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Cross-country multi-sectorial LMDI decomposition of aggregate energy consumption

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ABSTRACT

Although a cornerstone for development, past and current energy uses have often posed a major challenge for policy makers regarding energy planning and management. Within this context, in this paper an updated multi-sectorial cross-country assessment of energy consumption trends was undertaken, contributing to existing literature and to the public debate over policy efforts towards sustainable development of the energy sector. This cross-country assessment encompasses a set of developed and emerging countries (United Kingdom, Portugal, Brazil and China). Resorting to a Logarithmic Mean Divisia Index (LMDI), aggregate energy consumption was decomposed into three main explanatory effects: activity, structure and intensity. The major findings achieved reflect the relevance of intensity and activity effects in detriment of structural effect, since for all countries the main variations have been associated to both overall activity and intensity effect. Assessment of energy consumption trends through decomposition lens provides critical information regarding which is the dominant factor that should be focused during policy design, in order to improve overall energy consumption.

KEYWORDS

LMDI decomposition approach, energy consumption, energy intensity, energy efficiency, energy policy, sustainable development

INTRODUCTION

Although a cornerstone for development, past and current energy uses have often contributed to an imbalance of socio-economic and environmental dimensions of sustainability, posing a major challenge for policy makers regarding energy planning and management. As multi-dimensional implications of unsustainable energy use become further exposed, so does the need to develop and promote policies that reinforce resource and economy decoupling, while fostering environmental improvements. It is within this context that alternatives such as improvement of energy efficiency and incorporation of renewable energy sources (RES) become increasingly used both at national and international level. The multidimensional benefits of these alternatives contribute to conciliate conflicting interactions between energy and socio-economic and environmental dimensions (for further information regarding benefits see [1]). Therefore, assessment of energy efficiency is extremely relevant for future sustainability of energy policy decision-making. Within this context, this paper aims to promote an updated (1990-2012) multi-sectorial and cross-country assessment of energy intensity trends, contributing to existing literature and to the public debate over policy efforts towards sustainable development of the energy sector. This cross-country assessment encompasses a set of developed and emerging countries, with United Kingdom and Portugal representing the first and Brazil and China representing the later.

In virtue of sub-sectorial data constraints energy efficiency is measured through its proxy energy intensity, which is consistent with "Top down aggregate approach" for energy efficiency indicators from Sustainable Energy for All Initiative (SE4ALL) Global Tracking Framework ([2]. Notwithstanding, cross-country data comparability has been ensured by resorting to consistent dataset from the International Energy Agency (IEA) for energy consumption by sector, encompassing industry, transports and other sectors (commercial and public services and agriculture, forestry and fishing sector) and National Accounts Main Aggregate Database (UNStats) for economic data (GDP and sectorial Value Added). Changes in sectorial energy intensity were assessed resorting to an Index Decomposition Analysis (IDA) approach based on the multiplicative Log Mean Divisia Index (LMDI) decomposition method, enabling disaggregation of energy intensity into three main factors (activity, structure and intensity). Overall, the results obtained reflect the relevance of intensity effect regarding aggregate energy consumption, since, for all countries, main variations have been associated to both overall activity and intensity effect, in detriment of structural effect.

The remainder of the paper is organised as follows. Section 2 describes the methodological approach adopted in the study. Section 3 presents a brief overview of the main trends regarding energy and economy nexus for the four countries included in the study, measured through variations in energy consumption and energy intensity levels. In Section 4, the results from the application of the multiplicative LMDI decomposition approach are presented followed by a discussion of those results. Finally, Section 5 draws the main conclusion of the paper and future work. Introduction following keywords should include problem background, literature review of recent papers published in journals which clearly shows what is the not yet solved aspect of the problem, followed by the hypothesis which would settle the issue. The proposed methodology to prove or disapprove hypothesis should be briefly discussed, followed by resume of results achieved.

