Evaluation of decoupling of GDP and CO\textsubscript{2} emissions in EU-15

A Bekaliyev\textsuperscript{1}, A Junissov\textsuperscript{1}, Y Kakimov\textsuperscript{1} and S G Poulopoulos\textsuperscript{1,2}

\textsuperscript{1} Department of Chemical and Materials Engineering, School of Engineering and Digital Sciences, Nazarbayev University, 010000, Nur-Sultan, Kazakhstan

\textsuperscript{2} E-mail: stavros.poulopoulos@nu.edu.kz

Abstract. Generally, economic growth is accompanied by an increase in energy consumption, which consequently leads to higher levels of greenhouse gas emissions. These, in turn, are the causes of global warming, which is one of the most acute environmental problems nowadays. Decoupling occurs when environmental pressure can be decreased without the negative effect of the economic growth of a country. This study is focused on the investigation of the decoupling of the economy and environmental pressure. The analysis was carried out for EU-15 countries for the period between 1990 and 2014. For the evaluation of decoupling the Tapio decoupling elasticity method was used. This method provides the extent of decoupling of the economy and environmental pressure for each country. The economy was measured in terms of gross domestic product (GDP), while the environmental pressure was represented by CO\textsubscript{2} emissions from the public electricity and heat generation sector. The EU-15 countries were classified into three groups depending on the individual reduction targets following Kyoto Protocol. Group I had high values of reduction targets ranging from -28\% to -12.5\%, Group II had moderate values of reduction targets situated between -7.5\% and 0\%, and Group III had mild values of reduction targets from +4\% to +27\%. The results of this analysis show that there is strong fluctuation of the extent of decoupling between GDP and CO\textsubscript{2} emissions for each country in the specified period. Therefore, there are no clear patterns of decoupling intensity that can be observed. However, it is important to notice that in almost every country the decoupling between GDP and CO\textsubscript{2} emissions was either strong or weak. This study has shown that generally most of the countries achieved some extent of decoupling between the growth of the economy and the pressure on the environment. The countries that showed the decoupling of more than 80\% of the specified period are Luxemburg, Ireland, and Italy. For most of the countries, the decoupling was deteriorated by the financial crisis of 2008. Another possible reason for the decrease in decoupling is the extensive use of renewable energy resources. While their application lowers the CO\textsubscript{2} emissions, the high production and operation costs constrict the growth of the economy. Sweden, Finland, and Denmark had such situation.

1. Introduction

High energy consumption leads to the growing impact on climate change in the form of production of increased greenhouse gases (GHGs) emissions in the Earth’s atmosphere. They are the cause of the greenhouse effect, which in turn leads to global warming. Due to the improvement of the living standards the demand for energy, which is essential for many human activities, is increasing. This leads to growing emissions due to the high usage of fossil fuels such as coal, natural gas, and oil for combustion \cite{1,2,3}. For instance, countries, which follow the United Nations Framework Convention on Climate Change (UNFCCC), generate more than four-fifths of GHGs from the energy
production sectors [4]. Thus, this sector is the major producer of CO$_2$ emissions, which constitutes the largest portion of GHGs. Furthermore, it is estimated that CO$_2$ has the main contributor to global warming among GHGs, and was responsible for about 76% in 2010 [5]. Thus, many countries are setting goals to reduce the share of energy sources that led to CO$_2$ emissions. However, it is crucial to understand that alternative energy technologies are complex and often expensive [6], [7]. Therefore, mitigation of CO$_2$ emissions by the large-scale introduction of renewable energy sources may restrict economic growth.

