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Measuring the progress towards a resource-efficient European Union under the Europe 2020 strategy

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Abstract

Resource efficiency is an essential priority of the Europe 2020 Strategy, which under the Flagship Initiative for a Resource Efficient Europe calls for a shift towards a resource-efficient economy. In this context, indicators and composite indexes could be useful in order to evaluate the progress of the European Union towards the objectives of the Roadmap to a Resource Efficient Europe.

This paper benchmarks the 28 European members based on a composite index namely Resource-Efficiency Capacity Index. The index is based on the calculations of 29 variables which are grouped in three dimensions. The first dimension benchmarks EU-28 members according to the promotion of waste recycling, to the support of research and innovation in resource efficiency and to the implementation of environmental taxation. The second dimension benchmarks EU members according to energy efficiency in residential buildings and the third dimension according to the development of more sustainable transport modes. The three dimensions are aggregated for a final ranking.

The results indicate that Denmark receives the highest ranking with a composite index value of 3.35, followed by Sweden (3.22) and Finland (3.13) in 2013. The establishment of more effective policies is necessary in the member states with the lowest scores in the Resource-Efficiency Capacity Index: Slovakia (1.8), Malta (1.92) and Poland (1.93). Although the European Union has made considerable progress in this issue in the last decade, many actions should be still faced to increase resource efficiency as to inform more about the concept of life-cycle thinking to increase waste recycling, to make more attractive the system of public passenger transport, or to increase the energy efficiency of residential buildings, among others.

1. Introduction

Resource efficiency means "using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment. It allows us to create more with less and to deliver greater value with less input" - http://ec.europa.eu/environment/resource_efficiency/.
The increasing use of resources puts pressure on our planet and threatens the supply security (Yu *et al.,* 2017). Therefore, a more efficient use of resources would be essential in making progress to combat climate change and to achieve EU´s targets on greenhouse gas emissions (Tanning and Tanning, 2015). In this context, The European Commission put forward a Flagship Initiative for a Resource Efficient Europe (European Commission 2011a) as part of its 'Europe 2020 Strategy' (European Commission, 2010) to shift towards a resource-efficient, low-carbon economy. The Roadmap to a Resource Efficient Europe (European Commission, 2011b) is one of the main building blocks of the flagship initiative. The Roadmap to a Resource Efficient Europe sets a vision, for 2050, based on the importance of a sustainable management of all resources from raw materials to energy, water, land, air and soil. Policies based on increasing

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resource productivity and decoupling economic growth from resource use and its environmental impact are the basis of this regulation. More specifically, "making technological improvements, a significant transition in energy, industrial, agricultural and transport systems as well as changing producers´ and consumers´ behaviors" are the recommendations to obtain a resource-efficient Europe (European Commission, 2011b).

In that sense, (i) to avoid the generation of waste, (ii) to promote waste reuse and recycling, (iii) to support research and innovation in terms of resource efficiency, (iv) to protect the environment through the application of right prices, (v) to improve the energy efficiency of residential buildings or (vi) to shift away from goods and passengers transport by road to more environmentally-sustainable transport modes are some of the main challenges establish in the Roadmap to a Resource Efficient Europe.

In this context, the European Commission pointed out the need of indicators to measure progress towards the objectives proposed by the Roadmap to a resource efficient Europe. After a process to discuss and agree on indicators, the European Commission presented the Resource Efficiency Scoreboard[1] that includes 30 indicators for assessing the use of natural resources in the EU and for monitoring the progress towards a resource-efficient Europe (http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/index_en.htm)[2]. Specifically, the scoreboard includes a set of 20 indicators focusing on the sub-themes in the Roadmap that show progress in shifting the economy onto a more resource-efficient path (waste generation and treatment, research and innovation in environmentally related fields and environmental taxation), the pressure on nature and ecosystems and developments in key areas of basic needs with a high impact on the environment (nutrition, housing and mobility).

Although there are an ample number of indicators, composite indexes would be useful tools for policymakers to provide relevant information about the progress in the Roadmap to a Resource Efficient Europe. They are essential to summarize, focus and condense the great complexity of the environment to a manageable information amount (Godfrey and Todd, 2001). Thus, composite index could be useful to benchmarking of the performance of EU-28 countries across aspects that relate to resource-efficiency policies. Nevertheless, despite the research developed on resource efficiency (Section 2 shows a literature review), there is not an exhaustive index-based approach that allows to assessing the resource efficiency in the framework of the Roadmap to a Resource Efficient Europe. In fact, at EU level, the Sustainable Development of Energy, Water and Environment Systems (SDEWES) City Sustainability Index proposed by Kılkış (2015 and 2016) include some indicators related to sustainable transport, recycling or energy consumption. However, these analyses allows the benchmarking of the performance of cities (22 Mediterranean port cities and 12 Southeast European cities), but not EU- 28 countries. The objective of our paper is to obtain a composite index (namely Resource-Efficiency Capacity Index) to the benchmarking of the performance of EU-28 countries across aspects that relate to resource-efficiency policies in the framework of the Roadmap to a Resource Efficient Europe.

[1] The elaboration of the scoreboard involved all key stakeholders, to discuss and agree on indicators and targets by the end of 2013. Moreover, the selection of the indicators was also based on experts' consultations. For example, Mudgal et al (2012) identified and assessed indicators related to resource use and their environmental impacts and present recommendations for the implementation of indicators and targets in the EU policy context (http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/report.pdf)

[2] The Resource Efficiency Scoreboard was published the first time by the statistical office of the European Union (Eurostat) the 6 December 2013 (Scoreboard 2013) and the first full analytical report was published in November 2014 (European Commission, 2014)

For it, specific policies of the EU related to waste recycling, resource-efficiency research and innovation, energy and environmental taxation, energy efficiency of residential buildings and sustainable transport have been considered.

Research presenting policy recommendations on resource efficiency has been mainly centered in these issues. The change of consumption and production patterns in society is essential to eliminate waste before it is produced and thus to reduce its quantity and toxicity (Singh and Ordoñez, 2016). Therefore, prevention should be the primary aim, followed by its reuse and recycling, which are also key activities to make the environment cleaner. These activities require suitable policies that promote this environmentally friendly behavior in the society (Urbaniec *et al.,* 2016). Moreover, support of research and innovation on environmentally friendly, economically feasible and socially acceptable technological and non-technological solutions are essential in the field of resource efficiency (Kang and Lee, 2016). Another essential concept is the establishment of economic incentives to set a price for environmental damage as the tendency for people to overexploit resources of common property. Therefore, charges and subsidies can be established in order to internalize environmental costs (Hatfield-Dodds *et al.,* 2017). Regarding energy efficiency of residential buildings, it is another essential concept as buildings are responsible for a large share of energy consumption and greenhouse gas emissions, which require reinforcing legislation in order to promote sustainable energy consumption in society (Labanca *et al.,* 2015). Finally, more environmentally-sustainable transport modes are essential to reduce energy consumption which requires promoting the use of eco-friendly transport modes as well as to support innovative technologies (Robèrt *et al.,* 2017).

The proposed index is based on the calculations of 29 variables which are grouped in three dimensions related to those policies. The first dimension benchmarks EU-28 members according to the promotion of waste recycling, to the support of research and innovation in resource efficiency and to the implementation of environmental taxation. The second dimension benchmarks EU members according to energy efficiency in residential buildings and the third dimension according to the development of more sustainable transport modes. The three dimensions are aggregated for a final ranking. The results might be especially interesting for policy-makers to assess the existing policies as well as to identify which specific dimension/s need additional measures to achieve greater resource efficiency in the EU-28.

With this aim, the paper is structured as follows: firstly, literature review is carried out. Then, materials and method to develop the Resource-Efficient Capacity Index is explained. Subsequently, the Resource-Efficiency Capacity Index in the EU-28 is calculated for the years 2004 and 2013. The results obtained for the specific indices related to dimensions linked to resource- efficiency EU policies (transforming the economy, improving buildings and ensuring efficient mobility) as well as the results for the composite index are analyzed. A comparison of the REDCI for the years 204 and 2013 is done with the aim to study the progress made by each EU-28 member in the considered Resource Efficiency areas during that period. Finally, we discuss and conclude about the necessity of introducing improvements in resource-efficiency policies in the EU.

2. Literature review

Indicators and composite index have been used in the context of public policies as they would allow policy makers to simplify, quantify and analyze the dynamic and complex information in order to plan, monitor, assess and develop new policies (Bebbington *et al.*, 2007). In this context, indicators and composite indeces measuring some aspect of sustainability growth (as resource efficiency) have gained importance in the last years. Thus, the Living Planet Index is an indicator of global biodiversity that measure trends of species of vertebrates and calculates the sub-index for the three spheres (World Wildlife Fund, 1998). The Fossil Fuel Sustainability Index considers the independence, lifetime and environmental constraints and integrates them into a single index for coal, oil and natural gas (Ediger *et al*., 2007). On the other hand, the Composite Sustainability Performance Index allows industries to identify the key sustainability performance indicators and sets a framework to aggregate the indicators into a composite index (Singh *et al.,* 2007). Entire life cycle data to assess the ecological footprint conversion factors are considered by the Eco-Index Methodology (Chambers *et al*., 2014).

However, literature about resource-efficiency indicators and composite indeces is still recent and it is necessary to continue the research in this topic (Horton *et al*., 2016). At industrial level, in the case of symbiosis initiatives, Park and Behera (2014) developed eco-efficiency indicators, based on raw material consumption, energy consumption and greenhouse gas emissions, to quantify the economic and environmental performance of seven industrial symbiosis networks of the South Korea between 2007 and 2012. Similarly, Beloborodko and Rosa (2015) proposed production performance indicators in order to compare industrial symbiosis initiatives and cleaner production measures. More specifically, they developed normalization by cumulative added value and cumulative intensity indicators and applied them for the case of Latvia by means of case study method. Regarding chemical industry, Kalliski *et al.* (2016) developed real-time resource-efficiency indicators to monitor the energy and material efficiency. These indicators were grouped into material and energy flow analysis and the environmental impact of the production process. Similarly, Wang *et al.* (2016) analyzed the potential level of eco-efficiency improvements in the cement industry by developing production, usage and waste management indicators. In the case of energy industry, García-Álvarez *et al*. (2016a) developed an aggregated synthetic index of sustainable energy development based on indicators of economic development, social development and environmental protection. Its application to the EU-15 showed the necessity of better coordination and cooperation of member states´ energy policies. Likewise, in the context of resource productivity in the EU, García-Álvarez *et al*. (2016b) proposed an aggregate index to study the environmental and resources pressures from European energy activity. It was based on indicators of both greenhouse gas and other emissions (in the case of environmental pressure) and on indicators of hydrocarbons, fossil fuels, renewable and efficiency (in the case of resource pressure).