METHODOLOGICAL APPROACH

Index Decomposition Analysis (IDA) has been considered a well-established technique within energy policy scope, encompassing an increasing number of issues [3][4]. It comprises Laspeyres and Divisia based methods, allowing to disaggregate energy related indicators (e.g. energy and carbon intensities) into its main drivers [5]. Notwithstanding, properties such as absence of residual terms, time reversal and aptness to cope with zero or negative values within a dataset have contributed for the adoption of the Logarithmic Mean Divisia Index (LMDI) method (for a detailed review regarding method selection see, for example, [3]). Furthermore, these characteristics, have favoured this method for cross-country comparisons [6]. Energy decomposition featured herein results from a combination of activity, structural and intensity effects for each sector (i), following identity function as proposed by [7]:

$$E = \sum_i E_i = \sum_i Q * \frac{Qi}{Q}\frac{Ei}{Qi} = \sum_i QS_iI_i \tag{1}$$

Where (E=$\sum_i Ei$) denotes total final energy consumption, in each sector (i) encompassing industry, transport, agriculture, and service sectors and (Q=$\sum_i Qi$) represents the sum of the value added of each sector. Therefore, aggregate energy intensity (I) is given by the ratio between these two variables (Ei/Qi). Ratios illustrated in Equation (1), express structural changes (Dstr), linked to sectorial activity mix of the economy, and intensity changes (Dint), related to sectorial energy intensity shifts (which can be also regarded as a result of energy efficiency measures). While Q represents changes in activity effect (Dact), denoting changes associated with the overall economic activity of the country. Hence, based on Equation (1), change in the aggregate energy consumption (E), from year 0 to year t, can be rearranged as (Dtot):

$$Dtot = E^t/E^0 = \mathrm{DactDstr\,Dint} \tag{2}$$

In this paper, each one of these components has been estimated resorting to Ang and Liu (2001) multiplicative LMDI I formulae:

$$Dact = \exp(\sum_i wi * ln(\frac{Q^t}{Q^0})) = exp(\sum_i \frac{(E_i^t - E_i^0)/(lnE_i^t - lnE_i^0)}{(E^t - E^0)/(lnE^t - lnE^0)} * ln(\frac{Q^t}{Q^0})) \tag{3}$$

$$Dstr = exp(\sum_i wi * ln(\frac{S_i^t}{S_i^0})) = exp(\sum_i \frac{(E_i^t - E_i^0)/(lnE_i^t - lnE_i^0)}{(E^t - E^0)/(lnE^t - lnE^0)} * ln(\frac{S_i^t}{S_i^0})) \tag{4}$$

$$Dint = exp(\sum_i wi * ln(\frac{I_i^t}{I_i^0})) = exp(\sum_i \frac{(E_i^t - E_i^0)/(lnE_i^t - lnE_i^0)}{(E^t - E^0)/(lnE^t - lnE^0)} * ln(\frac{I_i^t}{I_i^0})) \tag{5}$$

Where w_i represents the weight function, providing sectorial shares within overall economy, activity structure and intensity allowing to improve and simplify other existing LMDI equations (namely LMDI II), by adding to previously mentioned properties consistency in sub-sectorial aggregation [7].

Regarding decomposition approach other aspects should also be taken into consideration due to their potential influence in decomposition outcome, namely data availability and timespan considered for the analysis. Therefore, to perform the empirical analysis a database was built from a combination of two well established and complementary data sources: the International Energy Agency (IEA) energy balance for final energy consumption by sector and the National Accounts Main Aggregate Database (UNStats) for economic data (e.g. Gross Domestic Product (GDP) and sectorial Value Added). Since both data sources follow a common activity classification criteria – the International Standard Industrial Classification (ISIC) – data comparability amongst focused countries is ensured. Annual chaining was undertaken, given consistency, multi-sectorial and long-term (1990-2012) nature of featured database. Similarly to [1], the value for 1990 "is set to equal 1", and yearly decomposition results were then linked to each other over that period of time. By promoting comparisons of consecutive years, chained energy intensity decomposition contributes to attain a "more realistic" measure of changes in overall energy intensity [8]. Although conveyed in economic terms, energy intensity (GDP expressed in US$ constant prices for 2005) has been adjusted enabling cross-country comparison [9]

Though improving existing constraints regarding data comparability, the use of value added for all sectors is far from being consensual, being considered inappropriate as an activity measure for residential and transport sectors (e.g. [10]and [11]). However, despite the recognition that these two sectors should be analysed separately, current lack of widely available data hinders this prospect [2]. Notwithstanding, despite this challenge, decomposition approach has been considered an insightful tool to assess structural changes for productive activities at sectorial level [2], as featured in this work.

