ORIGINAL ARTICLE

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Decoupling economic growth from greenhouse gas emissions: the case of the energy sector in V4 countries

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Abstract

Research background: The production and use of energy satisfies human needs, but also gives rise to a host of adverse environmental pressures, such as air pollution and waste generation. The issue of energy efficiency and climate chance resonates in the energy sector as one of the main producers of green-house gas emissions (GHG). While the European Union in general is doing well in reducing emissions and increasing the share of renewables, unfortunately, there are countries that are still far from reaching their goal.

Purpose of the article: The paper is focused on the quantitative assessment of the link between the economic growth of the energy sector and the production of GHG emissions by the energy sector in V4 countries during the period 1995–2016. For this purpose, decoupling analysis will be realized.

Methods: The decoupling of economic growth and the environmental pressures caused by this growth has a rich tradition within the sustainable development literature. The decoupling method was chosen for its ability to link economic and environmental indicators. Decoupling elasticity will be calculated with the aim of assessing the relationship between the economic growth of the energy sector (measured in GVA) and GHG emissions produced by the energy sector in V4 countries within the research period. Decoupling elasticity indicates different forms of the decoupling and coupling of the two variables.

Findings & Value added: The results of the analysis suggest the prevailing strong decoupling of the economic growth of the energy sector and GHG emissions produced by the energy sector, which can be considered a positive trend. The findings of this paper are relevant for the government, state and public institutions and stakeholders in general, who play important roles in the preparation of programs, projects and policies to make energy generation, transport and use more efficient and environmentally sustainable.

Introduction

Energy is currently one of the key factors of economic growth, and under the conditions of the gradual depletion of limited resources, it becomes a strategic issue. Most EU countries consider energy to be one of the priorities of their economic activity. Although fundamental for economic growth, energy production also has remarkable adverse impacts on the environment and human well-being. According to the report of the European Environmental Agency, fossil fuels dominate the European energy system, accounting for more than three-quarters of energy consumption in 2011 and almost 80% of greenhouse gas emissions (EEA, 2013).

The United Nations Framework Convention on Climate Change (UNFCC), adopted at the 1992 Rio Earth Summit in Rio de Janeiro, set the objective of the *"stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" "within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"* (UN, 1992). This objective specifically quantified the 1997 Kyoto Protocol, requiring an overall reduction in greenhouse gas emissions by 5.2% by the end of 2012 (by the end of the first control period 2008–2012) compared to the reference year 1990 for the countries included in Annex I of the UNFCCC.

In 2009, under the UNFCCC Copenhagen Accord (COP-15), the objective was to propose a maximum increase in the average global temperature by 2°C by 2100 compared to the pre-industrial revolution and a reduction in global greenhouse gas emissions by at least 50% (on the developed side of economy by at least 80%) by 2050. This goal was subsequently approved a year later at the Cancun Climate Conference (COP-16). The boundary of two degrees Celsius is the most widely accepted limit for a maximum temperature increase, but the reductions related to it cannot be quantified. An even more ambitious effort was taken in the Paris Agreement, the central aim of which is to avoid the negative impacts of climate change by limiting a global temperature rise below 2 degrees Celsius com-

pared to pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

The issue of energy efficiency and climate chance resonates in the energy sector as one of the main producers of GHG emissions. While the Union as a whole is doing well in reducing emissions and increasing the share of renewables, unfortunately, there are countries that are still far from reaching their goal. The aim of the paper is to discuss the link between the GHG emissions produced by the energy sector in V4 countries and the economic growth of the energy sector. To assess the relationship between the economic growth of the energy sector and greenhouse gas emissions produced in this sector, the decoupling method was applied, and decoupling elasticity was calculated, indicating different forms of decoupling or coupling of the two variables.

The paper is organized as follows. First, the EU climate and energy policy background is described, with a focus on recent policy actions and initiatives related to this topic, and the previous empirical research is reviewed. Section 2 outlines the research methodology and data sources used. The third section presents the results obtained, followed by the fourth section discussing the results and limitations of the research. The last section concludes the paper.

