Environmental taxes: drivers behind the revenue collected

Abstract

This paper investigates the determinants of environmental taxes revenue. While the effects of environmental taxations are well discussed across academic and political debate, less analysis have been specifically devoted to investigate the factors influencing the revenue variations. By using an Index Decomposition Techniques, the present paper separates the contribution of economic factors from the contribution provided by taxation rates and regulations. The data pertain to the period 2004-2016 and 25 European Member States are included in the analysis. Results show that stricter environmental taxation rates and regulations has been the main factor influencing the revenue increase just for 5 of the 25 countries considered in this paper. For the other Member States, economic growth and the role played in the European economic panorama have been the main drivers of variations. By providing a comparative analysis of the factors influencing the environmental taxes revenue of European areas, this paper contributes to identify how regulations and economic factors have influenced the sustainability paths of countries and can be used to support the design of policies across the EU.

Keyword: Environmental levies; Decomposition analysis; Green tax reform; Economic growth; EU Member States

Nomenclature

ETR	Environmental tax revenue
TI	Tax intensity effect. It is defined by the ratio of environmental taxes revenue and gross domestic product
SC	Structural change effect. It is calculated as the ratio between the gross domestic product of a specific country and the total gross domestic product generated by the countries considered in the decomposition exercise
G	Economic activity growth effect. It reflects changes of the total economic activity and it is used to quantify the environmental taxes revenue generated by economic growth
CH	Cumulated change. It summarizes the aggregated contribution provided by every; decomposition factors
GDP	Gross domestic product
EU	European Union
MS	Member States

1. Introduction

Environmental taxation is playing an important role in the environmental policies of the EU. Defined by a "tax base in physical unit (or proxy of it) of something that has a proven, specific negative impact on the environment" (UN et al., 2014), environmental taxes have been mainly introduced to internalise the negative effects of economic activities and to relieve some of the pressures on the environment (EEA, 2008). Since the 1990s, environmental taxation has also been used by Member States to shift the burden of taxation from growth-oriented factors, such as capital and labour, to welfare-reduction elements such as resources depletion and pollution (EEA, 2005; Ekins and Speck, 2009). Firstly prosed in the White Paper on Growth, Competitiveness and Employment (EC, 1993) the "green tax reform" is today an important element of the Europe 2020 strategy and environmental taxation is considered an enabling factor in achieving a smart, sustainable and inclusive economy (Eurostat, 2013).

Within the framework of EU regulations, Member States have generally freedom to design specific taxation systems. For this reason, a large panorama of environmental taxation rates and regulations presently exists among countries. For example, despite the application of the comprehensive energy taxation, established by the Directive 2003/96/EC, Member States are allowed to introduce tax reductions and exemptions. For the transport activities, the registration and the circulation taxes vary widely among countries. In addition, the pollution, waste and resource use taxes are differentiated, not just between Member States, but also among products and regions (EEA, 2016). If from one side, fiscal harmonisation can be useful to ensure good functioning of the internal market and to address the problems generated by cross-boundary pollution; On the other side, the freedom to design specific taxation systems is functional to help Member States in achieving domestic policy objectives. Within this context, the revenue collected, and the related differences existing over time and geographical areas, does not provide consistent information to evaluate the sustainability path of countries. That is because economic growth and more resource intensive activities, can produce a revenue increase similar to that generated by variations in the taxation rate and regulation.

The main research problem arising from the present situation is then related to the fact that the lack of information related to the drivers of revenue variations makes it difficult to identify if a revenue increase, taking place in a specific country during a specific period of time, is generated by an increasing level of pollution or by higher priority attributed to environmental protection. In fact, while the effects of environmental taxations and the possible impacts of allocation of the revenue collected are well discussed across academic and political debate, less studies have been specifically oriented to investigate how regulatory frameworks and economic variables are influencing the revenue collected (Ekins, 1999; Ekins et al., 2011; Carattini et al., 2018).

As highlighted by previous studies, the analysis of the drivers of revenue variations can provide important information to investigate the effect of taxation policies both on economic and environmental terms (Castiglione et al., 2018; Li and Masui, 2019). In addition, the comparative analysis of Member States, presently characterized by different economic and legislative structures, can support the design of consistent policies oriented to promote the sustainable path of countries. As previously highlighted by Castiglione et al. (2014) a better understanding of the main factors influencing environmental taxation can contribute to increase the effectiveness of this policy instrument.

To this purpose, the objective of this paper is to use a decomposition analysis to identify the main drivers of variations in the environmental taxes revenue collected by 25 European countries. By considering the contribution of different explanator factors, decomposition approaches have been previously used to analyse variations in the revenue collected (Aparicio et al., 2013; Baležentis and Kriščiukaitienė*,* 2015). However, as far as we know, no previous studies specifically focused on the revenue from environmental taxation.

By using the Index Decomposition Technique (IDA) proposed by Sun (1998), this paper analyses the main drivers that have influenced the variations in the environmental taxes revenue for the time period 2004-2016. The decomposition approach adopted in this paper have been previously applied to the energy and environmental field and have proven to be a suitable methodology for cross-country comparisons and time-series analysis (Ang et al., 2015; Andreoni and Galmarini, 2017).

The present paper contributes to the existing literature in different ways. Firstly, it uses, for the first time, an index decomposition technique to investigate the contribution that tax intensity, the economic structure and growth have played in the variations of the environmental taxes revenue. Secondly, it considers a case study of 25 European countries for the time period 2004-2016, that is particularly interesting as: *i)* it starts in 2004 when most of the eastern European countries joined the EU. Within this context, the results of the paper can contribute to the existing debate around the impact that European integration is playing in the reduction of the environmental pressures (EC, 2012); *ii)* it covers a time period including years both before and after the 2008 financial crisis. Most of the decomposition exercises performed so far, have been mainly focused on times of GDP growth and limited analysis have included the period that followed the global financial crash (Roinioti and Koroneos, 2017; Chen et al., 2018). From a theoretical perspective, the 2008 crisis represents an opportunity to investigate the role that economic crisis has provided to the variations of the taxation structures and to the variations of the revenue collected; *iii)* it includes the most recent available information, up to 2016. Finally, from a theoretical perspective, this paper provides a reverse standpoint of analysis. Up to now, most of the studies have investigated how environmental taxes can be used to drive economic and environmental changes. On the contrary, in this paper, the economic, the structural and the regulatory elements are used to explain the variations in the revenue collected. By shifting the focus of the analysis from "what can be done by collecting the revenue" to "what has been done to generate the revenue", the present paper provides a contribution to the design policies oriented to avoid, rather than to reduce or to repair, the impacts on environment.

The paper is structured as follow: Section 2 summarises the data. Section 3 provides a literature review of the main decomposition techniques and presents the decomposition approach used in this study. The results of the analysis are discussed in Section 4 while the conclusions are presented in Section 5.