ENERGY CONSUMPTION AND ENERGY INTENSITY TRENDS THROUGHOUT 1990-2012

This section presents a brief overview of the main trends regarding energy and economy nexus, measured through variations in energy consumption and energy intensity levels. With the exception of Brazil, countries exhibit a declining energy intensity pattern (E/Q), differing amongst them regarding energy consumption (EC) pattern, as illustrated in Figure 1.

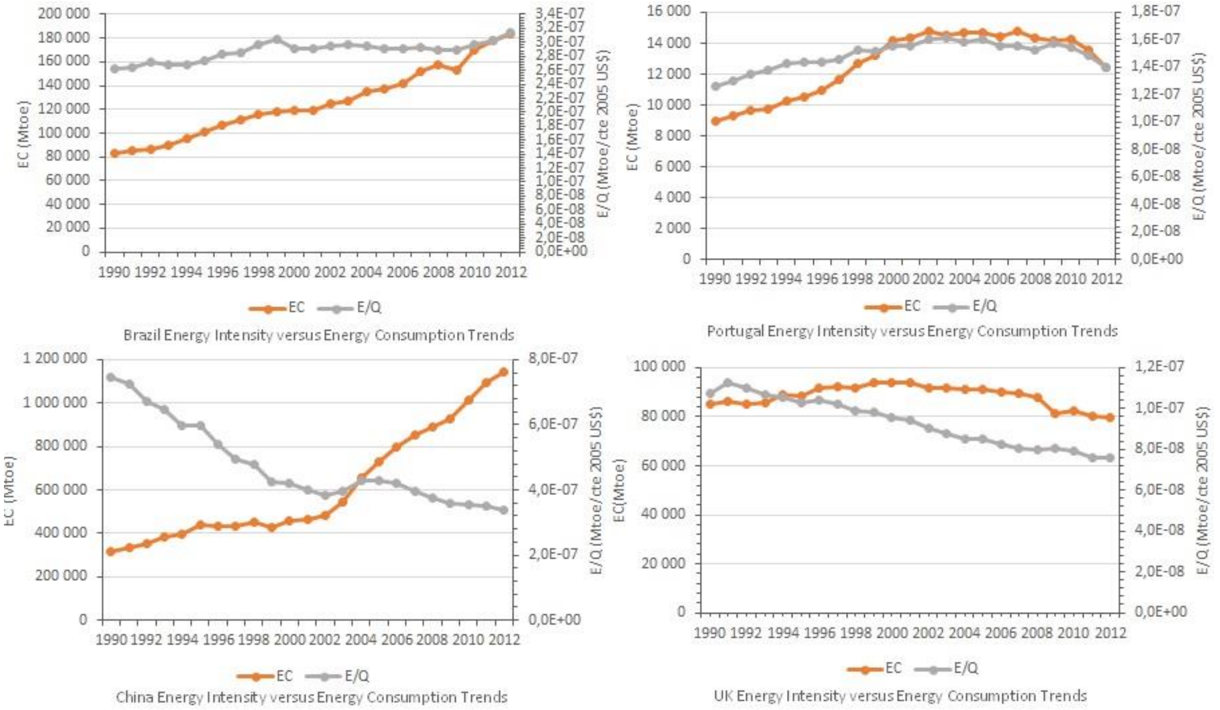

Figure 1. Cross-Country Energy intensity versus Energy consumption trend

In 2012 China displayed the most accentuated drop in overall energy intensity, with a 55% reduction comparatively to 1990 values. This reduction has been more accentuated between 1990 and 2002, followed by a slight increase from 2002 till 2005, decreasing once more till 2012. Contrasting with energy intensity decreasing trend is energy consumption. This indicator has increased an impressive 258% comparatively to 1990 value, and this increase was more accentuated during the last period (from 2002 onwards). A similar trend regarding energy consumption has been identified in Brazil. Here, increase in energy consumption (120%) was accompanied by a moderate increase of overall energy intensity (20%). Energy consumption seems to have increased steadily from 1990 till 2008, being offset and reaching its lowest value during 2009, but increasing afterwards until 2012. Energy intensity has reached its highest peak in 1999, decreasing and stabilizing until 2009, which increased afterwards until 2012.