Literature review

EU climate and energy policy background

The need to address environmental issues has been an inherent part of the European Union since its beginning, but this need became most visible in the 1990s, when the whole nature conservation agenda expanded from the national to European level. One of the first documents to address this issue was the Communication from the European Commission to the Council — The Greenhouse Effect and the Community (EC, 1988). With increasing interest in the issue of climate change, the scope for European Union activities is of course expanding; the substance of the matter implies that combating climate change is more of a global issue than a local issue. It is therefore not surprising that the EU has already started looking for the answer to this question. At that time, the EU has focused on reducing emissions through the European Union Emission Trading System (EU ETS). It has become the cornerstone of all other EU efforts to curb climate change. The ETS was developed in parallel to the regulatory instruments of the Kyoto Protocol and was later partly followed up. The EU ETS incorporates the

fulfilment of Kyoto requirements, but also aims to meet other EU goals and plans.

Climate and energy policies were developed during this period in parallel, but separately from each other. A significant change in this area occurred in 2008, when Brussel´s institutions presented a climate and energy package — one of the most ambitious legislative documents — where both policies converged. The legislative package represents the so-called 20–20–20 objectives. By 2020, the EU should reduce greenhouse gas emissions by 20% compared to 1990 (even by 30% if other developed countries in the world achieve comparable results), increase the share of renewable energy sources in total energy consumption to 20% and increase the energy efficiency of the European economy. Other binding targets are then to achieve a 10% share of biofuels in the fuel sector within the transport sector and to support the carbon capture storage (CCS) system. In the case of non-EU ETS sectors, the package also sets emission reduction targets for each country so that their overall volume is reduced by 20% by 2020.

In 2016, the European Commission issued a package of documents and legislative proposals entitled "Clean Energy for All Europeans" to change the current settings for energy and climate issues. Most of the existing targets are based on the previous energy package. The new package extends some of these targets and increases others by achieving them within the 2030 timeframe. The new energy package not only amends the current legislation but also brings about completely new proposals, such as the regulation on the governance of the Energy Union. In addition to a large number of explanatory documents and annexes, the package contains eight legislative proposals: 4 directives and 4 regulations. The documents relate to the electricity market, renewable energy sources, energy efficiency and the energy performance of buildings. All these changes at the EU level significantly influence the energy performance of all EU member states, as they are accompanied by a strong shift to the centralization of energy policy.

Previous empirical research

The mutual relationship between economic growth and the state of the environment is at the centre of interest of the environmental economy, both on the macro and micro levels. Many authors have widely discussed this topic since the second half of the last century. They have argued that continued economic expansion in a finite world is not possible; therefore, the use of material resources to produce economic growth cannot go on forever, and there has been a growing concern that such growth will cause irrep-

arable damage to our planet (Daly, 1993; Anderson, 2013; Panayotou, 2016). These assumptions are supported by Stern (2004), who notes that decomposition can help disentangle the true relations between development and the environment.

The correlation between economic growth and its (predominantly) negative environmental impacts has become the subject of studies by several authors. Ayres and van den Bergh (2005) modify conventional growth theories, stressing the importance of dematerialization. Several world economies are facing the dilemma of economic growth while seeking ways to ensure environmental protection. The main idea is to create divergence (decoupling), where increasing economic growth should be combined with a reduction in the amount of natural resources consumed (resource decoupling) and a reduction in the amount of waste produced (impact decoupling). Similar concepts based on retrospective analysis, such as dematerialisation, delinking or increasing energy efficiency, have been developed and described, e.g., in Ayres and van den Bergh, (2005), Mazzanti (2008) and others.

Within the extant environmental research, these approaches have been applied in several areas, e.g., the decoupling of economic activity and growth of transport (Ballingall *et al.*, 2003), decoupling of economic growth from transport CO_2 (Finel & Tapio, 2012; Tapio, 2005), decoupling of economic growth from resource productivity (Steger & Bleischwitz, 2017), decoupling of GHG emissions from economic growth (Vavrek & Chovancova, 2016), etc.

The wide application of these methods can also be found in the energy sector; e.g., Zhou *et al.* (2017) performed an analysis of the relationship and influencing factors between economic development and industrial-energy-related carbon emissions in China. Naminse and Zhuang (2018) investigated the mutual relation between energy intensity and CO_2 emissions, stating that heavy reliance on coal consumption is possibly a dominant cause for the increase in carbon dioxide emissions in China. In the European context, Chovancová and Vavrek (2020) performed resource and impact decoupling analysis with a focus on energy consumption in EU countries, where they assessed relations among energy-related emissions, consumption and the mitigation effect of renewable energy sources. The global perspective approach of Kan *et al*. (2019) assessed the decoupling states of GDP from all types of primary energy use under the consumption-based principle for the world economy and eight typical economies during 2000–2011.