2. Data

As reported above, the objective of this paper is to investigate the main factors influencing the variations in the environmental taxes revenue (ETR). To this purpose, a decomposition analysis is performed for 25 European countries. Since some data for specific variables or years are not available for Malta, Luxembourg and Croatia, these countries have not been included in the study. The period considered is between 2004-2016 that, as reported above, includes the most recent available information. The data have been taken from Eurostat that provides consistent information on environmental taxes and Gross Domestic Product (GDP). The harmonise index consumer price has also been used to harmonise the environmental taxes revenue and the GDP reported by Eurostat at current prices. According to Eurostat, the environmental taxes considered in this paper includes the energy taxes, the transport taxes and the pollution and the resource taxes (Eurostat, 2013).

As reported in Figure 1, the environmental taxes collected in the 25 European countries largely increased between 2004 and 2016. In the two years that followed the global financial crisis the revenue collected decreased by around 14,5 million Euro. However, in 2010, the environmental taxes revenue was already back to the level before crisis. From there, a sustained revenue increase has taken place for all the years up to 2016. When considering the growth rate of environmental taxes revenue and GDP, similar trends can be identified between 2004 and 2016. In particular, as reported in Figure 2, before 2008, the income generation grew quicker than the ETR. After that, the ETR had a growth rate slightly above GDP. As reported above, revenue variations and GDP are strictly connected.

The analysis of data, however, does not provide specific information about the sustainability path of countries. In particular, when the growth rate of environmental taxation lies above the growth rate of GDP, contrasting factors could have taken place. For example, stricter environmental regulations could have generated a growth variation similar to that generated by shift of production toward more resource intensive activities. In addition, the different regulation and economic structures of MS largely influenced the aggregated data presented below. Within this context, the decomposition of the main drivers of variations, is then an important step to identify how policies and characteristics of countries can influence the sustainability path of MS. To this purpose, a decomposition exercise is performed in the following sections.

Figure 1. ETR 25 EU MS (Million euro)

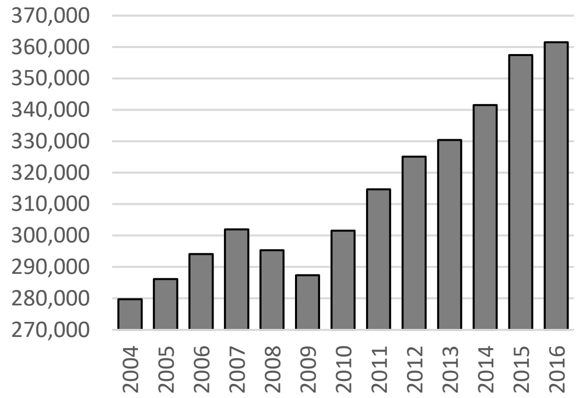
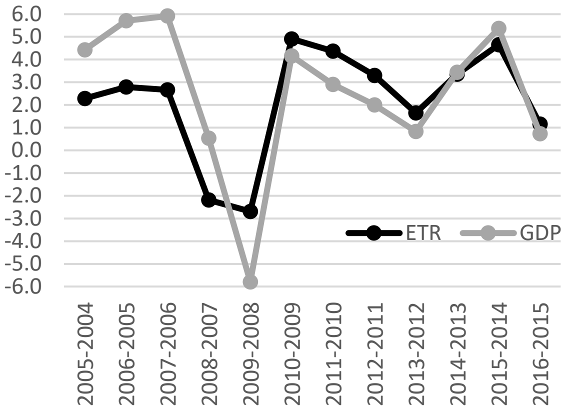


Figure 2. ETR and GDP growth rate (%Δ)



Source: Eurostat data

3. Decomposition analysis: literature review and methodology

3.1 Literature review

Decomposition techniques have been largely used to identify the contribution of different components of a specific variable. The Index and the Structural Decomposition Analysis together with the Shift Share and the Growth Accounting Approaches have been some of the main techniques used to investigate the relationships between driving forces and impacts.

The Shift Share and the Growth Accounting techniques have been largely applied in economics and have been used to decompose variations on employment, inequalities and growth (Chu and Cozzi, 2016; Chen and Zhang, 2018). On the contrary, the Index and the Structural Decomposition techniques have been mainly related to the energy and the environmental fields. The Structural Decomposition Analysis (SDA), firstly developed by Rose and Miernyk (1989), distinguishes the major sources of change by splitting an identity into its components. Based on the use of input-output tables, the SDA is suitable to offer a wide sectoral perspective and has been largely used to identify variations across sectors of activities (Su and Ang, 2012; Hawkins et al., 2015). Cansino et al. (2016), Liu and Liang (2017) and Xu at al. (2017), for example, investigates the drivers influencing emission changes in production and household consumption and Huang et al. (2017) and Croner and Frankovic (2018) decompose the energy intensity trends of sectors and countries. The availability of comparable cross-countries and regional data, together with the related environmental extensions, has also promoted the development of studies oriented to investigate the impacts of trade. Xu and Dietzenbacher, 2014; Su and Ang, 2016; Deng and Xu, 2017; Magacho et al., 2018 for example analyses the emission performance of countries and investigates the environmental impacts embodied on trade.

The Index Decomposition Analysis (IDA) has been developed from the index theory of economics. It mainly uses aggregated sector information and has been widely applied to perform cross-country comparisons of the drivers of changes between time 0 and time T. Over the last few decades, a large set of IDA extensions have been proposed and "perfect" decomposition techniques have been specifically designed to address the problem of the residuals rising in the decomposition results (Ang and Choi, 1997; Sun, 1998; Ang and Zhang, 2000; Chung and Rhee, 2001). The IDA and the related extensions have been largely used to investigate the driving factors of different environmental elements, such as emissions (Cansino et al., 2015; Ang and Su, 2016; Shahiduzzaman and Layton, 2017; Wang and Zhou, 2018) and energy and material use (Mulder and De Groot, 2012; Ang et al., 2015; Wang and Li, 2016; Wang et al., 2018a). The IDA has also been used to investigate decoupling trends (Zhou et al., 2017; Chen et al., 2018; Leal et al., 2019) and to analyse emissions and energy use of economic activities, such as transports (Andreoni and Galmarini, 2012a; Jennings et al., 2013; Lyu et al., 2016) and industrial sectors (Timma and Blumberga, 2014; Wang et al., 2018b).

Despite the methodological differences existing between SDA and IDA (Hoekstra and van den Bergh, 2003; Su and Ang, 2012) some attempts have been oriented to integrate the two decomposition approaches (Choi and Ang, 2012; Nie and Kemp, 2013; Choi and Oh, 2014) and to include the production-theoretical decomposition techniques (PDA) to analyse the role of production technology, such as technical efficiency and technological changes (Chen and Duan, 2016; Liu et al., 2018; Chen et al., 2019).

The decomposition techniques reported above, have been widely applied both as a diagnostic and simulation tool and the related discussions have been used to investigate the possible co-existence of environmental protection and growth. In addition, decomposition approaches have also been applied to support the forecasting analysis oriented to investigate the patterns of energy and natural resource uses (Meng et al., 2015; Meng et al., 2018; Li and Qin, 2019). Within this context, the decomposition of the environmental taxes revenue performed in this paper, and the analysis of the contribution played by tax intensity, economic structure and growth, can be used to investigate if European countries have moved toward increasing level of pollution or toward an higher environmental protection. In addition, the cross-country comparison can be used to identify successful examples of taxation structure and to support the design of sustainability policies both within and across European countries.