Contrasting with Brazil, United Kingdom presented a reduction of energy intensity and consumption trends. Energy intensity suffered a reduction of 29% comparatively to 1990 values, while energy consumption has reached a less accentuated drop (less 6 per cent). However, energy intensity trend has been decreasing since 1991, while energy consumption has suffered fluctuations, starting its decreasing trend later on, in 2001. Contrary to energy intensity, energy consumption has suffered recently a substantial drop between 2007 and 2009, reaching its lowest value in 2009, and increasing slightly in 2010 to decrease once again until 2012.

Meanwhile Portugal only recently (from 2007 onwards) presents a similar decreasing tendency, although with fluctuations. Yet, despite this, both indicators still present values above 1990 level (11% for energy intensity and 39% for energy consumption). Similarly to previous countries, the most accentuated drop in energy consumption has been reached in 2009. Notwithstanding, similar shifts in energy consumption, attributed to economic recession (2007-2009) have been identified in previous studies [8].

These contrasting trends are interconnected, depending on the composition and evolution of each country activity mix. For instance, if more energy intensive sectors tend to prevail, there will be more energy requirements leading to its increase overtime, and vice-versa. Therefore emphasizing the need to ascertain which economic sectors are more energy intensive [8]. Therefore, increase of both indicators in Brazil resulted from an increase in several sectors, two of which highly intensive (industry 13% and transport 31%). Meanwhile, China presented an overall decreasing energy intensity trend in virtue of accentuated decrease (-58%) of industry's energy intensity, and to a lower extent a decrease (-11%) of transport's energy intensity. Similarly, [12] have estimated that, during 1996-2010 period, secondary industry registered the highest decrease of energy intensity rate (44,08%) followed by tertiary industry (37,43%). Simultaneous decrease of energy consumption and energy intensity in the UK, reflect accentuated decrease of energy intensive sectors such as industry (- 43%) and transports (-25%) in contrast to less energy intensive sectors such as commercial and service sector. Likewise, comparing 1990 to 2012, Portugal has registered an accentuated increase of the weight of less energy intensive sectors. While industry decreased 19%, commercial and service sector increase far exceeded increase in transport sector (35%).

Assessment of these trends by decomposition approach can further ascertain which factor is impacting energy consumption, evidencing also interconnectivity between activity, structural and intensity effects.

RESULTS AND DISCUSSION

In this section results from multiplicative LMDI decomposition for the selected countries between 1990 and 2012 period are presented. Figure 2 shows shifts in total energy consumption according to variations in activity, structure and intensity effects.