Most of the research on decoupling economic growth and energy-related issues is based at the local, national or global scales. However, the literature

on environmental decoupling in terms of country clusters is relatively scarce. To narrow this gap, the present study focuses on V4 countries to analyse the decoupling of economic growth of the energy sector and energy-related emissions in these Central European countries.

Material and research methodology

For measuring both economic and environmental variables, many different sets of indicators have been used (Huttmanová, 2015; Adamišin & Vavrek, 2015). The most widely used indicator for measuring economic development is gross domestic product (GDP), either in the absolute form or per capita. Though this indicator is commonly used, many authors point out shortcomings of GDP, especially in the context of internationalization and globalization; e.g., it does not capture the associated environmental damage and pollution, domestic work, and changes in the quality of production, is unable to determine the values of goods provided by the public sector, does not reflect government debt and reflects market output only, while nonmarket is not taken into consideration. A phenomenon called "phantom GDP" (Anderson, 2010; Kotulič & Adamišin, 2012; Nečadová, 2012) has also been widely discussed. The problems related to GDP are also well discussed in the so-called "Stiglitz report" (Stiglitz *et al.*, 2009).

Many different environmental indicators have been used for assessing environmental performance, and the results vary depending on the selected set of indicators. Environmental indicators related to the energy sector can include energy productivity, CO_2 or GHG productivity, energy intensity in different sectors of the economy, the share of energy from renewable sources in gross final energy consumption, etc.

To assess the relation between economic growth and the environmental impacts caused by this growth, the decoupling method was applied. This method has a rich tradition within the sustainable development literature, and the concept is well described in one work (OECD, 2002), where the two main forms of decoupling are distinguished: absolute and relative decoupling. Relative decoupling is a state when the use of resources is constant, while economic performance is growing. Eventually, resource use is increasing, but at a lower rate than economic growth. Conversely, absolute decoupling is a state where resource use declines, but the economy still grows. While relative decoupling is quite common, absolute decoupling rarely occurs and can be achieved with the relatively slow growth of GDP (De Bruyn *et al*., 2009; Steger & Bleischwitz, 2009). Decoupling and its forms are illustrated in Figure 1.

This method was elaborated by Tapio (2005) and Finnel and Tapio (2012). For a better assessment of decoupling, they distinguished eight subcategories of decoupling (see Figure 2). Decoupling elasticity indicates the state of decoupling (decoupling subcategories) and is calculated according to formula (1).

This paper aims to quantitatively assess the environmental performance of the energy sector in V4 countries. The analysis is performed via the decoupling method, which allows for the assessment of the mutual relationship between the economic growth of the energy sector and the production of GHG emissions by the sector. The ratio of the GHG emissions of the energy sector and the gross value added (GVA) can be referred to as the GHG intensity of the energy sector.

Gross value added (GVA) is a newly created value obtained by institutional units from the use of their production capacities. GVA is used to estimate gross domestic product. It is determined as the difference between total output, valued at basic prices, and intermediate consumption, valued at purchase prices, and involves various sectors. In our study, we focus on the GVA of the energy sector.

The data for analysis were obtained from the databases of Eurostat (gross value added and greenhouse gases (consisting of CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFCs in CO_2 equivalent, PFCs in CO_2 equivalent, SF_6 in CO_2 equivalent, and NF_3 in CO_2 equivalent) produced by the energy sector.

The decoupling of GHG emissions produced by the energy sector and the economic growth of the energy sector presents the ratio of percentage units of changes in GHG emissions produced by the energy sector and percentage units of changes in gross value added of the sector in the analysed time period. Based on this model, decoupling elasticity e can be calculated as follows:

$$e = \% \, \Delta GHG \, / \, \% \, \Delta GVA \qquad (1)$$

The ratio of changes in GHG emissions of the energy sector (ΔGHG) and GVA (ΔGVA) can be divided according to Finel and Tapio (2012) into the following stages: strong decoupling, weak decoupling, expansive/recessive coupling, expansive/recessive negative decoupling and strong negative decoupling (see Figure 2).

