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Is energy consumption in the transport sector hampering both economic growth and the reduction of CO_2 emissions? A disaggregated energy consumption analysis

Sónia Almeida Neves [a], António Cardoso Marques [b,*], José Alberto Fuinhas [b]

[a] University of Beira Interior, Management and Economics Department, Portugal
[b] NECE-UBI[1], University of Beira Interior, Rua Marquês d'Ávila e Bolama, 6201-001, Covilhã, Portugal

1. Introduction

The reduction of the environmental impacts associated with the use of the energy has merited the increasing attention of not only academics but also policymakers. In the economy as a whole, the transport sector (hereafter TS) is one that has most delayed this shift towards a low-carbon economy. The historical data shows that action is required in this sector. In fact, in 2010, the TS consumed 19% of the global energy used, with 96% from oil. Moreover, the TS consumed 60% of the global oil used. Furthermore, the TS is also responsible for 23% of global CO_2 emissions (World Energy Council, 2011). Regarding European Union countries (EU), in 2014, the TS was consuming 33% of final energy consumption, 94% of it from petroleum products. Moreover, this sector is responsible for 25.5% of EU greenhouse gas emissions (GHG) (European Commission, 2016). Therefore, this sector represents a focal point for policymakers for several reasons. Firstly, the transport sector constitutes a key economic sector for the economy. Secondly, the sector is an intensive consumer of energy and is largely powered by fossil fuels due to the widespread use of thermal engines. Lastly, the harmful effect of the TS on the environment is well known.

Energy consumption in the TS can come from fossil fuels (e.g. diesel, gasoline), renewable fuels (e.g. biofuels and hydrogen fuel) and electricity. However, electricity consumption in the TS can be from renewable or non-renewable sources. Indeed, penetration of renewables has mainly occurred in electricity systems, so the objective of the incentives for electrification of the TS is to reduce its dependence on fossil fuels and decarbonise the economy. However, as is well known, the proportion of transportation powered by electricity remains low, and it occurs mainly in rail transport. As road transport is responsible for the largest part of total transport energy consumption, greater penetration by electricity is required. However, road transport remains heavily dependent on upgraded technological to achieve higher-capacity and enhance the lifecycle of electric vehicle batteries.

Considering that the transport sector is crucial for the dynamics of the entire economy, the interactions between economic growth, TS energy consumption, and CO_2 emissions have attracted particular attention in the literature (e.g. Chandran and Foon, 2013; Saboori et al., 2014a). Moreover, different transport infrastructures have been studied, specifically the length of both rail and road networks, in order to analyse the effects of new infrastructures on both economic growth and the environment (e.g. Achour and Belloumi, 2016a). However, the analysis of the individual effects of conventional and alternative sources remains scarce in the literature.

Therefore, this paper aims to fill this gap, by studying the dynamic linkage between economic growth, TS fossil fuels consumption, TS electricity consumption, TS renewable fuels consumption and TS CO_2 emissions. Moreover, rail infrastructure investment is considered in the analysis of energy consumption within this sector. Our decision to study rail infrastructure investment aims to capture (the effects) of new railway construction and of improving existing infrastructures (on economic growth, CO_2 emissions and on both conventional and alternative TS energy sources). In short, this paper aims to answer the following central questions: (i) what are the consequences of using both conventional and alternative sources on the transition to electric mobility, and on decarbonisation of the TS? Moreover, (ii) How have the alternative fuels affected the economic growth?

This paper is set out as follows. Section 2 discusses the literature focused on TS energy consumption. Section 3 is dedicated to describing both the data used and the methodology applied. In section 4, the results are presented, and then discussed in section 5. Finally, section 6 presents the conclusions.

* Corresponding author.
E-mail addresses: amarques@ubi.pt, acardosomarques@gmail.com (A.C. Marques).
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2. The implications of TS energy consumption -an overview of the state of the art

The interactions between energy consumption, economic growth (usually referred to as the energy-growth nexus) and CO_2 emissions has merited attention in the literature (e.g. Ozturk, 2010; Payne, 2010; Omri, 2014; Tiba and Omri, 2017). However, the results of the traditional energy-growth nexus could be dependent on the level of aggregation, i.e. when considered at the sectoral level (Abid and Sebri, 2012). Nonetheless, energy consumption is a critical variable to explain growth at both the aggregate and sectoral level (Camarero et al., 2015). This evidence has rendered the study of the TS energy consumption newsworthy and attractive to the literature, particularly the study of its influence on both economic growth and CO_2 emissions.

Costantini and Martini (2010) have tested Granger causality using the VECM approach for 26 OECD countries and 45 non-OECD countries from 1960 to 2005, considering the aggregate level, and disaggregating the sectors into: industry, transport, services, and residential. For the OECD panel, there is bidirectional causality between energy consumption and economic performance, at aggregate and sectoral levels. Regarding the non-OECD panel, the results differ from the aggregate to the sectoral level. In the aggregate level and industry sector, there is a unidirectional causality running from energy consumption to their respective economic variables. For the other sectors, the feedback hypothesis is supported, i.e. there is bidirectional causality between energy consumption and economic performance. Bidirectional causality between economic growth, CO_2 emissions and road TS energy consumption is supported for 27 OECD countries, employing a FMOLS from 1965 to 2008, by Saboori et al. (2014a). Similarly, for 5 ASEAN countries, namely Malaysia, Indonesia, Singapore, the Philippines and Thailand, a bidirectional long-run causality between energy consumption in the transport sector and CO_2 emissions was found from 1971 to 2008 (Chandran and Foon, 2013). In fact, the positive effect of energy consumption on CO_2 emissions in the transport sector is frequently found in the literature, as proven by Shahbaz et al. (2015).