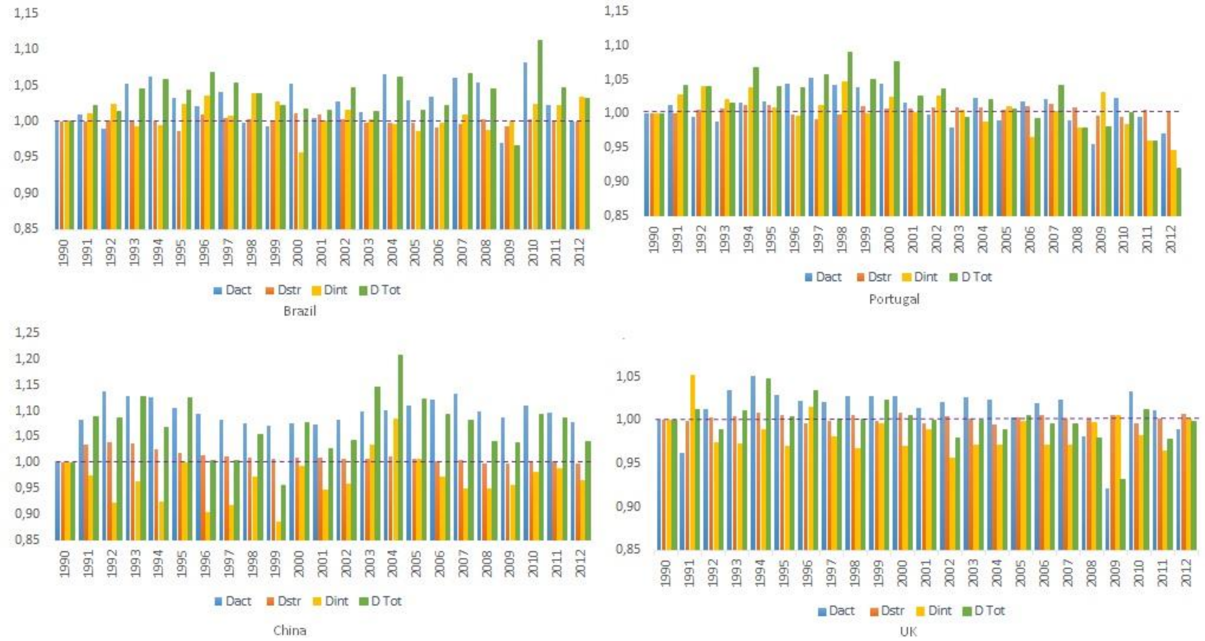

Figure 2. Results from Multiplicative LMDI Decomposition of Aggregate Energy Consumption

In order to better identify the main driving forces underlying final energy consumption, a classification criteria was adopted, similar to the one proposed by [10]. This criteria consists of three levels, that imply “no change” if variation of components equals 1.00 a negative connotation contributing to increase aggregate energy consumption if it exceeds 1.00 (being considered “substantial over 10 percentage points”) and positive when contributing to decrease aggregate energy consumption (below 1.00) [10].

The results shown on Figure 2 reflect the relevance of intensity effect regarding aggregate energy consumption. Furthermore, for all countries, the main variations have been associated with both activity and intensity effects, in detriment of structural effect. Effectively, according to Figure 2, contribution from this last effect is considered marginal, being the closest to “no change” level, i.e. Dtot= 1.00. From the analysis of Figure 2, it can be concluded that total decomposition (Dtot) closely follows either activity (Dact) or intensity (Dint) trends. Despite the contribution of these two explanatory effects, very few effects have contributed to aggregate energy consumption in a substantial way (exceeding established 10 percent criteria), with the exception of activity effect in China (during 1992-1995 and 2004-2007 period). This implies the direction of each contribution is not straightforward, requiring a country-specific insight.

Energy decomposition at country level

China’s energy consumption mirrors intensity effect, being counteracted by activity effect. With most yearly variations bellow 1.00, contribution from intensity effect towards decrease of final energy consumption is clear. These results reflect a positive effort to improve aggregate energy consumption by improving intensity effect of productive sectors. Effectively China has adopted several policies promoting energy conservation in most energy intensive sectors, namely industry promoting substantial decreases in overall energy intensity [13]. Although developed to promote energy savings, it is expected that such measures potentiate other socio-economic benefits. Health improvements and poverty alleviation have been mentioned as resulting from an improved and more efficient access to power generation [14]. Furthermore, by reducing energy consumption, entails a reduction of pollution emissions [8].

Despite the positive impact of the intensity effect on China’s energy consumption, this has increased (Dtot > 1.00) when comparing 2012 values to those of 1990, implying that the impact of the intensity effect was not strong enough to offset the overall economic activity growth. As a consequence, although energy intensity is decreasing, energy consumption is increasing, being consistent with previous energy intensity and energy consumption overview trends shown in Figure 2. However, as illustrated in this Figure, temporary disruptions by activity effect, although considered “substantial”, have been accompanied by an increase in intensity effect (e.g. during 2003-2004 period). Hence, in spite of relevant contribution from intensity effect to decrease energy consumption it is necessary to act upon other effects in order to improve aggregate energy intensity.

