EVALUATION OF DECOUPLING OF GDP, ENERGY, AND CO_2 EMISSIONS IN EU-15

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DECLARATION

I hereby, declare that this manuscript, entitled "*Evaluation of Decoupling of GDP, Energy, and CO_2 Emissions in EU-15",* is the result of my own work except for quotations and citations which have been duly acknowledged.

I also declare that, to the best of my knowledge and belief, it has not been previously or concurrently submitted, in whole or in part, for any other degree or diploma at Nazarbayev University or any other national or international institution.

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Abstract

Global warming, which is a consequence of the rapid increase of CO_2 emissions, has attracted the world's attention. Usually, the growth of economy occurs in parallel with the increase in energy demand, which in turn would lead to the high levels of GHG emissions. Decoupling provides reduction of environmental pressure without deterioration of economic growth of a country. In this study, decoupling relationship between GDP and CO_2 emissions from public electricity and heat generation sector was investigated for EU-15 for the period from 1990 to 2014. The decoupling assessment was performed by using two methods: the Tapio decoupling elasticity method and OECD decoupling factor method. Based on results of both of those methods the decoupling states were defined. The results demonstrate that the decoupling states between GDP and CO_2 emission intensity (CO_2 emissions from public energy and heat production sector) fluctuated to a significant extent during the entire study period 1990-2014 for EU-15. Thus, no clear patterns for decoupling states were observed. Nevertheless, almost in all countries strong and weak decoupling were mostly occurred between GDP and CO_2 emission intensity. In comparisons, the Tapio results represented more comprehensive picture of decoupling relationship between chosen indicators compared to the OECD method.

Under the Kyoto Protocol, EU-15 countries were committed to reduce their GHGs emissions to 8% below the 1990 levels between 2008 and 2012. According to EEA, total EU-28+Iceland emissions were below 1990 levels in 2014. It has been found that Austria, Denmark, Luxembourg and Spain produced significantly higher levels of emissions than their initial targets committed under the first commitment period 2008–2012 of Kyoto Protocol respect to 1990 levels. However, this tend to be not correlate with decoupling performance of countries in a specific sector. Among all countries of EU-15, only in Luxemburg the GDP strongly decoupled from CO_2 emissions from public energy and heat production sector for almost the entire period 1990-2014, although Luxemburg did not reach its emission reduction target. According to results, the decoupling states tend to be dictated by the rate of change of GDP and CO_2 emission intensity, which in turn depend on different factors. It was found that in general, decreasing the use of solid and liquid fuels, transition to nuclear power, shifting to more efficient technologies and growing shares of renewable energy sources in public electricity and heat production would promote decoupling of GDP from CO_2 emission intensity in EU-15 member countries. Furthermore, our investigation has shown that the 2008-2009 global

financial crisis had affected the economy and public energy and heat production sector of countries. As a result, the decoupling states of countries switched to strong negative decoupling state, which is the least desired state, during the crisis period and after it. Many researchers found that the population growth can significantly increase CO_2 emissions in a country. Since significant population increase had not been observed for the period of our study in EU-15, effect of this factor can be considered less significant, except for France and Spain. Because the human population remained fairly stable during 1990-2014 for almost all EU-15 member countries. In the future, decoupling analysis should be combined with the decomposition technique to confirm which factors has significant effect on decoupling trends.

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List of Abbreviations & Symbols

EU	European Union
GDP	Gross domestic product
GDP (billion 2010 USD using PPPs)	GDP value converted to US dollars using the yearly average 2010 purchasing power parities
GHGs	Greenhouse gasses
GFC	Global financial crisis
EEA	European Environment Agency

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Chapter 1- Introduction

1.1 The origin of research problem

The development of economy in many countries has been accompanied by an increasing pressure on the environment, which in some aspects has escalated into a global threat. Specifically, the human impact on the greenhouse effect may lead to a global change with an unprecedent negative effect on life on Earth. The primary reason for this undesired consequence is that human activities are based on increased energy consumption, which is supplied mainly through the combustion of fossil fuels that inevitable result in the release of increased amounts of greenhouse gases (GHGs) in the atmosphere. This leads in turn to climate change, which needs to be addressed in an economically feasible and environmentally safe way [1],[2]. According to data reported by the International Energy Agency (IEA), CO_2 emissions have significantly increased from 20 516.0 Mt to 33 513.3 Mt globally during 1990-2018 (Figure 1.1) [3]. Among GHGs, the effect of CO_2 gas on global warming is the most important one as its share in total anthropogenic GHGs emissions is the highest and estimated to be 76% (38±3.8 $GtCO_2eq/yr$, in 2010) [4]. Compared to the pre-industrial revolution period (1750-1850), the global average surface temperature has increased by 1.3 degree Celsius [5],[6]. This causes accumulation of extra heat in the Earth. In its turn, this extra heat changes seasonal temperature extremes in all regions of the planet. As a result, global warming poses a variety of challenges such as sea ice melting, behavior of living organisms begins to change in order to adapt to new circumstances of surrounding environment [7], [8]. The distinctive example of the consequence of global warming is a collapse of the coral reef ecosystems [9]. Coral reefs play an important role in the ecosystem of the Earth as they are main producers of the atmospheric oxygen [10]. Also, they provide habitat for fishes and other organisms in the ocean, and by this way coral reefs maintain the biodiversity in oceans [11]. However, an increase in sea temperature due to the global warming was correlated with decline in biological productivity of coral reefs [12]. Wilkinson [13] made prediction that if the current trend of global warming continue, coral reefs will be lost and their recovery may take approximately 20-40 years. But the consequences of global warming are still not fully understood because of its tremendous and long-lasting nature. To avoid further adverse effects of global warming, it is urgent to effectively control and reduce CO_2 emissions.

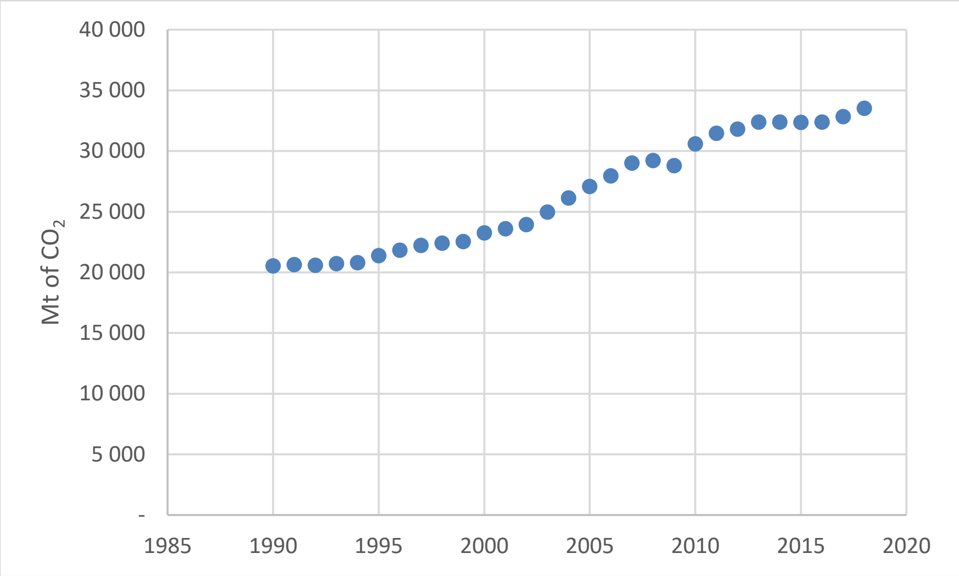

Figure 1.1. Total CO_2 emissions, World 1990-2018 [3].

Human development has resulted in an increased demand for energy [14],[15]. Energy is a key resource that is required to satisfy all kinds of human needs. Thus, energy production and consumption simultaneously account for high rate of CO_2 emissions [16], [17]. For instance, over 80 % of GHGs are generated from energy sector in Annex I Parties (the countries adopted the United Nations Framework Convention on Climate Change, list of countries here [18]), which means that energy sector is the major contributor of CO_2 emission. The main sources of energy in many countries are still fossil fuels such as natural gas, oil and coal, which generate enormous amounts of CO_2 after combustion processes [19]. The inefficient use of energy is another challenge that needs to be addressed. Specifically, the inefficient use of energy also causes increased CO_2 emissions. For that reason, many countries turn their attention to the energy-related CO_2 emissions and enhancing ability to obtain energy from sources that do not produce CO_2 emissions. It is necessary to highlight the importance of integrating renewable energy sources into the energy sector. The increase in the share of renewable energy sources in the energy production will have a positive effect on the environment in terms of CO_2 emissions [20],[21]. In fact, the ability of a country to maintain the level of CO_2 in the atmosphere by increasing the use of renewable energy sources is restricted by its economy. Because the generation of energy from renewable sources is currently expensive due to the complexity of technologies implemented there [22],[23].

Throughout time, most researchers have highlighted that economic growth is the main driving force of the rise in the atmospheric CO_2 concentration [24],[25],[26]. Thus, different methods have been utilized to analyze the relationship between economic growth (in terms of GDP) and environmental pressure such as CO_2 emissions, energy consumptions, SO_2 emissions, GHGs emissions, etc. [27],[28],[29]. Decoupling analysis is a commonly used technique to monitor the relation between the economic growth and environmental pressure of a country. The term decoupling was firstly used by the Organization for Economic Co-operation Development (OECD) in 2002 to explore the relationship between economic growth and consumption of energy [30]. Decoupling analysis assigns the decoupling state for relationship between economic growth and environmental pressure. The decoupling state (e.g. strong decoupling, weak decoupling, etc.) can be found by using methods such as Tapio and the OECD [31],[32]. Basically, environmental policies and measurements are relied on the results of decoupling analysis, which can be considered as an important tool in the substantial efforts for the mitigation of CO_2 emissions [18],[22].

Many countries and organizations adopted a series of actions and ways to combat global warming and climate change consequences on the environment. Countries obligating themselves to utilize those actions and ways through the sustainable development. The term “sustainable development” has various interpretations depending on the context of use, society and field [33], [34]. In our case, the definition proposed by Atkinson [35] is more applicable which states that sustainable development is an increase in per capita GDP, which is economic growth, without sacrificing natural resources. OECD is one of the leaders in cutting CO_2 emissions. The share of OECD countries in the global CO_2 emissions decreased 16% during the period 2001-2015 [31]. However, the level of global emissions of CO_2 is still high, which is a challenging issue. Therefore, cooperative efforts at the global scale is needed to address the issue of climate change. It is important to strengthen our efforts to achieve the CO_2 emission targets set. One of the efforts to reach those targets was the Kyoto Protocol which was an international agreement aimed to stabilize concentration of GHGs in the atmosphere in order to prevent side effects of global warming. EU-15 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom) is still highly dependent on fossil fuels, which are extensively used as the main source of energy [36], [37]. In 2008 the largest contributor of EU-15 GHGs emissions was energy sector (60%) [38]. The share of fossil fuel-based thermal plants decreased from 57% in 1990 to 44% in 2017 in the EU [39]. Therefore, the EU-15 countries are trying to address the problem of how to realize sustainable development in low carbon pattern.

1.2 Thesis aims and objectives

The objectives of this thesis work are: (1) to calculate decoupling indexes (OECD method) and decoupling elasticities (Tapio method) for EU-15 countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.) for the relationship between CO_2 emission intensity and GDP for the period 1990-2014; (2) evaluate the decoupling states between GDP and CO_2 emission intensity for each of 15 countries of EU over the period 1990 to 2014; (3) to carry out comparative analysis of advantages and disadvantages of the OECD method and the Tapio method for decoupling analysis.

Firstly, decoupling factor and decoupling elasticity values were calculated by using OECD method and the Tapio method, respectively. Then, based on resulting outputs of OECD and Tapio methods the decoupling states were identified. Finally, these two decoupling analysis methods were compared.

Chapter 2- Literature Review

2.1 Background to relationship between energy and environment

The unsustainable growth of economy has led to the deterioration of the quality of environment globally. The past few decades, the international community made some efforts to address an increase in global temperature which is happening mainly due to the accumulation of greenhouse gases (GHGs) in atmosphere. In terms of technological progresses as the efforts to mitigate CO_2 emissions, countries are attempting to design manufacturing units and processes that emit less CO_2 emissions [40]. For example, Benhelal et al. [41] analyzed global strategies and potentials to reduce CO_2 emissions produced during the cement production, because the cement industry is responsible for 5-7% of global CO_2 emissions. He highlighted that the most efficient alternative is the dry process with calciner, which can show up to 20% mitigation of CO_2 emissions in the processes. According to authors [41], there are still economic and technical challenges that challenge the wide-spread implementation of the dry process with calciner. Moreover, in order to reach the desired emission reduction targets, countries have been practicing different policies and regulations through adaptation and mitigation strategies

[42]. As for international collaborations and agreements, the United Nations Framework Convention on Climate Change (UNFCCC), which entered into force on 21 March 1994, is an international environmental agreement addressing global warming and contributing to the formation of subsequent environmental agreements such as the Kyoto Protocol and Paris Agreement [43]. Paris Agreement entered into force on 4 November 2016 and is targeting limit the increase of global average temperature to 1.5 degrees Celsius [44]. The Kyoto Protocol is a set of obligations to stabilize the atmospheric concentration of GHGs in the period 2008–2012 (the first commitment period), which came into effect on 16 February 2005 [45]. According to the first commitment period of the Kyoto Protocol [45], EU-15 countries were targeting to reduce GHGs emissions by 8% compared to 1990 levels. As a result, EU-28+Iceland as an aggregate reduced GHG emissions by 24% first commitment period of Kyoto Protocol [46]. The European Union Emissions Trading System (EU ETS) is a policy instrument to meet the targets established by the Kyoto Protocol [47]. EU ETS regulates the amount of emissions produced by installations (e.g. factories, power stations and other installations). It has four phases: phase I (2005-2007), phase II (2008-2012), phase III (2013-2020) and phase IV (2021-2030). The maximum amount of GHG emissions is called allowance, which can be auctioned off or traded among participants of EU ETS [47]. However, governments are forced to make less aggressive policies in a such way that their policies should not deplete economic growth of a country as it is also closely linked to society. Otherwise, they have to compensate the economic loss which is challenging process. Thus, there is a triangle of environment, society and economy, which are strongly interconnected with each other. Even there are discussions about delaying the reduction targets until there will be technical advances that will bring the GHGs emissions levels back down, even to unexpected levels ("overshoot" strategy) [48]. By the way, the achieving environmental targets may be possible by breakthroughs in decoupling trends in economic growth and environmental indicators such as GHGs emissions. The Intergovernmental Panel on Climate Change (IPCC) has confirmed that CO_2 is the main contributor of global GHG emissions [4]. Thus, CO_2 emission is mainly used environmental indicator among researchers. In addition, international energy agency (IEA) estimated that 41.7% of the global CO_2 emissions were produced from electricity and heat generation sector in 2018 [49]. Between 2008 and 2018, the share of electricity and heat generation sector in CO_2 emissions were almost stable (41% in 2008) [49]. Therefore, an indicator related to energy production can be an optimal option for the study. Furthermore, it is essential to identify whether chosen indicator moves into a desired direction or not. It can be evaluated by performing decoupling analysis which shows relationship between economic growth and

environmental pressure in our case. Decoupling is quantified by comparing the economic activity with environmental pressure, resource use and environmental impacts [50]. Decoupling of economic growth from environmental pressures is the most perforable state that happens when less environmental emissions are produced at the same time with economic development. As the development continues, environmental policies are not only tool to achieve less harmful pathway of growth of economy. Investments in sustainable technologies is another option to destruct link between economic growth and environmental pressure. Nevertheless, it seems to be that the final result is more important despite the way of achievements in the reduction of CO_2 emissions.

2.2 Methodology

2.2.1 Studies on decoupling methods

Decoupling is the breaking or de-linking of economic growth from increasing environmental indicators. The concept of decoupling is first introduced by Organization for Economic Cooperation and Development (OECD). According to OECD, decoupling is breaking the relationship between environmental pressure and economic growth, and can be divided into absolute and relative decoupling [50]. Special indicators are used to measure decoupling in which the environmental pressure serves as the numerator and the driving force is the denominator. Decoupling indicators convey the message about the change of relationship between environmental pressure and economic growth over time. OECD explores thirty-one sets of decoupling indicators associated with the majority of environmental issues. Some decoupling indicators can be further decomposed into several variables in order to efficiently identify any minor changes in environmental pressures [50]. In fact, the empirical results of decoupling analysis directly depend on the chosen indicator of environmental stress. Hence, indicators expand the decoupling analysis' application area. For example, it is possible to perform per sectoral decoupling analysis (e.g. industry, agriculture, transportation, etc.). Zhao et al. [51] pointed out that economic growth and carbon emissions of industry, agriculture, construction, transport, service and residential sectors were still at the coupling state in China. They came to this after performing decoupling analysis by using the OECD decoupling factor method. Thus, the OECD decoupling model is easy to handle and flexible in application. The decoupling model of OECD can therefore be expressed as:

$$D_f = 1 - \frac{(EP/DF)_t}{(EP/DF)_0} \quad (2.1)$$

where D_f is the decoupling factor and can be any value within the range (-∞; 1]; EP indicates environmental pressure; DF indicates driving force.

The OECD decoupling factor method was utilized by Lu and Lin et al. [52] to study decoupling of GDP from road energy demand and CO_2 emissions in Taiwan, Germany, Japan and South Korea. They found that increase in road energy demand was consistent with increased CO_2 emissions from transportation sector which resulted in coupling of these indicators with economic growth.

To express the different aspects of the term "decoupling", many concepts have been used in research works. De-linking is a widely used synonym of decoupling regardless of the context [53],[54]. It was applied to estimate the relationship between economic growth and environmental stress in most important industrialized and developing countries. In addition, re-linking term was firstly demonstrated in 1970 by Bruyn & Opschoor [54] in the same meaning as coupling.

Decoupling theory was further developed by Tapio [55], and the model developed is now widely used as the Tapio model. This method is the most widely used method among researchers to study decoupling process. Tapio used the *decoupling elasticity* in order to analyze the link between the transport volume growth and economic growth in the EU countries and Finland between 1970 and 2001. The GDP elasticity of transport CO_2 was introduced (Eq. 2.2):

$$\text{GDP elasticity of transport} = \frac{\%\Delta CO2}{\%\Delta GDP} \quad (2.2)$$

where $\%\Delta GDP$ and $\%\Delta CO_2$ are decoupling indicators of economic growth and transport CO_2 emissions, respectively.