Regarding proposals of integrated frameworks for resource-efficiency analysis, Huysman *et al.* (2015) highlighted the importance of indicators of resource extraction and use, environmental impact as well as natural versus waste resources in order to measure patterns of resource-efficient production and consumption. On the other hand, the Resource Efficiency Index of the World Resources Forum has developed resource footprints to rank business and countries in function of their efficiency in the use of resources (Tukker *et al*., 2015). This index has used a similar approach to the Resource-Efficiency Roadmap as both of them provide signals and measure progress in improving resource efficiency. Thus, the Resource-Efficiency Roadmap has measured the resource productivity as domestic material consumption divided by gross domestic product and has complemented this measure with other indicators, such as materials, land, water and greenhouse gas emissions. The Resource Efficiency Index of the World Resources Forum has also used material, land and water indicators although it has not considered greenhouse gas emissions but carbon indicators. Both indeces have provided alternatives to measure societal and economic progress in a more comprehensive way. The Resource-Efficiency Roadmap has been based on continuing the development of environmental account systems, integrating environmental externalities into national accounting as well as promoting the integration of environmental externalities. In the case of the Resource Efficiency Index of the World Resources Forum, it has been based on measuring how well the economy performs in terms of output (high quality lives) and, in this context, it has used the Human Development Index as indicator to measure well-being.

Bosseboeuf (2015) and Faberi *et al*. (2015) monitored and measured energy efficiency trends in the EU, in the framework of Odysee Mure Project, although they did not use a composite indicator. More specifically, Bossobeouf (2015) studied energy efficiency trends and policies in the household and tertiary sectors whilst Faberi *et al.* (2015) analyzed trends and policies for energy savings in transport industry. On the other hand, a comprehensive method to measure resource efficiency of products, processes and services in the context of sustainable development was set by Bach *et al*. (2016). They proposed 21 categories to measure impacts on the environment, physical and socio-economic availability of the used resources as well as their societal acceptance. Kılkıs (2016, 2015) proposed an integrated approach for the analysis of performance of cities by means of aspects that relate to the sustainable development of energy, water and environment systems. These studies developed the Sustainable Development of Energy, Water and Environment Systems (SDEWES) City Sustainability Index by using indicators of seven dimensions (energy consumption and climate, penetration of energy and carbon dioxide saving measures, renewable energy potential and utilization, water and environmental quality, carbon dioxide emissions and industrial profile, city planning and social welfare, research, development, innovation and sustainability policy). Its application to 22 Mediterranean port cities and 12 Southeast European cities, respectively, showed best practices and specific recommendations for the cities with the worst scores.

Nevertheless, despite the research developed on resource efficiency, there is not an exhaustive index-based approach that allows to assessing the resource efficiency from the application of the some policies, in the framework of the Roadmap to a Resource Efficient Europe, this is, those policies related to transform the economy, to improve buildings and to ensure efficient mobility. The joint analysis of these policies might be especially relevant in order to obtain more detailed information about which specific policy has involved better results in resource efficiency in the EU.

3. Material and Methods

Resource efficiency is one of the main challenges in governmental policies in the EU. In this context, some EU resource-efficiency policies related to specific sub-themes included in the Roadmap to a Resource Efficient Europe (European Commission, 2011b) are:

(i) *To transform the economy* by
   a. reducing the health and environmental impacts of waste, decreasing the generation of waste and promoting recycling,
   b. supporting resource-efficiency research and innovation and
   c. protecting the environment through the application of right prices, such as energy and environmental taxation;

(ii) *To improve buildings* by increasing both energy efficiency of residential buildings and energy-efficient household appliances and

(iii) *To ensure efficient mobility* by moving towards more energy-efficient and environmentally friendly modes of passenger and goods transports (rail or inland waterways transport are more energy-efficient modes than road transport as they produce less emissions per tonne-kilometre).

Table 1 provides existing European policies to implement the Roadmap in the specific sub-themes and the main targets set by European directives.

Table 1. Legislation to implement the Roadmap in the specific sub-themes

Objectives	Legislation	Type	Deadline
Transforming the economy			
In absolute decline of waste generated per capita	COM (2011)571 (Council of the European Union, 2011b)	Strategic	2020
Virtually eliminated landfilling	COM (2011)571 (European Union, 2011b)	Strategic	2020
Recycling+Reuse: 50% by weight paper, plastic, glass, metal from households	Directive 2008/98/EC (European Commission, 2008)	Binding	2020
Integrating eco-innovation in environmental and industrial policies.	Eco-innovation Action Plan (European Commission, 2011c)	Strategic	2020
Phase out environmentally harmful subsidies and substantially increase environmental taxes	COM (2011)571 (European Commission 2011b)	Strategic	2020
Improving buildings			
Minimizing energy performance standards for new building and for existing buildings that undergo major renovations.	Directive 2002/91/EU (European Commission, 2002)	Binding	2015
Zero-energy buildings	Directive 2010/31/EU (European Commission, 2010b)	Binding	2020
Ensuring efficient mobility			
1% yearly reduction in transport greenhouse gas emissions on average	COM(2011)571 (European Commission 2011b)	Strategic	2012
30% of road freight over 300 km shifts to rail/waterborne transport	COM(2011)144 (Council of the European Union, 2011c)	Strategic	2030
Reducing greenhouse gas emissions from the transport sector by 20% compared to 2008 levels	COM(2011)144 (Council of the European Union, 2011c)	Strategic	2030
Reducing greenhouse gas emissions from the transport sector by 60% compared to 1990 levels	(Council of the European Union, 2011c)	Strategic	2050

Source: Own elaboration

In order to develop a composite index of resource-efficiency to measure the progress of the member states in these three issues- (i) *Transforming the economy,* (ii) *Improving buildings* and (iii) *Ensuring efficient mobility*- a set of indicators are chosen from the Resource Efficiency Scoreboard (European Commission, 2014).

Following a description of the indicators and dimensions, but also the method to calculate the Resource-Efficiency Capacity Index are presented.

3.1. Resource Efficiency Indicators

European Commission presented in the Resource Efficiency Scoreboard http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/index_en.htm, 30 indicators for assessing the use of natural resources in the EU and for monitoring the progress towards a resource-efficient and circular economy. The scoreboard includes a set of specific indicators focusing on the sub-themes in the Roadmap[3] that show progress in shifting the economy onto a more resource-efficient path (waste generation and treatment, research and innovation in environmentally related fields and environmental taxation) and developments in key areas of basic needs with a high impact on the environment (such us nutrition, housing and mobility)[4].

The Resource-Efficiency Capacity Index (RECI) proposed is based on the calculations of those variables related to these sub-themes (dimensions) belonging to the Roadmap (i) *Transforming the economy,* (ii) *Improving buildings* and (iii) *Ensuring efficient mobility. These variables* are grouped in 5 categories which are later grouped in the mentioned three dimensions.

Details about number of variables as well as categories and dimensions are summarized in Table 2. Last column indicates whether the variable has a positive (P) or negative (N) impact on resource efficiency.

Table 2. Dimensions, categories and number of variables of the composite index

Index	Dimension	Category	Variable (units)	Impact
Resource Efficiency Capacity Index	Transforming the economy	Turning the waste into a resource	Generation of waste excluding major mineral wastes (kg.)	N
			Landfill rate of waste excluding major mineral wastes (dimensionless)	N
			Recycling rate of municipal waste (dimensionless)	C
			Recycling rate of e-waste (dimensionless)	P
		Supporting research & innovation	Eco-innovation index (EU=100)	P
		Getting the prices right	Environmental tax revenues (Mils €)	P
			Energy taxes (Mils €)	P
			Energy taxes by paying sector (dimensionless)	P
			Households	
			Industry and construction	
			Transportation and storage	
			Services (except transportation and storage)	
			Agriculture, forestry and fishing	
	Improving buildings	Improving buildings	Final energy consumption in households (tonnes of oil equivalent)	N
			Final energy consumption in households by	

[3] The Resource Efficiency Scoreboard also includes a sub-theme *Nature and ecosystems* which is not considered in our study as it is justified at the end of the discussion section.

[4] Nutrition is not included in our study as the last available data for the specific indicator in this area (the daily calorie supply from animal and vegetal products) is 2011.

		fuel (dimensionless)	
		Total petroleum products	N
		Gas	N
		Solid fuels	N
		Electrical energy	N
		Renewable energies	P
		Derived heat	N
Ensuring efficient mobility	Ensuring efficient mobility	Average carbon dioxide emissions per km from new passenger cars (gram of CO_2 per km)	N
		Pollutant emissions from transport (index2000 = 100)	N
		Nitrogen oxides	N
		Non-methane volatile organic compounds	N
		Particulates < 10µm	N
		Modal split of passenger transport (dimensionless)	
		Motor coaches, buses and trolley buses	P
		Passenger cars	N
		Trains	P
		Modal split of freight transport (dimensionless)	
		Railways	P
		Inland waterways	P
		Roads	N

Source: Own elaboration from Resource Efficiency Scoreboard http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/index_en.htm

3.1.1. Indicators of *Transforming the economy* dimension

Regarding the indicators of the dimension of "*Transforming the economy*", the variables are grouped into three categories: *Turning the waste into a resource*, *Supporting research & innovation* and *Getting the prices right.*

The first category ("*Turning the waste into a resource*") includes variables related to generation of waste and recycling. Thus *Generation of waste* is defined as the amount of waste generated by all economic sectors and households. It reflects the waste originated from production and consumption, excluding major mineral waste*s; Landfill rate of waste is* defined as the rate of waste landfilled (directly or indirectly) in a country per year. This indicator covers hazardous and non-hazardous waste from economic sectors and households, including waste from waste treatment and excluding major mineral wastes, contaminated soils and dredging spoils; *Recycling rate of municipal waste* is the rate of recycled municipal waste (material, composting and anaerobic digestion) divided by the total municipal waste. Municipal waste is the waste generated by households, small businesses and public administrations and institutions which is collected by the municipality; R*ecycling rate of e-waste* (REW) is an important indicator as electrical and electronic equipment waste (e-waste) has a risk to damage the environment. It also has a high potential for recycling in order to replace raw materials by secondary raw materials. For the calculation of this indicator, Eurostat uses the volume of electrical and electronic equipment put on the market (EM) during the previous three years to the reference year as proxy for the volume of *e-waste*. The REW equals the total collection of *e-waste* (TC) in the present year divided by the average of the EM of the three preceding years multiplied with a reuse and recycling rate (RRR)- which is the total amount of collected e-waste sent to treatment / recycling facilities- as it shown in Eq. 1:

$$\mathrm{REW}_t = \frac{\mathrm{TC}_t}{\sum_{i=1}^{3} \mathrm{EM}_{t-i} / 3} \mathrm{RRR}_t \qquad \text{(Eq. 1)}$$

Waste represents an enormous loss of resources in the form of both materials and energy, so the variables related to waste have a negative impact on resource efficiency, and the variables related to waste recycling a positive impact on resource efficiency.