These results, although peculiar, are consistent with [15] assessment of energy intensity of the Chinese economy. Whereby, simultaneous increase in energy intensive activities and products for non-productive sectors has contributed for the temporary increase in aggregate energy consumption [15]. Energy consumption and intensity effect have continued to decrease until 2008. This trend stabilized till 2009 (coinciding with international financial crisis). This event resulted in a shift regarding the contribution of each explanatory effect to energy consumption with intensity effect increasing energy consumption while activity effect decreases it, such as emphasized by ([8]. Meanwhile, structural effect contributed to moderate energy consumption (e.g. 2008-2009 and 2012).

This constitutes a positive step forward into promoting energy and environmental goals, without relying exclusively on energy intensity reduction policies [16]. Furthermore, during these years, this joint effect has contributed to decrease energy consumption, potentiating resource decoupling.

Similarly to China, United Kingdom (UK) is the only country where intensity component clearly contributed to decrease energy consumption. However, in the last few years of the analysis this component prevailed over contribution of activity effect (Dtot<1.00), contributing for UK’s aggregate energy consumption reduction (see Table 1). Once more, results have shown a strong correlation between energy consumption, intensity effect and economic activity, as illustrated in Figure 2. Conversely to China, these results suggest that UK has managed to attain resource decoupling, which is in line with [1] outcome for UK´s energy intensity decomposition. Obtained results suggest policy efforts in reducing energy consumption via intensity effect have been effective. Furthermore, measures contained in 2020 Strategy feature to a great extent energy savings through improvements in efficiency (20%), which are related to the intensity effect [17]. Notwithstanding, obtained results diverge from [17] findings. This divergence however could be associated to the fact that current study resorts to aggregate database, hindering the assessment of structural changes, affecting assessment of energy consumption drivers through decomposition approach.

From the results shown in Figure 2 another common behaviour of aggregate energy intensity trends and underlying shifts during financial crisis period (2007 to 2009) can be emphasised among the four countries analysed. During that period, both developed and emerging countries registered a decrease in energy consumption resulting from a decline in the level of economic activity. In 2009, United Kingdom suffered comparatively to previous year, a drop of 5% in aggregate energy consumption, 6 % regarding activity effect (Dact), and an increase of 1% regarding intensity effect (Dint). Meanwhile structural effect (Dstr) has not shifted considerably. Furthermore, recent recession displays a similar trend to 1990’s UK recession where structural component played a limited role in reducing energy consumption [18]. In spite of this, post crisis 2011-2012’s aggregate energy consumption has registered a slight increase, in accordance to energy intensity and consumption trends.

For Brazil, the results obtained do not evidence a clear positive correlation between intensity effect and energy consumption as for the case of China and UK. Although energy consumption follows the trend of activity effect for most of the timespan considered, this effect is somewhat compensated by both intensity (e.g. from 1993 to 1994) and structure effects (e.g. from 2003 to

2009). Notwithstanding, contrary to previous countries, aggregate energy consumption and energy intensity tends increase. This opposing trend is in line with [19] estimates. These contrasting trends are interconnected, depending on the composition and evolution of each country activity mix. For instance, if more energy intensive sectors tend to prevail, there will be more energy requirements leading to its increase overtime, and vice-versa. Therefore emphasizing the need to ascertain which economic sectors are more energy intensive [8].

Similarly to China and UK, structural effect plays a much smaller role comparatively to intensity or activity effects. These results reflect to a large extent socioeconomic improvements Brazil underwent in recent years, driven by activity and intensity effects [20]. However, while previous countries have also developed energy efficiency strategies to reduce energy consumption, Brazil's efforts have focused on diversifying energy mix towards less energy intensive alternatives [21].

Nonetheless, the 2009's economic crisis has also had repercussions regarding energy consumption and underlying explanatory effects. Effectively, much alike China and UK, overall energy consumption suffered an accentuated drop (8%), resulting from an 8% decrease in the activity effect (Dact), an 1% increase in the intensity effect (Dint), and a decrease (-1%) in the structure effect (Dstr), respectively. However, considering the four countries analysed in this study, Brazil presents one of the lowest energy intensity trends [22] resulting from high participation of renewable energy sources in energy mix [21].