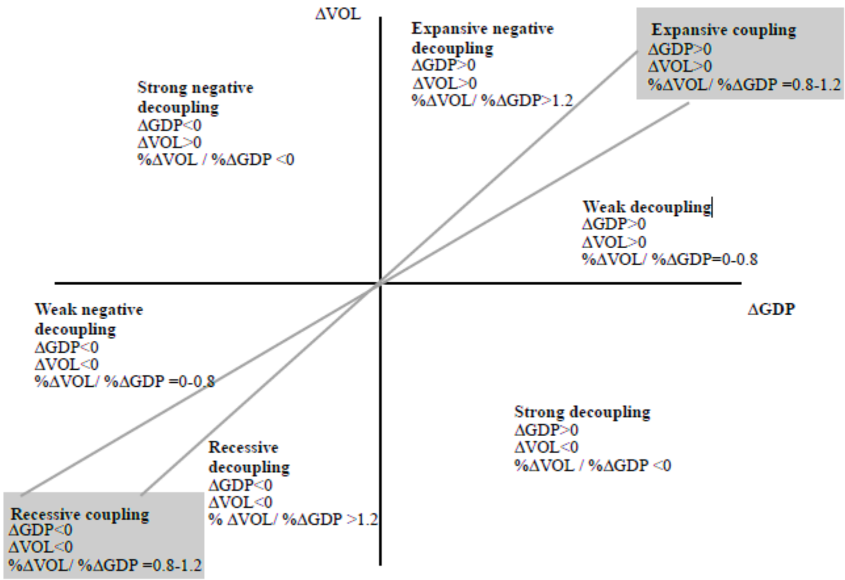

Figure 2.1: The degrees of coupling and decoupling of transport volume growth (DVOL) from economic growth (DGDP). Adapted from ref. [55]

Tapio model has eight possible states of decoupling as shown in Figure 2.1: coupling (0.8 < elasticity < 1.2), weak decoupling (0 < elasticity < 0.8), strong decoupling (elasticity < 0), recessive decoupling (elasticity < 1.2), expansive negative decoupling (elasticity > 1.2); strong negative decoupling (elasticity < 0) occurs when GDP decreases and traffic volume increases, while weak negative decoupling (elasticity > 1.2) occurs when both of GDP and traffic volume decreases. Liu et al. [56] studied decoupling relationship between energy related carbon emissions from manufacturing sectors and economic growth in China. They applied Tapio's decoupling elasticity method in order to evaluate decoupling state between energy related carbon emissions from manufacturing sectors and economic growth. Wang and Su [61] adopted the Tapio decoupling elasticity method (Eq. 2.3) to assess decoupling relationship between economic growth and carbon emissions in 192 countries. The results showed that developed countries improved their decoupling states from weak decoupling to strong decoupling between 2000 and 2014. As for developing countries, they did not show significant decoupling process between economic growth and carbon emissions.

$$DE = \gamma = \frac{\Delta CO2/CO2_0}{\Delta GDP/GDP_0} \quad (2.3)$$

In addition to the above two common methods, there is third type of decoupling method, which is called as the IGTX decoupling model. Initially, this method was introduced by Lu and Mao [57] as the IPAT model. However, IPAT model was not able to distinguish the difference between absolute and relative decoupling. The improved version of this model was developed by Wu et al. [58] to perform decoupling analysis of world economic growth and CO_2 emissions. The proposed decoupling model for computing the decoupling index is

$$I_e = G \times T \times X \tag{2.4}$$

where I_e denotes the waste emission, G the GDP, T the waste emission per unit of GDP, and X the waste discharge rate. Wu et al. [58] used this model to derive the decoupling index and after several mathematical manipulations the expression of the decoupling index is

$$D_e = \frac{te}{tek} = \frac{te}{g} \times (1+g) \tag{2.5}$$

where t_e = the average annual rate of decline in waste emission per unit of GDP; t_{ek} = the critical value when k = 0; g = the GDP annual growth rate for the time period of interest.

The IGTX decoupling model was utilized by Lu et al. [59] to investigate decoupling relationship between energy use and SO_2 emissions in the U.S. and China in 2000-2007. They found slightly more decoupling cases in the U.S. than China.

2.2.2 Comparison of the three decoupling models

The OECD decoupling index method is comfortable to apply for analysis due to its simplicity. There are only two variables: environmental pressure and driving force. Thus, less data is required to perform decoupling analysis. However, there are several shortcomings of this method; for example, sometimes it cannot distinguish between absolute decoupling state and relative decoupling state. Zhao et al. [60] reported that the OECD decoupling index method has less accurate precision. It can only roughly reveal the decoupling between the environmental pressure and the economic growth. This argument was consistent with the results of the Spearman’s rank correlation coefficient when the decoupling effect results of OECD, IGTX, and Tapio model were compared [58]. The OECD method showed a decoupling state between the two variables of interest almost in all cases while the rest two methods showed different decoupling states compared to the OECD model, and described them with a higher degree of correlation, which means that their results coincide with each other (IGTX and the Tapio methods) [58].

The Tapio model demonstrates more comprehensive decoupling states compared to OECD model because of availability of several decoupling states. Wu et al. [58] observed that the overall decoupling index calculated by using the IGTX decoupling model reveals greater uncertainty compared to the Tapio model. The reason for that is that the IGTX decoupling model uses the average rate of decline in CO_2 emissions intensity. However, for developing countries the amount of total CO_2 emissions does not fluctuate significantly and it is almost stable. This causes uncertainties in the outputs of decoupling indexes computed by the IGTX decoupling model. Therefore, long-term analyses are most preferred for the IGTX model. Nevertheless, the Tapio model has an advantage of being not restricted by the duration of the research period of interest. Thus, based on the literature review above it was decided to choose the OECD decoupling factor method and the Tapio model for decoupling analysis due to their simplicity in application and ease of understanding.

2.2.3 Studies on decomposition methods

Decomposition is a powerful tool to break down the influencing factors of CO_2 emissions. There are two popular decomposition techniques: the index decomposition analysis (IDA) and the structural decomposition analysis (SDA) [61]. Both of techniques have additive and multiplicative decomposition framework. Su et al. [61] conducted a comprehensive study comparing IDA and SDA methods. They reported that IDA is frequently used to explore the driving factors of energy use and its emissions. As far as SDA is concerned, it is used to study changes in energy consumption and emissions. Basically, the SDA is applied to examine the whole economy rather than its sectoral aspects. In the case of SDA, both whole economy and a specific sectoral decomposition analyses can be performed. Furthermore, IDA requires less data compared to SDA, which makes it a more applicable technique in decomposition analysis. The logarithmic mean Divisia index (LMDI) decomposition technique is an extensively used technique among IDA scholars [61],[62],[63],[64]. This technique can effectively help to explore the driving factors of CO_2 emissions. The number of studies that have used LMDI for the decomposition of CO_2 emissions has rapidly grown [65],[26],[66],[67]. One prominent advantage of the LMDI over other decomposition methods, such as the arithmetic mean Divisia Index (AMDI), is that it can handle residuals and able to solve “zero value” problems in the data [62]. Additive and multiplicative decomposition frameworks exist for the LMDI method. Chen et al. [31] applied the additive LMDI decomposition method to analyze CO_2 emissions in OECD from base year to report year. Their equation for LMDI decomposition is

$$\Delta C = \Delta C_{CF} + \Delta C_{FE} + \Delta C_{EG} + \Delta C_{GP} + \Delta C_{PP} + \Delta C_{P} \quad (2.6)$$

each variable is indicated in Table 2.

Table 2.1. Description of variables [31]**.**

Variable	Definition
ΔC_{CF}	changes in CO_2 emissions due to changes in CO_2 intensity of fossil energy
ΔC_{FE}	changes in CO_2 emissions caused by changes in energy consumption structure
ΔC_{EG}	changes in CO_2 emissions caused by changes in energy intensity
ΔC_{GP}	changes in CO_2 emissions owing to changes in per capita GDP
ΔC_{PP}	changes in CO_2 emissions caused by changes in population distribution
ΔC_{P}	represents changes in CO_2 emissions caused by changes in the size of population

As shown in Eq. 2.6, the change in CO_2 emissions in OECD was decomposed into six variables. The authors concluded that the energy intensity and per capita GDP are major contributors for changes in CO_2 emissions in OECD, while the population distribution has negligible effect. Zhang and Da [62] utilized the LMDI method to decompose energy related CO_2 emissions in China. They found four main driving forces of changes in CO_2 emissions: economic growth, energy intensity, industrial structure and final energy consumption structure. As a result, the values of economic growth factor almost kept increasing over the period and was proved as the main reason for the increase of CO_2 emissions during1996–2010 in China.

Decomposition technique results reveal changes in CO_2 emissions in a more detailed form. Consequently, many scholars have combined the decomposition technique with decoupling analysis in order to get a more realistic overview of the link between economic growth and environmental pressures. This decoupling model constructed on the basis of decomposition analysis is attracting the research interest of many scholars and is known as the extended decoupling model. For example, Zhang and Da [62] combined their decomposition results with decoupling analysis and introduced the total decoupling index (D^t), which is defined as follows:

$$D^t = \frac{\Delta F^t}{\Delta C^t gdp} = D^t_{ei} + D^t_{is} + D^t_{cs} \quad (2.7)$$

where ΔF^t represents the total inhibiting effect on CO_2 emissions, which is calculated as follows:

$$\Delta F^t = \Delta C^t - \Delta C^t_{gdp} = \Delta C^t_{ei} + \Delta C^t_{is} + \Delta C^t_{cs} \quad (2.8)$$

They defined three possible states for decoupling: *absolute decoupling* ($D^t \geq 1$), *relative decoupling* ($1 > D^t > 0$) and *no decoupling* ($D^t \leq 0$). The results of decoupling analysis showed that there is a relative decoupling between China's economic growth and CO_2 emissions during 1996 – 2010. The absolute decoupling states were observed in 1997, 2000 and 2001. The results were consistent with the real situation observed during these years. For example, China's government has shut down enterprises with low efficiency and with high emissions due to the Asian financial crisis and food disaster [68]. It should be noted that the combination of decomposition with decoupling analysis provide opportunity to observe the effect from changes of each driving force on decoupling state and to quantify the contribution of each factor to decoupling process.

Wang and Su [63] also used an integrated method of decoupling analysis and LMDI decomposition technique to examine the decoupling relationship between carbon emissions and economic growth in 192 countries [63]. The Kaya identity (Eq. 2.9) has been a key function in their integrated decoupling system. As it is a framework for LMDI decomposition technique under which the factors affecting CO_2 emissions are decomposed [69]. Consequently, they decomposed CO_2 emissions into four driving factors: population growth (ΔC_p), economic growth level (ΔC_g), the energy intensity (ΔC_e) and the carbon intensity (ΔC_f) (Eq. 2.10). As a result, their decoupling elasticity expression consists of Tapio model, LMDI and Kaya identity and can be expressed as in Eq 11. Authors concluded that the reduction of energy intensity is the most significant factor that promotes decoupling in most of the developing countries. Zhao et al. [60] employed a similar extended decoupling method to evaluate to what extent economic growth is decoupled from CO_2 emissions in China's five economic sectors. The results show that all sectors were at the weak decoupling state between 1992 and 2012. Lu et al. [52] applied the average Divisia index approach to decompose CO_2 emissions from highway transportation into five factors: emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth. Furthermore, authors used the decoupling index method proposed by OECD to evaluate decoupling of energy consumption and CO_2 emissions from GDP for each country.

$$CE = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{CE}{E} = p \times g \times e \times f \quad (2.9)$$

$$\Delta C = \Delta C_p + \Delta C_g + \Delta C_e + \Delta C_f \quad (2.10)$$

where P = population, E = energy consumption, g = the per-capita GDP, e = the energy intensity of GDP, f = the carbon intensity.

$$DE = \frac{\Delta CE/\Delta CE_0}{\Delta GDP/\Delta GDP_0} = \frac{(\Delta CE_p + \Delta CE_g + \Delta CE_e + \Delta CE_f)/CE_0}{\Delta GDP/\Delta GDP_0} \quad (2.11)$$

$$= \frac{(\Delta CE_p/CE_0 + \Delta CE_g/CE_0 + \Delta CE_e/CE_0 + \Delta CE_f/CE_0}{\Delta GDP/\Delta GDP_0}$$

$$= D_p + D_g + D_e + D_f$$

where D_p is population decoupling elasticity; D_g denotes affluence level decoupling elasticity, D_e denotes energy intensity decoupling elasticity and D_f represents carbon intensity decoupling elasticity. The methods discussed are summarized in Table 2.2.

From results of the literature presented above we can notice that the population change, economic growth and energy intensity and energy use are the main drivers of CO_2 emissions. These observations would be beneficial to explain the decoupling states in a country during the discussion of obtained results. Nevertheless, in this study we did not performed decomposition of CO_2 emissions because it is not within the scope of our focus.

Table 2.2. Literature review on decomposition

Authors	**Area**	**Period**	**Decomposition method**	**Decomposion result (driving forces)**	**Reference**
Liu et al.	China	1996-2012	LMDI additive	Production scale (ΔC_p), infrastructure (ΔC_s), energy intensity (ΔCi), fuel mix (ΔC_m), carbon emissions coefficient (ΔC_e)	[56]

Madaleno and Moutinho	EU	1990-2014	LMDI Additive and multiplicative	Carbon emission relative to the fossil fuel consumption (CI_0), fossil fuel consumption relative to the total energy consumption (EM^t_0), energy intensity (EI^t_0), imports of total oil products intensity (EP^t_0), total petroleum products (PP^t_0), population (P)	[70]
Moutinho et al.	EU-15	1995-2010	LMDI additive	carbon intensity (CI Effect), fossil fuel energy component (EM Effect), energy Intensity (EG Effect), the average renewable capacity productivity (GC Effect), capacity of renewable (Cap Ren) energy per capita (CP Effect), the changes in population (P Effect)	[19]
Lu et al.	Taiwan, Germany, Japan and South Korea	1990-2002	Average Divisia Index	emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth	[52]

2.3 Decoupling Analysis: EU-15

In this section, the results of the literature review on decoupling analysis in relation with EU-15 countries were discussed. EU-15 countries have high ambitions to reduce CO_2 emissions. As it was stated before (in Chapter 1), EU-15 countries were targeting to reduce GHGs emissions by 8% compared to 1990 levels in accordance with the Kyoto Protocol [45]. To redistribute the reduction target among 15 countries European Union members signed The Burden-Sharing Agreement (BSA) (Table 2.3) [71]. This agreement was formulated by considering the ability of each member of EU-15 to reach the emission targets relying on importance of equity and cost-efficiency. In EU, leaders endorsed more severe targets than the Kyoto in the EU climate and energy package [72].

Table 2.3. GHG emission reduction targets 2008-2012 per each EU-15 countries according to the Burden-Sharing Agreement and Kyoto Protocol [38],[46]**.**

Countries	Change 1990-2014	Targets
Austria	-3.2%	-13%
Belgium	-22%	-7.5%
Denmark	-27.6%	-21%
Finland	-17.1%	0%
France	-16.3%	0%
Germany	-27.8%	-21%
Greece	-3.3%	+25%
Ireland	+3.7%	+13%
Italy	-19.8%	-6.5%
Luxembourg	-16.3%	-28%
Netherlands	-15.8%	-6%
Portugal	+6.5%	+27%
Spain	+15%	+15%
Sweden	-24.4%	+4%
United Kingdom	-34.3%	-12.5%
EU-15		**-8%**

According to this package, EU countries should by 2020: (1) reduce greenhouse gas emissions by 20% (from 1990 levels); (2) increase the share of share of renewables in EU energy consumption by 20%; (3) improve energy efficiency by 20 % [73]. Therefore, to achieve CO_2 mitigation EU-15 countries are integrating energy efficient technologies, are changing structure towards using renewable energy sources and are implementing relevant environmental policies [72]. According to European Environment Agency (EEA) European environment — State and outlook 2010 report [37], in 2008 EU-15 showed 6.9% reduction in GHGs emissions compared to 1990 levels. In 2009 they further reduced their GHGs emissions by 13% compared to base-year levels [37]. EU-15 had met its target at the end of the first commitment period of the Kypoto protocol. In 2016, EEA reported that CO_2 emissions from electricity and heat production decreased by 25 % in EU-28+Iceland between 1990 and 2014 [74]. This statistic includes emission reduction data of new joined members of the EU. Although, it is still not clear that whether it was reached through decoupling of economic growth from CO_2 emissions produced from electricity and heat production.

Vehmas et al. [53] performed empirical studies on EU-15 countries for the period of 1973-1999. For that purpose, de-linking and re-linking methods with two different indicators were used: total primary energy supply (TPES) and carbon dioxide emissions from fuel combustion (CO_2). Vehmas et al. [53] observed a strong de-linking in the EU-15 countries during the years 1973-1999. Naqvi and Zwickl [75] analyzed the decoupling trends in eighteen EU countries during 1995-2008 with five pollution indicators such as CO_2, SO_X, NO_X, NH_3, PM10 and Energy use. They used the OECD decoupling method and performed it for sub-periods (1995-2001 and 2001-2008) not for year-by-year. Six broad economic sectors have been chosen as research area, namely, electricity, manufacturing, transport, agriculture, services, and other. The results of the study show that CO_2 and energy use had a weak decoupling in the electricity sector during 1995-2008. Almost all eighteen EU countries have small decoupling of CO_2 from economic growth in all sectors except for the electricity sector during the whole period. In general, decoupling factors are heterogenous across EU countries. Some countries are showing absolute decoupling in specific sectors while others are showing negative decoupling. Furthermore, switching from absolute decoupling to negative decoupling or in a opposite direction were observed for some EU countries depending on time, sector and environmental indicator. Sanye-Mengual et al. [76] identified decoupling of the environmental impacts of EU-28 consumption from the economic growth along the period 2005-2014. The decoupling trends were relatively alternated between weak decoupling and negative decoupling. Diakoulaki and Mandaraka [77] investigated decoupling of industrial growth from CO_2 emissions in the EU manufacturing sector. For that they calculated decoupling index in a different way from the OECD decoupling index method. The results showed that 7 countries of EU out of 14 had been reached decoupling of industrial growth from CO_2 emissions to some extent.