3.2 Decomposition methodology

The Kaya identity and a Perfect Decomposition Technique proposed by Sun (1998) are used in this paper to investigate the main factors influencing the environmental taxes revenue variations. The Kaya identity, generally used to express a variable as the products of different explanatory factors, has been largely used both for diagnostic and simulation purpose, and has been previously applied to a wide range of economic and environmental relationships (Kaya, 1990; Wu et al., 2016). The Perfect Decomposition Technique, proposed by Sun (1998) as a revised version of the Index Decomposition Analysis, has been specifically developed to eliminate the role of the residual in the decomposition results and has been largely applied for cross-country comparisons and time series analysis (Ang et al., 2003; Shyamal and Bhattacharya, 2004). Based on the principle of "jointly created and equally distributed" (Sun, 1996), Sun (1998) proposed to split the residual terms, among the variables that created them (Hoekstraa, and van der Bergh, 2003; Zhang, 2009). By suppressing the role of the residual, this decomposition technique is able to perform a more reliable and accurate analysis than the conventional Layspeyres and Divisia techniques (Ang and Liu, 2001; Shyamal and Bhattacharya 2004; Chen et al., 2018).

By adjusting the Kaya identity and the Index Decomposition Technique, the variations in the environmental taxes revenue are expressed in this paper as the product of the three explanatory factors reported in Table 1. Following Eurostat (2013) and OECD (2015), that identify taxation rate, economic structure and growth as some of the main elements influencing the revenue collected, the drivers of variations are expressed in this paper as the tax intensity effect (TI), the economic structure effect (SC) and the economic activity growth effect (G).

Table 1. Explanatory factors

Factor	Abbreviation	Description
ETR^t_i / GDP^t_i	TI	Environmental taxes intensity effect. It is defined by the ratio of environmental taxes revenue and GDP production. It reflects changes in the tax rate or in the introduction/abolition of new taxes.
GDP^t_i /GDP^t	SC	Structural change effect. It is calculated as the ratio between the gross domestic product of a specific country (GDPi) and the total GDP generated by the countries considered in the decomposition exercise. The SC effect has been previously used by Shyamal and Bhattacharya (2004) and Andreoni and Galmarini (2012b) to quantify the change in relative shares of different economic sectors. Since in this paper we are considering the economic activity of every country as a single aggregate, the approach previously adopted in Andreoni and Galmarini (2017) is used to account for the role that a specific country plays in the overall economic panorama. The aim is to identify the contribution provided by every country to the total GDP generation. Based on this equation, the SC provides useful information to identify the countries responsible for the main variations in the underlying structure of the European economic system.
GDP^t	G	Economic activity growth effect. It reflects changes of the total economic activity and it is used to quantify the environmental taxes revenue generated by economic growth.

In particular, equation (1) expresses the environmental taxes revenue of the *i*th country at time *t* (ETR^t_i) as the product of the intensity, the structural and the economic activity growth effects.

$$ETR^{\,t}_{\,i} = \sum_i \frac{ETR^{\,t}_{\,i}}{GDP^{\,t}_{\,i}} \times \frac{GDP^{\,t}_{\,i}}{GDP^{\,t}} \times GDP^{\,t} = \sum_i TI^{\,t}_{\,i} \times SC^{\,t}_{\,i} \times G^{t} \qquad (1)$$

where for a specific year (*t*), GDP_i^t refers to the value added of the *i*th country and GDP^t refers to the aggregated value added of all the countries considered in this paper. Since expression (1) runs from a base year 0 to a target year t, we can calculate the variation in the environmental taxes revenue over the period of time as (2):

$$\Delta ETR = ETR^{\,t} - ETR^{\,0} = TI + SC + G \qquad (2)$$

The calculation of each component reported in equation (2) are expressed by the following equations where the sums are intended over the individual country values and where the fractional multipliers are used according to Shyamal and Bhattacharya (2004) to equally distribute the residual among the decomposition factors.

Equation (3) calculates the environmental taxes intensity effect:

$$TI = \sum_i \Delta\, TI_i \times SC^0_i \times G^0 + \frac{1}{3}\sum_i \Delta\, TI_i \times \Delta SC_i \times \Delta G + \frac{1}{2}\sum_i \Delta TI_i\, (\Delta\, SC_i \times G^0 + SC^{\,0}_{\,i} \times \Delta G) \qquad (3)$$

Equation (4) calculates the structural change effect:

$$SC = \sum_i \Delta\, SC_i \times TI^0_i \times G^0 + \frac{1}{3}\sum_i \Delta\, TI_i \times \Delta SC_i \times \Delta G + \frac{1}{2}\sum_i \Delta SC_i\, (\Delta\, TI_i \times G^0 + TI^{\,0}_{\,i} \times \Delta G) \qquad (4)$$

Equation (5) calculates the economic activity growth effect:

$$G = \sum_i \Delta\, G_i \times TI_i^0 \times SC^0 + \frac{1}{3}\sum_i \Delta\, TI_i \times \Delta SC_i \times \Delta G + \frac{1}{2}\sum_i \Delta G_i\, (\Delta\, TI_i \times SC^0 + TI_i^{\,0} \times \Delta SC) \qquad (5)$$

4. Results and discussion

The decomposition technique presented above has been used in this paper to identify the main factors responsible for the variations of the environmental taxes revenue collected in 25 European countries for the time period 2004-2016. The tax intensity effects (TI) the structural change effect (SC) and the economic activity growth effect (G) have been the factors considered in the decomposition exercise.

Following the approach adopted by previous studies (Castiglione et al., 2014; Mouthino et al., 2015; Vehmas et al., 2018), that aggregates the European countries based on homogenous factors, the present paper analyses the similarities existing between Member States by considering two main groups of countries. Namely: Group 1, that includes the countries that have joined the EU before 2004 and that have a market economy mainly characterised by industrial and services activities; Group 2, that includes the countries that have joined the EU after 2004 and that are usually defined as former transition economies. Group 1 includes the north and the central European countries, such as Belgium, Denmark, Germany, France, Netherlands, Austria, Finland, Sweden, United Kingdom and Ireland; plus, the Mediterranean countries, such as Greece, Spain, Italy and Portugal. Group 2 includes Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia, Slovakia and Cyprus.

Based on the data reported below, similarities can be identified among the groups of countries considered in this paper. The main objective is to identify the characteristics of the environmental taxes revenue variations by proving a comparative analysis of Member States. In Tables 1a and 1b, the results are presented for the time period 2004-2016. In particular, the contribution provided by every decomposition factor and the cumulate change effect (CH) is reported for every country. The sign "-" and "+" are used to summarize a "decrease" or an "increase" in the ETR generated by every one of the decomposition drivers considered in the analysis. The disaggregated results for the time periods 2004-2008, 2008-2012, 2012-2016 and 2016-2004 are included in Tables A1 of the appendix together with the numerical value of the variations. In Figure 3, a graphical representation of the drivers is reported for the time period 2004-2016.