It was reported by numerous previous works that the increasing concentration of CO$_2$ in the atmosphere is often accompanied and caused by economic growth [8], [9], [10]. Thus, to assess the relationship of these two factors, different methods such as decoupling were designed. Decoupling is a popular method used for determining the relationship between the economic growth of a country and environmental pressure. This method estimates a decoupling state, which shows the extent to which economic growth is independent of the rise in environmental pressure. The analysis of these kinds of results might be beneficial for policymaking regarding the environment and CO$_2$ mitigation in particular [4], [6]. There are various versions of the decoupling method, but this paper is focused on the Tapio decoupling elasticity method. The subject for the analysis will be countries of EU-15. It consists of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and Sweden. The United Kingdom. EU-15 is one of the groups of countries that adopted the Kyoto Protocol, which aimed to reduce GHGs emissions. Their energy production sector is still dependent on fossil fuels, and it was responsible for three-fifth of GHGs emissions in 2008 [11]. The objectives of this work are: (a) application of the Tapio decoupling elasticity method for the period from 1990 to 2014 in the EU-15, where the economy is represented by GDP, while environmental pressure is represented by CO$_2$ emissions intensity; (b) evaluation of the decoupling states for GDP and CO$_2$ emissions intensity for EU-15 in the specified period.

2. Methodology

2.1. Data and variables

The IEA World Energy Balances database was the source for both variables in the period between 1990 and 2014 [12]. During the decoupling analysis, GDP acted as a measure of the economy, while CO$_2$ emission intensity acted as the environmental pressure. The former stands for Gross Domestic Product (GDP PPP) at market constant prices of 2010, where PPP stands for purchasing power parties. The latter is a ratio between CO$_2$ emissions and the electricity output, both produced during electricity generation related to public energy and heat consumption [13]. It is measured in g of CO$_2$ per kWh of electricity (gCO$_2$ per kWh). During the analysis, EU-15 countries were divided into groups of 5 based on the Kyoto Protocol individual GHGs reduction targets [14]. Group I consisted of the countries with high values of reduction targets: Austria (-13%), Denmark (-21%), Germany (-21%), Luxembourg (-28%), and the United Kingdom (-12.5%). Group II consisted of the countries with moderate values of reduction targets: Belgium (-7.5%), Finland (0%), France (0%), Italy (-6.5%), and Netherlands (-6%). Group III consisted of the countries with mild values of reduction targets: Greece (+25%), Ireland (+13%), Portugal (27%), Spain (+15%), and Sweden (+4%).

2.2. Tapio decoupling elasticity method

For this work, a certain version of the Tapio elasticity method was adopted from Wang and Su 2020 [15]. This method results in a decoupling elasticity (DE), which is also indicated as $\gamma$. The formulas for calculation via this method can be found below.

\[
DE = \gamma = \frac{\Delta CO_2/CO_2}{\Delta GDP/GDP_0} \tag{1}
\]

\[
\Delta CO_2 = CO_2(t) - CO_2(0) \tag{2}
\]

\[
\Delta GDP = GDP(t) - GDP(0) \tag{3}
\]
In these equations, \( \Delta \) is a change in CO2 or GDP between chosen year (t) and base year (0). In combination with DE these values can determine which of the eight decoupling state is happening. Table 1 shows all of the possible decoupling state. Among eight possible decoupling states, three represent positive decoupling, which is more desirable than others. They are strong decoupling, weak decoupling, and recessive decoupling.

### Table 1. Types of decoupling stated for the Tapio method and their conditions.

| Decoupling states           | \( \Delta C/C \) | \( \Delta GDP/GDP \) | Decoupling elasticity values (\( \gamma \)) |
|----------------------------|------------------|------------------------|-----------------------------------------------|
| Expansive negative decoupling | >0               | >0                     | \( \gamma > 1.2 \)                              |
| Strong negative decoupling  | >0               | <0                     | \( \gamma < 0 \)                                |
| Weak negative decoupling    | <0               | <0                     | \( 0 < \gamma < 0.8 \)                          |
| Weak decoupling             | >0               | >0                     | \( 0 < \gamma < 0.8 \)                          |
| Strong decoupling           | <0               | >0                     | \( \gamma < 0 \)                                |
| Recessive decoupling        | <0               | <0                     | \( \gamma > 1.2 \)                              |
| Expansive coupling          | >0               | >0                     | \( 0.8 < \gamma < 1.2 \)                        |
| Recessive coupling          | <0               | <0                     | \( 0.8 < \gamma < 1.2 \)                        |

### 3. Results and Discussions

#### 3.1 Decoupling analysis of Group I

According to the Tapio method, the decoupling states were fluctuating for all of the countries ranging from strong decoupling to strong negative decoupling. The factor that affected the decoupling in each country was the Global Financial Crisis (GFC) of 2008-2009, which caused a massive decline in economic activity [16]. For this period, the decoupling states went down to recessive decoupling in Austria and the United Kingdom; strong negative decoupling in Denmark and Luxembourg; and weak negative decoupling in Germany. As for the reduction targets, the real values were: Austria (-3.2\%), Denmark (-27.6\%), Germany (-27.8\%), Luxembourg (-16.3\%), United Kingdom (-34.3\%) [14].