According to Madaleno et al. [70], the driving forces of change in CO_2 emissions by using the LMDI method in EU-28 were decomposed for two periods: 1990–2004 and 2005–2014. The result of decomposition with driving factors is illustrated in Table 2.2. Authors highlighted that there was progressive increase in CO_2 emissions in EU-15 group before the implementation of the Kyoto Protocol. After the first (2005-2012) and second (2012-2014) commitment periods of the Kyoto Protocol there were huge decreases in CO_2 emissions in EU-15. This implies the effectiveness of the Kyoto Protocol to reach desired effects in the reduction of CO_2 emissions. However, Diakoulaki and Mandaraka [77] argued that the Kyoto Protocol has not significantly accelerated the reduction of CO_2 emissions in the post Kyoto period in EU-15. In another study done by Madaleno and Moutinho [36], the CO_2 emissions were decomposed into six effects by LMDI: (1) the changes in the CO_2 emissions compared to the import of petroleum products (denoted by CI effect), (2) the changes in the import dependency of petroleum products compared to total energy consumption (denoted by ID effect), (3) the change in energy intensity effect (denoted by EI effect), (4) changes in the economic structure effect (denoted by ES effect), (5) the changes in income compared to the population change (denoted by Ipc effect) and (6) the change in population size (denoted by Pp effect). Further, the Tapio method and LMDI jointly used in this article in order to evaluate decoupling process and estimate the impacts of those effects. The highest contributing effect to the change in CO_2 is carbon intensity (CI effect) of petroleum products. In fact, an increase in CI effect would cause an increase in CO_2 emissions. This result is consistent with other works that have been described before [78],[79]. From 2008 to 2009, the share of the renewable energy sources increased, and the final energy consumption decreased. This had a minor positive impact on the reduction of CO_2 emissions in EU-15. The reason is that positive changes in these two effects are not enough to compensate remaining negative effects. Therefore, authors came to the conclusion that the population growth effect and the economic growth effect were still the main contributors to the negative change in CO_2 emissions in EU-15. It should be noted that there was no case in which the increase in economic growth and decrease in CO_2 emissions happened simultaneously. Majority of researchers came to the same observation. Liaskas et al. [80] have used Park's method to identify the factors influencing changes in industrial CO_2 emissions in EU. Decomposition revealed that the total output, the share of each branch to the total output, the energy intensity and the fuel share in each industrial branch were the main driving forces of changes in industrial CO_2 emissions.

Continuous improvements in the carbon intensity are believed to reduce the overall CO_2 emissions. The promotion of renewable sources of energy are crucial to reduce the levels of CO_2 emissions and needs special attentions. Moutinho et al. [19] argued that without accounting the effects of renewable energies the effects of drivers of CO_2 emissions would be higher than their actual values. Thus, they added the average renewable capacity productivity (GC effect) and the renewable energy per capita (CP effect) terms into the decomposition expression. Most and Fichtner [23] presented a model-based approach to determine optimal conditions and asses market penetration of future options for generation of electricity with integration of renewable energy sources for EU-15. The obtained results showed that increasing the share of renewable sources of energy in electricity generation sector would decrease the marginal costs of CO_2 reduction. According to their forecast, the marginal costs of CO_2 reduction in EU-15 will decrease by 30% in 2030 in accordance with promotion of renewable energy sources.

Furthermore, Chovancová and Vavrek [81] assessed the decoupling relationship between GDP and renewable energy sources (RES) which are used for energy production in EU-28 for the time period 2008 and 2016. They used the following formula to quantitatively asses this relationship:

$$\text{DI RES} = \frac{\Delta RES}{\Delta GDP} \tag{3}$$

where DI RES – the decoupling index of RES; ΔRES - the change of RES during the study period; ΔGDP – the change of GDP during the study period.

Results showed that 25 out of 28 countries had positive DI values, which signal absolute coupling. However, authors claim that this shows the willingness of countries to reach sustainable development. Thus, it is important to refer to the renewable energy sources during the discussion of decoupling states.

In summary, previous studies mainly were focused on decoupling between economic growth and different environmental indicators for EU-15. As the public electricity and heat generation sector is the main contributor of CO_2 emissions in EU-15 [46], there is still lack of studies about decoupling process between economic growth and CO_2 emissions from public electricity and heat generation sector. Thus, this thesis work focuses on performance of EU-15 member countries in decoupling of economic growth from CO_2 emissions from public electricity and heat during the period from 1990 to 2014.

Chapter 3- Methodology and Data

3.1 Data and variables

This study covers the first 15 countries entering the European Union: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

The study uses data for GDP and CO_2 emission intensity from the IEA *World Energy Balances* database for the period from 1960 to 2014 [82]. GDP was used as the variable indicating economic growth. It is defined as the Gross Domestic Product (GDPPPP) at market constant prices of the year 2010. PPPs means purchasing power parities, which is defined by database reporters as “These data have been scaled up/down to the price levels of 2010 and then converted to US dollars using the yearly average 2010 purchasing power parities (PPPs)" [83]. CO_2 emission intensity, which is 1g of CO_2 per kWh of electricity (gCO_2 per kWh), was used as an environmental indicator. It is calculated as the ratio of CO_2 emissions generated during the production of public energy and heat related to electricity production, and the output of produced electricity and heat [84].

3.2 Methods

In this study, the OECD decoupling factor method and the Tapio decoupling method are mainly used to analyze the decoupling relationship between environmental indicator (CO_2 emission) and economic growth (GDP).

2.2.1 The OECD decoupling factor method

This method was introduced by OECD and is defined as the ratio between value of environmental pressure (e.g. t CO_2 emission intensity) and economic driving force (e.g. GDP) at the time period from base year 0 to reporting year t [14]. Possible decoupling states described in Table 3.1.

$$D_f = 1 - \frac{(EP/DF)_t}{(EP/DF)_0} \tag{3.4}$$

Table 3.1 Decoupling states by OECD decoupling factor [14].

Decoupling states	**ΔGDP**	**ΔC**	**Decoupling factor (D_f)**
Absolute decoupling	(0; +∞)	(-∞;0]	**(0; +∞)**
Relative decoupling	<0 and <ΔC		**(0; +∞)**
Non decoupling			**(-∞; 0)**
Perfect decoupling			**1**

2.2.2 The Tapio decoupling elasticity method

The Tapio decoupling elasticity method adopted by Wang and Su [63] was applied in this work to study the decoupling relationship between economic growth and carbon emissions. The decoupling elasticity (DE, also denoted as ɣ) is measured by Eq (3.2):

$$DE = \gamma = \frac{\Delta CO2/CO2_0}{\Delta GDP/GDP_0} \quad (3.5)$$

$$\Delta CO_2 = CO_{2(t)} - CO_{2(0)} \quad (3.3)$$

$$\Delta GDP = GDP_{(t)} - GDP_{(0)} \quad (3.4)$$

where Δ denotes the change of variable (CO_2 or GDP) from base year 0 to year t (Eq. 3.3., Eq. 3.4). Eight decoupling states of the Tapio decoupling elasticity were shown in Table 3.1. It is necessary to mention that the optimal decoupling state is strong decoupling among other states. However, strong negative decoupling is considered as the least expected decoupling state.

Table 3.2: Eight decoupling states of the Tapio decoupling elasticity [63]**.**

Decoupling states	**ΔC/C**	**ΔGDP/GDP**	**Decoupling elasticity values (ɣ)**
Negative decoupling			
Expansive negative decoupling	>0	>0	**ɣ > 1.2**
Strong negative decoupling	>0	<0	**ɣ < 0**
Weak negative decoupling	<0	<0	**0 < ɣ < 0.8**
Decoupling			
Weak decoupling	>0	>0	**0 < ɣ < 0.8**
Strong decoupling	<0	>0	ɣ < 0
Recessive decoupling	<0	<0	**ɣ >1.2**
Coupling			
Expansive coupling	>0	>0	**0.8 < ɣ < 1.2**
Recessive coupling	<0	<0	**0.8 < ɣ < 1.2**

Chapter 4- Results and Discussion

EU -15 countries were divided into 3 main groups based on individual reduction targets according to the Kyoto Protocol. Group I countries had high reduction target values ranging between -28% and -12.5%. They are: Austria (-13%), Denmark (-21%), Germany (-21%), Luxembourg (-28%), United Kingdom (-12.5%). Group II countries had moderate reduction target values ranging between -7.5% and 0%. They are: Belgium (-7.5%), Finland (0%), France (0%), Italy (-6.5%), Netherlands (-6%). Group III countries had mild reduction target values ranging between +4% and +27%. They are: Greece (+25%), Ireland (+13%), Portugal (27%), Spain (+15%), Sweden (+4%).

Note: All discussions of results of decoupling analysis in subsections 4.1, 4.2, 4.3 are based on the Tapio decoupling elasticity method. The results of OECD method were also demonstrated in tables but does not included in the discussions within those subsections.

4.1 Decoupling analysis in Group I countries: Austria, Denmark, Germany, Luxembourg, United Kingdom.

Table 4.1 shows the decoupling states between GDP and CO_2 emission intensity for Austria, Denmark, Germany, Luxembourg, United Kingdom during the period from 1990 to 2014. The decoupling analysis of individual countries are shown in Tables 4.1-4.10. According to results, there were heterogeneity of decoupling states ranging from strong negative decoupling (the worst decoupling state) to strong decoupling (the most desired decoupling state).

Decoupling analysis for GDP and CO_2 emission intensity shows that strong decoupling state was observed for all five countries. The highest number of strong decoupling state was observed for Luxemburg (75%, Figure 4.8), then for Germany (61%, Figure 4.6). United Kingdom and Austria showed strong decoupling of GDP from CO_2 emission intensity 58% (Figure 4.10) and 59% (Figure 4.2) respectively. Regarding to Denmark, only 32% (Figure 4.4) of cases were strong decoupling during the studying period. Strong negative decoupling states were observed rarely in Group I members except United Kingdom. It is important to emphasize that Germany and United Kingdom were accounted for 45% of the total reduction of GHG emissions in EU level during the first commitment period of Kyoto Protocol. But at the same time they were the largest emitters of GHGs within the EU aggregate during the period from 1990 to 2014 [46]. Germany’s breakthroughs in GHG emissions reduction were attributed to lowering of the carbon intensity of fossil fuels and increasing the share of renewable energy [85]. They came to a low carbon intensity by switching the type of fuel from coal to gas[46]. Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016 noted that the high GHGs reduction capacity of United Kingdom was mainly due to liberalization of energy market and changing fuel type from oil and coal to gas [86]. Other factors such as improvements in combined-cycle gas turbines contributed to lowering the emissions [87]. Many scholars agreed that the change in population (population effect) has significant impact on CO_2 emissions [78],[88]. The human population remained fairly stable during 1990-2014 in Group I countries. It seems that its effect on decoupling performance of those countries is negligible.

In the literature, it was found that many studies focus on the effect of population on CO_2 emissions. Lin et al. [89] found that the increase in population was one of the main primary drivers for the increase in CO_2 emissions in their study on decoupling of GDP from CO_2 emissions in South Africa (SA) for the period of 1990 to 2014. Madaleno and Moutinho [36] concluded that the population growth and economy growth still led to increase in CO_2 emissions in EU-15 in the period 1995-2014. From Figure 4.1a, it can be noticed that the population almost unchanged for Group I countries for the entire period. Thus, its effect on decoupling tend to be insignificant.

The 2007-2009 Global Financial Crisis (GFC) caused sharpest drop in economic activities of the world economy [90]. From Table 4.1 we can see that the impact of GFC can be observed for all members of Group I for the period 2008-2009. In this period their decoupling states were deteriorated to weak negative decoupling in Austria; strong negative decoupling in Denmark and Luxemburg; weak negative decoupling in Germany; and recessive decoupling in United Kingdom (Table 4.1). In its turn, this compelled the drivers of CO_2 emission to grow faster in many countries. Then, the decoupling state in all countries was improved to weak and strong decoupling states in successive years.

Table 4.1. Decoupling states for CO_2 emission intensity and GDP Group I

	Austria		Denmark		Germany		Luxemburg		United Kingdom	
Time	Tapio	OECD	Tapio	OECD	Tapio	OECD	Tapio	OECD	Tapio	OECD
1990-1991	Expansive coup.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Recessive dec.	0
1991-1992	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling
1992-1993	Strong neg. dec.	Non-decoupling	Recessive dec.	0	Weak neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1993-1994	Weak dec.	Non-decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1994-1995	Weak dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1995-1996	Weak dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1996-1997	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1997-1998	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1998-1999	Strong neg. dec.	Relative decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
1999-2000	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2000-2001	Weak dec.	Non-decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Expansive coup.	Relative decoupling
2001-2002	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	#DIV/0!	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2002-2003	Weak dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Recessive dec.	0	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2003-2004	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling
2004-2005	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2005-2006	Strong neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2006-2007	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling
2007-2008	Strong neg. dec.	Absolute decoupling	Recessive dec.	0	Strong dec.	Absolute decoupling	Recessive dec.	0	Recessive dec.	0
2008-2009	Weak neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Weak neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Recessive dec.	0
2009-2010	Weak dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling
2010-2011	Weak dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2011-2012	Strong neg. dec.	Absolute decoupling	Recessive dec.	0	Expansive neg. dec.	Non-decoupling	Weak neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling
2012-2013	Strong neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2013-2014	Strong neg. dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling

Generally, Austria producing lower emissions compared to other members of group I in the production of electricity and heat. The global financial crisis had an adverse impact on economy of Austria. Its CO_2 emission intensity has increased during 2009 and 2011 compared to pre-crisis period (Figure 4.1). Therefore, in post-crises period from 2009 till 2011, we see expansive negative decoupling state between GDP and CO_2 emission intensity (Table 4.2). After 2011, the decoupling conditions were improved from expansive negative decoupling state to strong decoupling state. From Table 4.2 we can observe significant decline in CO_2 emission intensity during 2011-2012, which resulted in strong decoupling of GDP from CO_2 emission intensity. The possible reason for this improvement might be amendments to the Green Electricity Act that implemented in 2002 in order to increase the share of renewable energy sources for the production of electricity [91]. Despite the fluctuations in CO_2 emission intensity trend (Figure4.1), Austria decreased its CO_2 emissions from public electricity and heat production sector during 1990-2014. However, Austria did not meet its Kyoto target (-13%) to reduce GHGs compared to 1990 levels (Table 2.3). Emissions from transport increased by 60 % from 1990 and 2010 in Austria. Hence, this can affect total GHGs emissions per capita in Austria, because transport sector is the second large contributor of GHGs after energy use [91].

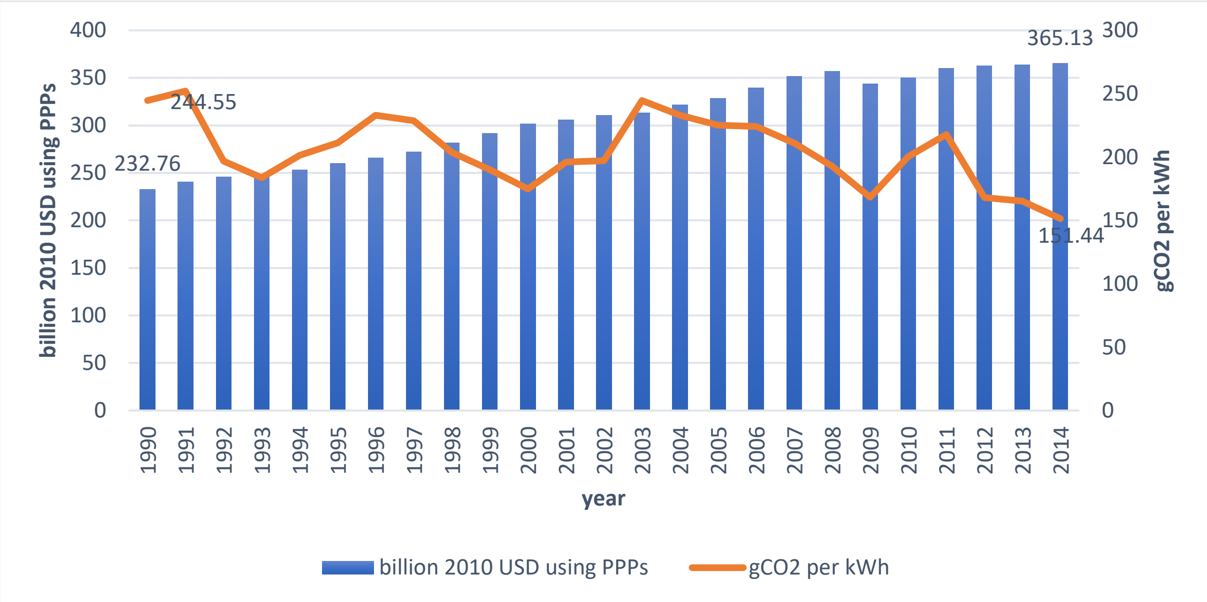

Figure 4.1. GDP and CO2 emission intensity in Austria for 1990-2014.

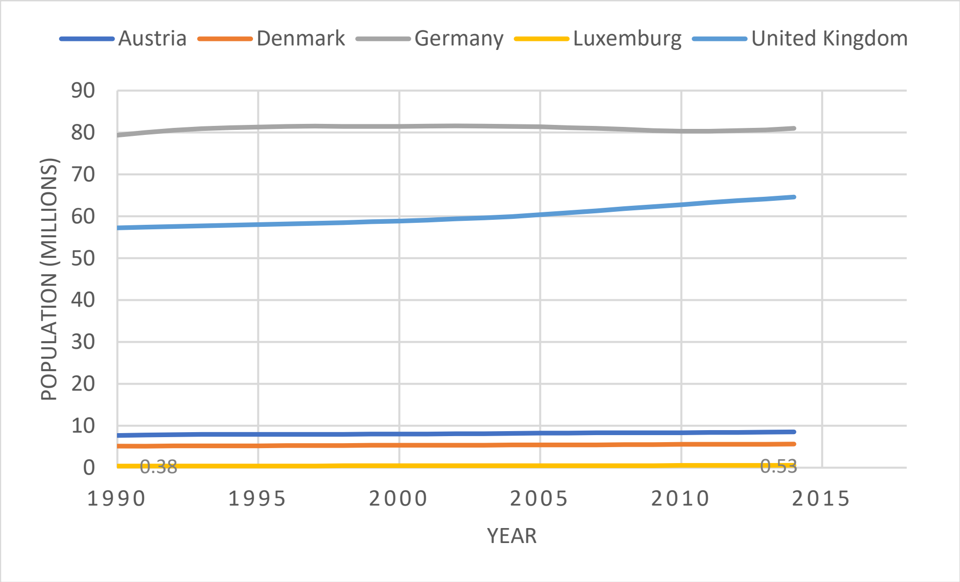

Figure 4.1a. Group I countries population during 1990-2014 [82]**.**

Table 4.2. Decoupling analysis results for GDP and CO_2 emission intensity Austria between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,031	0,034	0,892	Expansive coup.	0,004	Relative decoupling
1991-1992	-0,219	0,021	-10,454	Strong dec.	0,235	Absolute decoupling
1992-1993	-0,067	0,005	-12,676	Strong dec.	0,072	Absolute decoupling
1993-1994	0,097	0,024	4,040	Expansive neg. dec.	-0,071	Non-decoupling
1994-1995	0,048	0,027	1,816	Expansive neg. dec.	-0,021	Non-decoupling
1995-1996	0,103	0,024	4,287	Expansive neg. dec.	-0,077	Non-decoupling
1996-1997	-0,019	0,022	-0,846	Strong dec.	0,040	Absolute decoupling
1997-1998	-0,109	0,036	-3,056	Strong dec.	0,139	Absolute decoupling
1998-1999	-0,068	0,036	-1,893	Strong dec.	0,100	Absolute decoupling
1999-2000	-0,079	0,034	-2,357	Strong dec.	0,109	Absolute decoupling
2000-2001	0,121	0,013	8,970	Expansive neg. dec.	-0,106	Non-decoupling
2001-2002	0,005	0,017	0,314	Weak dec.	0,011	Relative decoupling
2002-2003	0,242	0,008	31,974	Expansive neg. dec.	-0,233	Non-decoupling
2003-2004	-0,048	0,027	-1,776	Strong dec.	0,073	Absolute decoupling
2004-2005	-0,033	0,021	-1,536	Strong dec.	0,053	Absolute decoupling
2005-2006	-0,005	0,034	-0,155	Strong dec.	0,037	Absolute decoupling
2006-2007	-0,059	0,036	-1,626	Strong dec.	0,092	Absolute decoupling
2007-2008	-0,086	0,015	-5,564	Strong dec.	0,100	Absolute decoupling
2008-2009	-0,127	-0,038	3,334	Recessive dec.	0,092	0
2009-2010	0,190	0,019	9,857	Expansive neg. dec.	-0,167	Non-decoupling
2010-2011	0,087	0,028	3,113	Expansive neg. dec.	-0,058	Non-decoupling
2011-2012	-0,228	0,008	-30,169	Strong dec.	0,234	Absolute decoupling
2012-2013	-0,017	0,003	-5,199	Strong dec.	0,020	Absolute decoupling
2013-2014	-0,084	0,004	-23,866	Strong dec.	0,087	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

