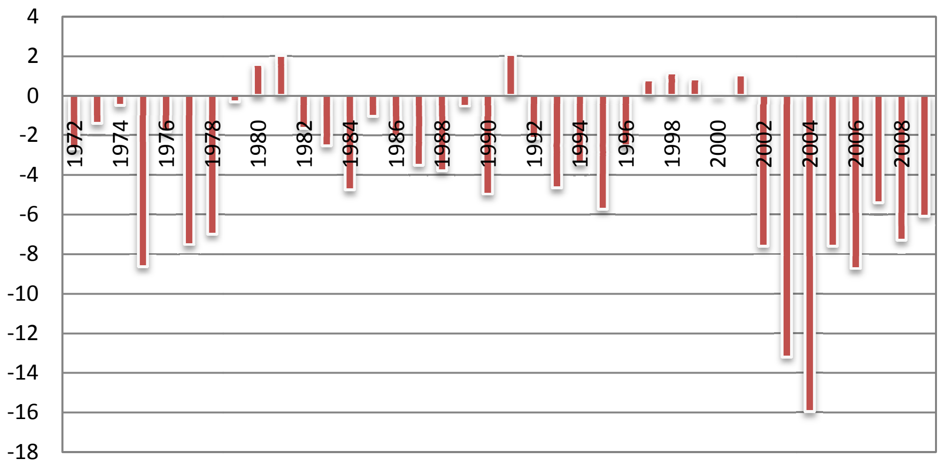
To complement the analysis we also present the results for China in which a continuous and strong materialization process is registered since 2002, probably as a result of the economy opening process.

Figure VIII: PGD indicator for energy use in the LA&C economies in 1971-2009 (in %).



Source: Authors own elaboration

Figure IX: PGD indicator for energy use in the China in 1971-2009 (in %).

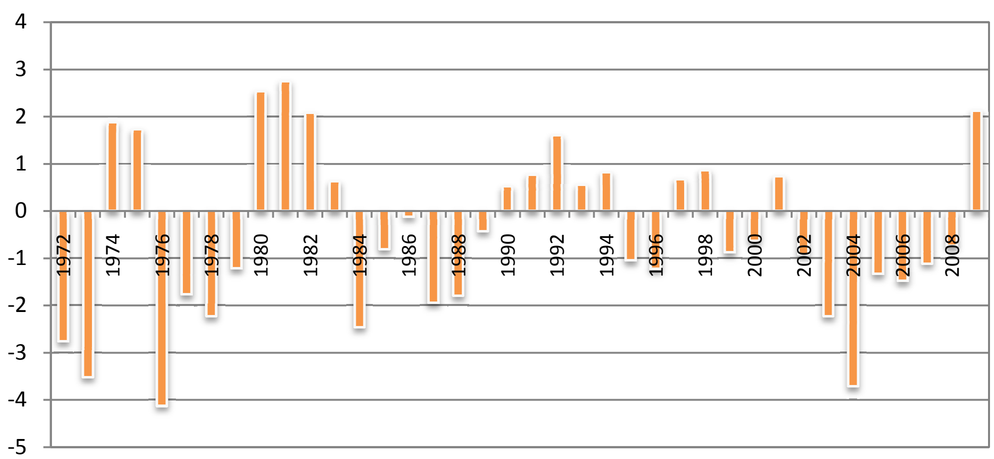


Source: Authors own elaboration

Finally, in order to deal with the key question of this research, we study product generational dematerialization of energy use for global economy to complement the regional analysis (Figure 10). We found only two medium-term dematerialization periods (positive values of the indicator for more than 3 years): 1980-1983 and 1990-1994, and two short term dematerialization episodes in 1974-1975 and 1997-1998. For the rest of the time period, global economy seems to have *materialized* from a generational viewpoint.

Somehow our results contradict those of Ziolkowska y Ziolkowski (2011) who found that for the 1972-2010 period the global economy can by characterized by the dominant trend of dematerialization. To some extent this contradictory results can be explained by the different indicators used for human environmental pressure. While Ziolkowska y Ziolkowski (2011) utilize oil crude consumption as a proxy of resources we use energy use, which includes the consumption of all primary energy sources. Probably, the use of oil may lead to dematerialization results not as a consequence of real reductions in energy consumption (and therefore environmental pressure), but for changes in the energy mix through substitutions between different energy sources. As it was previously mentioned, this interfuel substitution has been a common result of the energy policies applied after the 1970s oil crises.