### Table 2. Decoupling states for Group I.

| Time     | Austria    | Denmark    | Germany    | Luxembourg | United Kingdom |
|----------|------------|------------|------------|------------|----------------|
| 1990-1991| Expansive coup. | Expansive neg. dec. | Weak dec. | Strong dec. | Recessive dec. |
| 1991-1992| Strong dec.  | Strong dec. | Strong dec. | Weak dec. | Strong dec. |
| 1992-1993| Strong dec.  | Recessive dec. | Weak neg. dec. | Strong dec. | Strong dec. |
| 1993-1994| Expansive neg. dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1994-1995| Expansive neg. dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1995-1996| Expansive neg. dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1996-1997| Strong dec.  | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1997-1998| Strong dec.  | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1998-1999| Strong dec.  | Strong dec. | Strong dec. | Expansive neg. dec. | Strong dec. |
| 1999-2000| Strong dec.  | Strong dec. | Strong dec. | Strong dec. | Expansive neg. dec. |
| 2000-2001| Expansive neg. dec. | Strong dec. | Expansive neg. dec. | Strong dec. | Expansive coup. |
| 2001-2002| Weak dec.    | Strong dec. | N/A         | Strong dec. | Strong dec. |
| 2002-2003| Expansive neg. dec. | Expansive neg. dec. | Recessive dec. | Strong dec. | Expansive neg. dec. |
| 2003-2004| Strong dec.  | Strong dec. | Strong dec. | Strong dec. | Weak dec. |
| 2004-2005| Strong dec.  | Strong dec. | Strong dec. | Strong dec. | Weak dec. |
| 2005-2006| Strong dec.  | Expansive neg. dec. | Strong dec. | Strong dec. | Expansive neg. dec. |
| 2006-2007| Strong dec.  | Strong dec. | Expansive neg. dec. | Weak dec. | Strong dec. |
| 2007-2008| Strong dec.  | Recessive dec. | Strong dec. | Recessive dec. | Recessive dec. |
| 2008-2009| Recessive dec. | Strong neg. dec. | Weak neg. dec. | Strong neg. dec. | Recessive dec. |
| 2009-2010| Expansive neg. dec. | Strong dec. | Strong dec. | Strong dec. | Weak dec. |
| 2010-2011| Expansive neg. dec. | Strong dec. | Weak dec. | Strong dec. | Strong dec. |
| 2011-2012| Strong dec.  | Recessive dec. | Expansive neg. dec. | Weak neg. dec. | Expansive neg. dec. |
| 2012-2013| Strong dec.  | Strong neg. dec. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 2013-2014| Strong dec.  | Strong dec. | Strong dec. | Strong dec. | Strong dec. |

Austria showed strong decoupling 59% of the time. The longest streak of strong decoupling for Austria was between 2003 and 2008. Then it deteriorated in the next three years due to GFC. However, for the last three years, it improved to strong decoupling. However, it was not able to reach
the reduction target. It can be explained by the rise of emissions from transport by 60% between 1990 and 2010 [17]. So despite improvement in the energy sector, the goal was not achieved.

Denmark showed strong decoupling only 32% of the time. Despite that, it was able to outdo the reduction target. Between 1990 and 2011, the GHGs emissions declined by 24% due to the usage of natural gas instead of coal and the increasing share of renewable energy [17]. Denmark rapidly recovered from GFC and reached strong decoupling. It can be explained by the measures of fiscal consolidation [18]. The low share of decoupling means that emission reduction has affected economy.