Table 1a. Decomposition results - Group 1 (2004-2016)

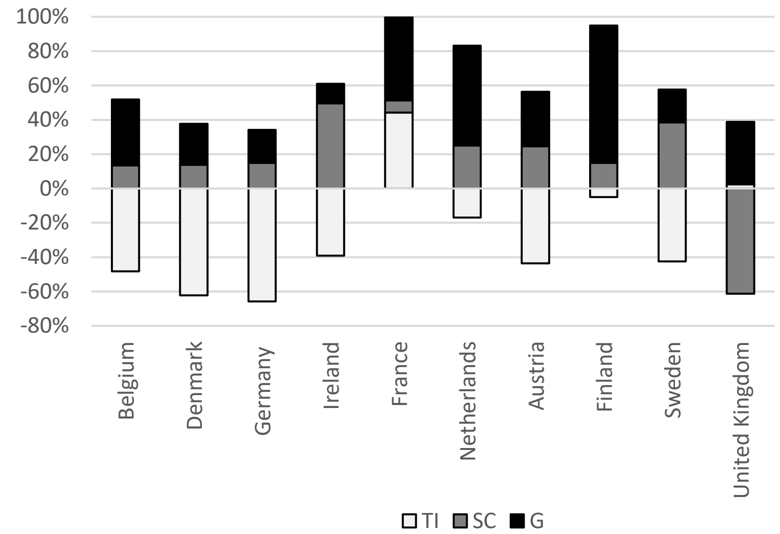
	Belgium	Denmark	Germany	Ireland	France	Netherlands	Austria
TI	-	-	-	-	+	-	-
SC	+	+	+	+	+	+	+
G	+	+	+	+	+	+	+
CH	+	-	-	+	+	+	+
	Finland	Sweden	United Kingdom	Greece	Italy	Portugal	Spain
TI	-	-	+	+	+	-	-
SC	+	+	-	-	-	-	-
G	+	+	+	+	+	+	+
CH	+	+	-	+	+	-	-

Table 1b. Decomposition results – Group 2 (2004-2016)

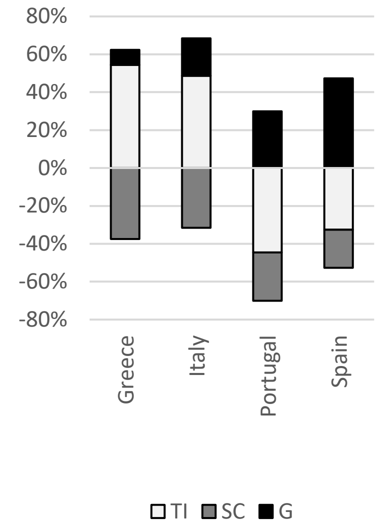
	Slovenia	Slovakia	Bulgaria	Estonia	Cyprus	Latvia
TI	+	-	-	+	-	+
SC	+	+	+	+	+	+
G	+	+	+	+	+	+
CH	+	+	+	+	-	+
	Lithuania	Hungary	Romania	Poland	Czech Republic	
TI	-	-	-	-	-	
SC	+	-	+	+	+	
G	+	+	+	+	+	
CH	+	-	+	+	+	

Figure 3. Decomposition results (2004-2016) (%Δ)

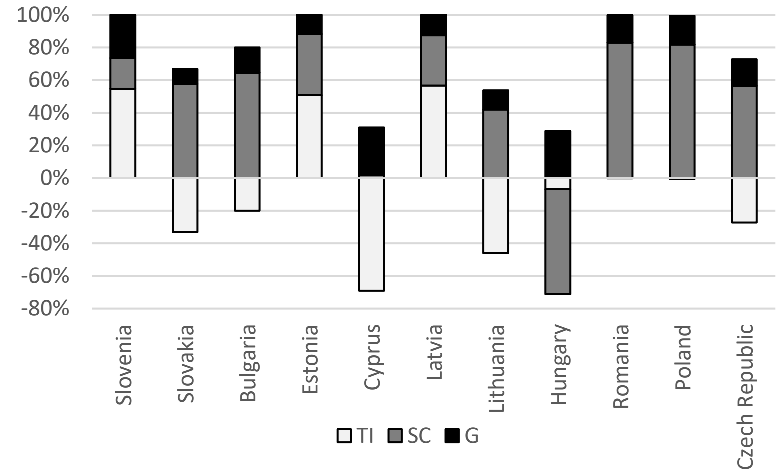
North and Central European Countries



Mediterranean Countries



Eastern European Countries



In the group of countries classified as north and central, the economic activity growth effect (G) has been the main driver contributing to the ETR increases. For these countries, the increasing production and the related enlargement of the taxation base have been the main elements influencing the positive variations in the revenue collected.

Sweden and Ireland have been the only exception, with the structural change effect (SC) contributing more than the G effect. After the 2008 crisis, both countries increased their role in the European economic panorama. During the years that followed the global financial crash, Ireland experienced a strong economic recovery, mainly driven by the multinational companies operating in the country and by the export of royalties attributed to the intellectual property assets registered in Ireland (EC, 2018). According to studies published by Fitzgerald (2012), Dalton and Enright (2013) and Whelan (2013), the real estate bubble and the related collapse of the property market had an immediate effect in the fall of domestic investments. However, the extreme openness of the Irish economy and the large importance of the pharmaceuticals sector, ending in the patent of certain key drugs, contributed to the quick recovery of the country. In Sweden, the greater stability and returns of the Swedish banks compared to the other European banks contributed to reduce the overall impacts generated by the crisis of 2008 (Jochem, 2010). Based on studies published by Fahlenbrach et al. (2012) and Berglund and Makinen (2019), the financial stability measures, adopted after the banking crisis of the 1990s, enable the Swedish economy to recover quickly than the other European countries.

For all of other north and central European countries, the structural change effect (SC) also contributed to increase the environmental taxes revenue collected between 2004 and 2016. The only exception has been United Kingdom that had a GDP growth rate generally lower than the European average. According to studies published by Griffith and Miller (2015) and by ONS (2018), the productivity reduction, that largely characterised the financial and the service sectors, has been the main factor contributing to reduce the role of UK in the European economic panorama.

When considering the Mediterranean countries, the following trends can be identified: the structural change effect (SC), and the related reduction of the contribution to the European economy, have generated a negative impact on the overall environmental taxes revenue increases. This result is consistent with the fact that Greece, Italy, Portugal and Spain have been among the Member States most affected by the global financial crash, with a recovery that has been slower than the other European countries (Quiggin, 2012). The reduction of international competitiveness, together with the low level of productivity and the extensive debt, largely contributed to reduce the European market share of Greece, Italy, Portugal and Spain (Lin et al., 2013). As pointed out by Vegetti and Adascalieti (2017) and by Gonzalez-Permia et al., (2018) the decrease in entrepreneurial action and the consequent impacts on competitiveness and growth, have been higher in Mediterranean countries where the access to finance has been more difficult than in other European areas. For these countries, however, as well as for all the North and Central European countries, the positive variations of GDP (G) that took place both in the period that preceded the financial crash (2003-2008) and in the period that followed the crisis (2012-2016), contributed to increase the environmental taxes revenue.

