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Three-level decoupling of energy use in Portugal 1995–2010

Zeus Guevara[a,b,*], Tiago Domingos[b]

[a] University Center of Tonalá, University of Guadalajara, Avenida Periférico 555, Ejido San José Tatepózco, 48525 Jalisco, Mexico
[b] MARETEC – Marine, Environment and Technology Centre, Department of Mechanical Engineering, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais, 1, 1049-001 Lisbon, Portugal

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ABSTRACT

Primary energy intensity in Portugal declined by 20% in the two decades to 2010, a significant achievement in energy decoupling. However, more progress is needed to comply with current EU climate directives. The objective of this work is to analyze the main determining factors of primary energy use that drove energy decoupling in Portugal in 1995–2010 with a focus on understanding the contribution of the three levels of energy consumption, and on identifying opportunities for policy intervention. To do so, we perform a structural decomposition analysis on a novel energy input-output model that includes the primary, secondary and useful levels of energy consumption and the conversion processes between them. The results show that Portugal experienced relative energy decoupling. While final energy and non-energy demands contributed to energy coupling, sectoral useful energy intensity, the structure and efficiency of the energy sector, end-use energy conversion efficiency and structural changes in the rest of the economy were the main decoupling forces. Moreover, the advantages of the proposed three-level decoupling analysis for energy policy are shown. In addition, to the best of our knowledge, the present paper constitutes the first energy input-output study to include useful energy flows (measured as exergy).

1. Introduction

Portugal in the last two decades has achieved one of the most consistent transitions to renewables of the energy sector in the developed world (EUROSTAT, 2015a; b; Mendiluce et al., 2010). In 1995, residential and industrial fuel and electricity needs were covered almost completely by oil and coal. By contrast, in 2010, renewables produced the largest share of electricity and natural gas (introduced in 1998), a cleaner alternative to other fossil fuels, was available to most consumers (Amador, 2010). The country reached a renewable share of total primary energy use of 23.5%, above the European target of 20% by 2020 (EU, 2009). In addition, between 2005 and 2010, its primary energy intensity declined by 20.6% (DGEG, 2012), which implies that the economy experienced energy decoupling, i.e., the economy reduced the use of primary energy resources per unit of economic activity (UNEP, 2011).

The energy transition occurred in parallel to several other phenomena: the economic structural transition towards services (Henriques, 2011); the integration in the European Economic and Monetary Union (Aguiar-Confraria et al., 2012; BdP, 2009); soaring international fossil fuel prices before 2008 (Carvalho et al., 2014; IEA, 2012a, 2012b); residential and industrial energy prices among the highest in the EU15 (EUROSTAT, 2016a; b; WB, 2016); and two economic crises, one domestic in 2003 and one global in 2007–2009 (Lourtie, 2012; Rodrigues and Reis, 2012). Under these uncertain conditions, Portugal balanced resources, policy and political will to comply with most of EU climate change and energy directives (see Section 2).

Currently, the country is committed to ambitious EU targets on emissions for 2030 (EEA, 2013; EU, 2015c), and is still lagging behind EU targets on energy efficiency (EU, 2012, 2015a) and renewable share in the transportation sector for 2020 (EU, 2009, 2015b). Energy policies should be updated to fulfill these current targets. In this respect, the analysis of energy trends (e.g., primary energy use, energy intensity, efficiency, etc.) can provide insights to the policy updating process in two ways: first, it can identify the areas where current policies have been successful and evaluate if further progress can be made in those areas; and second, it can identify areas of opportunity (missed or not adequately approached by current policies).

Our aim here is to identify the main factors behind the trend of primary energy use that drove energy decoupling in Portugal during the period 1995–2010 with a special focus on understanding the contribution to energy decoupling of the three levels of energy consumption in the economy (i.e., primary, secondary and useful) and of the conversion processes between these levels (hence the term three-level decoupling).

* Corresponding author at: University Center of Tonalá, University of Guadalajara, Avenida Periférico 555, Ejido San José Tatepózco, 48525 Jalisco, Mexico.
E-mail address: zeus.guevara@tecnico.ulisboa.pt (Z. Guevara).

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We build on the analysis of Guevara and Rodrigues (2016), which performed the first structural decomposition analysis of the trend in primary energy use in Portugal 1995–2010 with the objective of comparing the contributions to this trend of structural changes in the energy sector and in the rest of the economy.[1] They did so by developing an energy input-output model, in which energy transactions are accounted for separately from transactions in the rest of the economy (in contrast to the usual energy input-output models). They found that the structural changes and improvements in the primary-to-secondary conversion processes in the energy sector (e.g., introduction of natural gas power generation and deployment of renewable energy projects) had a larger contribution to decreasing primary energy use than structural changes in the rest of the economy (e.g., growth in the output share of services and changes in non-energy production processes). Also, they identified the direct energy intensity (i.e., the direct use of energy flows by non-energy industries per unit of total economic output) as the main driving factor for primary energy use reductions.

Here we develop the work of Guevara and Rodrigues (2016) in three new directions: (1) accounting for energy decoupling, for which we use the decoupling index that relates the changes in primary energy use to the growth of the economy; (2) providing policy recommendations regarding current energy regulation; and (3) including the useful level of energy consumption.