Germany showed strong decoupling 61% of the time. It even quickly recovered from effects of GFC. Moreover, it was able to overachieve the reduction targets. The reason are national climate strategies and policies like taxation for energy and emissions as well as rise of nuclear power share in electricity production [19], [20]. However, there was also introduction of new lignite fired power plants and coal power plants, which may have caused expansive negative decoupling in 2011-2013 [21]. There was a year, when decoupling state was unidentifiable, because GDP has not changed.

Luxembourg showed strong decoupling 75% of the time, which is the highest value not only in Group I but in the whole EU-15. It experienced the largest drop in CO2 emission intensity. This happened due to the closure of coal power plants and the opening of natural gas power plants, which resulted in a long period of strong decoupling (1992-1998 and 1999-2006). Nevertheless, it was not able to achieve the reduction target. The cause may be the transport sector, where the number of emissions increased three times between 1990 and 2011 [22]. So, the situation is similar to Austria.

The United Kingdom showed strong decoupling 58% of the time. It even had a long streak of strong decoupling between 1991 and 2000. However, it was deterriorated in the 21st century due to the closing of nuclear power plants and consequent increase in emissions [19]. Despite that, UK was able to achieve reduction values about three times bigger than the set target. This was possible due to the liberalization of the energy market and switching to natural gas and biomass in power plants [14].

3.2. Decoupling analysis of Group II
According to the Tapio method, the decoupling states were also not uniform in the specified period. This group was also affected by the GFC, so the decoupling state went down to strong negative decoupling for France and recessive decoupling for the rest of Group II. Nevertheless, all of the countries of Group II reduced emissions more than the initial targets. The actual reduction values are: Belgium (-22%), Finland (-17.1%), France (-16.3%), Italy (-19.8%), and Netherlands (-15.8%) [14].

| Time     | Belgium | Finland | France | Italy | Netherlands |
|----------|---------|---------|--------|-------|-------------|
| 1990-1991 | Strong dec. | Weak neg. dec. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 1991-1992 | Strong dec. | Recessive coup. | Strong dec. | Strong dec. | Strong dec. |
| 1992-1993 | Strong neg. dec. | Strong neg. dec. | Recessive dec. | Recessive dec. | Expansive neg. dec. |
| 1993-1994 | Expansive neg. dec. | Expansive neg. dec. | Strong dec. | Strong dec. | Strong dec. |
| 1994-1995 | Strong dec. | Strong dec. | Expansive neg. dec. | Expansive neg. dec. | Strong dec. |
| 1995-1996 | Strong dec. | Strong dec. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 1996-1997 | Strong dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1997-1998 | Expansive coup. | Weak dec. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 1998-1999 | Strong dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 1999-2000 | Weak dec. | Weak dec. | Weak dec. | Weak dec. | Weak dec. |
| 2000-2001 | Strong dec. | Strong dec. | Strong dec. | Strong dec. | Expansive neg. dec. |
| 2001-2002 | Strong dec. | Strong dec. | Expansive neg. dec. | Expansive neg. dec. | Strong dec. |
| 2002-2003 | Weak dec. | Weak dec. | Expansive neg. dec. | Expansive neg. dec. | Expansive neg. dec. |
| 2003-2004 | Strong dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 2004-2005 | Weak dec. | Weak dec. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 2005-2006 | Strong dec. | Weak dec. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 2006-2007 | Strong dec. | Strong dec. | Expansive neg. dec. | Strong dec. | Weak dec. |
| 2007-2008 | Strong dec. | Strong dec. | Expansive neg. dec. | Strong dec. | Recessive dec. |
| 2008-2009 | Recessive dec. | Strong dec. | Strong dec. | Recessive dec. | Recessive dec. |
| 2009-2010 | Expansive neg. dec. | Expansive coup. | Expansive neg. dec. | Strong dec. | Strong dec. |
| 2010-2011 | Strong dec. | Strong dec. | Strong dec. | Strong dec. | Strong dec. |
| 2011-2012 | Expansive neg. dec. | Strong neg. dec. | Expansive neg. dec. | Recessive coup. | Strong neg. dec. |
| 2012-2013 | Strong dec. | Recessive dec. | Strong dec. | Recessive dec. | Strong neg. dec. |
2013-2014 | Expansive neg. dec. | Strong neg. dec. | Strong dec. | Recessive dec. | Expansive neg. dec. |
--- | --- | --- | --- | --- | ---
Belgium showed strong decoupling 58% of the time. However, most of the time, the decoupling states fluctuated over the period. Even after the effects of GFC, the situation remained unstable, and the decoupling state altered between expansive negative and strong decoupling. The possible cause of such behavior is that between 2005 and 2011, energy consumption increased [23]. In addition, GFC caused the decline of GHG emissions, which may be the reason of three times reduction compared to initial targets. Moreover, by 2012, the share of renewable energy was 5.5% [23].