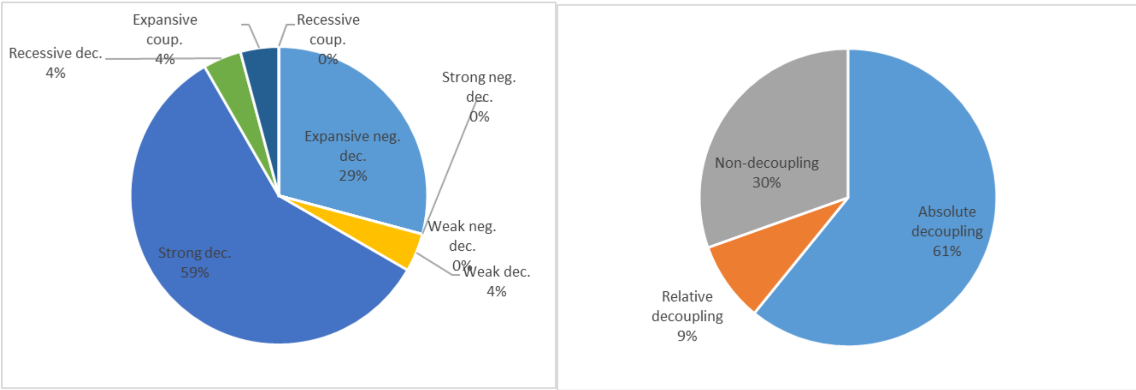

Figure 4.2. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Austria

Denmark was one of the countries that overachieved reduction targets by the 2008-2012 Kyoto Protocol (Table 2.3). The least percentage (32%) of occurrence of strong decoupling state corresponded to Denmark (Figure 4.4). From Table 4.3 we can see that there were expansive negative and even strong negative decoupling states (2008-2009, 2012-2013). The GDP remained strongly decoupled from CO_2 emission intensity during the period from 1996 to 2002. In general, from Figure 4.3 we can notice that Denmark reduced CO_2 emission intensity significantly from 681.6 gCO_2 per kWh t to 234.46 gCO_2 per kWh during the whole period of study. According to Ecologic Institute's report [91], GHGs emission from energy supply sector decreased by 24% for 1990-2011. This improvement in reduction came from combination of factors such as switching from coal to natural gas and increasing share of renewable energy [91]. The 2008-2009 global financial crisis also caused severe downtown in economy of Denmark which affected decoupling states between GDP and CO_2 emission intensity. However, they immediately improved decoupling states to strong decoupling state after 2008-2009 (Table 4.3). The improvement might be result of fiscal consolidation measures committed by government [92].

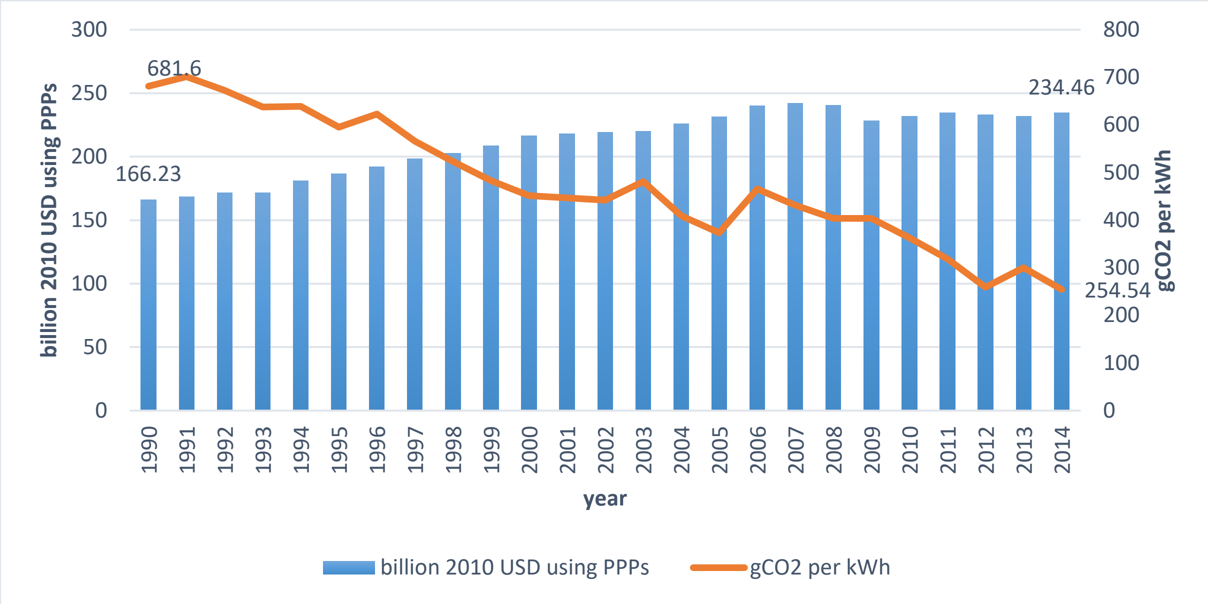

Figure 4.3. GDP and CO_2 emission intensity in Denmark for 1990-2014.

Table 4.3. Decoupling analysis results for GDP and CO_2 emission intensity Denmark between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,029	0,013	2,217	Expansive neg. dec.	-0,016	Non-decoupling
1991-1992	-0,041	0,020	-2,102	Strong dec.	0,060	Absolute decoupling
1992-1993	-0,051	-0,001	58,461	Recessive dec.	0,050	0
1993-1994	0,002	0,055	0,033	Weak dec.	0,051	Relative decoupling
1994-1995	-0,068	0,031	-2,221	Strong dec.	0,096	Absolute decoupling
1995-1996	0,046	0,029	1,583	Expansive neg. dec.	-0,016	Non-decoupling
1996-1997	-0,092	0,033	-2,814	Strong dec.	0,120	Absolute decoupling
1997-1998	-0,075	0,022	-3,367	Strong dec.	0,095	Absolute decoupling
1998-1999	-0,077	0,029	-2,630	Strong dec.	0,104	Absolute decoupling
1999-2000	-0,065	0,037	-1,734	Strong dec.	0,099	Absolute decoupling
2000-2001	-0,011	0,008	-1,349	Strong dec.	0,019	Absolute decoupling
2001-2002	-0,011	0,005	-2,271	Strong dec.	0,015	Absolute decoupling
2002-2003	0,089	0,004	22,999	Expansive neg. dec.	-0,085	Non-decoupling
2003-2004	-0,150	0,026	-5,696	Strong dec.	0,172	Absolute decoupling
2004-2005	-0,086	0,024	-3,513	Strong dec.	0,107	Absolute decoupling
2005-2006	0,246	0,038	6,472	Expansive neg. dec.	-0,200	Non-decoupling
2006-2007	-0,074	0,008	-9,012	Strong dec.	0,082	Absolute decoupling
2007-2008	-0,064	-0,007	8,915	Recessive dec.	0,057	0
2008-2009	0,001	-0,051	-0,021	Strong neg. dec.	-0,055	Non-decoupling
2009-2010	-0,103	0,016	-6,322	Strong dec.	0,117	Absolute decoupling
2010-2011	-0,122	0,012	-10,599	Strong dec.	0,132	Absolute decoupling
2011-2012	-0,186	-0,007	28,493	Recessive dec.	0,180	0
2012-2013	0,158	-0,005	-32,324	Strong neg. dec.	-0,164	Non-decoupling
2013-2014	-0,152	0,011	-13,899	Strong dec.	0,161	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

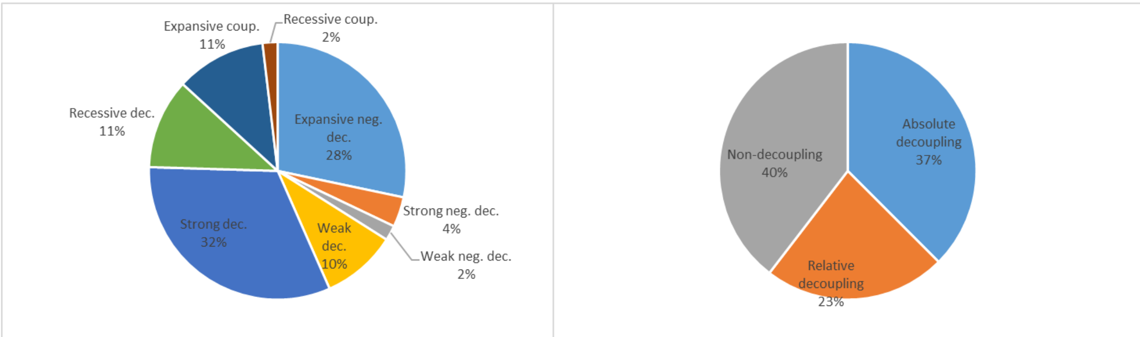

Figure 4.4. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Denmark

In general, to some extent GDP was decoupled from CO_2 produced by public electricity and heat production in Germany (Table 4.4). At the beginning of the period Germany's economy weakly decoupled from CO_2 emissions from public electricity and heat production [93]. German reunification might have effect on decoupling state between 1990 and 1991. Despite of being the largest GHGs emitter, Germany overachieved its target -27.8% reduction while its target was -21% respect to 1990 level (Table 2.3). Running national climate strategies and policies (e.g. energy or CO_2 taxation) contributed to reach the emission reduction targets [93]. From Figure 4.5 we can notice that Germany had the largest GDP compared to other members of Group I between 1990-2014, which could have positive effect on its decoupling performance. The sharp decrease (-0.064) in CO_2 emission intensity from 2007 to 2008 was observed in Germany, while the rate of change for GDP increased. Both of those changes resulted in strong decoupling state. This was consistent with the changes in energy sector of Germany occurred in this period. According to Annual European Union greenhouse gas inventory 1990–2008 and inventory report 2010 [74], the main reason for the sharp decrease in CO_2 emissions from public electricity and heat production was the extension of nuclear power use for electricity production. However, CO_2 emissions from public electricity and heat production were increased by 1.6% from 2011 to 2012. This happened mainly due to the operation of new lignite-fired power plants and an increase in the number of coal based power plants [94]. Consequently, those happened changes deteriorated decoupling state to expansive negative decoupling in 2011-2013 (Table 4.4).

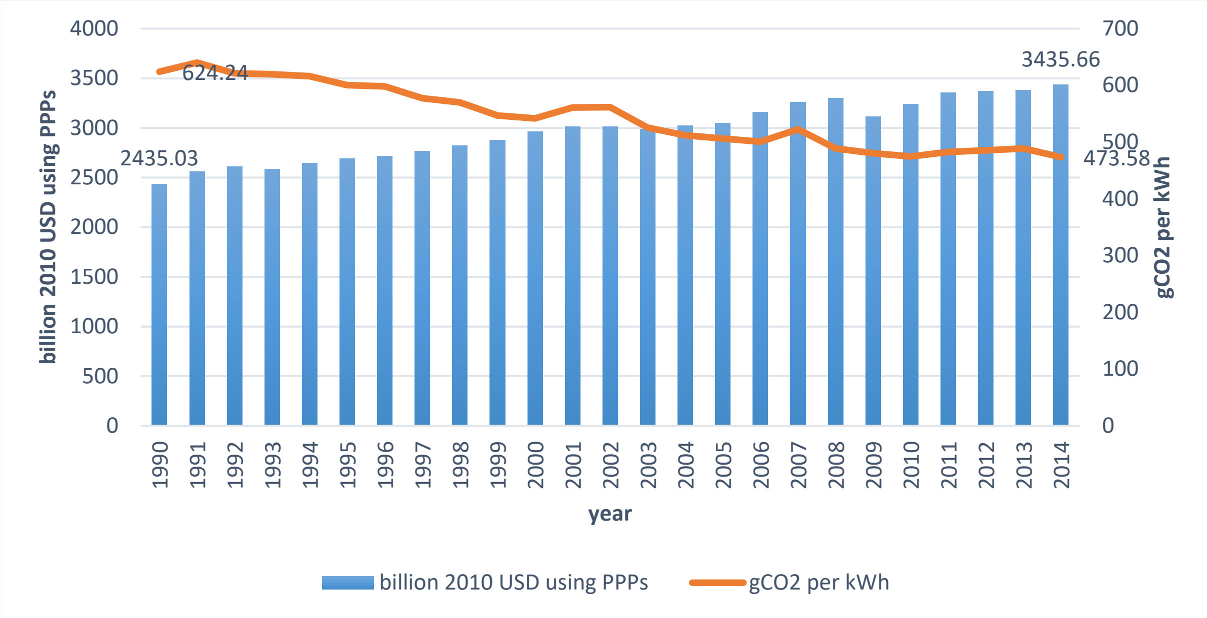

Figure 4.5. GDP and CO_2 emission intensity in Germany for 1990-2014.

Table 4.4. Decoupling analysis results for CO_2 emission intensity and GDP Germany between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,026	0,051	0,500	Weak dec.	0,024	Relative decoupling
1991-1992	-0,030	0,019	-1,539	Strong dec.	0,048	Absolute decoupling
1992-1993	-0,003	-0,010	0,271	Weak neg. dec.	-0,007	Non-decoupling
1993-1994	-0,006	0,025	-0,227	Strong dec.	0,029	Absolute decoupling
1994-1995	-0,025	0,017	-1,461	Strong dec.	0,042	Absolute decoupling
1995-1996	-0,004	0,008	-0,499	Strong dec.	0,012	Absolute decoupling
1996-1997	-0,035	0,018	-1,867	Strong dec.	0,052	Absolute decoupling
1997-1998	-0,013	0,020	-0,633	Strong dec.	0,032	Absolute decoupling
1998-1999	-0,041	0,020	-2,052	Strong dec.	0,059	Absolute decoupling
1999-2000	-0,009	0,030	-0,300	Strong dec.	0,037	Absolute decoupling
2000-2001	0,035	0,017	2,085	Expansive neg. dec.	-0,018	Non-decoupling
2001-2002	0,001	0,000	#DIV/0!	#DIV/0!	-0,001	Non-decoupling
2002-2003	-0,064	-0,007	9,078	Recessive dec.	0,058	0
2003-2004	-0,026	0,012	-2,240	Strong dec.	0,037	Absolute decoupling
2004-2005	-0,011	0,007	-1,534	Strong dec.	0,018	Absolute decoupling
2005-2006	-0,011	0,037	-0,303	Strong dec.	0,046	Absolute decoupling
2006-2007	0,044	0,033	1,335	Expansive neg. dec.	-0,011	Non-decoupling
2007-2008	-0,064	0,011	-5,958	Strong dec.	0,075	Absolute decoupling
2008-2009	-0,017	-0,056	0,301	Weak neg. dec.	-0,042	Non-decoupling
2009-2010	-0,012	0,041	-0,284	Strong dec.	0,050	Absolute decoupling
2010-2011	0,017	0,037	0,463	Weak dec.	0,019	Relative decoupling
2011-2012	0,006	0,004	1,374	Expansive neg. dec.	-0,002	Non-decoupling
2012-2013	0,006	0,003	2,102	Expansive neg. dec.	-0,003	Non-decoupling
2013-2014	-0,031	0,016	-1,931	Strong dec.	0,046	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

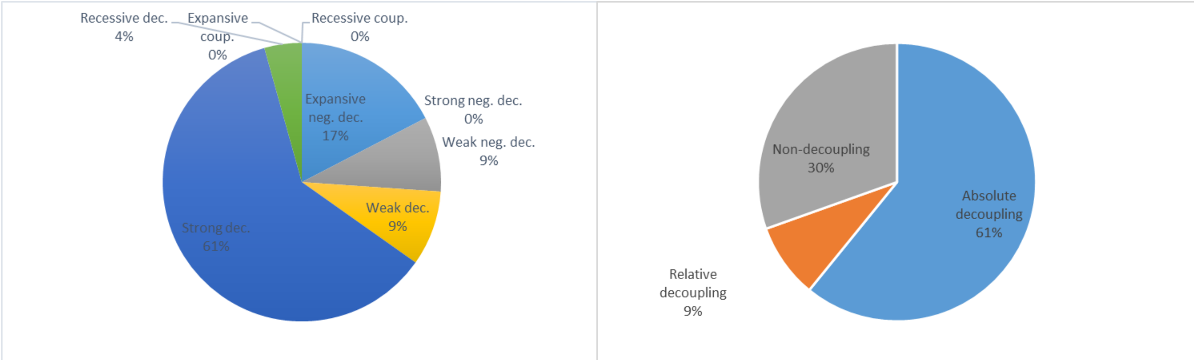

Figure 4.6. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Germany

Despite a very low GDP values compared to Germany, Luxemburg's public electricity and heat production sector significantly reduced CO_2 emissions between 1990 and 2014 (Figure 4.7). This resulted in strong decoupling of GDP from CO_2 emission intensity with 75% of occurrence. Luxemburg was only country which showed decoupling (strong, weak and recessive decoupling) for a long time. GDP decoupled from CO_2 emissions from public energy and heat production sector for almost the entire period from 1990 to 2014. At the end of first commitment period of Kyoto Protocol, Luxemburg decreased its GHGs emissions by 16.3% [46]. However, its reduction target according to the Burden Sharing Agreement (Table 2.3) was 28% reduction of GHGs compared to 1990 levels. This might be due to the transport sector which was responsible for more than half of total GHG emissions and in which GHG emissions almost tripled during 1990-2011[39]. Nevertheless, from 1990 to 2007 the GDP have grown at faster rate in Luxemburg while its CO_2 emissions was declined showing strong decoupling (75%) of economic growth from CO_2 emissions, except 1998-1999. (Table 4.5, Figure 4.8). For 1998-1999, the rate of growth of CO_2 emission intensity was higher than GDP's rate of growth accounting for expansive negative decoupling state. Closure of coal based electricity generation plants in 1997 and opening of natural gas-driven power plants were main reasons for the significant reductions in CO_2 during 1990-1998 [93]. The possible reason for keeping strong decoupling state for a long time between CO_2 and GDP was significant decrease in energy use (-64%) during 1990-2011. Also, an increase in renewable energy share % of primary energy supply by around 4% during the period from 2000 to 2010 might be positively influenced on emissions [95].