The “Supporting research & innovation” category includes the *Eco-innovation index* as indicator. It shows the well perform of the individual member states in eco-innovation compared to the EU average (which is equated with 100). The value of the index for each member state is calculated by the unweighted mean of the 16 sub-indicators grouped into five thematic areas (eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes). This indicator is published by the Eco-Innovation Observatory (2014) (http://www.eco-innovation.eu/>). Regarding the component of resource efficiency outcomes, it puts eco-innovation performance in the context of a country’s resource efficiency. The resource efficiency outcomes index is based on combined national statistics on domestic material productivity, domestic water productivity, inland energy productivity and GHG emissions intensity. Eco-innovation can support the realization of resource efficient Europe through increasing the resource efficiency performance of sectors and countries. In fact, eco-innovation can have a twofold positive impact on resource efficiency: it can increase the generated economic value, while at the same time decreasing pressures on the natural environment. Thus, this variable has a positive impact on resource-efficiency.

The category *“Getting the prices right*” includes variables related to energy and environmental taxes. Thus, *Environmental tax revenues* are the proportion of total revenues for environmental taxes (including taxes on transport, energy, pollution and resources) in Gross Domestic Product (GDP). The tax base is a physical unit of something that has a specific negative impact on the environment. *Energy taxes* show the total amount of energy tax revenue in millions of euro for all economic activities and household but also for non-residents. The *Energy taxes by paying sector* shows the percentage of energy taxes revenue collected by each sector (households, industry and construction, transportation and storage, services) as a proportion of the total amount of energy tax revenue. The Roadmap to a resource-efficient Europe (European Union, 2011b.) indicates that "Green tax reforms", which consist of increasing environmental taxes, while reducing others, have a role to facilitate the restructuring towards a more resource efficient economy as they reflects a certain degree of internalization of environmental impacts in the national economies. Thus environmental tax revenue is an indicator supporting the assessment of progress towards "greening" the taxation system. These taxes also generate revenue that can potentially be used to promote further environmental protection. Thus we have considered that environmental taxes have positive impact on resource-efficiency.

3.1.2. Indicators of *Improving buildings* dimension

With regard the dimension of “Improving buildings”, this area focuses on the energy spent in households. The EU target is to reduce this energy consumption by improving the energy efficiency of residential buildings and their electric appliances. Therefore, *Final energy consumption in households* (which measures the total final residential energy consumption) and *Final energy consumption in households by fuel* (solid fuels, total petroleum fuels, gas, electrical energy, derived heat and renewable energies) have been chosen as indicators to measure the progress toward this dimension.

As the Roadmap to a resource-efficient Europe (European Union, 2011b.) pointed out, "over the 20th century, the world increased its fossil fuel use by a factor of 12, whilst extracting 34 times more material resources"; Thus, energy consumption based on coal, oil, and natural gas have a negative on resource efficiency as fossil fuels draw on finite resources that will eventually dwindle. In contrast, energy consumption based on renewable energy resources- such as wind and solar energy- have a positive impact on resource efficiency as they are constantly replenished and will never run out.

3.1.2. Indicators of *Ensuring efficient mobility* dimension

Finally, the indicators chosen to measure the progress towards the dimension of "Ensuring efficient mobility" are related to pollutant emissions from transport and mode of transport of passengers and freights in inland transport. Thus**,** *Average carbon dioxide emissions per km from new cars* measures the average emissions of carbon dioxide per kilometer by new passenger cars registered in a given year; *Pollutant emissions from transport* analyzes the transport emissions of nitrogen oxides, non-methane volatile organic compound and particulate matter (< 10μm).

Regarding the mode of transport, *Modal split of passenger transport* measures the share of each mode of transport in total inland transport (motor coaches, buses and trolley buses, passenger cars and trains) based on the transport performance expressed in passenger-kilometers (pkm, which represents one passenger travelling a distance of one kilometer). Moreover, *Modal split of freight transport* is defined as the percentage share of each inland mode of transport (roads, railways and inland waterways) in total transport expressed in ton-kilometers (tkm).

Road transport by cars which is considered the least sustainable passenger transport mode as they use petroleum which determines considerable resource impacts and environmental impacts. Thus, emissions from transport variables and variables related to transport of persons in passenger cars and transport of freight in roads have a negative impact on resource efficiency.

European citizens should shift towards more energy efficient by shifting from individual road to rail and other public passenger transport. Thus *Modal split of passenger transport* -motor coaches, buses and trolley buses and trains- and *Modal split of freight transport*- railways and inland waterways- have a positive impact on resource-efficiency.

3.2. Method to calculate the Resource-Efficiency Capacity Index

Once the variables have been chosen, the methodology to calculate the Resource-Efficiency Capacity Index (RECI) is developed through the following phases based on Udo and Jason (2009). Calculation is based on the different observed and obtained data for each one of the 29 variables in the EU-28 member states. In order to control the country size, a per capita calculation was done for some variables.

Firstly, a national relative performance (*NRP_{ij}*) is calculated for each variable by using the general formula:

$$NRP_{ij} = \frac{\left(NPD_{ij} - WPD_j\right)}{\left(BPD_j - WPD_j\right)} \qquad \text{(Eq. 2)}$$

where i represents each nation in the sample (i=1,…, 28), NPD_{ij} the National Performance Data of country i for variable j, WPD_j the Worst Performance Data in the EU-28 countries and BPD_j the Best Performance Data in the sample. When the variable j has a positive (P) impact on resource efficiency the WPD_j corresponds with the minimum value in the data set and the BPD_j corresponds with the maximum value in the data set. If the indicator j has negative (N) impact on resource efficiency the WPD_j corresponds with the maximum value in the data set and the BPD_i corresponds with the minimum value in the data set. The normalized values have an identical range between 0 and 1.

Secondly, the composite index for each category ($CI_{i,m}$) is calculated by simply averaging[5] of the corresponding variables belonging to each category as:

$$CI_{i,m} = \frac{1}{N} \times \sum_{j=1}^{N} NRP_{ij} \qquad \text{(Eq. 3)}$$

where *m* represents each category (m=*Turning the waste into a resource, Supporting research and innovation, Getting the prices right Improving buildings and Ensuring efficient mobility*) and N the number of variables used to define the category. Category index scores for have an identical range between 0 and 1 (a value of 1 means that a country has the best performance in all indicators included in that category and 0 the worst performance).

Thirdly, for each dimension of the composite index (k= *Transforming the economy*, *Improving buildings* and *Ensuring efficient mobility*) and for each country i, a following score is calculated:

$$DI_{i,k} = \sum_{m=1}^{M} CI_{i,m} \qquad \text{(Eq. 4)}$$

where *M* is the number of categories considered in each dimension. Composite index scores for each dimension (and country) are obtained by aggregating category index scores, so the lower limit are 0 and the upper limit is equal to the number of categories included in each dimension

Finally, the Resource-Efficiency Capacity Index (RECI) of each nation is calculated as the sum of the three dimensions scores:

$$RECI_i = \sum_{k=1}^{3} DI_{i,k} \qquad \text{(Eq. 5)}$$

Resource-Efficiency Capacity Index has a range between 0 and 5.

[5] Weights could reflect the relative importance of each of the variables. Thus, weights may be based on experts' consultations or the analyst's perceptions of the attitude of policy makers, among other. Multivariate techniques, as principal component analysis, present an empirical and relatively more objective option for weight selection. See Booysen (2002) for a very interesting discussion of weighting procedures and examples of weights used by known composite index. This author indicates that since different weighting systems imply different results and, given the subjectivity inherent in many of these weighting systems, no weighting system is above criticism. The first option, though, is to employ a uniform weighting system in compiling index values as Singh, et al (2009) pointed out.

Table 3 shows the main descriptive statistics of the variables used in the analysis. In an average EU-28 generates 2054.8 kg per capita of waste, and it has landfill rate of waste of 38%. The average of Recycling rate of municipal waste and recycling rate of e-waste are 31.9% and 33.9% respectively. Regarding the Eco-innovation index, the lowest is 38 (Bulgaria) and the highest is 138 (Finland and Sweden). The Environmental tax revenues represents in average 7.4% of total revenues from taxes and social contributions and 2.6% of the GDP. Household is the sector that most energy taxes paid (43.7 % on average). This sector, that consumes 0.6 tones of oil equivalent pc of energy, has a high proportion of it final energy consumption based on fossil- fuels (13.2%, 12.2% and 20.3% of petroleum, gas and solid fuels respectively). Regarding transport variables, the European average in carbon dioxide emissions per km from new passenger cars is 128.9 gram of CO_2 per km. On average, the EU-28 members have a decrease emissions from transport in relation of year 2000 (nitrogen oxides emissions, non-methane volatile organic compounds emissions and particulates < 10µm emissions have decreased 22.6%, 67.6% and 34% respectively R*ecycling rate of e-waste* compared to the year 2000). EU-28 members do not use preferably environmentally friendly forms of transports as passenger transport in individual cars represents the 82.0% in total inland passenger-km and freight transport in road represents % 77.1 in total of inland freight tone-km.