When considering the taxes intensity effect (TI) differences can be highlighted among the countries included in first group. In line with the evidence provided by Kurtinaityte-Venediktoviene et al. (2014), the decomposition results reported in this paper highlight that the evolution of environmental taxation has taken different paths across European countries. In particular, all the Member States included in the first group, with exception of Greece, France, Italy and United Kingdom reduced the taxes intensity effect. This means that the quantity of revenue collected for the incidence of environmental taxation has decreased. The global financial crisis and the related concerns on competitiveness and growth have induced some Member States to reduce some of the environmental taxation rate or to introduce tax refunds and exemptions. In Denmark, for example, the energy taxes have been reduced to the EU's minimum rate and in 2009 Netherland abolished the air passenger duty due to concerns on competitiveness and growth (The Ecological Council, 2013; 2016; Withana et al., 2014). Based on data reported in Table A1 of the appendix, the largest TI drops have taken place in the countries historically characterised by stringent environmental regulation, such as Denmark, Germany and Sweden. Having already implemented the green tax reform, and being characterised by some of the highest taxation rates, these countries have partially reduced the environmental constraints as a measure for competitiveness and growth (Kurtinaitytė-Venediktovienė et al., 2014). As reported by EEA (2016), these often-quoted eco-leaders countries had the largest reduction in the ratio of environmental tax revenues to GDP. On the contrary, countries such as Greece, France, Italy and United Kingdom have moved in the opposite direction and have shift taxation from labour to pollution. Italy and Greece have for example recently implemented specific taxation reforms to further increase the environmental taxation rate. Being characterised by some of the lowest level of employment, and by two of the highest tax burden on labour in the EU, these countries are gradually shifting the tax burden away from labour to more growth-friendly forms of taxation (EC, 2013; EC, 2016). In a similar way, the package of measures adopted in Ireland to respond to the financial crash of 2008 included a number of environmental taxes such as the carbon tax, the water pricing system and a revision of the vehicle registration tax (VRT) (Witana et al., 2014). As highlighted by Chitiga (2017) and Radulescu (2017), the environmental tax reform and the related possibility to reduce the fiscal pressure on capital and labour had an important role in the recovery of the countries most affected by the crisis.

In the second group of countries, that includes the former transition economies such as the Member States that joined the EU after 2004, the environmental taxes revenue increases have been mainly influenced by positive variations of the structural change effect (SC). Opposite to the trend performed by United Kingdom and by the four Mediterranean countries, the annexation to EU has contributed to increase the economic role that these Member States are playing in the European economic panorama (ad exception of Hungary, where based on OECD 2016, the large macroeconomic imbalances and the low level of productivity that followed the global financial crash, have reduced the contribution provided to the European GDP generation). In addition, according to data reported in Table 1 of the appendix, the largest structural change variations have taken place in the years that followed the annexation to EU, and that preceded the global financial crash (2004-2008). According to Campos et al. (2018) the increased level of trade and financial integration, together with common market and regulations contributed to increase productivity and growth of the countries that joined the EU. In addition, the reduction of the technology gap and the inflows of direct investments from the central European institutions improved the quality of human capital with positive effects on exports and growth (Tang, 2016). For all the eastern European countries, the economic growth activity effect (G) also contributed to increase the revenue collected.

When analysing the taxes intensity effect (TI) different trends can be identified. In particular, in Slovenia, Estonia and Latvia the TI effect has largely contributed to increase the overall environmental taxes revenue. According to Eurostat (2018), these countries have recently increased the share of environmental taxes on total taxes and social contribution, and have also been the only countries to increase the environmental taxes as a percentage of GDP. For all the other countries, namely: Slovakia, Bulgaria, Lithuania, Hungary, Poland, Romania plus Cyprus the TI effect has played a negative contribution to the overall environmental taxes revenue increases. As reported by EC (2016a), since in these countries the environmental tax reform hasn't been fully implemented, the adjustments of existing taxes and/or the introduction of new environmental taxes has a great potential both in terms of revenue increase as well as in terms of competitiveness and growth.

To sum up, the following main patterns can be identified:

- For all the countries considered in this paper, economic growth (G effect) contributed to increase the environmental taxes revenue collected between 2004 and 2016. However, during the period that followed the global financial crash (2008-2012), the GDP reduction contributed to drop the revenue increases for all the 25 Member States.

- For the north and the central European countries, the economic factors, such as the economic activity growth effect (G) and the structural change effect (SC) have been the main drivers of environmental tax revenue increases.
- Most of the north and central European countries (with exception of France and United Kingdom) have reduced the tax intensity effect (TI). In particular, in Denmark and Germany, the TI variation has been the main factor driving the overall reduction of the environmental taxes revenue collected between 2004 and 2016.
- For all the Mediterranean countries, the structural change effect (SC), and the related reduction of the role provided to the European GDP generation, has played a negative contribution to the environmental taxes revenue increases.
- On the contrary, for all the eastern European countries (with exception of Hungary), plus Ireland and United Kingdom, the structural change effect (SC) has been the main driver of revenue increases.
- For 20 of the 25 countries considered in this paper, the economic factors, such as the economic activity growth effect (G) and the structural change effect (SC), have been the main drivers of revenue increases. For the remaining five, namely: Italy, Greece, Slovenia, Estonia and Latvia, the tax intensity effect (TI) has been the most important driver. These five countries have moved toward a more sustainable system. In particular, they have reduced the relative contribution that economic factors have played in the generation of the environmental taxes revenue, and have increased the role of taxation rate and regulation. However, it is important to highlight that some of the countries that moved toward a more sustainable path, such as Slovenia, Estonia and Latvia had an environmental regulation structure generally lower than the European average. On the contrary, the countries that mostly reduced the tax intensity effect, such

as Germany, Denmark and Sweden have some of the highest environmental standard in EU.

5. Conclusions

The environmental taxes revenue collected by countries, and the related differences over time and geographical areas, does not provide exhaustive information around the sustainability path of countries. That is because economic growth and more resource intensive activities, can produce a revenue increase similar to that generated by changes in the taxation rate and regulation. The decomposition of the main drivers of revenue variations can provide important information to evaluate if countries have moved toward activities that have increase the level of pollution or toward higher environmental protection. Within this context, the main objective of this paper is to investigates the contribution that economic (SC and G effects) and regulatory (TI effect) factors have provided in the variations of the environmental taxes revenue collected by 25 European countries for the time period 2004-2016.

The main results show just 5 of the 25 Member States have moved toward a more sustainable system. In particular, Italy, Greece, Slovenia, Estonia and Latvia have been the only countries to increase the role of taxation rates and regulations and to reduce the relative contribution that economic factors have played in the generation of the revenue collected. For all the other Member States, economic growth and structural change effect have been the main drivers of environmental tax revenue variations.