Figure X: PGD indicator for energy use in the global economy in 1971-2009 (in %).



Source: Authors own elaboration

4. Concluding remarks

The core objective of this paper was discussing the possibilities of pursuing a global long term dematerialization. To this purpose we have studied the historical evolution of energy intensities in different regions of the world, and the policies implemented by developed countries to reduce energy consumption per unit of output and their real potential to reduce energy intensity in other regions.

From the data analyzed through this paper, it is straightforward that the increase in energy consumption is a key characteristic of modern economies, no matter their development stage. As argue by some authors, this fact is related to the exosomatic energy metabolism of the economies (Ramos-Martin, 2001; Ramos-Martin et al, 2007; Ramos-Martin et al, 2009; Sorman et al, 2009). Therefore, in this context, the sole study of relative (or intensive) variables in order to discuss the dematerialization or decoupling or the economy seems to lead to poor or erroneous outcomes.

Our results do not support the *dematerialization* hypothesis. We did not find evidence for long term product generational dematerialization for any of the groups of countries under study. This situation is even clearer for developing regions such as LA&C and China. Moreover, from a wider perspective global economy seems to have *materialized* in the majority of the period under analysis.

Some questions come out from these results: Which will be the real impact of the economic-environmental measures that have emerged in the last decades? Will these initiatives induce global *de-coupling* and *de-carbonization* of the economies? Or will they induce more de-localization of energy/material intensive activities from developed to developing countries?

There is still no a unique and clear answer to none of these questions. The outcomes will depend on political decisions of policy makers as well as current and future institutional frameworks arising from international arrangements, such as the Kyoto Protocol.

However, in the near future it would be required that developing regions do not follow the same energy pattern than developed ones, but that they design innovative strategies in order to change the global trend of environmental pressure. As stated by Grossman and Krueger (1995) developing countries have the opportunity to learn from history and thereby avoid some of the mistakes of earlier growth experiences. In an increasing frame of ecological concerns and environmental hazards it will be extremely important that low-income countries turn their attention to preservation of the environment at earlier stages of development than developed ones.

5. Appendix: Data and sources

Table A1: List of High income OECD countries

Australia	Hungary	Poland
Austria	Iceland	Portugal
Belgium	Ireland	Slovak Republic
Canada	Israel	Slovenia
Czech Republic	Italy	Spain
Denmark	Japan	Sweden
Estonia	Korea, Rep.	Switzerland
Finland	Luxembourg	United Kingdom
France	Netherlands	United States
Germany	New Zealand	
Greece	Norway	

Table A2: List of Latin American countries

Antigua and Barbuda	Dominica	Peru
Argentina	Dominican Republic	Puerto Rico
Aruba	Ecuador	Sint Maarten (Dutch part)
Bahamas, The	El Salvador	St. Kitts and Nevis

Barbados	Grenada	St. Lucia
Belize	Guatemala	St. Martin (French part)
Bolivia	Guyana	St. Vincent and the Grenadin
Brazil	Haiti	Suriname
Cayman Islands	Honduras	Trinidad and Tobago
Chile	Jamaica	Turks and Caicos Islands
Colombia	Mexico	Uruguay
Costa Rica	Nicaragua	Venezuela, RB
Cuba	Panama	Virgin Islands (U.S.)
Curacao	Paraguay	

6. References

Agras, J., Chapman, D., 1999. A dynamic approach to the Environmental Kuznets Curve Hypothesis. Ecological Economics 28, 267–277.

Bair, J. 2005. Global capitalism and commodity chains: looking back, going forward, Competition & Change (2), 153-80.

Beaudreau, B., 2005. Engineering and economic growth. Structural Change and Economic Dynamics 16, 211-220.

Beckerman, W., 1992. Economic Growth and the environment: whose growth? Whose environment? World Development 20 (4), 481-496.