Table 3. Descriptive data analysis. Year 2013

Variable	Units	Mean	Min	Max	St.Dev.
Generation of waste	kg per capita	2054.8	620.0	8589.0	1571.4
Landfill rate of waste	%	38.0	1.0	93.0	27.2
Recycling rate of municipal waste	%	31.9	2.6	64.5	15.4
Recycling rate of e-waste	%	33.9	9.9	62.6	12.2
Eco-innovation index	Index (EU=100)	84.7	38.0	138.0	30.8
Environmental tax revenues	% of total revenues from taxes and social contributions	7.4	4.5	10.5	1.7
	% of total revenues GDP	2.6	1.6	4.3	0.7
Energy taxes	Mils EUR pc	0.5	0.1	1.8	0.4
Energy taxes paid by households	%	43.7	0.0	74.4	16.0
Energy taxes paid by Industry and construction	%	18.8	4.0	41.7	10.0
Energy taxes paid by Transportation and storage	%	13.9	0.1	26.1	5.8
Energy taxes paid by Services	%	14.4	0.0	32.1	7.3
Energy taxes paid by Agriculture, forestry and fishing	%	3.0	0.0	7.5	2.4
Final energy consumption in households	Tonnes of oil equivalent pc	0.6	0.2	0.9	0.2
Final consumption of Total petroleum products in households	%	13.2	0.1	38.0	12.9
Final consumption of gas in households	%	12.2	0.0	37.9	13.2
Final consumption of Solid fuels in households	%	20.3	1.3	45.6	13.4
Final consumption of Electrical energy in households	%	26.8	12.0	62.1	12.5
Final consumption of Renewable energies in households	%	3.3	0.0	33.9	7.3
Final consumption of Derived heat in households	%	25.3	0.0	73.5	21.0
Average carbon dioxide emissions per km from new passenger cars	Gram of CO_2 per km	128.9	109.1	147.1	10.8
Nitrogen oxides emissions from transport	Index (2000 = 100)	77.4	21.6	172.1	34.1
Non-methane volatile organic compounds emissions from transport	Index (2000 = 100)	32.4	10.9	79.5	13.9
Particulates < 10µm emissions from transport	Index (2000 = 100)	66.0	20.1	118.2	21.0
Modal split of passenger transport: Motor coaches, buses and trolley buses	% in total inland passenger-km	12.4	3.3	22.3	4.8
Modal split of passenger transport: Passenger cars	% in total inland passenger-km	82.0	67.5	91.4	4.8

Modal split of passenger transport: Trains	% in total inland passenger-km	6.1	0.8	12.7	3.3
Modal split of freight transport: Railways	% in total inland freight tone-km	19.5	1.1	60.4	14.6
Modal split of freight transport: Inland waterways	% in total inland freight tone-km	7.9	0.0	38.9	10.6
Modal split of freight transport: Roads	% in total inland freight tone-km	77.1	39.6	100.0	16.4

Source: Own elaboration from European Commission (n.d.), Eurostat database, http://ec.europa.eu/eurostat/data/database (European Commission, 2015a) (Last update: 10 December 2016- with that date, the most recent year for which all variables are available is 2013). The complete Scoreboard database is available at http://ec.europa.eu/eurostat/web/europe-2020-indicators/resource-efficient-europe.

4. Results

In this section, we show a cross-country comparison of the obtained results for the REDCI for the year 2013. A deep analysis of the results is done for each dimension of the capacity index (*Transforming the economy, Improving buildings and Ensuring efficient mobility*). It allows us to explain in more detail the success factors and the necessity of establishing new specific policies in member states with high and low values respectively in the aggregated indeces. Moreover, a comparison of the capacity index is done for years 2003 and 2014.

4.1. Index of "Transforming the Economy"

Figure 1 shows the results obtained in the Index of *Transforming the Economy* in 2013 according to Eq. 2, Eq. 3 and Eq.4. Denmark (2.20), Sweden (2.15), Finland (2.12), Germany (1.95) and United Kingdom (1.83) have the highest score in the EU-28.

However, the worst results are obtained for Slovakia (0.81), Malta (1.06), Poland (1.1), Estonia (1.16) and Bulgaria (1.16) with the consequent negative impact on resource efficiency. Moreover, these countries do not always remain constant in each group for years 2004 and 2013 (see Table 4). In this context, in relative terms of 2004, Austria, Slovenia and the Netherlands worsened their positions above 10% and Slovenia and the Netherlands improved their positions above 20% in 2013 as it is shown in the last column of Table 4.

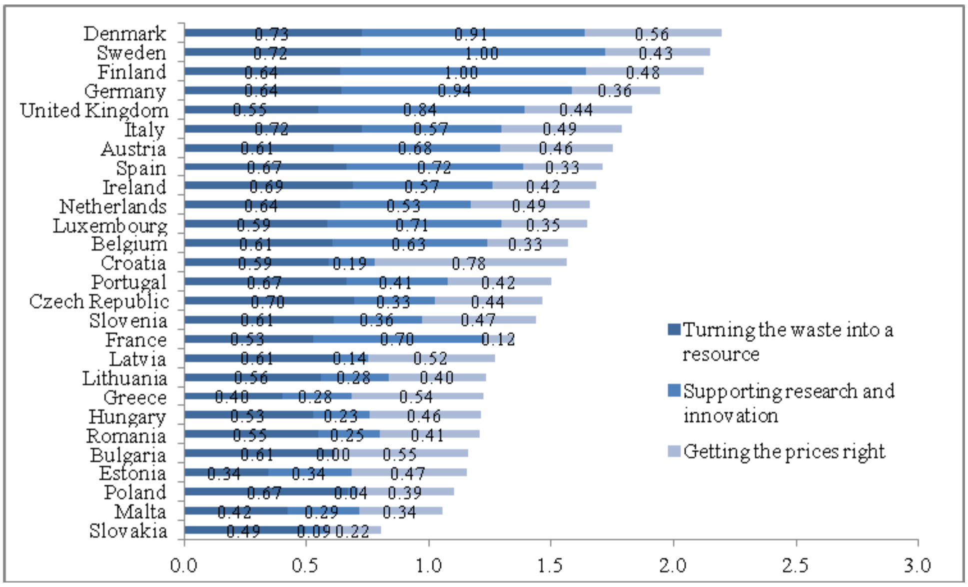


Figure 1. Index of *Transforming the Economy*. EU-28. 2013.

Denmark (2.20), Sweden (2.15), Finland (2.12), Germany (1.95) and United Kingdom (1.83) have caused a high transformation of the economy as it is shown in the values of their three sub-indices. The cases of Denmark, Sweden and Finland are emphasized because they are at least 0.6 points higher than the EU-28 average in the three sub-indices of *transforming the economy* as it is shown in Table 4.

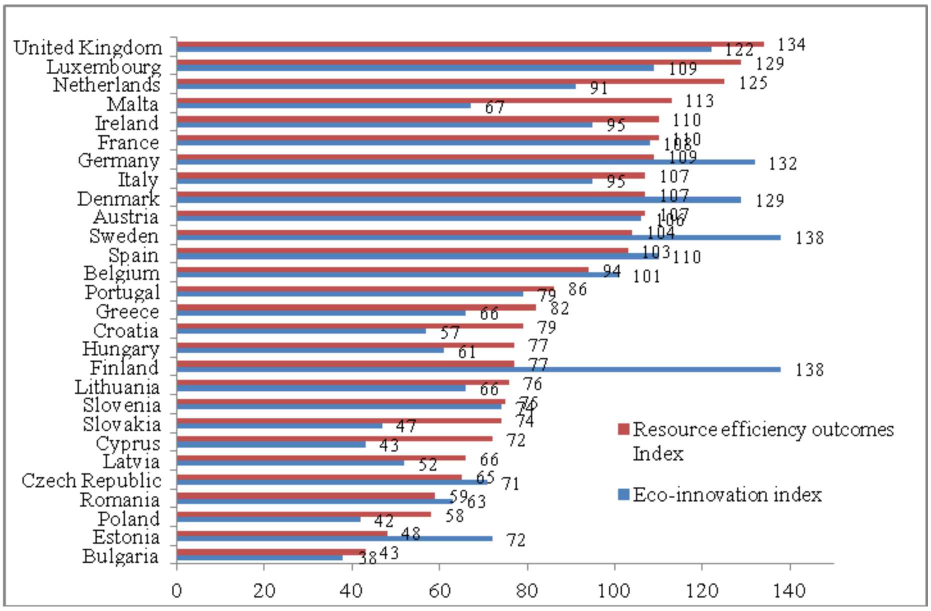
Table 4. Results in Sub-indices of *Turning the Waste into a Resource*, S*upporting Research Innovation* and *Getting the Prices Right*. EU-28. 2013 and 2004.

EU-28*	2013				2004	Index change (%)
	Index Transforming the Economy	Sub-indices			Index Transforming the Economy	
		Turning the waste into a resource	Supporting research and innovation	Getting the prices right		
Denmark	2.20	0.73	0.91	0.56	2.42	-9.09
Sweden	2.15	0.72	1.00	0.43	1.89	13.76
Finland	2.12	0.64	1.00	0.48	2.03	4.43
Germany	1.95	0.64	0.94	0.36	2.06	-5.34
UK	1.83	0.55	0.84	0.44	1.79	2.23
Italy	1.79	0.73	0.57	0.50	1.74	2.87
Austria	1.75	0.61	0.68	0.46	2.21	-20.81
Spain	1.71	0.67	0.72	0.33	1.39	23.02
Ireland	1.69	0.69	0.57	0.42	1.60	5.62
Netherlands	1.66	0.64	0.53	0.49	1.88	-11.70
Luxembourg	1.65	0.59	0.71	0.35	1.69	-2.37
Belgium	1.57	0.61	0.63	0.33	1.58	-0.63
Croatia	1.56	0.59	0.19	0.78	1.24	25.81
Portugal	1.50	0.67	0.41	0.42	-	-
Czech Rep.	1.46	0.70	0.33	0.44	1.26	15.87
Slovenia	1.44	0.61	0.36	0.47	1.64	-12.20
France	1.35	0.53	0.70	0.13	1.41	-4.26
Latvia	1.27	0.61	0.14	0.52	1.24	2.42
Lithuania	1.24	0.56	0.28	0.40	1.12	10.71
Greece	1.22	0.40	0.28	0.54	-	-
Hungary	1.22	0.53	0.23	0.46	-	-
Romania	1.21	0.55	0.25	0.41	1.02	18.63
Bulgaria	1.16	0.61	0.00	0.55	1.41	-17.73
Estonia	1.16	0.34	0.34	0.47	0.74	56.76
Poland	1.10	0.67	0.04	0.40	1.34	-17.91
Malta	1.06	0.42	0.29	0.35	1.22	-13.11
Slovakia	0.81	0.49	0.09	0.22	1.08	-25.00
Cyprus	-	0.51	0.05	-	-	-

*Cyprus is not included as there is not information to calculate its sub-index in the category "*Getting the prices right*"

The success of these member states is given by being leaders in the EU in eco-innovation. In the case of Denmark, a wide range of public institutions has supported eco-innovation by means of policy-making, direct funding and co-financing programmes for investment and development (European Commission, 2015b). These programmes have allowed this country to be leader in eco-innovation in air, water, waste, energy and clean transport areas. Likewise, eco-innovation has been an essential concept in Sweden´s and Finland´s environmental policy strategies (their sub-indices of supporting and research innovation duplicate the value of the EU-28 average). Sweden has obtained a strong reputation in environmental performance that is based on a pro-active approach to develop technological innovation in waste management, water and sewage treatment, renewable energy, air purification and increasing energy efficiency (Eco-Innovation Observatory, 2014). Finally, in Finland, the innovation policy incorporates the integration of environmental issues within all aspects of research and development. Besides, this country considers other environmental strategies and measures, in which environmental taxes can be emphasized.