The third direction is particularly relevant for the analysis of energy decoupling because the useful level of energy consumption is closer to the actual end-use energy services –i.e., the purpose of energy consumption (Ayres and Warr, 2009; Nakićenović and Grübler, 1993); and because it completes the chain of conversion processes that energy flows experience throughout the economy (Cullen and Allwood, 2010; UNDP, 2000). Moreover, energy conversion efficiency of end-use technologies are central to energy management policies – see, e.g., IEA (2013) or ADEME (2012). Therefore, energy transition analyses that do not include the useful level of energy consumption are of limited relevance in assessing energy trends and the effectiveness and improvement opportunities of energy policy.

The inclusion of the useful level of energy consumption is done by developing an energy input-output model that accounts for useful energy flows and end-use energy conversion processes along with primary and secondary energy flows and primary-to-secondary energy transformation processes. Our model is based on the multi-factor energy input-output model (Guevara and Domingos, 2017) and uses the concept of useful exergy, i.e., "the minimum amount of work required to produce a given end-use", obtained from the conversion of secondary energy flows (Ayres et al., 2003; Nakićenović et al., 1996), see Section 3.

The exergy metric is selected to account for energy flows at the useful level of energy consumption because this metric is related to the quality of energy flows rather than to quantity only (Ayres et al., 1998; Guevara et al., 2016). In addition, this metric provides information of energy degradation (Dincer and Rosen, 2012) and provides a better standard for comparing of useful energy flows that are different in physical sense, e.g., heat at different temperature and mechanical drive (Cullen and Allwood, 2010).

The proposed model describes primary energy use as a function of 10 factors: Three energy efficiency indicators (direct useful exergy intensity, and primary-to-secondary and secondary-to-useful energy efficiencies); four characteristics of end-use energy consumption (structure of secondary-to-useful conversion processes, aggregate final non-energy demand and its composition, and composition of direct useful exergy demand); and three economic features of the rest of the economy (economic structure, aggregate final non-energy demand and its composition). The advantage of multiple factors is that each factor is self-contained, i.e., it represents a specific set of related production processes or related transactions in the economy (instead of one aggregate factor representing non-related energy and non-energy production processes or transactions as in conventional energy input-output models).

Furthermore, the selected period under study (1995–2010) encompasses the major energy transition to renewables and natural gas (see above), and the launch and evolution of climate change policies (see Section 3).

The literature on this energy transition –including the study mentioned above by Guevara and Rodrigues (2016)– is scarce. Serrenho et al. (2014) and Serrenho et al. (2016) studied the useful exergy trends in the country. The latter estimated the trends of useful exergy trends in the period 1856–2010 along the agriculture-industry-service transitions. They found that the economy-wide useful exergy intensity (total useful exergy consumption per unit of economic activity, i.e., GDP) had an almost constant trend (20% around its 154-year average), slightly increasing between 1995 and 2009. The former analyzed the period 1960–2009 in comparison to other EU15 countries. Portugal and Greece had a rising trend of economy-wide useful exergy intensity, in contrast to most other countries, due to a weak industrial sector and large growth of residential useful exergy consumption. Moreover, Mendiluce et al. (2010) performed an index decomposition analysis (IDA) of Portuguese primary energy intensity in 1995–2006 and found that the structural effect was the sole driver of the decrease in intensity. Henriques (2011) concluded, through IDA, that structural changes in the industrial and service sector had the effect of reducing the direct energy intensity (i.e., secondary energy intensity of producing sectors) in Portugal between 1971 and 2006. Also, through IDA, Voigt et al. (2014) found that technological change was the main driver of improvements in primary energy intensity in Portugal during 1995–2007 –in contrast to Mendiluce et al. (2010). In addition, Pereira and Belbute (2014) found a high level of persistence in secondary energy demand in Portugal 1990–2012, which implies that changes in secondary energy demand tend to be persistent in response to temporary energy shocks, leading to less transient shocks to the overall economy and long lasting effects of environmental policies; and Silva et al. (2013) concluded that in the period of 1971–2011 Portuguese economic growth, energy intensity and CO_2 emissions were cointegrated for long run relationship after performing a Multivariate Granger causality test.

Finally, to the best of our knowledge, no other existing energy input-output study has included the useful level of energy consumption before.[2] Therefore, this study represents a novelty in the field of energy input-output analysis.

The paper is structured as follows: Section 2 describes the evolution of climate change and energy policies in Portugal; Section 3 presents the proposed energy input-output model with the inclusion of the useful level of energy consumption; Section 4 discusses data and data processing; Section 5 discusses the results; and Section 6 presents the

[1] Few other studies about energy-related input-output analysis of Portugal are found in literature: Alcántara and Duarte (2004) performed an comparative structural decomposition analysis of energy intensity between EU15 in 1995, they concluded that structural changes was the main factor of difference for the Portuguese energy intensity; Cruz (2009) analyzed the energy and emission relationships in Portugal in 1992 and found that scale effects of final energy demand were not related to the energy flows with higher primary energy content; and Pereira da Silva et al. (2013) evaluated job creation of renewable energy projects by 2008 and concluded that solar photovoltaic generation had the largest impact on employment.

[2] To illustrate this, none of 45 published energy-related studies using structural decomposition analysis between 1995 and April 2017 included useful energy flows. These studies were compiled by Su and Ang (2012) for 1999–2010, by Guevara (2014) for 1995–2014, and by us for 2015-April 2017 –adding 12 studies: Croner and Frankovic (2016); Deng et al. (2016); Gavrilova and Vilu (2015); Guevara et al. (2017); Guevara and Rodrigues (2016); Kim and Heo (2016); Lan et al. (2016); Llop (2017); Nie et al. (2016); Sharify and Hosseinzadeh (2015); Wang and Wang (2015); and Wei et al. (in press).