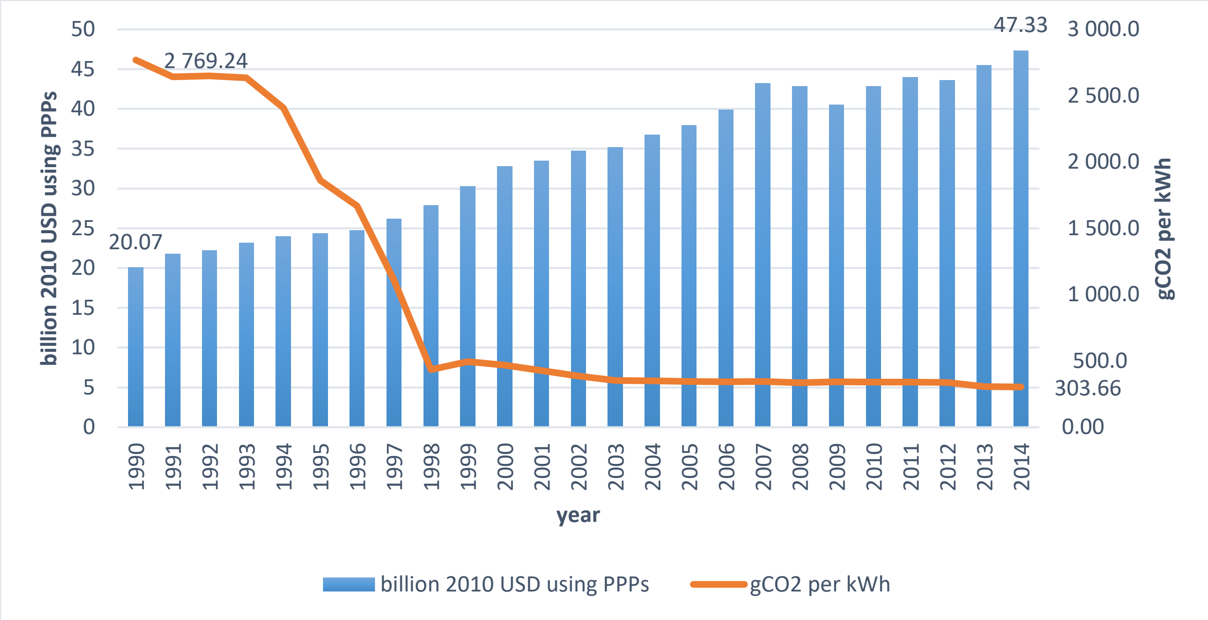

Figure 4.7. GDP and CO_2 emission intensity in Luxemburg for 1990-2014.

Table 4.5. Decoupling analysis results for CO_2 emission intensity and GDP Luxemburg between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,046	0,086	-0,532	Strong dec.	0,122	Absolute decoupling
1991-1992	0,003	0,018	0,141	Weak dec.	0,015	Relative decoupling
1992-1993	-0,006	0,042	-0,132	Strong dec.	0,046	Absolute decoupling
1993-1994	-0,086	0,038	-2,265	Strong dec.	0,120	Absolute decoupling
1994-1995	-0,227	0,015	-15,571	Strong dec.	0,238	Absolute decoupling
1995-1996	-0,103	0,015	-6,805	Strong dec.	0,117	Absolute decoupling
1996-1997	-0,335	0,059	-5,672	Strong dec.	0,372	Absolute decoupling
1997-1998	-0,608	0,065	-9,369	Strong dec.	0,632	Absolute decoupling
1998-1999	0,138	0,084	1,642	Expansive neg. dec.	-0,050	Non-decoupling
1999-2000	-0,057	0,085	-0,668	Strong dec.	0,130	Absolute decoupling
2000-2001	-0,084	0,021	-3,957	Strong dec.	0,104	Absolute decoupling
2001-2002	-0,099	0,036	-2,749	Strong dec.	0,131	Absolute decoupling
2002-2003	-0,087	0,014	-6,152	Strong dec.	0,100	Absolute decoupling
2003-2004	-0,008	0,044	-0,173	Strong dec.	0,049	Absolute decoupling
2004-2005	-0,011	0,032	-0,341	Strong dec.	0,042	Absolute decoupling
2005-2006	-0,005	0,051	-0,095	Strong dec.	0,053	Absolute decoupling
2006-2007	0,003	0,084	0,035	Weak dec.	0,075	Relative decoupling
2007-2008	-0,024	-0,008	2,934	Recessive dec.	0,016	0
2008-2009	0,023	-0,054	-0,423	Strong neg. dec.	-0,081	Non-decoupling

2009-2010	-0,009	0,057	-0,152	Strong dec.	0,062	Absolute decoupling
2010-2011	-0,005	0,026	-0,186	Strong dec.	0,030	Absolute decoupling
2011-2012	-0,006	-0,008	0,697	Weak neg. dec.	-0,003	Non-decoupling
2012-2013	-0,092	0,044	-2,106	Strong dec.	0,130	Absolute decoupling
2013-2014	-0,009	0,041	-0,210	Strong dec.	0,047	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

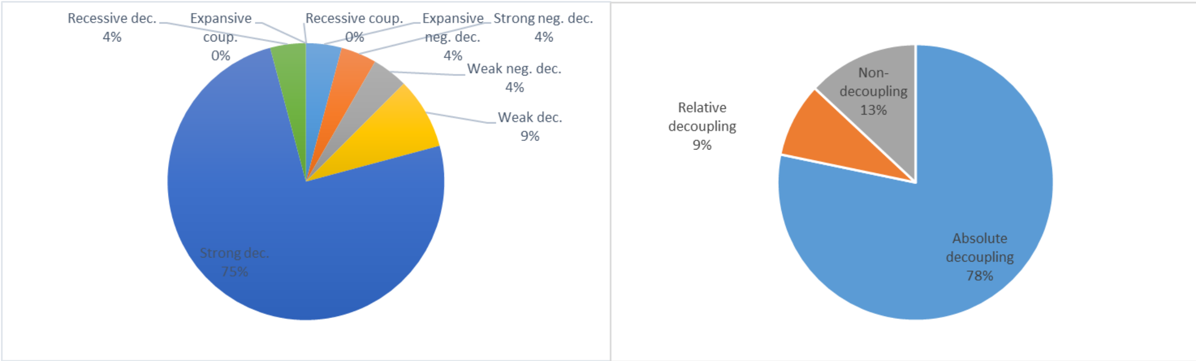

Figure 4.8. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Luxemburg

Comparing GDP values among Group I countries, United Kingdom was second country with highest GDP values for the period 1990-2014 (Figure 4.9). During this period, GDP increased in parallel with decrease in CO_2 emissions from public electricity and heat production sector. Furthermore, United Kingdom was one of the countries that showed largest absolute reduction during 1990-2008 [93]. From 1991 to 2000, GDP of United Kingdom strongly decoupled from CO_2 emission intensity (Table 4.6). United Kingdom emitted lower GHG emissions (-34.5%) than the level committed under the Kyoto Protocol (-12.5%) (Table 2.3). Several factors might have impact to reach overachievement as this. According to Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016 [46], the primary reason for that was liberalization of energy market and switching of power plants from coal and oil to natural gas and biomass. Between 2000 and 2008 the emissions from electricity production sector increased due to closure of some nuclear power stations [93]. Therefore, we see expansive negative decoupling and weak decoupling states for GDP and CO_2 emission intensity for this period. Then, from the period 2007-2008 to 2009-2009 the recessive decoupling state was observed between GDP and CO_2 emission intensity which means growth rate of both indicators were negative (Table 4.6).

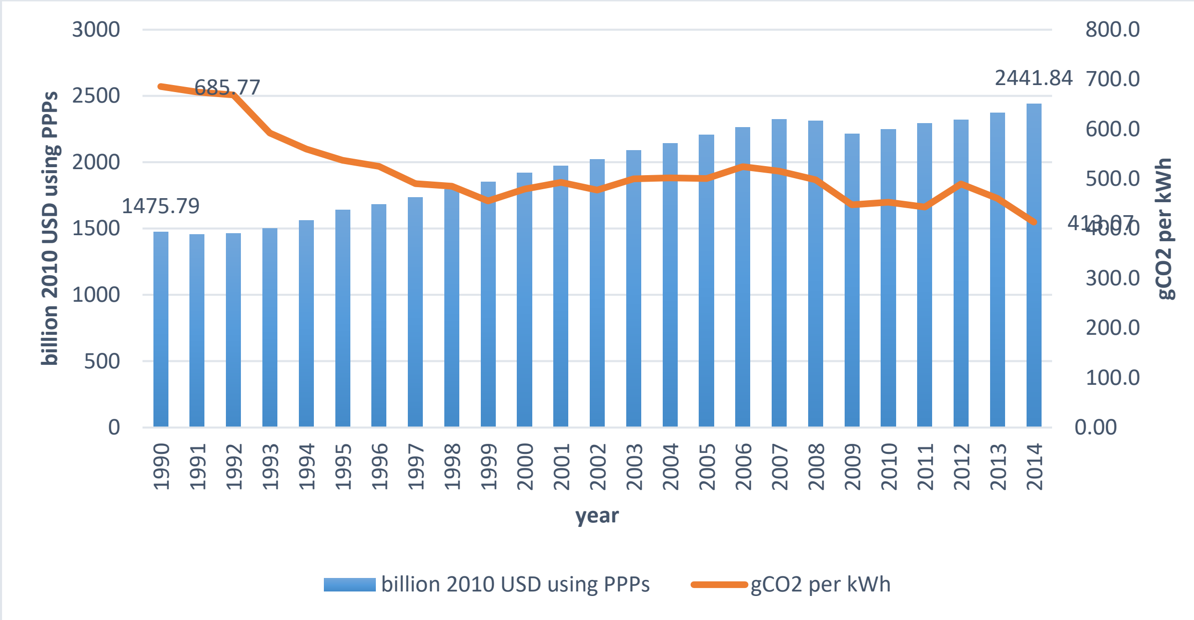

Figure 4.9. GDP and CO_2 emission intensity in United Kingdom for 1990-2014.

Table 4.6. Decoupling analysis results for CO_2 emission intensity and GDP United Kingdom between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,016	-0,012	1,311	Recessive dec.	0,004	0
1991-1992	-0,008	0,004	-1,849	Strong dec.	0,013	Absolute decoupling
1992-1993	-0,115	0,026	-4,345	Strong dec.	0,138	Absolute decoupling
1993-1994	-0,054	0,040	-1,342	Strong dec.	0,091	Absolute decoupling
1994-1995	-0,040	0,049	-0,817	Strong dec.	0,085	Absolute decoupling
1995-1996	-0,023	0,027	-0,865	Strong dec.	0,048	Absolute decoupling
1996-1997	-0,067	0,031	-2,151	Strong dec.	0,095	Absolute decoupling
1997-1998	-0,011	0,034	-0,313	Strong dec.	0,043	Absolute decoupling
1998-1999	-0,060	0,031	-1,935	Strong dec.	0,089	Absolute decoupling
1999-2000	0,052	0,038	1,378	Expansive neg. dec.	-0,014	Non-decoupling
2000-2001	0,027	0,028	0,985	Expansive coup.	0,000	Relative decoupling
2001-2002	-0,031	0,025	-1,225	Strong dec.	0,054	Absolute decoupling
2002-2003	0,046	0,033	1,387	Expansive neg. dec.	-0,012	Non-decoupling
2003-2004	0,004	0,025	0,174	Weak dec.	0,020	Relative decoupling
2004-2005	-0,002	0,030	-0,063	Strong dec.	0,031	Absolute decoupling
2005-2006	0,048	0,027	1,787	Expansive neg. dec.	-0,020	Non-decoupling
2006-2007	-0,018	0,026	-0,689	Strong dec.	0,043	Absolute decoupling
2007-2008	-0,034	-0,005	7,289	Recessive dec.	0,029	0
2008-2009	-0,100	-0,042	2,386	Recessive dec.	0,061	0
2009-2010	0,011	0,015	0,706	Weak dec.	0,004	Relative decoupling
2010-2011	-0,022	0,020	-1,106	Strong dec.	0,041	Absolute decoupling
2011-2012	0,105	0,012	8,874	Expansive neg. dec.	-0,092	Non-decoupling

2012-2013	-0,059	0,022	-2,723	Strong dec.	0,079	Absolute decoupling
2013-2014	-0,103	0,029	-3,517	Strong dec.	0,129	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

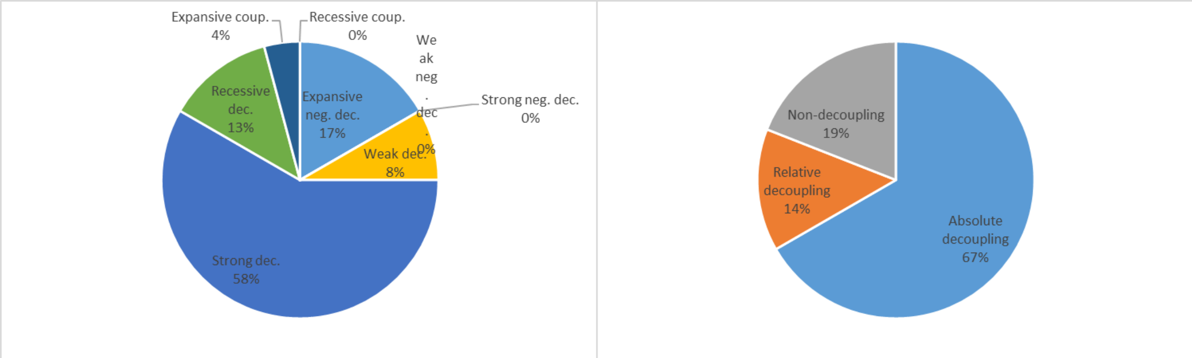

Figure 4.10. The percentage of each decoupling state by Tapio (left) method and OECD method (right). United Kingdom

4.2 Decoupling analysis in Group II countries: Belgium, Finland, France, Italy, Netherlands.

This group includes countries with less strict reduction targets under Kyoto Protocol. Their emission reduction targets were ranging between -7.5% and 0%. These relatively less strict requirements had in a certain degree positive impact on countries to reach their Kyoto Protocol targets. As a result, all member countries of this group reduced GHGs emission more than expected (Table 2.3). The decoupling states for these five countries were not uniform during the entire study period (Table 4.7). The occurrence of strong decoupling state was highest in Netherland with 63% (Figure 4.20) and lowest was observed for Finland with 46% (Figure 4.14). According to EEA retrospective GHG trend analysis [93], final energy demand has been decreasing since 2014 in France, Italy, and Netherlands. This made remarkable achievements in the reduction in the overall EU GHG emissions. The global crisis had affected the economy of group II countries in 2008-2009. As shown in Table 4.7, GDP in France did not decouple from CO_2 emissions from public electricity and heat production sector. The rest four countries' GDP recessively decoupled from CO_2 emissions during 2008-2009, which means that the rate of change of economy decreased slower than the rate of change of environmental pressure. The population in Group II countries had not changed noticeably during the period of analysis except France. This implies that the population did not influence the reduction of CO_2 and decoupling state.

Table 4.7. Decoupling states for CO_2 emission intensity and GDP Group II

	Belgium		Finland		France		Italy		Netherlands	
Time	Tapio	OECD	Tapio	OECD	Tapio	OECD	Tapio	OECD	Tapio	OECD
1990-1991	Strong dec.	Absolute decoupling	Weak neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1991-1992	Strong dec.	Absolute decoupling	Recessive coup.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1992-1993	Strong neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Recessive dec.	0	Recessive dec.	0	Expansive neg. dec.	Non-decoupling
1993-1994	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1994-1995	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
1995-1996	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1996-1997	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1997-1998	Expansive coup.	Non-decoupling	Weak dec.	Relative decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1998-1999	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
1999-2000	Weak dec.	Relative decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling	Weak dec.	Relative decoupling
2000-2001	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2001-2002	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
2002-2003	Weak dec.	Relative decoupling	Weak dec.	Relative decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling
2003-2004	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2004-2005	Weak dec.	Relative decoupling	Weak dec.	Relative decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2005-2006	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2006-2007	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling
2007-2008	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Recessive dec.	0	Strong dec.	Absolute decoupling
2008-2009	Recessive dec.	0	Recessive dec.	0	Strong neg. dec.	Non-decoupling	Recessive dec.	0	Recessive dec.	0
2009-2010	Expansive neg. dec.	Non-decoupling	Expansive coup.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2010-2011	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2011-2012	Expansive neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Recessive coup.	0	Strong neg. dec.	Non-decoupling
2012-2013	Strong dec.	Absolute decoupling	Recessive dec.	0	Strong dec.	Absolute decoupling	Recessive dec.	0	Strong neg. dec.	Non-decoupling
2013-2014	Expansive neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Recessive dec.	0	Expansive neg. dec.	Non-decoupling

In general, Belgium was a country that overachieved individual reduction target of -7.5 under Kyoto Protocol by reducing to -22% relative to 1990 level. CO_2 emissions from public electricity heat production decreased from 357.56 to 206.84 gCO_2 per kWh in parallel with increase in GDP from 292.19 to 441.73 billion 2010 USD between 1990 and 2014 (Figure 4.11). The period after the global financial crisis showed alternation of expansive negative decoupling and strong decoupling states (Table 4.8). During this period, increased GDP done at the expense of increased level of CO_2 emissions from electricity and heat production sector which led to expansive negative decoupling state. As Shishlov et al. [109] noticed that one of the factors of overachievement of the Kyoto Protocol targets was the financial global crises which reduced GHGs emissions. This tends to be true in case of Belgium. Belgium was a country that were not able to decrease energy consumption instead it was increased by 6% during 2005 and 2011 [96]. This could be explanation for low reduction of CO_2 emissions during this period compared to 1994-1999 (Figure 4.11). Belgium's share of renewable in energy gross final energy consumption was increased by only 2.6% between 2005-2010. Its share in electricity consumption increased by 6.5% during 2005-2011. To promote renewable energy different support schemes designed by government. For instance, the scheme called 'green certificates' was implemented in Flanders in 2009. This might be possible reason for an increase in renewable energy to 5.5% in 2012 [96]. Nevertheless, Belgium's energy consumption was highly dependent on fossil fuels during 1990-2014.