Germany has one of the highest recycling rates in Europe in 2013 (second place after Slovenia in 2013) (European Commission, 2015b). Likewise, it is leader in eco-innovation areas related to circular economy technologies (such as, automatic separation processes and decentralized water treatment) and renewable energy technologies as a consequence of the use of relevant action plans and funding for research (Eco-Innovation Observatory, 2014). United Kingdom has been characterized by a good performance in eco-innovation areas related to renewable energy, energy efficiency and waste recycling. It is highlighted that UK has the highest score in the component of resource efficiency outcomes of the eco-Innovation Index[6], as it is shown in Figure 2.



Source: Eco-Innovation Index (http://www.eco-innovation.eu)

Figure 2: Eco-Innovation Index and Resource Efficiency Outcomes Index. EU-28. 2013

It should be noticed that, although these member states (Denmark, Sweden, Finland, Germany and United Kingdom) have high scores in the index of category *supporting research and innovation*, none of them has a value of 1 in the categories of *turning the waste into a resource* and *getting the prices righ*t. Therefore, reinforcing measures are still necessary in these issues in these member states in order to obtain greater resource efficiency.

On the other hand, the worst values of the index of *transforming the economy* are observed in Slovakia (0.81), Malta (1.06), Poland (1.10), Lithuania (1.16) and Bulgaria (1.16). Slovakia causes the lowest transformation of the economy due to the scarce attention that eco-innovation and environmental taxes receive in this member state. Its eco-innovation is below the EU-28 average and it is among the member states with lower eco-innovation performance

[6] Country profiles and explanation of the Eco-Innovation Index and its dimensions can be found at http://www.eco-innovation.eu/

(Eco-innovation Observatory, 2014). Likewise, the share of environmental taxes revenue in proportion to Slovakia´s gross domestic product is the fifth-lowest percentage in the EU-28 (Ecologic Institute, 2014). Therefore, a reinforcement of its innovation policy framework and environmental tax policy should be necessary in order to improve its resource efficiency.

Poland and Bulgaria are characterized by having the worst values in s*upporting research and innovation* (values close to zero). The main problems in Poland are given by the difficult access to capital, uncertain return on investment and weak economic and fiscal incentives to encourage eco-innovation (European Commission, 2015b). In the case of Bulgaria, the improvements of the legislative framework have not been enough due to the persistence of economic, technical, financial, environmental and administrative barriers that hindered eco-innovation. Moreover, according to the component of resource efficiency outcomes of the eco-Innovation Index, Bulgaria is ranged as last among the EU 28 (as it was shown in Figure 2).

In Malta, the establishment of measures to promote high quality recycling was introduced after 2013 which reduced the value of its sub-index of *turning the waste into a resource*. Finally, Estonia has had weaknesses in its research and innovation as the low level of investment in the past and older technologies reduced material, water and energy productivity. Hence, a reinforcement of its present regulatory framework should be developed.

The scores of the index of *transforming the economy* show that, in relative terms of 2004, Austria, Slovenia and the Netherlands worsened its position in 20.81%, 12.20% and 11.70% respectively whilst Croatia and Spain improved their situation in 25% and 23.02%, respectively, in the period 2004-2013.

Austria (2.21 in 2004 and 1.75 in 2013) has developed an environmental tax policy that resulted in both share of environmental tax revenues in total tax revenues and implicit tax rate on energy lower than the EU-28 average (Ecologic Institute, 2014). These characteristics, together with the evolution of the other member states in these variables, resulted in a worsening in the relative position of Austria. In the case of Slovenia (1.64 in 2004 and 1.44 in 2013), a largest cohesion and environmental project has been required. It has been implemented in 2015 with the creation of the Regional Waste Management Centre whose aim is intended for mechanical-biological processing of waste, separately collected biological waste to produce compost, and residual municipal waste (European Commission, 2015b). In the Netherlands (1.66 in 2004 and 1.88 in 2013), eco-innovation concept has not been very explicit in its regulation during the period analyzed although nowadays it has been gaining more attention in policy making (Eco-Innovation Observatory, 2014).

The improvement of Croatia (1.24 in 2004 and 1.56 in 2013) is given by environmental tax that involve 8.9% of overall tax revenue in 2012 and it is above the EU-28 average (Ecologic Institute, 2014). In the case of Spain (1.39 in 2004 and 1.71 in 2013), allocation of government for environmental research and development is higher than in most of other member states, which resulted in greater resource and energy efficiency in production processes (European Commission, 2015b).

4.2. Index of "Improving Buildings"

Figure 3 shows the results obtained in the Index of *Improving Buildings* in 2013 according to Eq.2. Romania (0.83), Slovenia (0.78), Latvia (0.77), Portugal (0.77) and Bulgaria (0.76) have the highest score in the EU-28. However, the worst results are obtained for Malta (0.45), Ireland (0.49), Luxembourg (0.51), Belgium (0.54) and Sweden (0.55) with the consequent negative impact on resource efficiency.

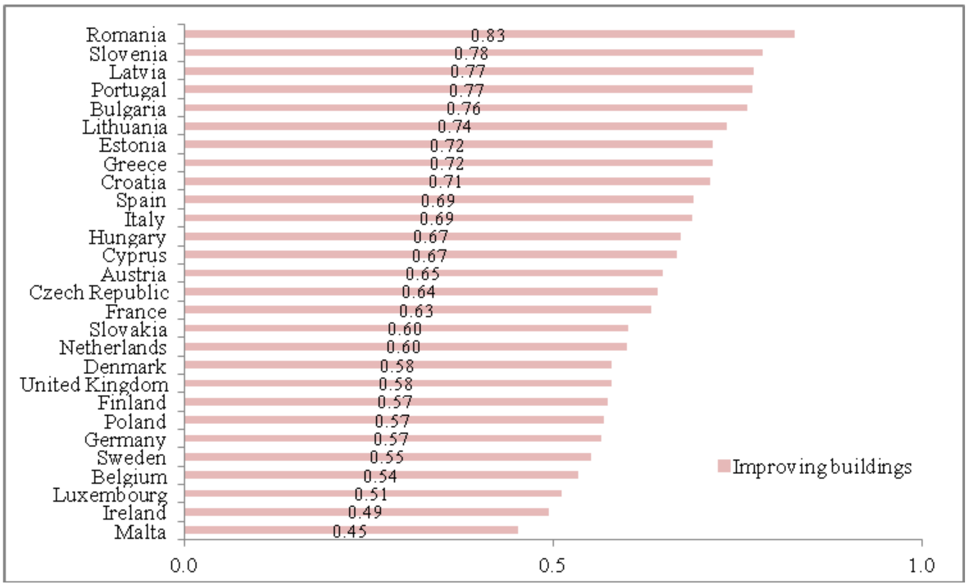


Figure 3. Index of *Improving Buildings*. EU-28. 2013

The case of Romania is emphasized (its index value is almost 0.20 points higher than the EU-28 average). This member state has developed important improvements in energy efficiency for household heating (0.7 points higher than the EU-28 average in 2012) as the development of behavioral savings linked to greater prices and lower incomes (Bosseboeuf, 2015).

Latvia, Slovenia and Bulgaria have been characterized by having the largest share of renewable energy in the EU in 2012 (around 45% in Latvia and above 30% in Slovenia and Bulgaria) (Ecologic Institute, 2014). Likewise, Slovenia has long-running programmes providing personal advice for encouraging households´ energy saving behavior and has introduced energy management system in ministries and municipalities since 2012 that requires energy audits and energy accounting. In the case of Portugal, a very strong reduction in household energy consumption is observed since 2008 (by above 4% by year) and it is above the energy efficiency requirements of the Energy Services Directives (Bosseboeuf, 2015).

On the other hand, the lowest scores in the building index are observed in Malta (0.45), Ireland (0.49), Luxembourg (0.51), Belgium (0.54) and Sweden (0.55). Thus, reinforcing actions in energy efficiency policies are necessary in these member states. So, Malta has had lower improvements in energy efficiency than the EU-28 average and Luxembourg and Sweden have been characterized by having a large use of electricity for space heating (more than twice the EU-28 average). In the cases of Belgium and Ireland, recent regulations have been developed in this field although their implementation has been still scarce and new legislation might be necessary (Build up, 2013).

With regard to the progress made for each EU-28 country in energy-efficiency building from 2003 to 2013, it is shown in Table 5.