Although there exist well-known limitations in decomposition analysis (Ang and Liu, 2007; Janssens-Maenhout, 2013) the results presented in this paper are in line with the analysis provided by European Commission (2015), according to which most of the countries are not doing enough to switch the tax burden form labour to environment. In particular, despite of the recommendation included in the Europe 2020 strategy (EC, 2012), most of the Member States have reduced the contribution of the environmental taxes revenue in relation to total taxes and GDP. The decomposition results also highlight how the exiting flexibilities in establishing taxation rate and regulation have been used by Member States to support specific policy objectives. Just after the global financial crash, the European countries historically characterized by stringent environmental regulations, such as Denmark, Germany, Netherland and Sweden, have for example partially reduced the environmental constraints to increase competitiveness and growth. On the contrary, some of the countries most affected by the crisis, such as Greece, Italy and Ireland have used the environmental tax reform to reduce the pressure on capital and labour. The possibility to change taxation rate and regulation as instrument to support internal policy objectives can contribute to sustain the economic development of countries. However, the related demand for production and consumption, summarized by the positive variations of economic growth (G) and structural change (SC) effect, can generate spillover effects on pollution and natural resource use.

For this reason, further analysis would be needed to investigate if economic activities have moved toward more sustainable practices or to increased environmental pressure. Decomposition analysis, investigating the environmental taxes revenue collected from different economic sectors will be functional to that. In addition, the analysis of the revenue collected from households can be used to investigate the impacts of income, sustainable consumption and efficiency gains, to the country-scale level of energy and natural resource demand. The decomposition of the revenue across different categories of environmental taxes (such as the energy, the transport and the pollution and the resources use) can also be used to forecast the impact of policies both at European and Member States level.

The main implication for theory and practice are related to the fact that the decomposition exercise performed in this paper provides a reverse standpoint of analysis. Up to know, most of the studies have focused on the economic and environmental impacts of revenue collection.

On the contrary, the present paper investigates how economic and taxation elements have influenced the revenue collected. By shifting the focus of analysis from the impacts, to the drivers of revenue, this paper provides a better understanding of environmental taxation and can be used to increase the effectiveness of this policy instruments. In addition, the comparative analysis of European Member States contributes to identify how different economic and regulatory framework can influence the sustainability path of countries.

By providing a disaggregated analysis of the drivers influencing the environmental taxes revenue, this paper contributes to the existing debate around environmental protection and economic growth and highlights how the environmental taxes revenue collected by Member States does not provide exhaustive information around the sustainability paths of countries. Within this context, the main recommendation relates to the fact that the use of disaggregated analysis, oriented to decompose the role of economic and regulatory factors, would need to be adopted in the design policies oriented to reconcile growth and environmental protection.

Reference

Andreoni, V., Galmarini, S., 2012a. European CO_2 emission trends: a decomposition analysis for water and aviation transport sectors. Energy Journal 45, 595-602

Andreoni, V., Galmarini, S., 2012b. Decoupling economic growth from carbon dioxide emission: a decomposition analysis of Italian energy consumption. Energy 44, 682-691

Andreoni, V., Galmarini, S., 2017. Drivers in CO_2 emissions variation: A decomposition analysis for 33 world countries. Energy 103, 27-37

Ang, B.W., Choi, K.H., 1997. Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. Energy Journal 18(3), 59-73

Ang, B.W., Liu, F.L., 2001. A new energy decomposition method: perfect in decomposition and consistent in aggregation. Energy 26(6), 537-548

Ang, B.W., Liu, F.L., Chew, E.P., 2003. Perfect decomposition techniques in energy and environmental analysis. Energy Policy 31, 1561-1566

Ang, B.W., Liu, N., 2007. Viewpoint: Energy decomposition analysis: IEA model versus other methods. Energy Policy 35, 1426-1432

Ang, B.W., Su, B., 2016. Carbon emission intensity in electricity production: a global analysis. Energy Policy 86, 233-238

Ang, B.W., Xu, X.Y., Su, B., 2015. Multi-country comparisons of energy performance: The index decomposition analysis approach. Energy Economy 47, 68-76

Ang, B.W., Zhang, F.P., 2000. A survey of index decomposition analysis in energy and environmental studies. Energy 25(12), 1149-76

Aparicio, J., Borras, F., Pastor, J.T., Vidal, F., 2013. Accounting for slacks to measure and decompose revenue efficiency in the Spanish Designation of Origin wines with DEA. European Journal of Operational Research 231, 443-451

Baležentis, T., Kriščiukaitienė, I., 2015. The factors of milk revenue change in Lithuania: index decomposition analysis based on the Shapley value. Management Theory Studies for Rural Business and Infrastructure Development 37(1), 8-16

Berglund, T., Makinen, M., 2019. Do banks learn from financial crisis? The experience of Nordic banks. Research in international business and finance 47, 428-440

Campos, N.F., Coricelli, F., Moretti, L., 2018. Institutional integration and economic growth in Europe. Journal of Monetary Economics, in press.

Cansino, J.M., Sanchez-Braza, A. Rodriguez-Arevalo, M.L., 2015. Driving forces of Spain's CO_2 emissions: A LMDO decomposition approach. Renewable and Sustainable Energy Reviews 48, 749-759

Cansino, J.M., Roman, R., Ordonex, M., 2016. Main drivers of changes in CO_2 emissions in the Spanish economy: A structural decomposition analysis. Energy Policy 89, 150-159

Carattini, S., Baranzini, A., Lalive, R., 2018. Is Taxing Waste a Waste of Time? Evidence from a Supreme Courte Decision. Ecological Economics 148, 131-151

Castiglione, C., Infante, D., Minervini, M.T., Smirnova, J., 2014. Environmental taxation in Europe: What does it depend on? Cogent Economics & Finance 2, 1-8

Castiglione, C., Infante, D., Smirnova, J., 2018. Non-trivial Factors as Determinants of the Environmental Taxation Revenues in 27 EU Countries. Economies 6(7), 1-20

Chen, J., Wang, P., Cui, L., Huang, S., Song, M., 2018. Decomposition and decoupling analysis of CO_2 emissions in OECD. Applied Energy 231, 937-950

Chen, L., Duan, Q., 2016. Decomposition analysis of factors driving CO_2 emissions in Chinese provinces based on production-theoretical decomposition analysis. Natural Hazards 84(1), 267-277

Chen, Y.P., Zhang, Y., 2018. A decomposition method on employment and wage discrimination and its application in urban China (2002-2013). World Development 110, 1-12

Chen, J., Xu, C., Cui, L., Huang, S., Song, M., 2019. Driving factors of CO_2 emissions and inequality characteristics in China: A combined decomposition approach. Energy Economics 78, 589-597

Chitiga, G., 2017. Environmental Taxes: Pollution/Resources. Romania's Situation as Compared with EU Member States. In: Financial Studies. Institute for Economic Forecasting: Bucharest, Romania, 234-238

Choi, K.H. Ang, B.W., 2012. Attribution of changes in Divisia real energy intensity index – An extension to index decomposition analysis. Energy Economics 34(1), 171-176