Finland showed strong decoupling 46% of the time. Between 1997 and 2008, there was strong decoupling, except for several years with weak decoupling. Despite the initial target of maintaining the level of emissions of 1990, Finland was able to achieve a reduction of -17.1%. The main reason for such developments is switching from oil to electricity in the heating sector [25]. However, it was reported that Finland had high levels of GHG emissions per capita [19]. This may be explained by the weather conditions and low prices of energy, which incentivize energy use.

France showed strong decoupling 50% of the time. However, it was very unstable and often changed to expansive negative decoupling, which occurred 42% of the time. It is suggested that the highest share of nuclear power in the heat and electricity production sector had a positive influence on the decoupling especially in 2010-2014, excluding 2011-2012 [26]. In terms of reduction targets, the situation is similar to Finland. By the end of the study period, France was responsible only for 3.2% of GHGs produced in electricity generation in the EU-28+Iceland [14].

Italy showed strong decoupling 58% of the time. It was especially prominent in the period between 1990 and 2002 with couple disturbances by weak and recessive decoupling and expansive negative decoupling in 1994-1995. During 1990-2008 the energy consumption increased, which might have been the reason for occasional expansive negative decoupling. So, Italy prioritized renewable energy and reached the share of 23% in electricity production between 2005-2011 [27]. Thus, Italy was able to overachieve the Kyoto Protocol reduction target trifold.

The Netherlands showed strong decoupling 63% of the time. It occurred almost throughout the study period with occasional disturbances by expansive negative decoupling. However, the last three years of the period had strong negative and expansive negative decoupling. The cause of this is the growth of CO2 emissions in public electricity and heat generation between 2011 and 2014 [14]. Otherwise, Netherlands also overachieved the reduction targets set by the Kyoto Protocol.

3.3. Decoupling analysis of Group III

According to the Tapio method, similar to previous groups, the decoupling states were very unstable. The effect of GFC was drastic for this group. The decoupling states went down to recessive decoupling for Portugal and Spain, weak negative decoupling for Greece and Ireland, strong negative decoupling states for Sweden. Unlike Group I and II, this group was not able to fully recover in the post-crisis period. Despite that, all countries were able to meet the reduction targets. The real values are: Greece (-3.3%), Ireland (+3.7%), Portugal (+6.5%), Spain (+15%), and Sweden (-24.4%) [14].

Greece showed strong decoupling 46% of the time. Moreover, the GDP of Greece decoupled from CO2 emissions intensity between 1995 and 2006, except for 1999-2000. However, GDP has been affected by GFC and decreased for the rest of the period. Nevertheless, the CO2 emissions intensity has also been declining. The possible reason is the fact that the share of renewable energy in electricity production grew to 14.6% by 2011 [28]. Moreover, the share of oil-based power plants dropped to 6% by 2007 [29]. Thus, Greece was able to overachieve the Kyoto Protocol goal.

Ireland showed strong decoupling 67% of the time. It experienced positive decoupling between 1990 and 2007. During 1990-2006 the economy grew rapidly, which led to GHG emissions per capita [24]. Despite that, the number of emissions from electricity production was unchanged. Thus, Ireland was able to meet the Kyoto Protocol targets. However, the main emitter sector in Ireland is agriculture, so more focus should be there instead of electricity and heat generation [24].
Table 4. Decoupling states for Group III.