Table 5. Evolution of the Index of Improving Buildings. EU-28. 2004 and 2013

EU-28	Index of Improving Buildings		
	2013	2004	Index

			change (%)
Romania	0.83	0.78	6.41
Slovenia	0.78	0.70	11.43
Latvia	0.77	0.81	-4.94
Portugal	0.77	0.80	-3.75
Bulgaria	0.76	0.71	7.04
Lithuania	0.74	0.75	-1.33
Estonia	0.72	0.70	2.86
Greece	0.72	0.66	9.09
Croatia	0.71	0.68	4.41
Spain	0.69	0.69	0.00
Italy	0.69	0.64	7.81
Hungary	0.67	0.63	6.35
Cyprus	0.67	0.71	-5.63
Austria	0.65	0.65	0.00
Czech Republic	0.64	0.61	4.92
France	0.63	0.65	-3.08
Slovakia	0.60	0.59	1.69
Netherlands	0.60	0.62	-3.23
Denmark	0.58	0.58	0.00
United Kingdom	0.58	0.58	0.00
Finland	0.57	0.59	-3.39
Poland	0.57	0.57	0.00
Germany	0.57	0.59	-3.39
Sweden	0.55	0.54	1.85
Belgium	0.54	0.54	0.00
Luxembourg	0.51	0.52	-1.92
Ireland	0.49	0.52	-5.77
Malta	0.45	0.46	-2.17

In relative terms of 2004, Spain, Austria, Denmark, United Kingdom, Poland and Belgium remain constant. Ireland and Cyprus worsened their positions above 5% and Slovenia improved their position above 10%. Romania, Slovenia, Latvia, Portugal and Bulgaria have caused improvements in the buildings as it is shown in the values of their indices of improving buildings.

The scores of the index of *improving buildings* show that, in relative terms of 2004, Ireland and Cyprus worsened its position in 5.77% and 5.63% respectively whilst Slovenia improved its situation in 10% in the period 2004-2013.

Ireland (0.52 in 2004 and 0.49 in 2013) and Cyprus (0.71 in 2004 and 0.67 in 2013) have been characterized by great thermal use of electricity (space heating, cooking and water heating) (around 50%) and higher share for electrical appliances and lighting (around 20%) respectively (Bosseboeuf, 2015).

The improvement of Slovenia (0.70 in 2004 and 0.78 in 2013) has been given by the intensive use of programmes to encourage households´ energy saving behavior and the use of energy management systems in public sector.

Although these member states have good scores in this index, none of them has a value of 1. Therefore, reinforcing measures are still necessary in *improving buildings* in all member states in order to obtain greater resource efficiency.

4.3. Index of "Ensuring Efficient Mobility"

Figure 4 shows the results obtained in the Index of *Ensuring Efficient Mobility* in 2013. Hungary, Czech Republic, Croatia, Malta and Spain have the highest score in the EU-28. However, the worst results are obtained for Greece, Austria, Ireland, Cyprus and Bulgaria with the consequent negative impact on resource efficiency.

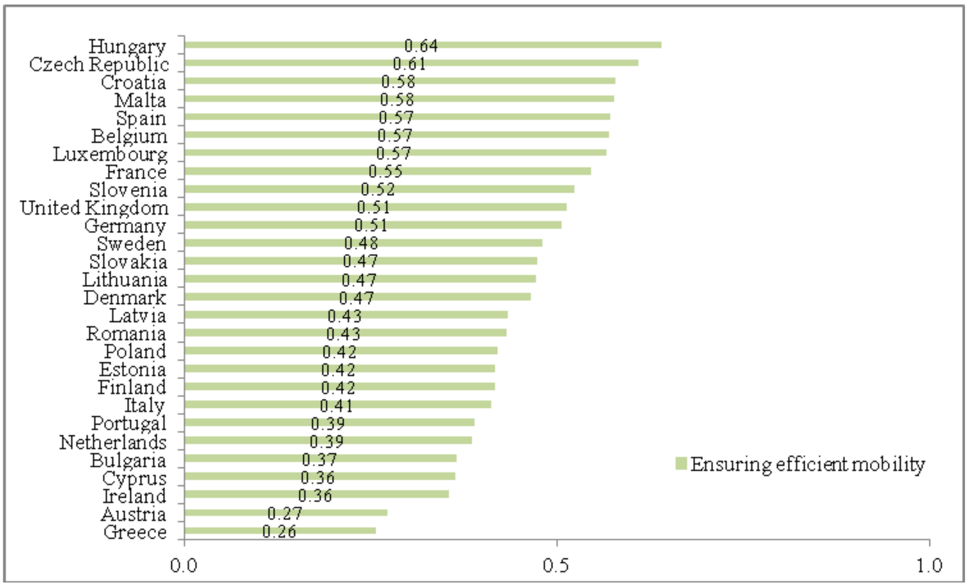


Figure 4. Index of *Ensuring Efficient Mobility*. EU-28. 2013

These countries do not always remain constant in each group for 2004 and 2013. In this context, in relative terms of 2004, Austria and Cyprus worsened their positions above 35% and Luxembourg improved its position above 100% in 2013 as it is shown in the last column of Table 6.

Hungary, Czech Republic, Croatia, Malta and Spain have caused greater efficiency in their mobility. Hungary has been characterized by being among the member states with the highest number of modal shift measures to provide more energy-efficient transport (fiscal, normative and infrastructural measures). Czech Republic and Croatia have the highest use of public transport in the EU (Faberi *et al*., 2015). Likewise, Croatia has developed the "polluter pays" principle in a transport measure that penalizes vehicles with higher emission levels.

In the case of Malta, it is among the only six member states that had emissions below 120gCO_2/km in 2013 for new cars (Faberi *et al.*, 2015) as the registration of relatively small cars. Spain has developed an exhaustive regulatory framework based on the 2005-2007 and 2011-2020 Action Plans. These regulations include fifteen measures categorized into modal transfer to more efficient transport modes, efficient use of means of transport and improvement of the energy efficiency in vehicles. These actions have allowed this member state to get more efficiency in its mobility.

Despite these member states have a suitable management in the index of ensuring efficient mobility, none of them has a value of 1. Therefore, reinforcing measures are still necessary in this issue in these member states in order to obtain greater resource efficiency.

On the other hand, the lowest values of the Index of *Ensuring Efficient Mobility* are observed in Greece (0.26), Austria (0.27), Ireland (0.36), Cyprus (0.36) and Bulgaria (0.37). Greece and

Ireland cause low efficiency in the mobility that can be explained by having a share of rail and water lower than 10%. Likewise, Greece´s average specific consumption of the car fleet is five times EU-28 average (Faberi *et al*., 2015). In the cases of Austria and Cyprus, the share of cars in the domestic energy consumption of transport is above 60% (Faberi *et al*., 2015) with the consequent reduction in efficient mobility. Bulgaria has been characterized by a reduction in the share of efficient transport modes –rail and water- as well as a reduction in the use of public transport. Therefore, it is important to reinforce the regulatory framework in these member states.

The scores of the index of *ensuring efficient mobility* show that, in relative terms of 2004, Austria and Cyprus worsened their positions in 38.64% and 36.84% respectively while Luxembourg improved its situation in 119.23% in the period 2004-2013.

In the cases of Austria (2.21 in 2004 and 1.75 in 2013) and Cyprus (0.36 in 2004 and 0.57 in 2013), the share of cars in the domestic energy consumption has been very high (above 60%) (Faberi *et al*., 2015), which worsened their positions in this index. The improvement of Luxembourg has been given by the modal shift from private to collective modes during this period.

Table 6. Evolution of the Index of Ensuring Efficient Mobility. EU-28. 2004 and 2013

EU-28	Ensuring Efficient Mobility		
	2013	2004	Index change (%)
Hungary	0.64	0.61	4.92
Czech Republic	0.61	0.54	12.96
Croatia	0.58	0.33	75.76
Malta	0.58	0.47	23.40
Spain	0.57	0.45	26.67
Belgium	0.57	0.52	9.62
Luxembourg	0.57	0.26	119.23
France	0.55	0.43	27.91
Slovenia	0.52	0.45	15.56
United Kingdom	0.51	0.36	41.67
Germany	0.51	0.46	10.87
Sweden	0.48	0.42	14.29
Slovakia	0.47	0.48	-2.08
Lithuania	0.47	0.33	42.42
Denmark	0.47	0.48	-2.08
Latvia	0.43	0.52	-17.31
Romania	0.43	0.41	4.88
Poland	0.42	0.53	-20.75
Estonia	0.42	0.59	-28.81
Finland	0.42	0.38	10.53
Italy	0.41	0.41	0.00
Portugal	0.39	0.43	-9.30
Netherlands	0.39	0.48	-18.75
Bulgaria	0.37	0.46	-19.57
Cyprus	0.36	0.57	-36.84
Ireland	0.36	0.37	-2.70
Austria	0.27	0.44	-38.64
Greece	0.26	0.34	-23.53

4.4. Resource-Efficiency Capacity Index

In Figure 5, we can observe the results obtained for the Resource-Efficiency Capacity Index[7] in 2013. Denmark (3.35), Sweden (3.22), Finland (3.13), Germany (2.99) and Austria (2.98) have the highest values in that index and therefore greater resource efficiency. However, the worst results are obtained for Slovakia (1.8), Malta (1.92), Poland (1.93), Lithuania (2.25) and Bulgaria (2.28).

The success of the first five member states in the Resource-Efficiency Capacity Index has been given by the development of a suitable management of resources related to waste management, energy consumption, transport efficiency as well as the development of research and innovation and environmental tax policies. The following characteristics are emphasized: a) the development of a wide range of policies to support eco-innovation (in Denmark), b) the use of a pro-active approach to develop environmental technologic innovation (in Sweden), c) the establishment of a suitable environmental tax policy (in Finland), d) the implementation of national programmes based on waste management that encourage recycling (in Germany) and e) the establishment of an intensive environmental performance in air and water quality, waste management, nature protection and organic farming (in Austria).