Choi, K.H., Oh, W., 2014. Extended Divisia index decomposition of changes in energy intensity: A case of Korean manufacturing industry. Energy Policy 65, 275-28

Chu, A.C., Cozzi, G., 2016. Growth accounting and endogenous technical change. Economics Letters 146, 147-150

Chung, H.S., Rhee, H.C., 2001. A residual-free decomposition of the sources of carbon dioxide emissions: a case of the Korean industries. Energy 26(1), 15-30

Croner, D., Frankovic, I., 2018. A structural decomposition analysis of global and national energy intensity trends. The Energy Journal 39(2), 219-231

Dalton, M., Enright, S., 2013. The Impact of the Patent Cliff on Pharma-Chem output in Ireland, Working Paper 1, Dublin: The Department of Finance

Deng, G., Xu, Y., 2017. Accounting and structure decomposition analysis of embodied carbon trade: A global perspective. Energy 137, 140-151

EC, 1993. Growth, competitiveness, and employment. The challenges and ways forward into the 21st century. COM (93) 700 final, Luxembourg

EC, 2012. Europe 2020: a European Strategy for Smart. Sustainable and Inclusive Growth. Communication COM, Final European Commission, Brussels, 2010

EC, 2013. Tax reforms in EU Member States: Tax policy challenges for economic growth and fiscal sustainability. European Economy N.5, Directorate General for Economic and Financial Affairs, Luxembourg

EC, 2015. Tax reforms in EU Member States - 2015 Report. Taxation Papers, 58, Brussels

EC, 2016. Recent Tax Reforms in Italy: The Impact on Households and Workers. Economic brief 020, Luxembourg

EC, 2016a. Study on assessing the environmental fiscal reform potential for EU28. European Commission, Luxembourg

EC, 2018. Economic performance by countries https://ec.europa.eu/info/business-economy-euro/economic-performance-and-forecasts/economic-performance-country_en (accessed 10 February 2019)

EEA, 2005. Market-based instruments for environmental policy in Europe. EEA Technical Report No 8/2005, European Environment Agency, Copenhagen

EEA, 2008. Effectiveness of environmental taxes and charges for managing sand, gravel and rock extraction in selected EU countries. Technical Report No 2/2008, European Environmental Agency, Copenhagen

EEA, 2016. Environmental taxation and EU environmental Policies. Technical Report No 17/2016, European Environmental Agency, Copenhagen

Ekins, P., 1999. European environmental taxes and charges: Recent experience, issues and trends. Ecological Economics 31, 39-62

Ekins, P., Pollitt, H., Barton, J., Blobel, D., 2011. The implication for households of environmental tax reform (ETR) in Europe. Ecological Economics 70(12), 2472-2485

Ekins, P., Speck, S. (Eds), 2009, Environmental tax reform (ETR): resolving the conflict between economic growth and the environment, Oxford University Press, Oxford

Eurostat - Environmental taxes revenue data http://ec.europa.eu/eurostat/en/web/products-datasets/-/ENV_AC_TAX (accessed 10 February 2019)

Eurostat - GDP data http://ec.europa.eu/eurostat/web/national-accounts/data/main-tables (accessed 10 February 2019)

Eurostat, 2013. Environmental taxes: a statistical guide, Luxembourg

Eurostat, 2018. Environmental tax statistics http://ec.europa.eu/eurostat/statistics-explained/index.php/Environmental_tax_statistics (accessed 10 February 2019)

Fahlenbrach, R., Prilmeier, R., Rene, M.S., 2012. This time is the same: using bank performance of 1998 to explain bank performance during the recent financial crisis. Journal of Finance 67, 2139-2185

Fitzgerald, J., 2012. Financial Crisis, Economic Adjustment and a Return to Growth in the EU. Revue de l'OFCE, Debates and Policies – 127

Gonzalez-Pernia, J.L., Guerrero, M., Pena-Legazkue, A.J., 2018. Economic recession shake-out and entrepreneurship: Evidence from Spain. BRQ Business Research Quarterly 21(3), 153-167

Griffith, R., Miller, H., 2015. Weak productivity growth is not confined to a few sectors of the economy. Institute for Fiscal Studies https://www.ifs.org.uk/publications/7821 (accessed 10 February 2019)

Hawkins, J., Ma, C., Schilizzi, S., Zhang, F., 2015. Promises and pitfalls in environmental extended input-output analysis for China: A survey of the literature. Energy Economics 48, 81-88

Hoekstra, R., van der Bergh, J.C.J.M., 2003. Comparing structural and index decomposition analysis. Energy Economics 25, 59-64.

Huang, X.Y., Zhou, J.Q., Wang, Z., Deng, L.C., Hong, S., 2017. Structural decomposition analysis of China's industrial energy consumption based on input-output analysis. IOP Conference Series: Earth and Environmental Science 63(1) 0102041

Janssens-Maenhout, G., Paruolo, P., Martelli, S., 2013. Analysis of Greenhouse Gas Emission Trends and Drivers, JRC Science and Policy Report, Luxembourg

Jennings, M., Gallachoir, B.P.O., Schipper, L., 2013. Irish passenger transport: Data refinements, international comparisons and decomposition analysis. Energy Policy 56, 151-164

Jochem, S., 2010. Sweden country report. In: Bertelsmann Stifftung (Ed.), Managing the crisis a comparative assessment of economic governance in 14 economies. Gutersloh Bertelsmann Stifftung

Kaya Y. Impact of carbon dioxide emission on GNP growth: Interpretation of proposed scenarios. In: Paper presented to IPCC energy and industry subgroup, response strategies working group, Paris; 1990.

Kurtinaitytė-Venediktovienė, D., Pereira, P., Černiauskas, G., 2014. Environmental taxes in Northern Europe. The recent evolution and current status in the Baltic countries. Socialiniu Mokslu Studijos Societal Studies 6(2), 331-348

Leal, P.A., Cardoso, A., Fuinhas, J.A.F., 2019. Decoupling economic growth from GHG emissions: Decomposition analysis by sectoral factors for Australia. Economic Analysis and Policy 62, 12-26

Li, G., Masui, T., 2019. Assessing the impacts of China's environmental tax using a dynamic computable general equilibrium model. Journal of Cleaner Production 208, 316-324

Li, H., Qin, Q., 2019. Challenges for China's carbon emissions peaking in 2030: A decomposition and decoupling analysis. Journal of Cleaner Production 207, 857-865

Lin, C.Y.-Y., Edvinsson, L., Chen, J., Beding, T., 2013. National Intellectual Capital and the Financial Crisis in Greece, Italy, Portugal, and Spain, Springer Briefs in Economics, New York.