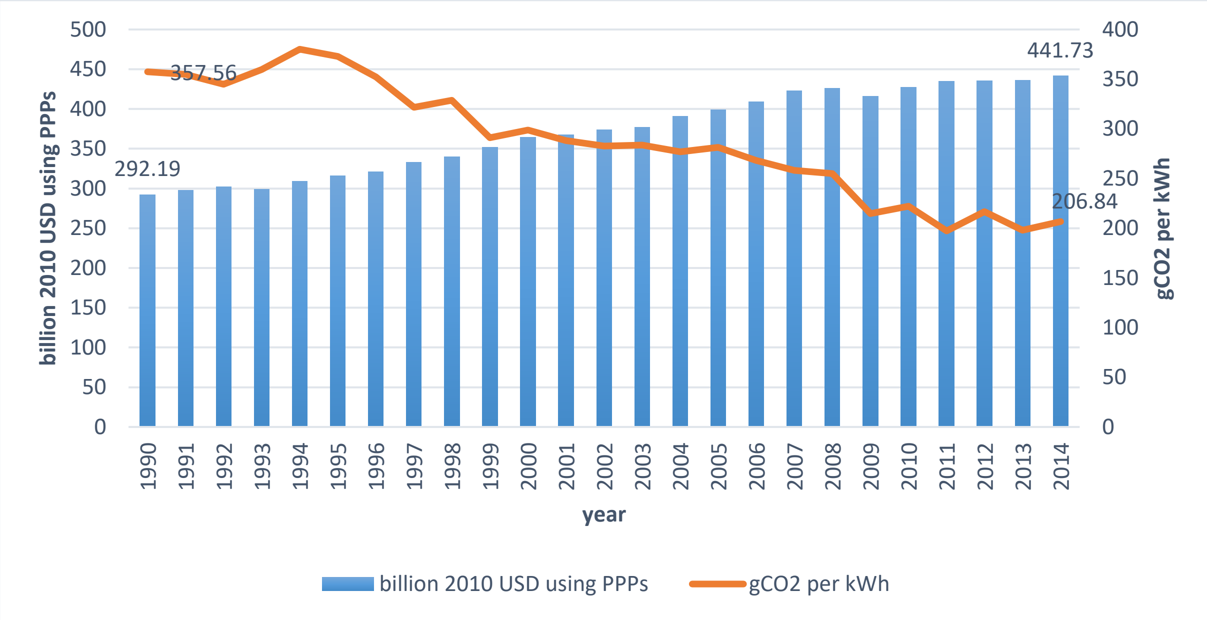

Figure 4.11. GDP and CO_2 emission intensity in Belgium for 1990-2014.

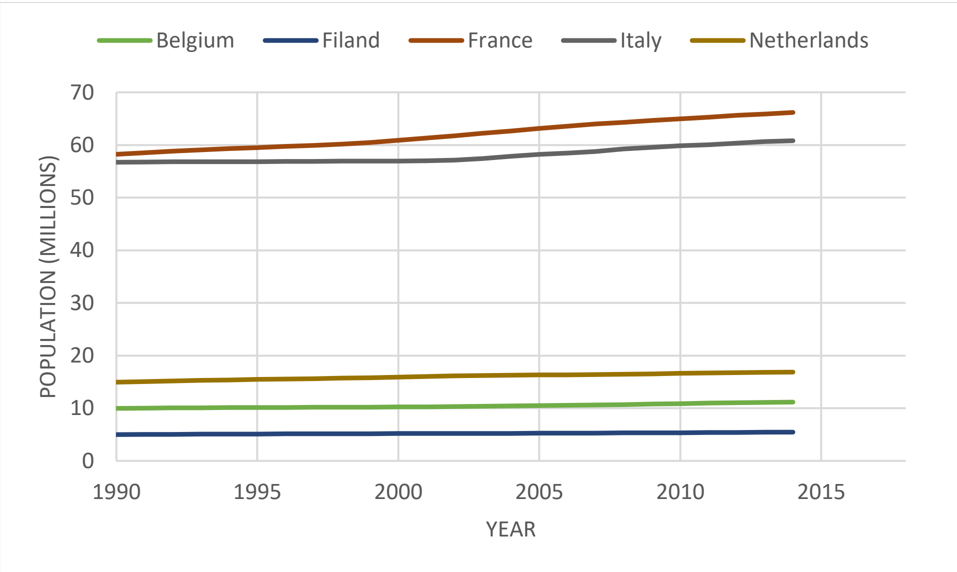

Figure 4.11a. Group II countries population during 1990-2014 [82].

Table 4.8. Decoupling analysis results for CO_2 and GDP Belgium between 1990-2014

Time	$\Delta CO_2/CO_2$	$\Delta GDP/GDP$	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,007	0,018	-0,404	Strong dec.	0,025	Absolute decoupling
1991-1992	-0,028	0,015	-1,843	Strong dec.	0,043	Absolute decoupling

1992-1993	0,043	-0,010	-4,452	Strong neg. dec.	-0,053	Non-decoupling
1993-1994	0,057	0,032	1,758	Expansive neg. dec.	-0,024	Non-decoupling
1994-1995	-0,019	0,024	-0,799	Strong dec.	0,042	Absolute decoupling
1995-1996	-0,055	0,016	-3,469	Strong dec.	0,070	Absolute decoupling
1996-1997	-0,087	0,037	-2,347	Strong dec.	0,120	Absolute decoupling
1997-1998	0,022	0,020	1,119	Expansive coup.	-0,002	Non-decoupling
1998-1999	-0,115	0,036	-3,218	Strong dec.	0,145	Absolute decoupling
1999-2000	0,027	0,036	0,740	Weak dec.	0,009	Relative decoupling
2000-2001	-0,036	0,008	-4,399	Strong dec.	0,043	Absolute decoupling
2001-2002	-0,019	0,018	-1,055	Strong dec.	0,036	Absolute decoupling
2002-2003	0,004	0,008	0,488	Weak dec.	0,004	Relative decoupling
2003-2004	-0,024	0,036	-0,665	Strong dec.	0,058	Absolute decoupling
2004-2005	0,016	0,021	0,758	Weak dec.	0,005	Relative decoupling
2005-2006	-0,047	0,025	-1,892	Strong dec.	0,071	Absolute decoupling
2006-2007	-0,036	0,034	-1,074	Strong dec.	0,068	Absolute decoupling
2007-2008	-0,013	0,007	-1,741	Strong dec.	0,020	Absolute decoupling
2008-2009	-0,158	-0,023	6,911	Recessive dec.	0,138	0
2009-2010	0,035	0,027	1,294	Expansive neg. dec.	-0,008	Non-decoupling
2010-2011	-0,112	0,018	-6,223	Strong dec.	0,127	Absolute decoupling
2011-2012	0,098	0,002	64,287	Expansive neg. dec.	-0,096	Non-decoupling
2012-2013	-0,086	0,000	-534,142	Strong dec.	0,086	Absolute decoupling
2013-2014	0,045	0,013	3,321	Expansive neg. dec.	-0,031	Non-decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

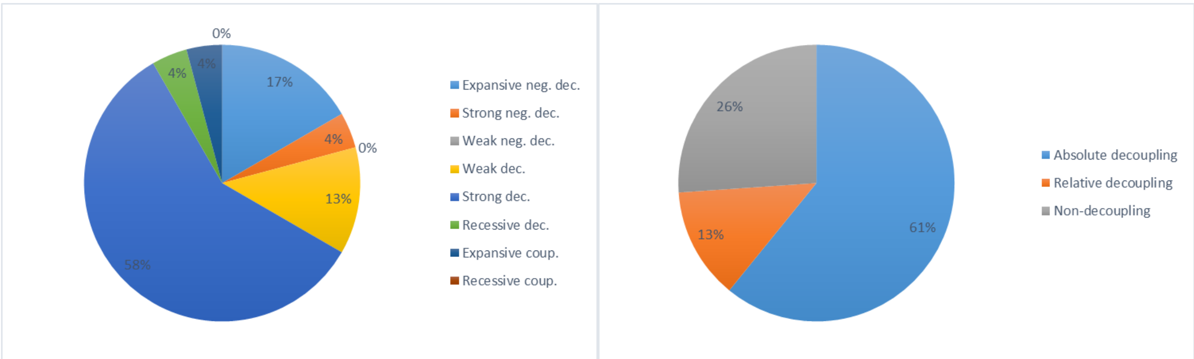

Figure 4.12. GDP and CO_2 emission intensity in Belgium for 1990-2014.

As for Finland, respect to the Kyoto Protocol its target was keep the level of GHG emissions at the level of 1990. GHG emissions decreased by 17.1% compared to the 1990 base year level (Table 2.3). This sharp declining trend was consequence of the shift from oil-based heating to district and electric heating [97]. Improvements in energy efficiency also contributed to low carbon patterns. The level of CO_2 emission intensity decreased from 354.91 gCO_2 per kWh in 1990 to 206.84 gCO_2 per kWh in 2014 (Figure 4.13). GDP also increased by 27.7% in parallel with change in CO_2 emission intensity. During 1997-2008 GDP of country strongly decoupled from CO_2 emission intensity, but in some cases, decoupling between them was weak (Table 4.9). According to EEA analysis [93], Finland showed relatively high level of per capita GHG emissions. They claim that this happened due to the combination of two factors: the severe climatic conditions and low energy prices, which led to extensive use of energy. However, Kara et al. [98] found that emission trading system had increased a price for electricity generation in Finland because of high dependence of electricity on carbon emitting resources. In addition, this may delay progresses in more efficient technologies. Because the uncertainties arising from emission trading system had dropped investments to develop new technologies. These two possibilities an increase and decrease of electricity generation's price, could be reason for the variation of decoupling states between GDP and CO_2 emission intensity. A high negative rate of change (-0.158) in CO_2 emission intensity was observed during the global financial crisis in 2008-2009. At the same time GDP also declined with a rate change of -0.083 (Table 4.9). However, lower the value of the rate change of CO_2 emission intensity resulted in recessive decoupling rather that weak negative decoupling.

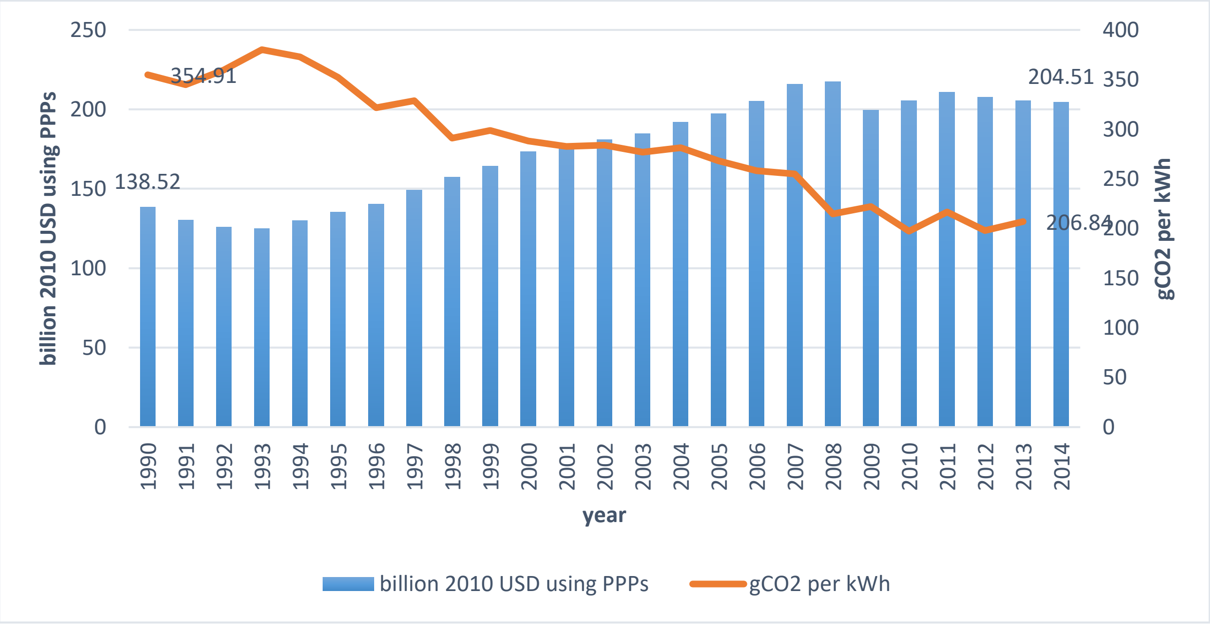

Figure 4.13. GDP and CO_2 emission intensity in Finland for 1990-2014.

Table 4.9. Decoupling analysis results for CO_2 and GDP Finland between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,007	-0,059	0,125	Weak neg. dec.	-0,055	Non-decoupling
1991-1992	-0,028	-0,033	0,848	Recessive coup.	-0,005	Non-decoupling
1992-1993	0,043	-0,007	-5,810	Strong neg. dec.	-0,051	Non-decoupling
1993-1994	0,057	0,039	1,440	Expansive neg. dec.	-0,017	Non-decoupling
1994-1995	-0,019	0,042	-0,453	Strong dec.	0,059	Absolute decoupling
1995-1996	-0,055	0,037	-1,510	Strong dec.	0,089	Absolute decoupling
1996-1997	-0,087	0,062	-1,395	Strong dec.	0,141	Absolute decoupling
1997-1998	0,022	0,054	0,407	Weak dec.	0,031	Relative decoupling
1998-1999	-0,115	0,044	-2,581	Strong dec.	0,152	Absolute decoupling
1999-2000	0,027	0,056	0,477	Weak dec.	0,028	Relative decoupling
2000-2001	-0,036	0,026	-1,383	Strong dec.	0,060	Absolute decoupling
2001-2002	-0,019	0,017	-1,118	Strong dec.	0,035	Absolute decoupling
2002-2003	0,004	0,020	0,190	Weak dec.	0,016	Relative decoupling
2003-2004	-0,024	0,039	-0,616	Strong dec.	0,061	Absolute decoupling
2004-2005	0,016	0,028	0,571	Weak dec.	0,012	Relative decoupling
2005-2006	-0,047	0,041	-1,167	Strong dec.	0,084	Absolute decoupling
2006-2007	-0,036	0,052	-0,704	Strong dec.	0,084	Absolute decoupling
2007-2008	-0,013	0,007	-1,800	Strong dec.	0,020	Absolute decoupling
2008-2009	-0,158	-0,083	1,909	Recessive dec.	0,082	0
2009-2010	0,035	0,030	1,164	Expansive coup.	-0,005	Non-decoupling
2010-2011	-0,112	0,026	-4,350	Strong dec.	0,134	Absolute decoupling
2011-2012	0,098	-0,014	-6,825	Strong neg. dec.	-0,113	Non-decoupling
2012-2013	-0,086	-0,011	7,680	Recessive dec.	0,075	0
2013-2014	0,045	-0,004	-10,953	Strong neg. dec.	-0,049	Non-decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

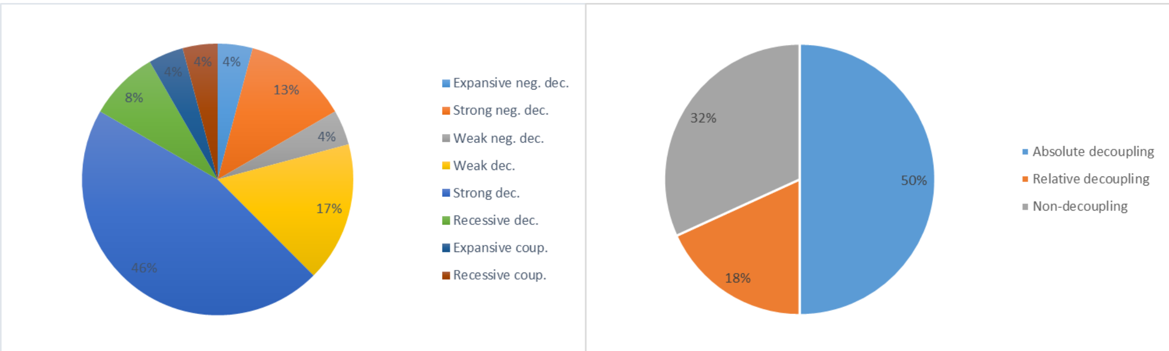

Figure 4.14. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Finland

According to Kyoto Protocol targets (Table 2.3), France was obligated to keep its GHG emissions level unchanged since 1990. Nevertheless, France was able to reduce total CO_2

emissions by 16.3% between 1990 and 2014. For France, Kara et al. [98] made estimation that France will profit from emission trading system by trading allowances as it had large share of nuclear power in electricity generation. This large share of nuclear energy for power generation accounted for relatively low CO_2 emission from the electricity and heat production sector during 1990-2014 (Figure 4.15). The share of GHG emissions from the electricity generation in France formed only 3.2% of total GHG emissions in EU-28+Iceland by the end of study period [46]. Relatively less variation of decoupling states was observed for France (Figure 4.16). There were only four states of decoupling between economic growth and environmental pressure. Two of them were recessive decoupling and strong negative decoupling states which had the equal share of occurrence (4%) between 1990 and 2014. The rest were in the share of strong decoupling with 50% and expansive negative decoupling state with 42% occurrence. Based on Table 4.10, it is difficult to see clear trend of decoupling states. The largest increase (0.390) in the rate of growth of CO_2 was observe in 1997-1998 showing expansive negative decoupling from GDP. The population of France increased by about 10 million during 1990-2014 (Figure 4.11a). The effect of this might be reason for slow reduction of CO_2 emissions from public electricity and heat generation for the period 1994-2014 after the sharp increase happened in 1991. A study found that electricity generation from nuclear power during 2010-2014 had positive impact on economic growth and reduced GHG emissions from electricity generation in France [99]. This might be reason for strong decoupling relationship between GDP and CO_2 emissions from public electricity and heat production during 2010-2014 excluding 2011-2012 (expansive neg. dec.).