Results

For the purpose of this study, the analysis of the relationship between the GHG emissions produced by the energy sector (GHG) and the gross value added (GVA) of the energy sector in V4 countries (Czech Republic, Hungary, Poland and Slovakia) in the period 1995–2016 was performed. For comparison, the EU average is added in Table 1. The analysed period is divided into seven sections S1–S7 (see Table 1). %ΔGHG and %ΔGVA values were calculated using data from publicly available databases of Eurostat (GHG and GVA). Subsequently, the value of decoupling elasticity was calculated using equation 1.

The ratio of changes in GHG emissions produced by the energy sector (vertical axis) to changes in GVA of the energy sector (horizontal axis) was used to create a decoupling model (Figure 3). Based on the position in the model, countries are divided within each period in the following subcategories.

Expansive coupling: in this subcategory, both the environmental impact (in terms of GHG emissions) and economic growth of the energy sector (measured in GVA) grew at a similar rate. In this subcategory, we have no representatives, which can be considered a positive aspect.

Weak decoupling: in this subcategory, the GVA of the energy sector and GHG emissions both increase, but the GVA grows faster than the GHG emissions produced by the energy sector. Decoupling occurs to some extent because GHG emissions grow more slowly than the GVA, but it is weak since the absolute amount of produced GHG emissions of the energy sector nevertheless continues to grow. This subcategory includes Hungary in the period 1995–1998 and 2013–2016, the Czech Republic in the periods 1998–2001 and 2004–2007, and Poland in the period 2004–2010. The development in the European Union shows weak decoupling in one case, particularly in 2001–2004.

Strong decoupling: in this subcategory, the GVA increases, and the production of GHG emissions decreases. Thus, the GVA elasticity of the production of GHG emissions is below 0. This is the case of absolute decoupling and the best case for both the economy and the environment. This subcategory is in our survey most frequently; almost 50% of analysed cases belong to this group, which is positive.

Recessive decoupling: in this subcategory, both GVA and the production of GHG emissions decrease, but the production of GHG emissions decreases more rapidly than GVA. The GVA elasticity of production of GHG emissions is over 1.2. There are two countries in this subcategory: the Slovak Republic in 2013–2016 and Hungary in 2007–2010.

Recessive coupling: in this subcategory, both the production of GHG emissions and GVA of the energy sector have decreased at a similar rate. In this subcategory, there are two representatives: the Czech Republic in 1995 – 1998 and Slovakia in 2010–2013.

Recessive negative decoupling: in this subcategory, GVA and the production of GHG emissions both decrease, but GVA decreases faster than emissions. The decoupling elasticity is over 0.8. There are three cases present in this subcategory, the Czech Republic, in the period 2013–2016, Hungary in 2010–2013 and Slovakia in 2007–2010.

Strong negative decoupling: in this subcategory, GVA decreases, the production of GHG emissions increases, and e < 0. Strong negative decoupling here represents the worst case of performance. In this subcategory, there are two representative countries: the Slovak Republic in the period 1998–2001 and Poland in 2001–2004 and 2013–2016. In these periods, the economic growth of these countries decreased slightly, but GHG emissions increased.

In the category of *weak negative decoupling***,** the GVA of the energy sector and GHG emissions produced by the sector both increase, although the emissions increase faster than the GVA. Here, e > 1.2. In this subcategory, we have no representatives, which can be considered a positive aspect.

Discussion

Greenhouse gas emissions have fallen since 1990 in V4 countries, in particular, due to the collapse of inefficient industry, increasing energy efficiency and launching of nearly zero carbon energy sources; both GDP and per-capita GDP are still well above the EU average (due to the structure of the growing economy and the energy mix and the existing savings potential). The question is how these countries can support new political and technological solutions towards the goal of a low-carbon economy.

One option is engagement with states that have chosen to develop low-carbon technology, but waiting for technological progress may prove less costly. Although pioneering countries can take their own initiatives, the competitive edge of developing new applications must be kept so long as they can recover the costs. Decarbonization seems to be economically beneficial in the long run but costly in the short and medium term. Part of the decarbonization investment should go to science and research to launch a wave of progressive innovations.

At the EU level, the so-called Strategic Energy Technology Plan (EU, 2017) is the basic pillar of the transition to a low-carbon-energy future. This plan, among other things, defines 19 strategic technologies to ensure the necessary level of greenhouse gas emission reductions in the energy sector. Not all of these technologies are equally developed, and not all of them are appropriate for all Member States. The issue of "national specifics" in relation to individual low-carbon technologies is a hot topic in ongoing debates, including in V4 countries, on the appropriateness of climate conditions for some technologies, prevailing public attitudes or different starting situations.