As TS energy consumption is extremely harmful to the environment, the analysis of the factors that influence TS energy consumption has received considerable attention in the literature. This literature has focused on total TS energy consumption and on different infrastructures (e.g. road, cargo, and rail) and on different countries. In this way, it was proven that economic growth, population and transport infrastructure are positive factors to increase TS energy consumption in Tunisia (Achour and Belloumi, 2016b). Additionally, for the same country, Mraihi et al. (2013), focused only on road transport-related energy consumption, and concluded that it is positively affected by vehicle fuel intensity, vehicle intensity, economic growth, urbanised kilometres and national network. With regard to the Chinese TS, energy consumption is boosted by transportation activity while energy intensity decreases it (Zhang et al., 2011). Additionally, focusing on cargo transportation in China, both the intensity of goods carried and the cargo transportation infrastructure have a negative impact on cargo transport-related energy consumption, while economic growth boosts it (Wu and Xu, 2014).

There are several policies on course to promote the reduction of GHG emissions and oil use by the TS. However, the literature indicates that if only a few countries reduce their oil use, the objective of reducing oil extraction could be achieved, but the ultimate goal of reducing global CO_2 emissions may not be (Eliasson and Proost, 2015). Therefore, the transition to alternative TS energy sources, such as renewable fuels and electricity, ought to be pursued with this objective in mind. The literature shows that both biofuels and electricity could be beneficial for climate protection (Nanaki and Koroneos, 2016; Nocera and Cavallaro, 2016). However, the alternative TS energy sources raise new problems. On the one hand, the associated costs to produce biofuels and hydrogen remain high (Ajanovic and Haas, 2011; Sanz et al., 2014; Shafiei et al., 2017). On the other hand, the electrification of the TS raises new problems for electricity systems. In fact, they might not be able to deal with any additional demand caused by charging the batteries for electric mobility. However, the literature shows that with controlled charging of plug-in vehicles during off-peak, there is no need to increase the installed capacity, and the impact on the cost of electricity is less than 5% (Razeghi and Samuelsen, 2016). Accordingly, an additional policy is needed to promote charging electric vehicles when there are high levels of renewable production, and time-of-use tariffs, which take account of pollutant gas emissions, should be adopted (Coffman et al., 2017).

The literature is not consensual about the most efficient pathway to achieve a low-carbon TS. On the one hand, the simultaneous use of the both policy instruments and alternative fuels could be more effective in reducing both energy consumption and GHG emissions (Ajanovic and Haas, 2016). On the other hand, the simultaneous use of the both hydrogen and electricity could be more effective in reducing GHG emissions (Shafiei et al., 2017). In summary, the literature has analysed the performance of the different pathways to achieve to low-carbon TS (e.g. Ajanovic and Haas, 2016; Shafiei et al., 2017). Moreover, the literature has focused on the effects resulting from TS energy consumption on both economic growth and CO2 emissions (e.g. Saboori et al., 2014b). Following the goal of decarbonising the TS, analysis of the effects of conventional and alternative TS energy sources on economic growth and GHG emissions remains scarce in the literature.

3. Data and methodology

This study uses annual panel data from 1995 to 2014 for 15 OECD countries. The countries were selected strictly in accordance with the criteria of data availability for the longest time span and they are: Australia, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Luxembourg, Slovak Republic, Spain, Sweden, Turkey, United Kingdom, and the United States.

The variables used in the study include: Gross Domestic Product per capita (*GDP_PC*), TS fossil fuels (coal, crude, oil and natural gas) consumption per capita (*FF_PC*), TS electricity consumption per capita (*ELE_PC*), TS renewable fuels consumption per capita[2] (*RES_PC*), total CO_2 emissions from TS (CO_2), total energy consumption in the economy minus that of the TS per capita (*EN_PC*), and rail investment (*RAIL*). It is worthwhile to note that all the transport-related energy consumption variables, includes total sectoral energy use. Since all the variables have been converted into their natural logarithms, a constant of 1 was added to each of them to resolve the issue of observation loss on the database. Hereafter, the prefix "L" means a natural logarithm and "D" means a first-difference of the variables. Table 1 shows the variables' description, descriptive statistics and database source.

The *GDP* per capita is used as an economic growth proxy, as is frequently done in the literature (e.g. Saboori et al., 2014a, b). Energy consumption in the transport sector is expressed in kg of oil equivalent per capita (e.g. Achour and Belloumi, 2016a; Saboori et al., 2014a). Regarding the transport infrastructure, usually, the infrastructure expressed in km was used, specifically in both rail and road length (e.g. Achour and Belloumi, 2016a). Although this variable is capable of analysing the effects of building new infrastructures, it may not be able to capture a technological upgrade of the existing infrastructures, particularly regarding more efficient technologies and the enhancement of the conditions for the users. Therefore, we use the investment in rail infrastructure, measured in constant LCU. To further clarify, this variable comprises the investment in building new infrastructures and the improvement of the existing network, and it is determinant for analysing rail performance (OECD, 2017). Furthermore, road infrastructure investment was tested in the estimations, but its inclusion did not bring additional explanatory power to the models.

[2] This variable comprises the direct use of biofuels by the transport sector, and does not account for renewable electricity in accordance with IEA Headline Global Energy Data, (2016 edition).