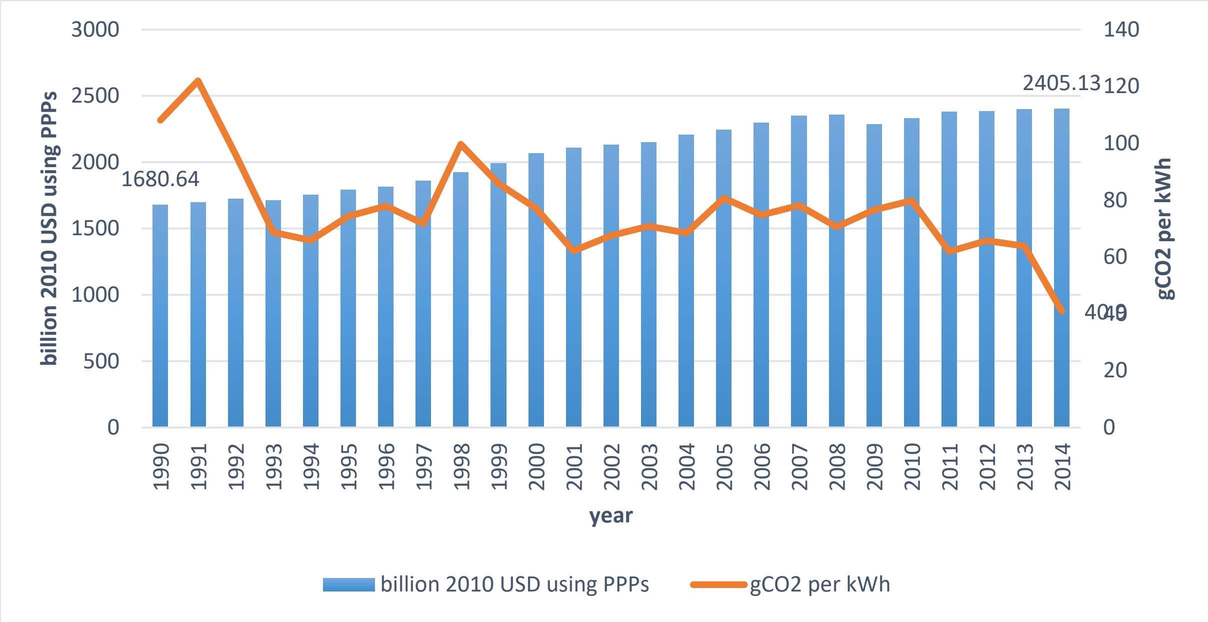

Figure 4.15. GDP and CO_2 emission intensity in France for 1990-2014.

Table 4.10. Decoupling analysis results for CO_2 and GDP France between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,128	0,010	12,317	Expansive neg. dec.	-0,116	Non-decoupling
1991-1992	-0,211	0,016	-13,191	Strong dec.	0,223	Absolute decoupling
1992-1993	-0,287	-0,006	46,805	Recessive dec.	0,282	0
1993-1994	-0,040	0,023	-1,721	Strong dec.	0,062	Absolute decoupling
1994-1995	0,128	0,021	6,135	Expansive neg. dec.	-0,105	Non-decoupling
1995-1996	0,049	0,014	3,530	Expansive neg. dec.	-0,035	Non-decoupling
1996-1997	-0,080	0,023	-3,403	Strong dec.	0,101	Absolute decoupling
1997-1998	0,390	0,036	10,959	Expansive neg. dec.	-0,342	Non-decoupling
1998-1999	-0,140	0,034	-4,094	Strong dec.	0,168	Absolute decoupling
1999-2000	-0,101	0,039	-2,596	Strong dec.	0,134	Absolute decoupling
2000-2001	-0,195	0,020	-9,965	Strong dec.	0,210	Absolute decoupling
2001-2002	0,087	0,011	7,755	Expansive neg. dec.	-0,075	Non-decoupling
2002-2003	0,048	0,008	5,908	Expansive neg. dec.	-0,040	Non-decoupling
2003-2004	-0,034	0,028	-1,212	Strong dec.	0,060	Absolute decoupling
2004-2005	0,180	0,016	11,191	Expansive neg. dec.	-0,161	Non-decoupling
2005-2006	-0,074	0,024	-3,099	Strong dec.	0,095	Absolute decoupling
2006-2007	0,045	0,024	1,885	Expansive neg. dec.	-0,020	Non-decoupling
2007-2008	-0,096	0,002	-49,400	Strong dec.	0,098	Absolute decoupling
2008-2009	0,085	-0,029	-2,905	Strong neg. dec.	-0,118	Non-decoupling
2009-2010	0,042	0,020	2,145	Expansive neg. dec.	-0,022	Non-decoupling
2010-2011	-0,225	0,021	-10,818	Strong dec.	0,241	Absolute decoupling
2011-2012	0,062	0,002	33,964	Expansive neg. dec.	-0,060	Non-decoupling
2012-2013	-0,028	0,007	-4,337	Strong dec.	0,035	Absolute decoupling
2013-2014	-0,359	0,002	-199,754	Strong dec.	0,361	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

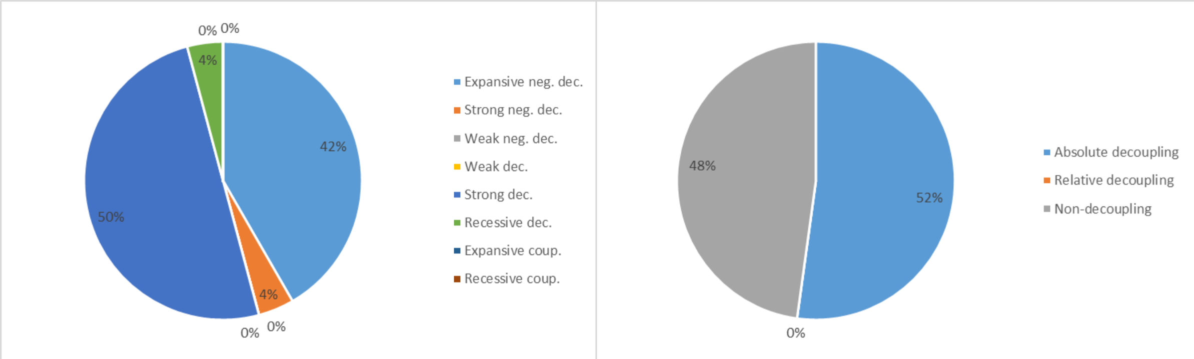

Figure 4.16. The percentage of each decoupling state by Tapio (left) method and OECD method (right). France

Italy also overachieved its Kyoto target to hold on CO_2 emissions the same level as in 1990 by 19.8% at the end of the study period. From Figure 4.17 we can see that CO_2 emissions from public electricity and heat production fell from 581.5 gCO_2 per kWh to 330.9 gCO_2 per kWh. At the same time, GDP of Italy increased 1693.31 to 1967.7 billion 2010 USD. CO_2 emission intensity strongly decoupled from GDP in 58% of the cases during the entire study period. During the period from 1990 to 2002, there were strong decoupling relationship (at some points recessive and weak) between two indicators of interest except 1994-1995 (Table 4.11). The global financial crisis had negative impact on both of economy and electricity production sector of Italy. It can be seen from Table 4.11 that during the crisis period 2007-2009 the rate of change of GDP and CO_2 emission intensity were negative. Italian government highly prioritized the renewable energy to promote energy efficiency [100]. However, some researcher were skeptical about the renewable energy in this context [101]. Increased electricity consumption during 1990-2008 might be the driver of GHGs emissions from electricity production sector. Thus, at some periods of time we observe fluctuations in CO_2 emission intensity resulted in expansive negative decoupling state (Figure 4.17). Looking at Table 4.11, the rate of change of CO_2 emission intensity had only negative values between 2005-2011. This attributed to the increase of proportion of electricity covered by renewable sources, which increased to 23%, in Italy between 2005-2011.

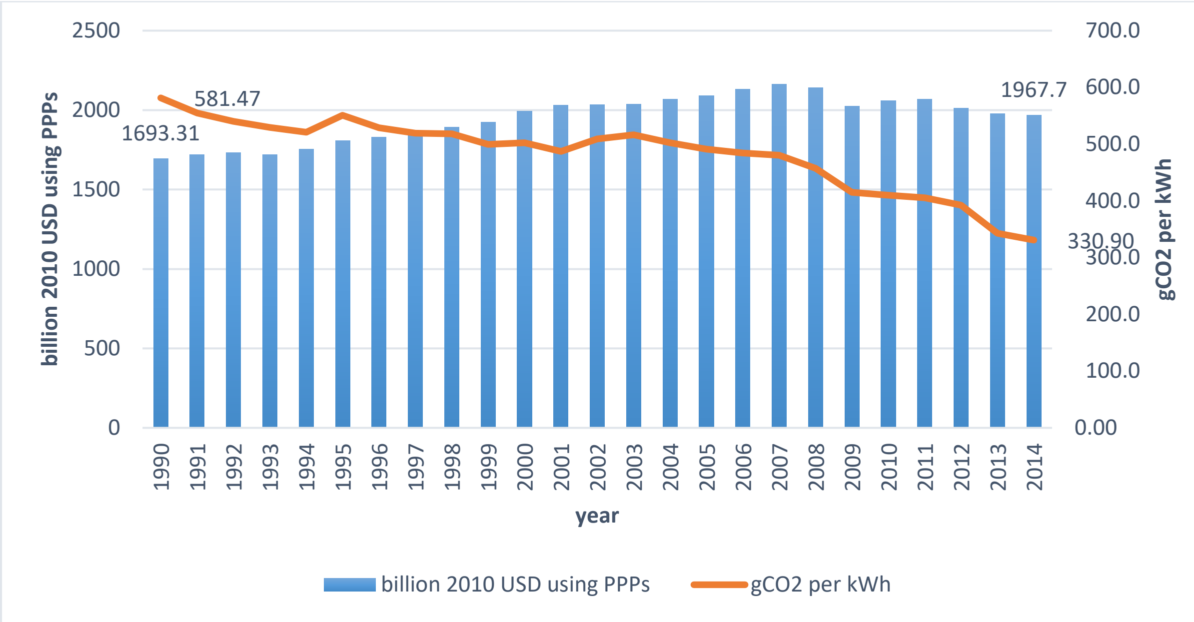

Figure 4.17. GDP and CO_2 emission intensity in Italy for 1990-2014

Table 4.11. Decoupling analysis results for CO_2 and GDP Italy between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,046	0,015	-2,985	Strong dec.	0,060	Absolute decoupling
1991-1992	-0,026	0,008	-3,160	Strong dec.	0,034	Absolute decoupling
1992-1993	-0,020	-0,009	2,326	Recessive dec.	0,011	0
1993-1994	-0,016	0,022	-0,761	Strong dec.	0,037	Absolute decoupling
1994-1995	0,058	0,029	1,996	Expansive neg. dec.	-0,028	Non-decoupling
1995-1996	-0,039	0,013	-3,056	Strong dec.	0,052	Absolute decoupling
1996-1997	-0,018	0,018	-0,998	Strong dec.	0,036	Absolute decoupling
1997-1998	-0,002	0,016	-0,113	Strong dec.	0,018	Absolute decoupling
1998-1999	-0,036	0,016	-2,308	Strong dec.	0,051	Absolute decoupling
1999-2000	0,005	0,037	0,140	Weak dec.	0,031	Relative decoupling
2000-2001	-0,030	0,018	-1,705	Strong dec.	0,047	Absolute decoupling
2001-2002	0,045	0,003	17,959	Expansive neg. dec.	-0,042	Non-decoupling
2002-2003	0,015	0,002	9,600	Expansive neg. dec.	-0,013	Non-decoupling
2003-2004	-0,028	0,016	-1,746	Strong dec.	0,043	Absolute decoupling
2004-2005	-0,023	0,009	-2,402	Strong dec.	0,032	Absolute decoupling
2005-2006	-0,013	0,020	-0,648	Strong dec.	0,032	Absolute decoupling
2006-2007	-0,008	0,015	-0,570	Strong dec.	0,023	Absolute decoupling
2007-2008	-0,048	-0,010	4,606	Recessive dec.	0,038	0
2008-2009	-0,093	-0,055	1,692	Recessive dec.	0,040	0
2009-2010	-0,012	0,017	-0,695	Strong dec.	0,029	Absolute decoupling
2010-2011	-0,010	0,006	-1,712	Strong dec.	0,016	Absolute decoupling

2011-2012	-0,033	-0,028	1,159	Recessive coup.	0,005	0
2012-2013	-0,127	-0,017	7,244	Recessive dec.	0,111	0
2013-2014	-0,035	-0,004	7,815	Recessive dec.	0,030	0

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

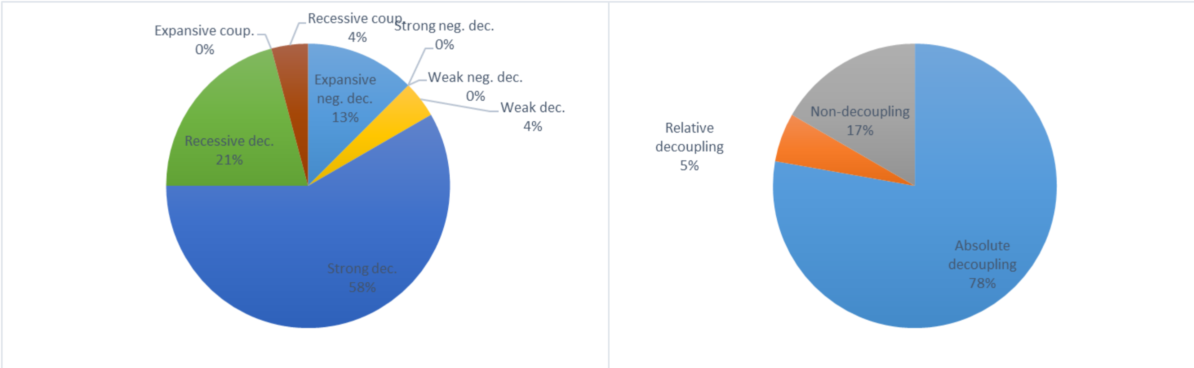

Figure 4.18. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Italy

Netherlands was in the list of countries which reduced GHG emissions (-15.8%) more than they committed to reduce (-6%) under Kyoto Protocol (Table 2.3). In general, to some extent GDP strongly decoupled from the CO_2 emission intensity during the entire study period (Table 4.12). The decrease in CO_2 emission intensity during 2005-2011 was attributed to decrease in energy intensity at a rate of 9% and energy consumption by 3% between 2005-2011 [102]. However, some researchers have argued that a decrease in energy intensity could indicate improvements in energy sectors. Massimo and Lester [103] performed a stochastic demand frontier approach for whole economy aggregate for 29 OECD countries from 1978 to 2006. They concluded that the energy intensity cannot always indicate efficiency improvements in energy use. The CO_2 emission from public electricity and heat generation significantly increased in between 2011 and 2014. In 2014, Netherlands together with Germany and France emitted 58% of total GHG emissions of the EU-28 + Iceland [46]. This deteriorated decoupling state between GDP and CO_2 emission intensity to strong negative decoupling for 2011-2013. The last period (2013-2014) exhibited expansive negative decoupling between GDP and CO_2 emission intensity indication of a recovery of emission situation (Table 4.12).

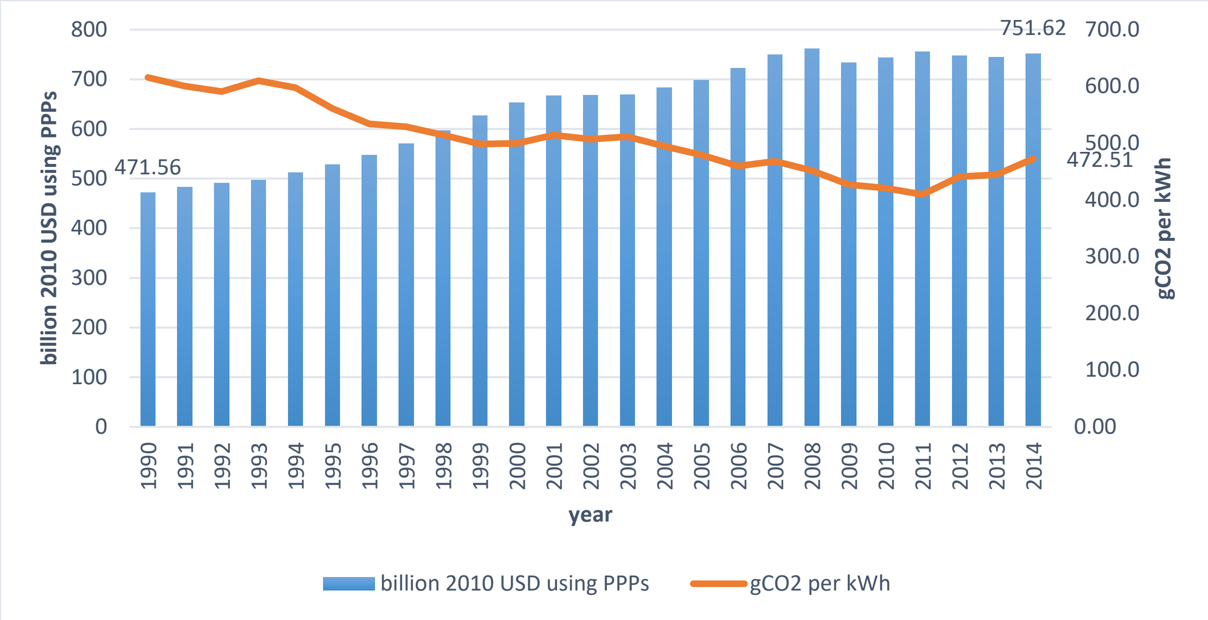

Figure 4.19. GDP and CO_2 emission intensity in Netherlands for 1990-2014.