Bernardini, O., Galli, R. 1993. Dematerialization: Long-term trends in the intensity of use of materials and energy. Futures 25 (4), 431–448

Canas, Ä; Ferrao, P.; Conceiça, P., 2003. A new environmental Kuznets curve? Relationship between direct material input and income per capita: evidence from industrialized countries. Ecological Economics 46, 217-229.

Cleveland, C., 2003. Biophysical constraints to economic growth. Encyclopedia of Life Support Systems, (EOLSS Publishers Co. Oxford, UK).

Cleveland, C.J., Ruth, M., 1999. Indicators of dematerialization and the materials intensity of use. Journal of Industrial Ecology 2 (3), 15-50.

Cleveland, C., Costanza, R., Hall, C. Kaufmann, R., 1984. Energy and the U.S. Economy: A Biophysical Perspective. Science 31 (225), 890 – 897.

Cole, M., 2004. Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. Ecological Economics 48, 71– 81

Dasgupta, S., Laplante, B., Mamingi, N., 2001. Pollution and capital market in developing countries. Journal of Environmental Economics and Management 42, 310-335.

Dasgupta, S., Laplante, B., Wang H., Wheeler, D., 2002. Confronting the Environmental Kuznets Curve, Journal of Economic Perspectives, 16 (1), 147-168.

Dinda, S., Coondoo, D., 2006. Income and emission: a panel data-based cointegration analysis. Ecological Economics 57, 167–181.

Georgescu-Roegen, N., 1971. The entropy law and the economic process. Cambridge, Mass, Harvard University.

Gereffi, G., 2001, The Value of Value Chains: Spreading the Gains from Globalisation . Special issue of the IDS Bulletin, Vol. 32, No. 3, July. Institute of Development Studies at the University of Sussex, Brighton, UK.

Gereffi, G., Dubay, K., Lowe, M. 2008. Manufacturing Climate Solutions: Carbon-Reducing Technologies and U.S. Jobs. Durham, NC: Center on Globalization, Governance & Competitiveness, Duke.

Giampietro, M., Mayumi, K., Ramos-Martin, J. 2009. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. *Energy* 34 (3), 313-322.

Grossman G, Krueger AB., 1991. Environmental impacts of a North American free trade agreement. NBER, working paper 3914.

Grossman, G., Krueger, A., 1995. Economic growth and the environment. The Quarterly Journal of Economics 110 (2), 353-377.

Harbaugh, W. T., Levinson, A. y Molloy Wilson, D., 2002. Reexamining the empirical evidence for an environmental Kuznets Curve. Review of Economics and Statistics 84 (3), 541-551.

Holtz-Eakin, D., Selden, T.M., 1995. Stoking the fires? CO2 emissions and economic growth. Journal of Public Economics 57, 85–101.

Howard Geller, H., Harrington, P., Rosenfeld, A., Tanishima, S., Unander, F. Polices for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy 34 (5) 556–573

Jevons F., 1990. Greenhouse: a paradox. Search 1990; 21(5).

Kaufmann, R., 1992., A Biophysical analysis of the energy/real GDP ratio: implications for substitution and technical change. Ecological Economics 6 (1), 35-56.

Luzzatti, T., Orsini, M., 2009. Investigating the energy-environmental Kuznets curve. Energy 34, 291-300.

Malenbaumn W., 1978. *World demand for raw materials in 1985 and 2000*, M^{c} Graw-Hill, New York.

Panayotou T., 1993. Empirical tests and policy analysis of environmental degradation at different stages of economic development. Working paper, technology and environment programme, International Labour Office, Geneva.

Pargal, S.; Wheeler, D., 1996. Informal Regulation of Industrial Pollution in Developing Countries: Evidence from Indonesia. The Journal of Political Economy, Vol. 104 (6), 1314-1327.

Perman, R., Stern, D.I., 1999. The Environmental Kuznets Curve: Implications of Nonstationarity. Centre for Resource and Environmental Studies, Working Papers in Ecological Economics No. 9901.

Perman, R., Stern, D.I., 2003. Evidence from panel unit root and cointegration tests that the environmental Kuznets curve does not exist. Australian Journal of Agricultural and Resource Economics 47, 325–347.