Important topics related to technology are science, research and technological development, which can accelerate the development of some technologies. New resource management methods are rapidly gaining in importance. From this perspective, it is important at the national and European levels to set the right objectives and priorities in this area and to create favourable conditions for science, research and innovation, including prerequisites for commercial use.

The results of the analysis show that during the examined period, countries reached different levels of decoupling. The majority of examined cases fall under the subcategory of strong decoupling, which can be considered very positive, i.e., the energy sector grows, and the GHG emissions produced by this sector decrease. However, as with all studies, this study has limitations. First, the decoupling method is a simple tool to visualize the mutual relationship between economic performance and related environmental impacts, although it does not reveal the environment's capacity to sustain, absorb or resist various adverse impacts. Elasticity values cannot convey the message of whether the economic performance of the energy sector is sufficiently decoupled from negative environmental impacts, such as GHG emissions production.

Another issue related to decoupling is the 'rebound effect', which requires addressing the concern that energy or resource efficiency gains in energy or resource use may paradoxically lead to the greater use of energy and resources, respectively (Binswanger, 2001). Some studies on micro-level rebound effects have concluded that the rebound effect is not a major problem and does not undermine the case for investing in energy and resource efficiency or productivity (Greening *et al*., 2000; Herring, 2004; Berkhout *et al*., 2000; Schipper, 2000). According to Sorrell (2007), the direct rebounds range from 0% to 40%.

At the macroeconomic level, the implications of the rebound effect are more difficult to follow, especially from a decoupling point of view. Where energy or material efficiency increases, the divergence is at the level of

economic activity, which, in theory, should be higher with energy or material efficiency gains than without such gains. To decouple economic growth from adverse environmental impacts, some authors recommend the transition of the economy from manufacturing industries, which are energy- and material-intensive, towards the service sector. Although, in this case, the values of decoupling elasticity might improve, adverse environmental impacts are usually only externalized; i.e., they are moving to other countries that export energy-intensive products.

Nevertheless, using the decoupling method brings about many advantages. The quantification of the extent of decoupling makes it possible to assess whether decoupling policies and strategies are sufficient for reaching the goal of environmental sustainability and allows us to track the trends, compare the extent of decoupling among countries and set future decoupling targets. The results of decoupling analysis can facilitate environmental policy-making processes.

Conclusions

The issue of mitigating the negative impact of energy production directly affects all European Union Member States. The current European climate and energy policy is guided by commitments and objectives in an attempt to move towards an energy-saving, low-carbon economy by 2050.

In this study, we focused on V4 countries, which have several common features: historical, political, economic and geographic. Additionally, in the energy sector, we can determine some common features, such as (1) high dependence on the imports of primary energy sources, (2) high energy intensity of the economies and (3) relatively low share of renewable energy sources in the energy mix.

Using the method of decoupling, we determined the rate of decoupling elasticity, thus disengaging the economic growth of the energy sector and the production of GHG emissions by the energy sector in individual V4 countries within the monitored periods and compared it to the EU average. On the basis of the analysis, it can be concluded that strong decoupling prevails, which means that the energy sector of these countries is growing, while the production of GHG emissions is declining. Despite this positive finding and quite a number of reforms within the energy sector implemented in V4 countries, these countries are EU countries with higher energy intensity, mostly due to historical context, economic structure and the state of development.

The authors believe that every state and every individual should take part of the responsibility for global problems such as climate change. Therefore, it is necessary to convince the public as a whole and its individual interest groups that this problem exists, that the effort to find solutions is growing in all cultural countries (regardless of their standard of living), and finally that even a small contribution of a particular state, a particular stakeholder and an individual makes sense.

References

Adamišin, P., & Vavrek, R. (2015). Analysis of the links between selected socio-economic indicators and waste man-agement at the regional level in the Slovak republic. In P. Nijkamp (Ed.) *5th Central European conference in regional science - conference proceedings*. Košice: Technical University of Košice.

Ayres, R. U., & van den Bergh, J. C. J. M. (2005). A theory of economic growth with material/energy resources and dematerialization: interaction of three growth mechanisms. *Ecological Economics*, *55*(1). doi: 10.1016/j.ecolecon.2004.07.023.