| Time    | Greece           | Ireland          | Portugal         | Spain            | Sweden           |
|---------|------------------|------------------|------------------|------------------|------------------|
| 1990-91 | Strong dec.      | Weak dec.        | Weak dec.        | Strong dec.      | Strong dec.      |
| 1991-92 | Expansive neg. dec. | Weak dec. | Expansive neg. dec. | Strong dec. | Strong neg. dec. |
| 1992-93 | Recessive dec.   | Strong dec.      | Expansive dec.   | Recessive dec.   | Recessive dec.   |
| 1993-94 | Strong dec.      | Strong dec.      | Strong dec.      | Strong dec.      | Expansive dec.   |
| 1994-95 | Expansive coup.  | Strong dec.      | Expansive neg. dec. | Strong dec. | Strong dec.      |
| 1995-96 | Strong dec.      | Strong dec.      | Strong dec.      | Strong dec.      | Expansive neg. dec. |
| 1996-97 | Strong dec.      | Strong dec.      | Expansive neg. dec. | Strong dec. | Strong dec.      |
| 1997-98 | Strong dec.      | Strong dec.      | Weak dec.        | Strong dec.      | Weak dec.        |
| 1998-99 | Strong dec.      | Strong dec.      | Expansive neg. dec. | Expansive neg. dec. | Strong dec. |
| 1999-2000 | Expansive coup. | Strong dec.      | Strong dec.      | Strong dec.      | Strong dec.      |
| 2000-2001 | Weak dec.      | Weak dec.        | Strong dec.      | Expansive neg. dec. | Strong dec.      |
| 2001-2002 | Strong dec.      | Strong dec.      | Expansive neg. dec. | Expansive neg. dec. | Expansive neg. dec. |
| 2002-2003 | Strong dec.     | Strong dec.      | Recessive dec.   | Strong dec.      | Expansive dec.   |
| 2003-2004 | Strong dec.     | Strong dec.      | Expansive neg. dec. | Weak dec.      | Strong dec.      |
| 2004-2005 | Strong dec.     | Weak dec.        | Expansive neg. dec. | Expansive coup. | Strong dec.      |
| 2005-2006 | Strong dec.     | Strong dec.      | Strong dec.      | Strong dec.      | Expansive neg. dec. |
| 2006-2007 | Expansive coup. | Strong dec.      | Strong dec.      | Expansive neg. dec. | Strong dec.      |
| 2007-2008 | Recessive dec.  | Recessive dec.   | Strong dec.      | Strong dec.      | Strong neg. dec. |
| 2008-2009 | Weak neg. dec.  | Weak neg. dec.   | Recessive dec.   | Recessive dec.   | Strong neg. dec. |
| 2009-2010 | Weak neg. dec.  | Expansive neg. dec. | Strong dec. | Strong dec.      | Expansive neg. dec. |
| 2010-2011 | Weak neg. dec.  | Strong dec.      | Strong neg. dec. | Strong neg. dec. | Strong dec.      |
| 2011-2012 | Weak neg. dec.  | Expansive neg. dec. | Strong neg. dec. | Strong neg. dec. | Recessive dec. |
| 2012-2013 | Recessive dec.  | Strong dec.      | Recessive dec.   | Expansive neg. dec. | Expansive neg. dec. |
| 2013-2014 | Expansive neg. dec. | Strong dec. | Strong dec. | Expansive neg. dec. | Strong dec. |

Portugal showed strong decoupling only 38% of the time. The decoupling states fluctuated vigorously throughout the whole period. The longest period was only between 2005-2008, and then it went down because of GFC. In 2011 Portugal was able to achieve a 46.5% share of renewable electricity [30]. This is the reason it was able to overachieve the Kyoto Protocol target. However, it has probably affected economic growth and caused the deterioration of the decoupling states.

Spain showed strong decoupling 42% of the time. Yet, it was very unstable and often deteriorated to negative expansive decoupling, which as a result, occurred 29% of the time. Between 2005 and 2011, the share of renewable energy in electricity consumption has grown by 67% [31]. Despite that, decoupling states still deteriorated in the last years of the chosen period, and Spain was able to reach the level of emissions exactly set by the Kyoto Protocol. It has been reported that Spain had the highest effect of the population on the CO2 emissions among EU-15 [3]. The population increased roughly by 6 million between 1990 and 2014, which may have affected the decoupling [12].