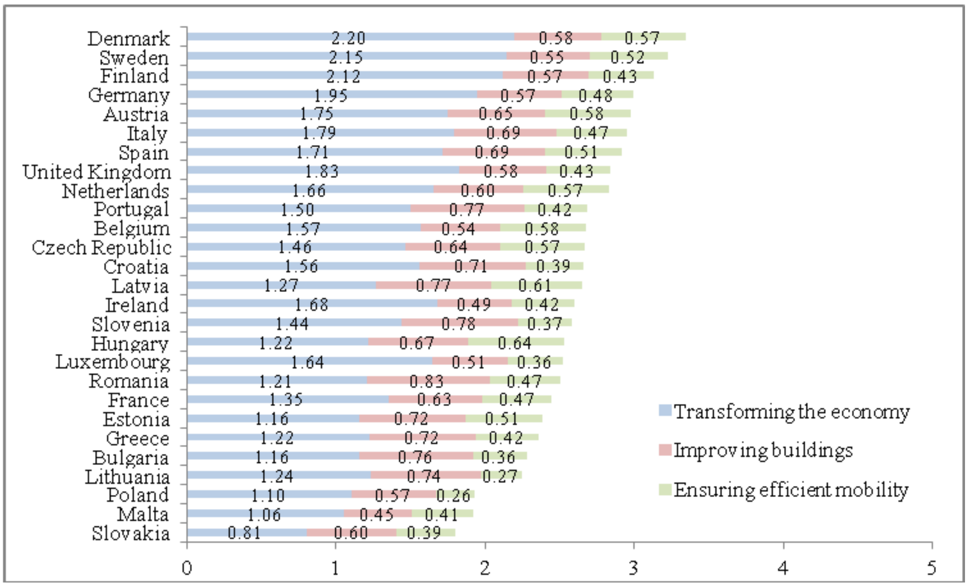


Figure 5. Resource-Efficiency Capacity Index. EU-28. 2013

Reinforcing policies are necessary in member states with the lowest values in the Resource-Efficiency Capacity Index (Slovakia, Malta, Poland, Lithuania and Bulgaria). As recommendations, we propose the coordination of resource-efficiency policies concerning both more sustainable consumption and production, in order to obtain the 2020, 2030 and 2050 targets in resource efficiency and climate change.

Table 7 shows the progress made by each member state towards a more resource-efficiency economy in 2004 and 2013.

[7] When data is excessively dispersed, the inclusion of outliers could substantially influences results as Booysen (2002) pointed out. One of the procedures to the correction of outliers is based on the calculation of the 97,5th and 2,5th percentiles values. Later, maximum and minimum values are replaced by their respective percentile values. This is a proper procedure of very ample distributions (World Economic Forum, 2002). In our case, the inclusion of extreme values did not substantially influence our results.

Table 7. Evolution of the Resource-Efficiency Capacity Index. EU-28. 2004 and 2013

EU-28	Resource-Efficiency Composite Index		
	2013	2004	Index change (%)
Denmark	3.35	3.48	-3.74
Sweden	3.22	3.3	-2.42
Finland	3.13	3.11	0.64
Germany	2.99	3	-0.33
Austria	2.98	2.99	-0.33
Italy	2.95	2.85	3.51
Spain	2.92	2.79	4.66
United Kingdom	2.84	2.78	2.16
Netherlands	2.83	2.73	3.66
Portugal	2.69	2.65	1.51
Belgium	2.68	2.58	3.88
Czech Republic	2.67	2.57	3.89
Croatia	2.66	2.52	5.56
Latvia	2.65	2.5	6.00
Ireland	2.6	2.49	4.42
Slovenia	2.59	2.48	4.44
Hungary	2.53	2.44	3.69
Luxembourg	2.52	2.4	5.00
Romania	2.5	2.26	10.62
France	2.45	2.2	11.36
Estonia	2.38	2.19	8.68
Greece	2.36	2.16	9.26
Bulgaria	2.28	2.15	6.00
Lithuania	2.25	2.03	10.84
Poland	1.93	-	-
Malta	1.92	-	-
Slovakia	1.8	-	-
Cyprus	-	-	-

The countries positioned in each group do not always remain constant for 2004 and 2013. In this context, in relative terms of 2004, France, Lithuania and Romania improved their position above 10% in 2013 as it is shown in the last column of Table 7. However, there is not important worsening of this composite index in relative terms. Between 2004 and 2013, France (2.2 in 2004 and 2.45 in 2013) and Lithuania (2.03 in 2004 and 2.25 in 2013) have been characterized by developing new actions in *improving buildings* that derived in greater resource efficiency. In the case of Romania (2.26 in 2004 and 2.5 in 2013), the measures established in *ensuring efficient mobility* have improved their situation in resource efficiency.

5. Discussion

The results of this paper shows that the EU should continue working in resource efficiency in order to achieve the targets set for 2020, 2030 and 2050 in resource efficiency and climate change. It is essential as the traditional model of economic development based on increasingly resource use and harmful emissions does not seem sustainable in the long-term. Nowadays, resource efficiency and climate change are policy priorities in the EU policies. In fact, the second objective of the 7th Environment Action Programme establishes the need to "*turn the European Union into a resource-efficient, green and competitive low-carbon economy*" (European Commission, 2013).

The best scores in the Resource-Efficiency Capacity Index have been obtained for Denmark, Sweden, Finland, Germany and Austria. *Denmark* has been characterized by a suitable performance in the dimension of transforming the economy. It is leader in the categories of turning the waste into a resource and getting the prices right. On the one hand, waste management and separate collection has been mainly regulated in Denmark by the municipalities regarding source separation and separate collection of household and household-like waste (European Commission, 2015b). On the other hand, this member state has the highest implicit tax rate on energy in the EU-28 (Eurostat) with the consequent positive impact on developing an efficient use of energy resource. *Sweden* and *Finland* have developed an important support of research and innovation. More specifically, eco-innovation has been a key component in their environmental policy strategies. Both member states have implemented policies that have encouraged research and development in water treatment, waste management and renewable production. *Germany* and *Austria* have also been characterized by outstanding values in the dimension of transforming the economy. In the case of Germany, it has been characterized by good waste infrastructures and recycling rates as well as a strong standing in solutions of innovative waste management (Eco-innovation Observatory, 2014). Austria has developed a relevant environmental performance in areas related to waste management, water quality and nature protection that have improved its standing in resource efficiency.

Regarding the worst results of the Resource-Efficiency Capacity Index, the cases of Cyprus, Slovakia, Malta, Poland and Lithuania have been identified. *Cyprus* and *Slovakia* might require actions to reinforce research and innovation support. In the case of Cyprus, it has not a sectoral concentration that can encourage innovation but it is dominated by small and medium enterprises. Slovakia has been characterized by a weak framework of research and development and innovation although it has implemented a new Research and Innovation Strategy for Smart Specialization that might be considered as a first step in this issue (Eco-innovation Observatory, 2014). *Malta* has the worst value in the index of improving building which can have been motivated by the lack of reduction of energy consumption in the period 2005-2012 (Ecologic Institute, 2015). In this context, this member state implemented the third National Energy Efficiency Action Plan in 2014 that proposed an obligation scheme for the only electricity supply and distribution company to cover part of the target from the Energy Efficiency Directive as well as the establishment of obligatory energy audits and systems of energy management for large enterprises. *Poland* and *Lithuania* might mainly require reinforcing actions in research and innovation support to develop an integrated approach in this issue that allow them to eliminate the most important barriers to eco-innovation. Economic nature and administrative barriers are emphasized in the case of Poland whilst the establishment of scarce measures to promote and understand eco-innovation and the lack of cooperation between business and academia are the essential issues in the case of Lithuania (Eco-innovation Observatory, 2014).

Intermediate positions have been obtained for the rest of member states. Reinforcing measures should be developed to improve their positions in the Resource-Efficiency Capacity Index. In the cases of *Italy* and *Estonia,* the implementation of additional measures to ensure efficient mobility might be necessary. The results suggest that *Spain* and *France* require reinforcing policies to improve their positions in terms of environmental and energy taxes (category of getting the prices right). It is emphasized the case of France with the lowest share of environmental tax revenues in overall tax revenue in the EU in 2012 (Ecologic Institute, 2015). *United Kingdom* should develop measures related to energy efficiency improvements particularly in commercial and industrial sectors (category of improving buildings) (Ecologic Institute, 2015). Regarding *Belgium* and *Luxembourg*, the results indicate the necessity of establishment reinforcing actions in energy efficiency (category of improving buildings) and both environmental and energy taxes (category of getting the prices right). Therefore, the development of measures in these member states related to reduce final energy consumption in households and to increase environmental/energy taxes might be essential to increase their resource efficiency. *Czech Republic, Croatia, Slovenia, Hungary* and *Greece* require additional measures in supporting research and innovation due to their low values in eco-innovation (lower than the EU-28 average). In addition to actions to support research and innovation, *Bulgaria, Romania* and *Latvia* also might require new measures in order to increase the share of efficient transport modes (category of efficient mobility). Finally, the results suggest that *the Netherlands* and *Portugal* should develop reinforcing actions in the category of ensuring efficient mobility. These actions should be complemented by additional legislation in the category of ensuring efficient building in the case of *Ireland* as greenhouse gas emissions of this member state has been widely created by households (only behind agricultural sector) (Ecologic Institute, 2015).

In conclusion, we can indicate that all member states should continue making efforts in the field of resources efficiency, including the member states with the best results in the Resource-Efficiency Capacity Index. In this context, integrated production-consumption systems that fulfill societal functions should be developed, rather than seeking isolated efficiency improvements. Thus, the member states with best results (Denmark, Sweden, Finland, Germany and Austria) also require additional measures to achieve that integrated system. The results suggest that Denmark, Sweden and Germany might need additional measures in the dimension of improving buildings as they have values below the EU-28 average (in the cases of Denmark and Sweden). Measures related to increase energy efficiency, such as, the development of programmes to encourage households´ energy saving behavior might be especially relevant. In the case of Austria, the establishment of reinforcing actions in the dimension of ensuring efficient mobility may be interesting as it has the second worst value in this index (only behind Greece). Measures related to promote public transport and thus to reduce the use of private cars, might be recommended. Finally, in the case of Germany, the results suggest that the combination of both improving buildings and efficient mobility actions can be essential to improve its resource efficiency.

Finally, it is necessary to consider that the results obtained for this paper contribute, in a complementary manner, to the EU Resource Efficiency Scoreboard (European Commission, 2014) by means of the calculation of a composite index that simplifies the complexity related to resource-efficiency management into a single value. The index developed in this paper might allow policy-makers to make comparisons between member states in order to propose new actions in this field.