Ballingall, J., Steel, D., & Briggs, P. (2003). Decoupling economic activity and transport growth : the state of play in New Zealand. In T. Brennand (Ed). *26th Australasian transport research forum Wellington New Zealand*. Wellington: Institute of Highway Technology

Berkhout, P. H. G., Muskens, J. C., & Velthuijsen, W. J. (2000). Defining the rebound effect. *Energy Policy*, 28(6-7). doi: 10.1016/S0301-4215(00)00022-7.

Binswanger, M. (2001). Technological progress and sustainable development: what about the rebound effect? *Ecological Economics*, *36*(1). doi: 10.1016/S0921-8009(00)00214-7.

Bruyn, S. de, Markowska, A., Jong, F. de, & Blom, M. (2009). *Resource productivity, competitiveness and environmental policies*. Delft report. Retrieved from http://cedelft.eu (1.04.2019).

Chovancová, J., & Vavrek, R. (2020). (De) coupling analysis with focus on energy consumption in EU countries and its spatial evaluation. *Polish Journal of Environmental Studies*, *29*(3). doi: 10.15244/pjoes/110613.

Daly, H. E. (1993). Steady-state economics: a new paradigm. *New Literary History, 24*(4). doi: 10.2307/469394.

Directorate-General for Research and Innovation (European Commission) (2018). The Strategic Energy Technology (SET) Plan. Joint Research Centre. doi: 10.2777/48982

EC (1988). The greenhouse effect and the Community. Communication to the Council. Commission work programme concerning the evaluation of policy options to deal with the "Greenhouse Effect." Draft Council Resolution on the greenhouse effect and the Community. COM (88) 656 final, 16 November 1988.

EEA (2013). Final energy consumption by sector (CSI 027/ENER 016). Retrieved form http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consum ptionby-sector-5/assessment-1 (28.10.2018).

Finel, N., & Tapio, P. (2012). Decoupling Transport Co2 From GDP. In *Finland futures research centre ebook*. Helsinki: University of Turku.

Greening, L. A., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption - the rebound effect - a survey. *Energy Policy*, *28*(6-7). doi: 10.1016/S0301-4215(00)00021-5.

Herring, H., & Roy, R. (2007). Technological innovation, energy efficient design and the rebound effect. *Technovation, 27*(4). doi: 10.1016/j.technovation.2006 .11.004.

Huttmanová, E. (2015). Evaluation of sustainability in the EU countries using selected indicators of sustainable development. In *Environmental economics, education and accreditation in geosciences: ecology, economics, education and legislation. Vol. 3 : Conference proceedings : 15th international multidisciplinary scientific geoconference SGEM*. doi: 10.5593/SGEM2015/ B53/S21.036.

Kan, S., Chen, B., & Chen, G. (2019). Worldwide energy use across global supply chains: Decoupled from economic growth? *Applied Energy*, *250*. doi: 10.1016 /j.apenergy.2019.05.104.

Kotulič, R., & Adamišin, P. (2012). Economic effects of the foreign direct investments management on the development of Slovak regions. In V. Klímová & V. Žítek (Eds.). *International colloquium on regional sciences:15th international colloquium on regional sciences*. Brno: Masaryk University.

Mazzanti, M. (2008). Is waste generation de-linking from economic growth? Empirical evidence for Europe. *Applied Economics Letters*, *15*(4). doi: 10.108 0/13504850500407640.

Naminse, E., & Zhuang, J. (2018). Economic growth, energy intensity, and carbon dioxide emissions in China. *Polish Journal of Environmental Studies*, *27*(5). doi: 10.15244/pjoes/78619.

Nečadová, M. (2012). Is GDP an appropriate indicator of economic performance and social progress in the context of globalization? *Acta Oeconomica Pragensia*, *20*(5).

OECD (2002). Indicators to measure decoupling of environmental pressure from economic growth. In *The OECD Environment Programme*. OECD.

Panayotou, T. (2016). Economic growth and the environment. In N. Haenn, R. Wilk & A. Harnish (Eds.). *The environment in anthropology: a reader in ecology, culture, and sustainable living*. NYU Press.

Schipper, L., & Grubb, M. (2000). On the rebound? Feedback between energy intensities and energy uses in IEA countries. *Energy Policy*, *28*(6-7). 10.1016/ S0301-4215(00)00018-5.

Sorrell, S. (2007). The rebound effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. UK Energy research centre.