Sweden showed strong decoupling only 38% of the time. Moreover, it often was interrupted by expansive negative decoupling, which constitutes 33% of the cases. In the period between 1970 and 2010, the industry shifted from oil to electricity back and forth depending on the oil prices [32]. It may have caused the fluctuations in the decoupling states. Sweden had overachieved the Kyoto Protocol targets by a large difference. It is caused by the fact that in the 1990s already hydropower and nuclear power constituted 90% of electricity production [33].

4. Conclusion

Overall, for the entire period the decoupling states of each country were fluctuating unpredictably. Thus, it was impossible to determine a specific relationship of decoupling between CO2 emissions intensity from public energy and heat production sector and GDP for EU-15 as a group. The only country that showed positive decoupling state (recessive, weak, strong) for almost an entire period was Luxembourg. At the same time, Luxembourg was one of two countries together with Austria, which was not able to meet the reduction target set by the Kyoto Protocol agreement. The possible reason for this situation is that there were increasing amounts of GHGs emissions transport sector, which despite other efforts of these countries did not allow to reach the reduction targets. From this a conclusion that total performance of the country in terms of GHG emissions reduction can be different from sectoral
efforts can be made. Other countries that were close to Luxembourg and were able to show positive decoupling more than 80% of the time were Ireland and Italy.

The countries, which had higher share of renewable energy such as Denmark, Finland, and Sweden, had a potential for larger CO\textsubscript{2} emissions mitigation. Nevertheless, intensive introduction of renewable sources of energy can have negative outputs. Their high cost of operation and production that comes with widespread use might constrict the growth of economy. Thus, in these countries an occasional deterioration of the decoupling states was observed. Despite that, overall, for all of the EU-15 countries positive decoupling states were the most prevalent.

Generally, diminishing the use of fossil fuels, and changing to more efficient technologies as well as increasing the share of renewable energy sources improved decoupling of GDP from CO\textsubscript{2} emission intensity in EU-15 countries. It was observed that GFC had a serious effect not only on the economy of countries, but also on their GHG emissions. GFC led to deterioration of the decoupling states to almost in all of 15 countries of EU during 2008-2009.

For the future works, it is recommended to perform a decoupling analysis in combination with decomposition of CO\textsubscript{2} emissions. This will be beneficial, since it will identify the main drivers of CO\textsubscript{2} emissions for a more detailed analysis.

References

[1] OECD 2002 Sustainable Development: Indicators to measure decoupling of environmental pressure from economic growth *The Organisation for Economic Co-operation and Development*

[2] Filippini M and Hunt L C 2011 Energy Demand and Energy Efficiency in the OECD Countries: A Stochastic Demand Frontier Approach *The Energy Journal* **32**

[3] Moutinho V, Madaleno M and Silva P M 2015 Which factors drive CO\textsubscript{2} emissions in EU-15? Decomposition and innovative accounting *Energy Efficiency* **9** 1087–113

[4] UNFCCC 2018 Parties United Nations Climate Change

[5] Edenhofer O 2014 *Climate change 2014: mitigation of climate change: Working Group III contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change* (New York, NY: Cambridge University Press)

[6] Dogan E and Seker F 2016 Determinants of CO\textsubscript{2} emissions in the European Union: The role of renewable and non-renewable energy *Renewable Energy* **94** 429–39

[7] Möst D and Fichtner W 2010 Renewable energy sources in European energy supply and interactions with emission trading *Energy Policy* **38** 2898–910

[8] Chen L, Yang Z and Chen B 2013 Decomposition Analysis of Energy-Related Industrial CO\textsubscript{2} Emissions in China *Energies* **6** 2319–37

[9] Ren S, Yin H and Chen X H 2014 Using LMDI to analyze the decoupling of carbon dioxide emissions by China's manufacturing industry *Environmental Development* **9** 61–75

[10] Shao S, Yang L, Gan C, Cao J, Geng Y and Guan D 2016 Using an extended LMDI model to explore techno-economic drivers of energy-related industrial CO\textsubscript{2} emission changes: A case study for Shanghai (China) *Renewable and Sustainable Energy Reviews* **55** 516–36