Portugal's aggregate energy consumption reflects the influence of two main effects: activity and intensity. They counteract or align each other over the analysed period of time, being offset by structure effect. For instance, for the 1992 to 1993 period whereas activity effect contributes to decrease energy consumption, both intensity and structure effects tend to increase aggregate energy consumption. Therefore, an increase in overall energy consumption is observed. This trend is reversed during the 1997-1998 period, with both activity and intensity effect increasing energy consumption, while structure effect contributes to the opposite direction, i.e. decreasing energy consumption. In 2009, energy intensity decreases following activity effect, being coincident with socioeconomic crisis. In fact, although from 2008 to 2009 energy consumption in Portugal remained relatively stable, the three components that explain the change in energy consumption show a different path: energy consumption declines due to the activity and structure effects but increases due to the intensity effect. From this period onwards there has been a pronounced decrease of intensity and activity effects, which is very likely related to the great recession the country experienced in those years.

Obtained results are in line with [23] estimates, according to which recession and "weak economic growth" have contributed for decrease in energy consumption and intensity. However, [23] also claims there has been substantial transition into service sector, although reductions in energy consumption have been mainly attributed to improvements in energy intensity.

Therefore, the results obtained require a careful interpretation given the aggregate nature of used database. This inhibits accounting for shifts at structural level, leading to overlap and misinterpretation between structure and intensity effects [24]. This shortcoming should be taken into account given decomposition approach being a widely used tool in energy planning decision-making, potentially avoiding development of misconceived policies [11].

CONCLUSION

Although a cornerstone for development, past and current energy uses have often posed a major challenge for policy makers regarding energy planning and management. The use of tools such as decomposition approach can contribute to improve energy related decision-making by identifying and exposing main driving forces underlying different energy consumption growth paths [8]. Resorting to a Logarithmic Mean Divisia Index (LMDI) method, as proposed by [7] aggregate energy consumption was decomposed into three main explanatory effects: activity effect (Dact), structure effect (Dstr) and intensity effect (Dint). Hence, assessment of energy consumption trends, through decomposition lens, provides critical information regarding which is the dominant factor that should be focused during policy design, in order to improve overall energy consumption.

Overall obtained results seem to indicate the prevalence of the intensity and activity effects in explaining changes in aggregate energy consumption. For all the analysed countries, main variations have been associated with those two effects, in detriment of structural effect. Notwithstanding, the direction of each contribution is not straightforward, requiring a country-specific insight. As expected energy consumption presented an increasing trend in emerging countries (Brazil and China), contrasting with decreasing trend in developed countries (UK and Portugal). For China and UK intensity effect clearly contributed to decrease aggregate energy intensity, reflecting and reinforcing the relevance energy intensity has gained within energy policy scope. However, these efforts have often been offset by activity effect, clearly contributing to increase overall energy consumption. Reflecting the need to adopt a more holistic perspective to promote energy conservation, namely addressing effects that had a marginal contribution towards energy conservation improvements (structural effect).

Meanwhile although being influenced by both these effects, contribution of intensity effect to improve overall energy consumption is not as straightforward for Brazil and Portugal. Notwithstanding contrary to Brazil, Portugal presents a decreasing energy consumption trend that coincided with 2007-2009 period. This period corresponds to economic recession, and affected all countries without exception, clearly influencing activity and intensity contribution to overall energy consumption. Therefore improvements of intensity effect resulted from a combination of policies focusing energy efficiency and economic recession. Although affected by this event, Brazil's energy consumption and intensity has grown, requiring measures at energy intensity level to improve energy conservation. Hence, based on main drivers, decomposition approach can contribute to develop a strategic approach appropriate for each country. Furthermore by taking into consideration all factors influencing energy consumption developed policies can benefit other energy priorities, such as environmental concerns.

Notwithstanding, further studies, resorting to a more disaggregate approach could provide more in-depth course of action. However, in order to promote such a cross-country comparison, a more detailed, universal access database would be required.

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