Steger, S., & Bleischwitz, R. (2017). Decoupling GDP from resource use, resource productivity and competitiveness: a cross-country comparison. In R. Bleischwitz, P. Welfens & Z. X. Zhang (Eds). *Sustainable growth and Resource productivity: economic and global policy issues*. Taylor & Francis. doi: 10.4324/9781351279208-11.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets Curve. *World Development*, *32*(8). doi: 10.1016/j.worlddev.2004.03.004.

Stiglitz, J. E., Sen, A., & Fitoussi, J. (2009). *Report by the Commission on the Measurement of Economic Performance and Social Progress*. Retrieved form http://www.stiglitz-sen-fitoussi.fr/documents/rapport_anglais.pdf (3.11.2018).

Tapio, P. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy, 12*(2). doi: 10.1016/j.tranpol.2005.01.001.

UN (1992). United Nations framework convention on climate change. United Nations, 1992. Retrieved form https://unfccc.int/resource/docs/convkp/ conveng.pdf (2.11.2018).

UNEP (2011). Decoupling natural resource use and environmental impacts from economic growth. Retrieved form https://wedocs.unep.org/handle/20.500. 11822/9816 (25.11.2018).

Vavrek, R., & Chovancova, J. (2016). Decoupling of greenhouse gas emissions from economic growth in V4 countries. *Procedia Economics and Finance, 39*. doi: 10.1016/s2212-5671(16)30295-7.

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*. doi: 10.1016/j.jclepro.2016.09.115.

Annex

Table 1. The values of decoupling elasticity of the V4 countries (1995–2016)

		S1 (1995-1998)	S2 (1998-2001)	S3 (2001-2004)	S4 (2004-2007)	S5 (2007-2010)	S6 (2010-2013)	S7 (2013-2016)
Czech Republic (CZ)	%ΔGHG	-7,06	1,30	-0,88	0,42	-7,40	-10,47	-0,56
	%ΔGVA	-7,14	22,91	31,05	56,35	34,45	1,18	-10,71
	e	0,99	0,06	-0,03	0,01	-0,21	-8,91	0,05
Hungary (HU)	%Δ GHG	1,18	-2,10	-0,23	-4,90	-9,18	-15,29	7,98
	%Δ GVA	53,65	11,16	36,78	27,83	-1,05	-21,80	11,98
	e	0,02	-0,19	-0,01	-0,18	8,75	0,70	0,67
Poland (PL)	%Δ GHG	-6,69	-5,89	2,32	2,85	0,04	-3,80	0,23
	%Δ GVA	16,56	58,46	-0,26	45,62	26,99	17,20	-6,73
	e	-0,40	-0,10	-9,04	0,06	0,00	-0,22	-0,03
Slovakia (SK)	%Δ GHG	-3,52	1,99	-6,29	-6,13	-3,93	-9,43	-7,73
	%Δ GVA	1,28	-21,31	277,84	64,05	-5,12	-9,22	-4,06
	e	-2,75	-0,09	-0,02	-0,10	0,77	1,02	1,91
EU (current composition)	%Δ GHG	-0,23	0,66	0,99	-1,94	-6,55	-7,42	-4,71
	%Δ GVA	-	-	15,56	17,37	12,33	6,92	1,64
	e	-	-	0,06	-0,11	-0,53	-1,07	-2,87

Source: own calculations based on Eurostat (2017).

Figure 1. Relative and absolute decoupling of economic growth and environmental impacts (modified from UNEP, 2011)
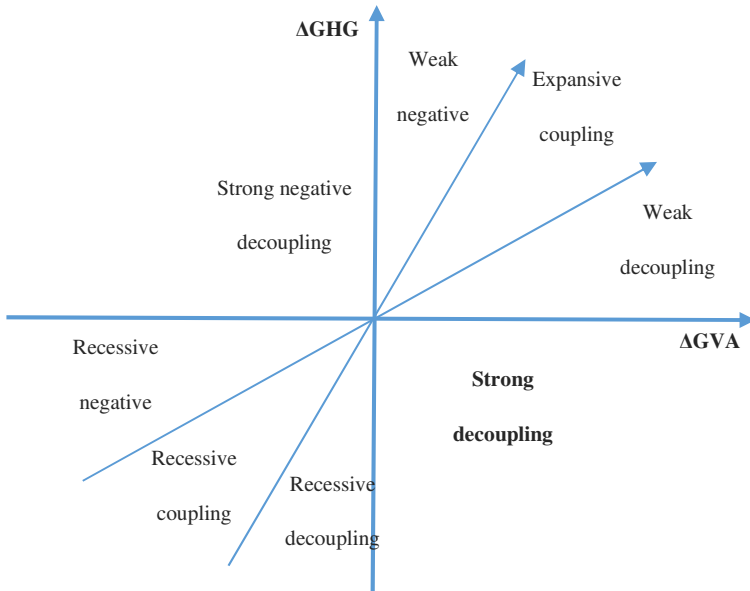