Ramos-Martin, J. 2001. Historical Analysis of Energy Intensity of Spain: From a "Conventional View" to an "Integrated Assessment", Population and Environment: A Journal of Interdisciplinary Studies 22 (3): 281-313.

Ramos-Martin, J., 2005. *Complex systems and exosomatic energy metabolism of human societies,* PhD Thesis, Universitat Autònoma de Barcelona.

Ramos-Martin,J., Giampietro, M., Mayumi, K. 2007. On China's exosomatic energy metabolism: An application of multi-scale integrated analysis of societal metabolism (MSIASM). Ecological Economics 63 (1), 174–191.

Ramos-Martín, J., Cañellas-Boltà, S., Giampietro, M., Gamboa, G. 2009. Catalonia's energy metabolism: Using the MuSIASEM approach at different scales. Energy Policy 37 (11), 4658–4671

Recalde, M.; Ramos Martin, J., 2012. Going beyond energy intensity to understand the energy metabolism of nations: The case of Argentina. Energy 37 (1), 122-132.

Richmond, A. K., Kaufmann, R. K., 2006. Energy prices and turning points: the relationship between income and energy use/carbon emissions. Energy Journal 27(4), 157–80.

Romero-Ávila, D., 2008. Questioning the empirical basis of the environmental Kuznets curve for CO2: New evidence from a panel stationarity test robust to multiple breaks and cross-dependence. Ecological Economis 64, 559-574.

Schmalensee, R., Stoker, T. M., Judson, R. A., 1998. World Carbon Dioxide Emissions: 1950-2050. Review of Economics and Statistics, LXXX, 15-27.

Shafik, N., Bandyopadhyay, S., 1992. "Economic growth and environmental quality: time series and cross-country evidence" Policy Research Working Paper, World Development Report, WPS 904.

Sorman A., Giampietro, M., Lobo A., Serrano, T. 2009 . Applications of the MuSIASEM approach to study changes in the metabolic pattern of Catalonia. *Reports on Environmental Sciences 4.* Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona.

Stern, D. I., 2004. The Rise and Fall on the Environmental Kuznets Curve. World Development 32 (8), 1419-1439.

Stern, D. I., Cleveland, 2004. Energy and Economic Growth. Rensselaer Working Papers in Economics 0410.

Stern, D. I., Common, M. S., 2001. Is there an Environmental Kuznets Curve for sulfur? Journal of Environmental Economics and Management 41, 162-178.

Stern, D., Common, M., Barbier, E., 1996. Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development. World Development 24 (7), 1151-160.

Sun, J.W., 2001. Energy demand in the fifteen European Union countries by 2010: a forecasting model based on the decomposition approach. *Energy 26(6), 549-560*.

Sun, J.W., 2003. Dematerialization in Finnish energy use, 1972-1996. *Energy Economics 25, 23-32.*

Sun, J.W., Meristo, T. 1999. Measurement of Dematerialization/Materialization: A Case Analysis of Energy Saving and Decarbonization in OECD Countries, 1960–95. Technological Forecasting and Social Change 60 (3), 275–294.

Suri V., Chapman D., 1998. Economic growth, trade and energy: implications for the environmental Kuznets curve. Ecological Economics 25, 195–208

Wagner, M., 2008. The carbon Kuznets curve: A cloudy picture emitted by bad econometrics? Resource and Energy Economics 30, 388–408.

Wieringa K, De Vries HJM, Hoogervorst NJP. In: Samson HD, Tjeenk Willink BV, editors. National Environmental Outlook 1990-2010; 1992. p. 55-65. Alphen aan den Rijn.

World Bank (2012). World development Indicators and Global Development Finance. The World databank. Available at: http://databank.worldbank.org

Zilio, M., 2011. La Curva de Kuznets Ambiental: evidencia para América Latina y el Caribe, PhD Thesis, Universidad Nacional del Sur, Bahía Blanca.

Zilio, M., Recalde, M., 2011. GDP and environment pressure: the role of energy in Latin America and The Caribbean. *Energy Policy 39 (12), 7941-7949*

Ziolkowska, J.R.; Ziolkowski, B., 2011. Product generational dematerialization indicator: A case of crude oil in the global economy. Energy 36, 5925-593