We would like to point out that the sub-theme Nature and ecosystems included in the Roadmap to a Resource Efficient Europe (European Commission, 2011b) has not been yaken into account in the elaboration of the REDCI composite index. In fact a further research will be done based on EU strategic policies for reducing the pressure on biological resources (such sources of minerals, metals and energy, as well as stocks of fish, timber, water, fertile soils, clean air, biomass and biodiversity) and ensuring a smarter use of these resources for the future. The Resource Efficiency Scoreboard includes in Nature and ecosystems sub-theme indicators on farmland bird populations, the area of organic farming and on landscape fragmentation. Clean air as a resource is monitored by two air pollution indicators which show the level of exposure of the urban population to particulate matters. The threat to land and soils as important resources is analyzed by indicators on soil erosion by water and by the gross nutrient balance in agricultural land. Moreover, the Resource Efficiency Scoreboard includes a series of complementary indicators on key natural resources such as water, land, materials and carbon, which will take account of the EU's global consumption of these resources. The ample number of indicators available make necessary a detailed analysis of "nature resource Efficiency" in the framework of the Roadmap to a Resource Efficient Europe. Therefore the research can be extended to elaborate a "nature resource Efficiency capacity Index" to the benchmarking of the performance of EU-28 countries across aspects relate to nature-resource-efficiency policies.

6. Conclusions

Resource efficiency is a key priority for policy-makers in the EU as this concept is one of the seven flagship initiatives in Europe 2020 Strategy. In this context, a Resource-Efficiency Capacity Index is developed based on the calculation of 29 variables classified into 3 dimensions with are related to sub-themes included in the Roadmap to a Resource Efficient Europe (European Commission, 2011b): transforming the economy, improving buildings and ensuring efficient mobility. The composite index may be a useful tool for policy-makers to obtain essential information on this field in order to plan, monitor, assess and develop new resource-efficiency policies.

Results show better scores in Denmark, Sweden, Finland, Germany and Austria. They have been characterized by the development of suitable resource management polices related to waste management, energy consumption, transport efficiency as well as the development of research and innovation and environmental tax policies. Nevertheless, the worst results are obtained for Cyprus, Slovakia, Malta, Poland and Lithuania. In these member states, reinforcing action plans are necessary to get the EU´s 2020 and 2050 targets on resource efficiency and climate change.

The EU has mainly had a positive trend from a production perspective, which is more sustainable, but it has made less progress from a consumption perspective. Therefore, policy-makers have to face important challenges based on new governance approaches that transcend national boundaries and engage businesses and society more fully.

References

Bach, V., Berger, M., Henßler, M., Kirchner, M., Leiser, S. et al. 2016. Integrated method to assess resource efficiency–ESSENZ. J. Clean. Prod. 137, 118–130

Bebbington, J., Brown, J., Frame, B. 2007. Accounting technologies and sustainability assessment models. Ecol. Econ. 61, 224–236.

Beloborodko, A., Rosa, M., 2015. The Use of Performance Indicators for Analysis of Resource Efficiency Measures. Energ. Proced. 72, 337–344.

Booysen, F.2002, An overview and evaluation of composite indices of development. Social Indicators Research, 59, 115-151.

Bosseboeuf, D., 2015. Energy efficiency trends and policies in the household and tertiary sectors. Odyssee-Mure, EU.

Build up, 2013. EPBD Implementation in Belgium Brussels Capital Region - Status at the end of 2012, http://www.buildup.eu/sites/default/files/content/CA3-National-2012-Belgium-Brussels-ei.pdf

Chambers, N., Simmons, C., Wackernagel, M. 2014. Sharing nature's interest: ecological footprints as an indicator of sustainability. Routledge, New York.

Council of the European Union, 2011c. White Paper Roadmap to a single European transport area –towards a competitive and resource efficient transport system. COM (2011) 144 final. European Commission, Brussels.

Da Graça Carvalho, M., 2012. EU energy and climate change strategy. Energy 40, 19–22.

Eco-innovation Observatory, 2014. Eco-innovation in member states. 2013. Eco-innovation Observatory, Belgium.

Ecologic Institute, 2015/2014. Assessment of climate change policies in the context of the European Semester-2015/2014.Semester-2014. Ecologic Institute, Berlin.

Ediger, V.S., Hosgor, E., Surmeli, N.A., Tathdil, H., 2007. Fossil sustainability index: an application of resource management. Ener Policy 35, 2969–2977.

European Commission, 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. European Commission, Brussels.

European Commission, 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. European Commission, Brussels.

European Commission, 2009. 2020 Climate and Energy Package. European Commission, Brussels.

European Commission 2010a Europe 2020 – A strategy for smart, sustainable and inclusive growth. COM(2010) 2020 final. March 2010.

European Commission, 2010b. Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. European Commission, Brussels.

European Commission 2011a. A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. COM(2011) 21 final. January 26, 2011.

European Commission, 2011b. Roadmap to a Resource Efficient Europe. COM/2011/0571 final, European Commission, Brussels.

European Commission, 2011c. Eco-innovation Action Plan. European Commission, Brussels.

European Commission, 2013. The 7th Environment Action Programme. European Commission, Brussels.

European Comission, 2015a. Eurostat database, http://ec.europa.eu/eurostat/data/database

European Commission, 2015b. Assessment of separate collection schemes in the 28 capitals of the EU. European Commission, Brussels.

European Commision, 2014. Resource Efficiency Scoreboard. European Commission, Brussels,.http://ec.europa.eu/environment/resource_efficiency/documents/re_scoreboard_2014.pdf

European Commission. 2016. Proposal of a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast), European Commission, Brussels.

European Environment Agency, 2011. Resource efficiency in Europe. Policies and approaches in 31 EEA member states and cooperating countries. European Environment

Agency, Copenhagen Resource efficiency and the low-carbon economy. European Environment Agency, Copenhagen.

European Environment Agency, 2015. The European environment state and Outlook 2015.

Faberi, S., Paolucci, L., Lapillonne, B., Pollier, K., 2015. Trends and policies for energy savings and emissions in transport. Odyssee-Mure, EU.

García-Alvarez, M.T., Moreno, B., Soares I., 2016a. Analyzing the sustainable energy development in the EU-15 by an aggregated synthetic index.. Ecol. Indic. 60, 996–1007.

García-Álvarez, M.T., Moreno, B., Soares, I. 2016b. Analysing the Environmental and Resource Pressures from European energy activity: An aggregated Index. Energy 115, 1375–1384.

Godfrey, L., Todd, C., 2001. Defining thresholds for freshwater sustainability indicators within the context of South African water resource management. 2nd WARFA/Waternet Symposium about Integrated Water Resource Management: Theory, Practice, Cases, Cape Town, South Africa, http://www.waternetonline.ihe.nl/aboutWN/pdf/godfrey.pdf

Hatfield-Dodds, S., Schandl, H., Newth, D., Obersteiner, M., Cai, Y., Baynes, T., West, J., Havlik, P., 2017. Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies. J. Clean. Prod.144, 403–414.

Horton, P., Koh, L., Guang, V.S., 2016. An integrated theoretical framework to enhance resource efficiency, sustainability and human health in agri-food systems. J. Clean. Prod. 120, 164–169.

Huysman, S., Sala, S., Mancini, L., Ardente, F., Alvarenga, R.A., De Meester, S., Mathieux, F., Dewulf, J., 2015. Toward a systematized framework for resource efficiency indicators. Resour. Conserv. Recy. 95, 68–76.

Kalliski, M., Beisheim, B., Enste, U., Krämer. S. 2016. Real-time resource efficiency indicators. Hauptbeitrag 1-2, 64–71.

Kang, D., Lee, D.H., 2016. Energy and environment efficiency of industry and its productivity effect. J. Clean. Prod. 135, 184–193.

Kılkış, Ş. (2015). Composite index for benchmarking local energy systems of Mediterranean port cities. Energy 92, 622–638.

Kilkış, Ş. (2016). Sustainable Development of Energy, Water and Environment Systems Index for Southeast European Cities. J. Clean. Prod, 130, 222–234.

Labanca, N., Suerkemper, F., Bertoldi, P., Irrek, W., Duplessis, B., 2015. Energy efficiency services for residential buildings: market situation and existing potentials in the European Union. J. Clean. Prod. 109, 284–295.

Mudgal, S., Tan, A., Lockwood, S., Eisenmenger, N., Fischer-Kowalski, M., Giljum, S., & Brucker, M. 2012. Assessment of Resource Efficiency Indicators and Targets. Final Report. European Commission-DG Environment, BIO Intelligence Service. http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/report.pdf

Park, H.S., Behera, S.K., 2014. Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks. J. Clean. Prod, 64, 478–485.

Robèrt, K. H., Borén, S., Ny, H., Broman, G., 2017. A strategic approach to sustainable transport system development-Part 1: attempting a generic community planning process model. J. Clean. Prod. 140, 53–61.

Scoreboard, R. E. 2013. Thirty indicators to measure resource efficiency in the EU. no. December.

Singh, J., Ordoñez, I., 2016. Resource recovery from post-consumer waste: important lessons for the upcoming circular economy. J. Clean. Prod.134, 342–353.

Singh, R. K., Murty, H. R., Gupta, S. K., & Dikshit, A. K. 2009, An overview of sustainability assessment methodologies. Ecol. Indic. 9, 189-212.

Singh, R.K., Murty, H.R., Gupta, S.K. and Dikshit, A.K. (2007). Development of composite sustainability performance index for steel industry. Ecol. Indic. 7, 565–588.

Tanning, L., Tanning, T., 2015. Analysis of the Resource Productivity of New Members of the European Union. J. Behav. Econ. Financ. Account. Econ. Transp. 3, 21–31.

Tukker, A., Guinée, J., van Oers, L., Van der Voet, E., 2015. Towards a resource efficiency index of nations. Discussion Paper of the World Resources Forum Association, Switzerland.

Udo, V.E., Jansson, P.M.. 2009. Bridging the gaps for global sustainable development: A quantitative analysis. J. Environ. Manage. 90, 3700–3707.

Urbaniec, K., Mikulčić, H., Duić, N., Lozano, R., 2016. SDEWES 2014–Sustainable Development of Energy, Water and Environment Systems. J. Clean. Prod. 130, 1–11.

Wang, W., Jiang, D., Chen, D., Chen, Z., et al. 2016. A Material Flow Analysis (MFA)-based potential analysis of eco-efficiency indicators of China's cement and cement-based materials industry. J. Clean. Prod, 112, 787–796.

World Economic Forum (WEF), 2001. Environmental sustainability index. WEF, United States. http://www.ciesin.columbia.edu/indicators/ESI.

World Wildlife Fund (WWF), 1998. Living Planet Report 1998. WWF, Gland.

Yu, Y., Chen, D., Hu, S., Kharrazi, A., Zhu, B., 2017. Advancing factors influencing resource productivity through the use of the material utility framework. J. Clean. Prod. 142, 1892–1900.