Figure 2. Decoupling between GHG emissions and GVA (modified from Finel and Tapio, 2012)
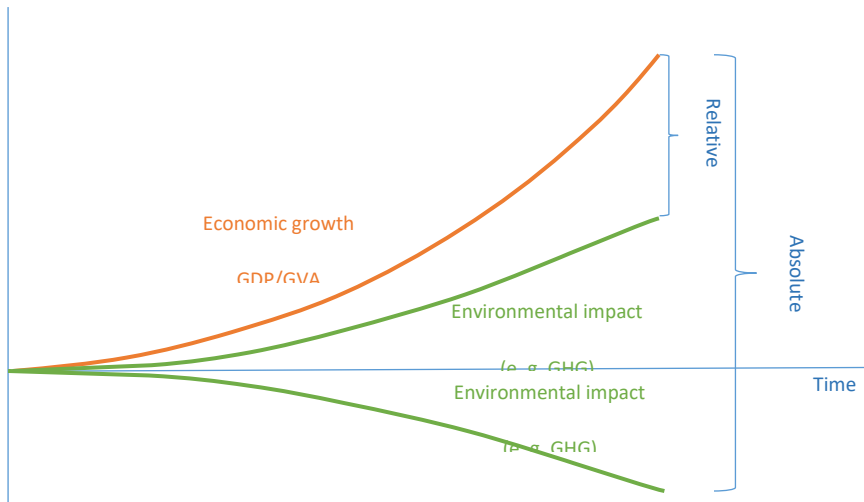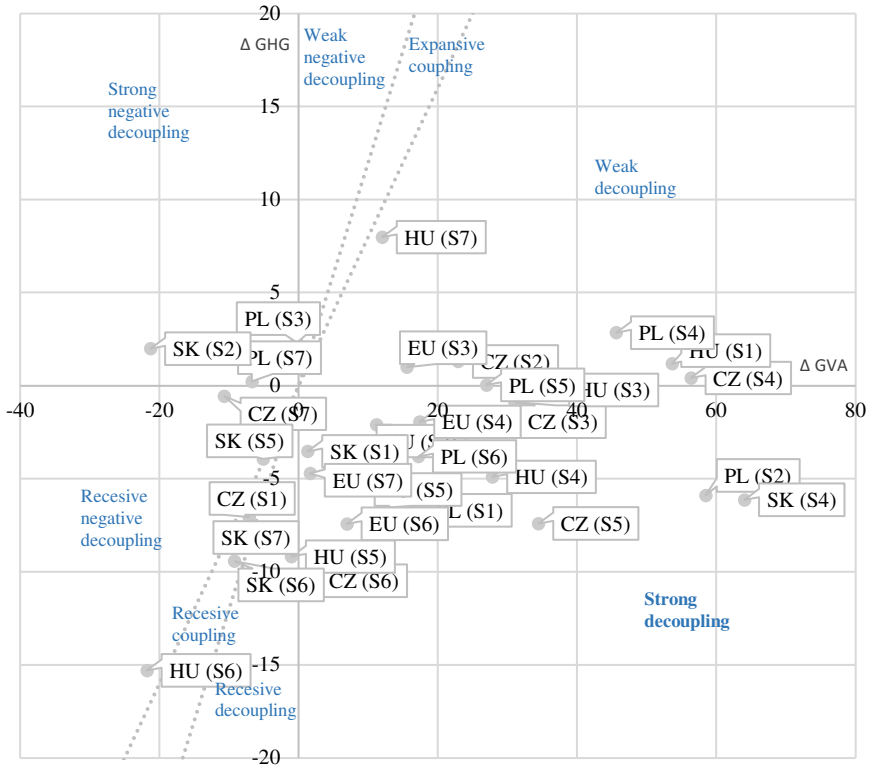
Figure 3. The distribution of V4 countries into subcategories of decoupling

Source: own calculations based on Eurostat (2017).