[11] Gordon D, Pristupa A, Bidordinova A, Scheiner S, Hayden A, Monstadt J, Kern K and Macdonald D 2013 *Allocating Canadian Greenhouse Gas Emission Reductions Amongst Sources and Provinces: Learning from Germany and the EU* (Toronto: University of Toronto)

[12] IEA Data overview *IEA - International Energy Agency*

[13] EEA 2015 Overview of electricity production and use in Europe *European Environment Agency*

[14] EEA 2016 Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016 *European Environment Agency*

[15] Wang Q and Su M 2020 Drivers of decoupling economic growth from carbon emission – an empirical analysis of 192 countries using decoupling model and decomposition method *Environmental Impact Assessment Review* **81** 106356
[16] Cheung W, Fung S and Tsai S-C 2010 Global capital market interdependence and spillover effect of credit risk: evidence from the 2007–2009 global financial crisis Applied Financial Economics 20 85–103

[17] Dreblow E, Duwe M, Wawer T, Donat L, Zelljad E, Ayres A and Poblocka A 2013 Assessment of climate change policies in the context of the European Semester. Country Report: Denmark. Ecologic Institute - Science and Policy for a Sustainable World

[18] OECD 2011 Restoring Public Finances The Organisation for Economic Co-operation and Development

[19] EEA 2011 Greenhouse gas emissions in Europe: a retrospective trend analysis for the period 1990 - 2008 European Environment Agency

[20] EEA 2010 Annual European Union greenhouse gas inventory 1990–2008 and inventory report 2010 European Environment Agency

[21] Velten E K, Donat L, Duwe M and Bozsoki I 2014 Assessment of climate change policies in the context of the European Semester Country Report: Germany Ecologic Institute - Science and Policy for a Sustainable World

[22] EEA 2019 Adaptation challenges and opportunities for the European energy system European Environment Agency

[23] Donat L, Velten E K, Duwe M, Najdawi C and Wevers M 2014 Assessment of climate change policies in the context of the European Semester Country Report: Belgium Ecologic Institute - Science and Policy for a Sustainable World

[24] Smith L O, Velten E K and Maroulis G 2014 Assessment of climate change policies in the context of the European Semester Country Report: Ireland Ecologic Institute - Science and Policy for a Sustainable World

[25] Smith L O, Velten E K, Donat L, Duwe M, Brückmann R and Pilvik R 2014 Assessment of climate change policies in the context of the European Semester Country Report: Finland Ecologic Institute - Science and Policy for a Sustainable World

[26] Marques A C, Fuinhas J A and Nunes A R 2016 Electricity generation mix and economic growth: What role is being played by nuclear sources and carbon dioxide emissions in France? Energy Policy 92 7–19

[27] Donat L, Velten E K, Prahl A and Zane E B 2014 Assessment of climate change policies in the context of the European Semester Country Report: Italy Ecologic Institute - Science and Policy for a Sustainable World

[28] Eberle A, Donat L, Velten E K and Maroulis G 2014 Assessment of climate change policies in the context of the European Semester Country Report: Greece Ecologic Institute - Science and Policy for a Sustainable World

[29] Theodosiou G, Koroneos C and Stylos N 2014 Environmental impacts of the Greek electricity generation sector Sustainable Energy Technologies and Assessments 5 19–27

[30] Eberle A, Velten E K, Duwe M and Trenepohl N 2014 Assessment of climate change policies in the context of the European Semester Country Report: Portugal Ecologic Institute - Science and Policy for a Sustainable World

[31] Donat L, Velten E K, Prahl A, Duwe M and Zane E B 2014 Assessment of climate change policies in the context of the European Semester Country Report: Spain Ecologic Institute - Science and Policy for a Sustainable World

[32] Svensson E, Nilsson L, Haraldsson M and Gustafsson A 2012 Energy Efficiency Policies and Measures in Sweden BUILD UP - The European Portal for Energy Efficiency in Buildings

[33] Kara M, Syri S, Lehtilä A, Helynen S, Kekkonen V, Ruska M and Forsström J 2008 The impacts of EU CO2 emissions trading on electricity markets and electricity consumers in Finland Energy Economics 30 193–211