Liu, L-J., Liang, Q-M., 2017. Changes to pollutants and carbon emission multipliers in China 2007-2012: An input-output structural decomposition analysis. Journal of Environmental Management 203, 76-86

Liu, X., Zhou, D., Zhou, P., Wang, Q., 2018. Factors driving energy consumption in China: a joint decomposition approach. Journal of Cleaner Production 172, 724-734

Lyu, W., Li, Y., Guan, D., Zhao, H., Zhang, Q., Liu, Z., 2016. Driving forces of Chinese primary air pollution emissions: an index decomposition analysis. Journal of Cleaner Production 133, 136-144

Magacho, G.R., McCombie, J.S.L., Guilhoto, J.J.M., 2018. Impacts of trade liberalization on countries' sectoral structure of production and trade: A structural decomposition analysis. Structural Change and Economic Dynamics 46, 70-77

Meng, M., Shang, W., Zhao, X., Niu, D., Li, W., 2015. Decomposition and forecasting analysis of China's energy efficiency: An application of three-dimensional decomposition and small-sample hybrid models. Energy 89, 283-293

Meng, M., Fu, Y., Wang, X., 2018. Decoupling, decomposition and forecasting analysis of China's fossil energy consumption from industrial output. Journal of Cleaner Production 177, 752-750

Moutinho, V., Carrizo Moreira, A., Silva, P.M., 2015. The driving forces of change in energy-related CO_2 emissions in Eastern, Western, Northern and Southern Europe: The LMDI approach to decomposition analysis. Renewable and Sustainable energy Reviews 50, 1485-1499

Mulder, P., De Groot, H.L.F., 2012. Structural change and convergence of energy intensity across OECD countries, 1970–2005. Energy Economics 34(6), 1910–1921

Nie, H., Kemp, R., 2013. Why did energy intensity fluctuate during 2000-2009? A combination of index decomposition analysis and structural decomposition analysis. Energy for Sustainable Development 17(5), 482-488

OECD, 2015. Towards Green Growth? Tracking Progress. OECD Green Growth Studies, OECD Publishing, Paris

OECD, 2016. Economic Survey – Hungary overview www.oecd.org/eco/survey/economic-hurvey-hungary.htm (accessed 10 February 2019)

ONS, 2018. The 2008 recession 10 years on https://www.ons.gov.uk/economy/grossdomesticproductgdp/articles/the2008recession10yearson/2018-04-30 (accessed 10 February 2019)

Quiggin, J., 2012. Zombie Economics: How Dead Ideas Still Walk among Us. Princeton University Press, p. 229

Radulescu, M., Sinisi, C.I., Popescu, C., Iacob, S.E., Popescu, L., 2017. Environmental Tax Policy in Romania in the Context of the EU: Double Dividend Theory. Sustainability 9, 1-20

Roinioti, A., Koroneos, C., 2017. The decomposition of CO_2 emissions from energy use in Greece before and during the economic crisis and their decoupling from economic growth. Renewable and Sustainable Energy Reviews 76, 448-459

Rose, A., Miernyk, W.H., 1989. Input-Output Analysis: The First Fifty Years. Economic Systems Research 1, 229-271

Shahiduzzaman, Md., Layton, A., 2017. Decomposition analysis for assessing the United States 2025 emission targets: How big is the challenge? Renewable and Sustainable Energy Reviews 67, 372-383

Shyamal, P., Bhattacharya, R.N., 2004. CO_2 emission from energy use in India: a decomposition analysis. Energy Policy 32, 585-593

Su, B., Ang, B.W., 2012. Structural decomposition analysis applied to energy and emissions: Some methodological development. Energy Economics 34(1), 177-188

Su, B., Ang, B., 2016. Multi-regional comparisons of emission performance: The structural decomposition analysis approach. Ecological Indicators 67, 78-87

Sun, J.W., 1996. Quantitative analysis of energy consumption, efficiency and savings in the world, 1973-1990. Turku School of Economics Press, series A-4

Sun, J.W., 1998. Accounting for energy use in China, 1980-94. Energy 23, 835-849

Tang, D., 2016. Has the Financial Integration affected the European Union (EU) trade with the New Member Countries from Central and Eastern Europe (CEEC) during 1994-2013? The Journal of Economic Asymmetries 13, 8-20

The Ecological Council, 2013. Impacts of Energy Taxation on Competitiveness of Denmark www.ecocouncil.dk (accessed 10 February 2019)

The Ecological Council, 2016. Fact Sheet: The Danish motor vehicle taxes www.ecocouncil.dk (accessed 10 February 2019)

Timma, L., Blumberga, D., 2014. Index decomposition analysis for energy sectors in Latvia. Energy Procedia 61, 2180-2183

UN, EU, FAO, IMF, OECD, World Bank, 2014, System of Environmental-Economic Accounting 2012 — Central Framework. SEEA, UN, New York

Vehmas, J., Kaivo-oja, J., Luukkanen, Y., 2018. Energy efficiency as a driver of total primary energy supply in the EU-28 countries – incremental decomposition analysis. Heliyon 4(10), 1-23

Vegetti, F., Adascalitei, D., 2017. The impact of the economic crisis on latent and early entrepreneurship in Europe. International Entrepreneurship and Management Journal 13(4), 1289-1314

Wang, Q., Li, R., 2016. Journey to burning half of global coal: Trajectory and drivers of China's coal use. Renewable and Sustainable Energy Reviews 58, 341-346

Wang, H., Zhou, P., 2018. Assessing global CO_2 emission inequality from consumption perspective: An Index Decomposition Analysis. Ecological Economics 154, 257-271

Wang, B., Wang, Q., Wei, Y-M., Li, Z-P., 2018a. Role of renewable energy in China's energy security and climate change mitigation: An index decomposition analysis. Renewable and Sustainable Energy Reviews 90, 187-194

Wang, Q., Hang, Y., Su, B., Zhou, P., 2018b. Contributions to sector-level carbon intensity change: An integrated decomposition analysis. Energy Economics 70, 12-25

Whelan, K., 2013. Ireland's Economic Crisis: The Good, the Bad and the Ugly. University College of Dublin, Center for Economic Researches, Working Paper 13/06

Withana, S., ten Brink, P., Illes, A., Nanni, S., Watkins, E., 2014. Environmental Tax Reform in Europe: Opportunities for the future. Institute for European Environmental Policies – Final Report, London

Wu, Y., Shen, J., Zhang, X., Skitmore, M., Lu, W., 2016. The impact of urbanization on carbon emissions in developing countries: A Chinese study based on the U-Kaya method. Journal of Cleaner Production 135, 589-603

Xu, Y., Dietzenbacher, E., 2014. A structural decomposition analysis of the emissions embodied in trade. Ecological Economics 101, 10-20

Xu, S-C., Zhang, L., Liu, Y-T., Zhang, W-W., He, Z-X, Long, R-Y., et al., 2017. Determination of the factors that influence increments in CO_2 emissions in Jiangsu, China using the SDA method. Journal of Cleaner Production 142, 3061-3074

Zhang, M., Mu, H., Ning, Y., Song, Y., 2009. Decomposition of energy-related CO2 emission over 1991-2006 in China. Ecological Economics 68, 2122-2128

Zhou, X., Zhang, M., Zhou, M., Zhou, M., 2017. A comparative study on decoupling relationship and influence factors between China’s regional economic development and industrial energy-related carbon emissions. Journal of Cleaner Production 142, 783-800