Table 4.12. Decoupling analysis results for CO_2 and GDP Netherlands between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,024	0,024	-0,992	Strong dec.	0,047	Absolute decoupling
1991-1992	-0,016	0,017	-0,945	Strong dec.	0,033	Absolute decoupling
1992-1993	0,032	0,013	2,535	Expansive neg. dec.	-0,019	Non-decoupling
1993-1994	-0,020	0,030	-0,689	Strong dec.	0,049	Absolute decoupling
1994-1995	-0,061	0,031	-1,944	Strong dec.	0,089	Absolute decoupling
1995-1996	-0,049	0,036	-1,376	Strong dec.	0,082	Absolute decoupling
1996-1997	-0,009	0,043	-0,204	Strong dec.	0,050	Absolute decoupling
1997-1998	-0,027	0,045	-0,607	Strong dec.	0,070	Absolute decoupling
1998-1999	-0,032	0,051	-0,627	Strong dec.	0,078	Absolute decoupling
1999-2000	0,003	0,042	0,064	Weak dec.	0,038	Relative decoupling
2000-2001	0,030	0,021	1,392	Expansive neg. dec.	-0,008	Non-decoupling
2001-2002	-0,014	0,001	-13,943	Strong dec.	0,015	Absolute decoupling
2002-2003	0,008	0,003	2,967	Expansive neg. dec.	-0,006	Non-decoupling
2003-2004	-0,033	0,020	-1,619	Strong dec.	0,052	Absolute decoupling
2004-2005	-0,031	0,022	-1,423	Strong dec.	0,051	Absolute decoupling
2005-2006	-0,041	0,035	-1,154	Strong dec.	0,073	Absolute decoupling
2006-2007	0,018	0,037	0,491	Weak dec.	0,018	Relative decoupling
2007-2008	-0,035	0,017	-2,030	Strong dec.	0,051	Absolute decoupling
2008-2009	-0,055	-0,038	1,465	Recessive dec.	0,018	0
2009-2010	-0,015	0,014	-1,074	Strong dec.	0,029	Absolute decoupling
2010-2011	-0,026	0,017	-1,590	Strong dec.	0,042	Absolute decoupling
2011-2012	0,076	-0,011	-7,236	Strong neg. dec.	-0,088	Non-decoupling
2012-2013	0,009	-0,005	-1,742	Strong neg. dec.	-0,014	Non-decoupling

2013-2014	0,063	0,010	6,219	Expansive neg. dec.	-0,052	Non-decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

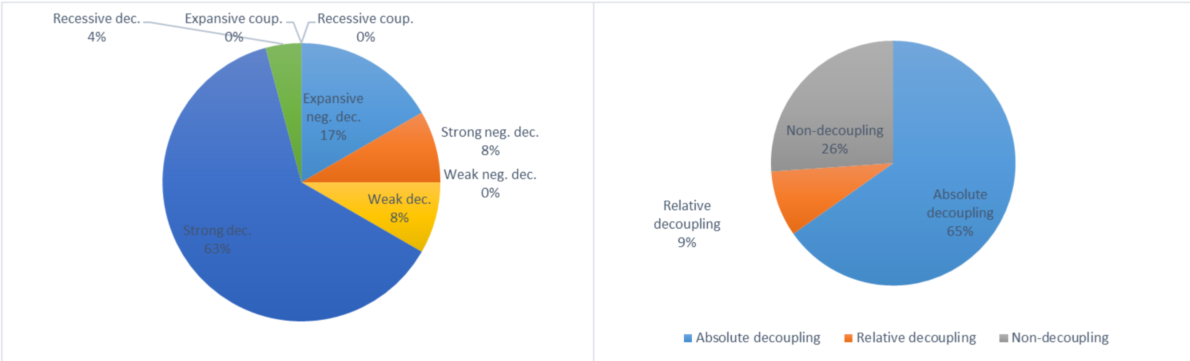

Figure 4.20. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Netherlands

4.3 Decoupling analysis in Group III countries: *Greece, Ireland, Portugal, Spain, Sweden.*

Group III includes countries with mild reduction target values respect to the first commitment period (2008-2012) Kyoto Protocol ranged between +4% and +27%, namely: Greece (+25%), Ireland (+13%), Portugal (27%), Spain (+15%), Sweden (+4%). Portugal, Spain, Sweden showed irregular trend of decrease of CO_2 emission intensity, except Greece and Ireland from 1990 to 2014. Sweden emitted the lowest amount of CO_2 to generate heat and electricity while the other members produced at least 250 gCO_2 per kWh in the period between 1990 and 2014 (Figures 4.21, 4.23, 4.25, 4.27, 4.29). For this group member countries financial crisis also drastically affected their economy and emission reduction performance during 2008-2009. As a result, we can notice from Table 4.13 that decoupling states changed to recessive decoupling (Portugal and Spain) even to weak negative decoupling (Greece and Ireland) and strong negative decoupling states (Sweden). Compared to group I and II countries' decoupling trends during post-crisis period (2009-2014), this group countries were not able to completely recover the strong decoupling relationship between GDP and CO_2 emission intensity. Also, from Figure 4.21a we can notice that the population almost did not change from 1990 to 2014 in Group III countries except Spain. Therefore, the population might be had influence on decoupling performance only in Spain.

Table 4.13. Decoupling states for CO_2 emission intensity and GDP Group III

Time	Greece		Ireland		Portugal		Spain		Sweden	
	Tapio	OECD	Tapio	OECD	Tapio	OECD	Tapio	OECD	Tapio	OECD
1990-1991	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Strong neg. dec.	Non-decoupling
1991-1992	Expansive neg. dec.	Non-decoupling	Weak dec.	Relative decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Recessive coup.	Non-decoupling
1992-1993	Recessive dec.	0	Strong dec.	Absolute decoupling	Recessive dec.	0	Recessive dec.	0	Strong neg. dec.	Non-decoupling
1993-1994	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
1994-1995	Expansive coup.	Relative decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
1995-1996	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
1996-1997	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
1997-1998	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling
1998-1999	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
1999-2000	Expansive coup.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling
2000-2001	Weak dec.	Relative decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2001-2002	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling
2002-2003	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Recessive dec.	0	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2003-2004	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Weak dec.	Relative decoupling	Strong dec.	Absolute decoupling
2004-2005	Strong dec.	Absolute decoupling	Weak dec.	Relative decoupling	Expansive neg. dec.	Non-decoupling	Expansive coup.	Relative decoupling	Strong dec.	Absolute decoupling
2005-2006	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2006-2007	Expansive coup.	Relative decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
2007-2008	Recessive dec.	0	Recessive dec.	0	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Strong neg. dec.	Non-decoupling
2008-2009	Weak neg. dec.	Non-decoupling	Weak neg. dec.	Non-decoupling	Recessive dec.	0	Recessive dec.	0	Strong neg. dec.	Non-decoupling
2009-2010	Weak neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling
2010-2011	Weak neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling
2011-2012	Weak neg. dec.	Non-decoupling	Expansive neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Strong neg. dec.	Non-decoupling	Recessive dec.	0
2012-2013	Recessive dec.	0	Strong dec.	Absolute decoupling	Recessive dec.	0	Recessive dec.	0	Expansive neg. dec.	Non-decoupling
2013-2014	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling	Strong dec.	Absolute decoupling	Expansive neg. dec.	Non-decoupling	Strong dec.	Absolute decoupling

Referring to the Kyoto Protocol, it was allowed to increase GHG emissions for Greece by 25% compared to the 1990 levels (Table 2.3). Despite of that, Greece overachieved its reduction target and reduced GHGs emission by 3.3 % during the first commitment period of the Kyoto Protocol. Beginning from 1995 to 2006, Greece's economy strongly decoupled from emissions from public electricity and heat production during almost the entire period, except 1999-2001 (Table 4.14). The level of CO_2 emission intensity arising from the production of public electricity and heat decreased by 33.45% during 1990-2014 (Figure4.21). However, the GDP had been increasing and had reached a peak in 2007 after which it deceased again. This is due to the negative impact of financial crises. The recession of Greece's economy after crisis lasted till the end of study period (2010-2014) presenting decline in GDP. In this sense, GDP and CO_2 emission intensity had weak negative decoupling state from 2008 to 2012. According to literature [104], the proportion of renewable electricity in Greece raised from 8.9% to 14.6% between 2005 and 2011. This might be reason for steady decline in CO_2 emission intensity during this period (Figure 4.21). Theodosiou et al. [105] estimated for Greece that 90% of electricity produced by thermal power plants and the rest 10% belongs to hydroelectric energy and other renewable energy sources. The main fuel of thermal power plants was lignite (fossil fuel) which produces huge amount of CO_2 emissions [105]. From 1999 to 2007, the percentage of oil-based power generation decreased to 6% [105]. These factors can affect the changes in CO_2 emission intensity.

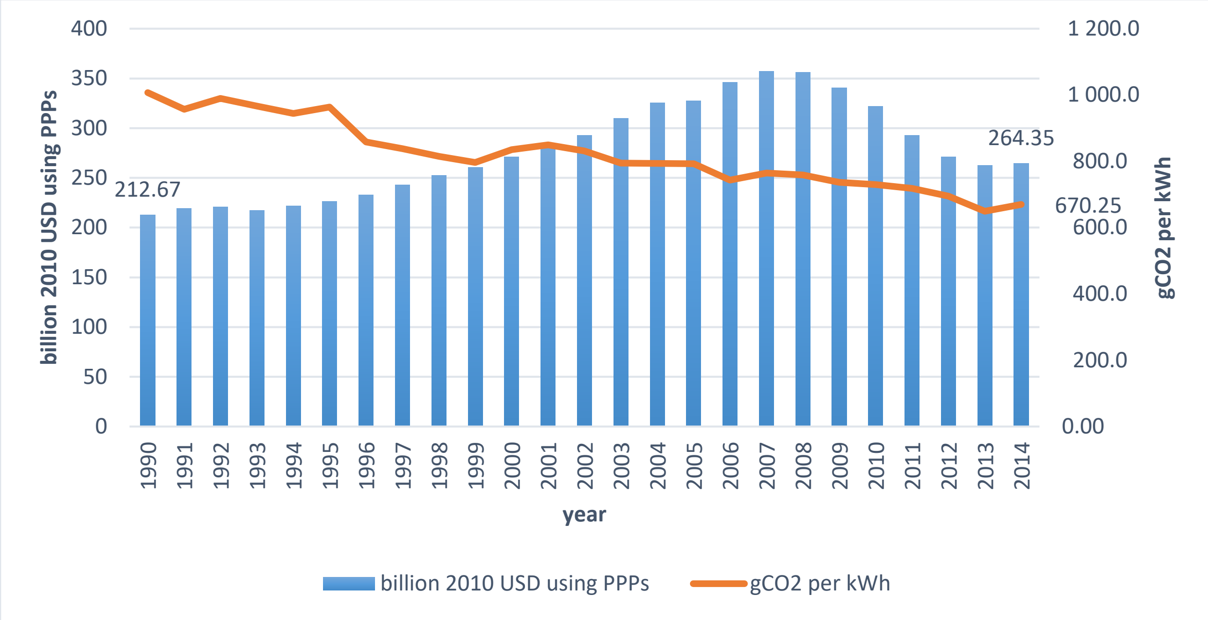

Figure 4.21. GDP and CO_2 emission intensity in Greece for 1990-2014.

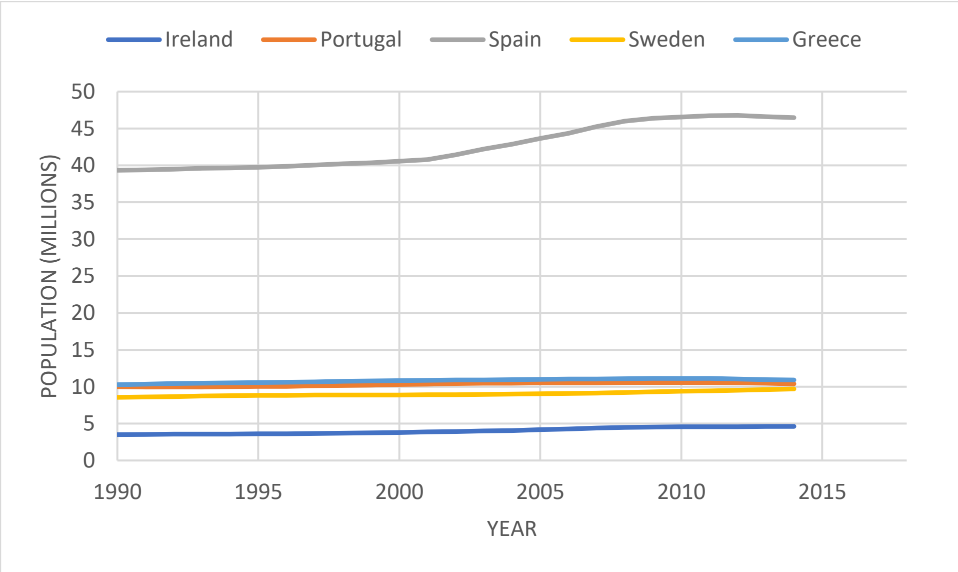

Figure 4.21a. Group III countries population during 1990-2014 [82].

Table 4.14. Decoupling analysis results for CO_2 emission intensity and GDP Greece between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,050	0,031	-1,601	Strong dec.	0,078	Absolute decoupling
1991-1992	0,034	0,007	4,843	Expansive neg. dec.	-0,027	Non-decoupling
1992-1993	-0,023	-0,016	1,466	Recessive dec.	0,008	0
1993-1994	-0,023	0,020	-1,150	Strong dec.	0,042	Absolute decoupling
1994-1995	0,021	0,021	0,994	Expansive coup.	0,000	Relative decoupling
1995-1996	-0,110	0,029	-3,829	Strong dec.	0,134	Absolute decoupling
1996-1997	-0,023	0,045	-0,523	Strong dec.	0,065	Absolute decoupling

1997-1998	-0,028	0,039	-0,711	Strong dec.	0,064	Absolute decoupling
1998-1999	-0,023	0,031	-0,747	Strong dec.	0,052	Absolute decoupling
1999-2000	0,050	0,042	1,178	Expansive coup.	-0,007	Non-decoupling
2000-2001	0,016	0,038	0,425	Weak dec.	0,021	Relative decoupling
2001-2002	-0,021	0,039	-0,533	Strong dec.	0,058	Absolute decoupling
2002-2003	-0,044	0,058	-0,756	Strong dec.	0,096	Absolute decoupling
2003-2004	-0,002	0,051	-0,032	Strong dec.	0,050	Absolute decoupling
2004-2005	-0,001	0,006	-0,135	Strong dec.	0,007	Absolute decoupling
2005-2006	-0,063	0,057	-1,114	Strong dec.	0,113	Absolute decoupling
2006-2007	0,029	0,033	0,886	Expansive coup.	0,004	Relative decoupling
2007-2008	-0,007	-0,003	2,223	Recessive dec.	0,004	0
2008-2009	-0,029	-0,043	0,677	Weak neg. dec.	-0,015	Non-decoupling
2009-2010	-0,009	-0,055	0,171	Weak neg. dec.	-0,048	Non-decoupling
2010-2011	-0,016	-0,091	0,179	Weak neg. dec.	-0,083	Non-decoupling
2011-2012	-0,032	-0,073	0,436	Weak neg. dec.	-0,044	Non-decoupling
2012-2013	-0,066	-0,032	2,060	Recessive dec.	0,035	0
2013-2014	0,032	0,007	4,898	Expansive neg. dec.	-0,025	Non-decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

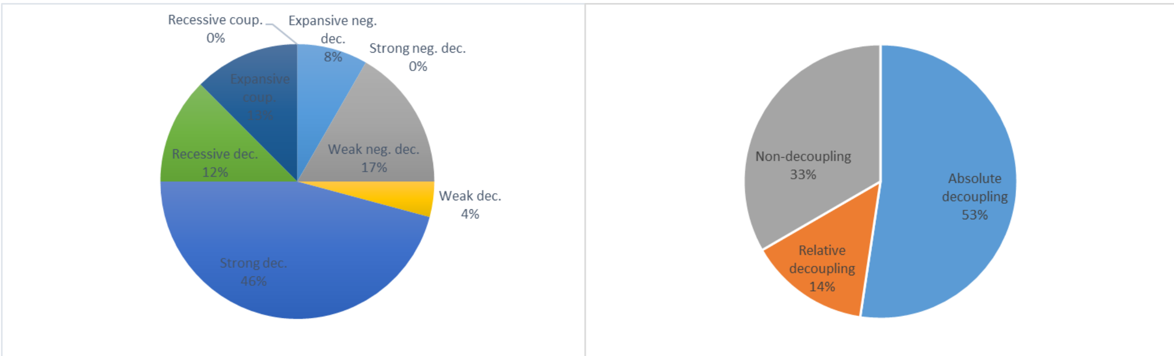

Figure 4.22. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Greece

Ireland met the target under the Kyoto Protocol by which GHGs emissions were allowed to increase by 13% compared to 1990 levels (Table 2.3). The CO_2 emission intensity had downward trend between 1990-2014 (Figure 4.23). At the same time GDP had upward trend by 2008, then slightly decreased during 2008-2011. After that, it again started to decline until the end of the period. These changes were consequences of the global financial crisis. The rapid expansion of Ireland's economy during the 1990-2006 resulted in an increase in total GHG emissions per capita [106]. However, this did not influence the emission level of electricity production sector. The primary reason could be that the agriculture was the largest emitter of GHGs in Ireland [106]. From Figure 4.24 we can observe that the occurrence frequency of strong decoupling is the highest (67%). Thus, we can see that from 1990 to 2007 the decoupling between GDP and CO_2 emission intensity was strong (Table 4.15). 11% and 14% declines were observed in the energy intensity and final consumption of Ireland during 2005-2011 [106]. This was contributed to the decrease in emissions from public electricity and heat generation during 2005-2011.

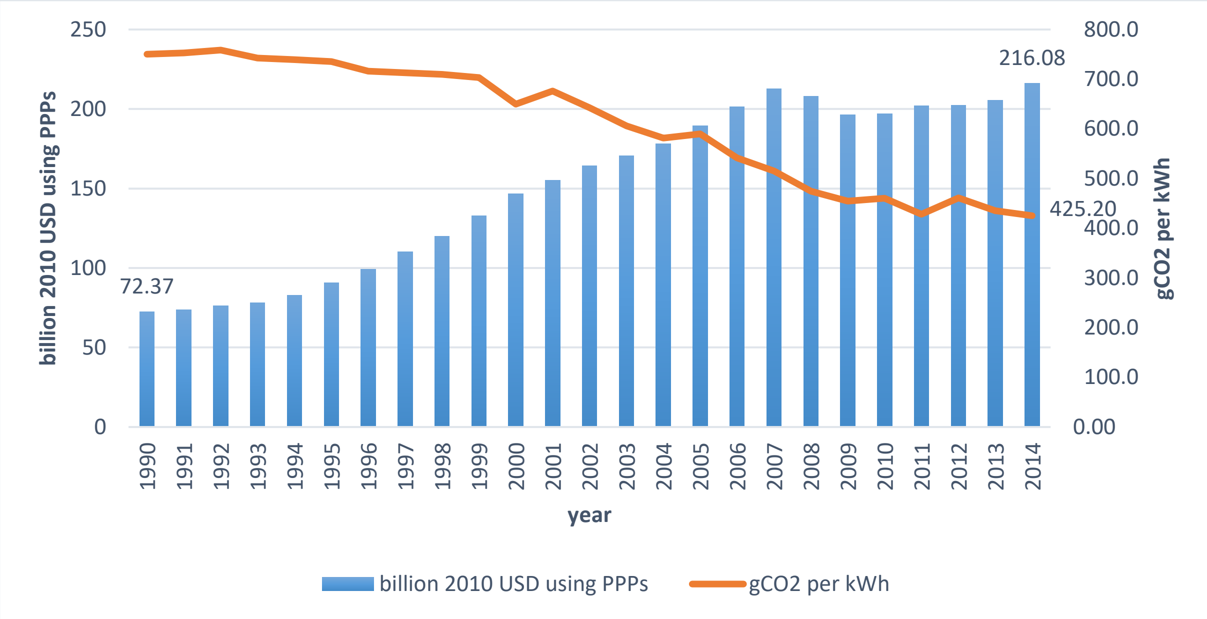

Figure 4.23. GDP and CO_2 emission intensity in Ireland for 1990-2014.

Table 4.15. Decoupling analysis results for CO_2 emission intensity and GDP Ireland between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,004	0,019	0,191	Weak dec.	0,015	Relative decoupling
1991-1992	0,008	0,033	0,229	Weak dec.	0,025	Relative decoupling
1992-1993	-0,022	0,027	-0,802	Strong dec.	0,047	Absolute decoupling
1993-1994	-0,004	0,058	-0,074	Strong dec.	0,058	Absolute decoupling
1994-1995	-0,005	0,096	-0,048	Strong dec.	0,092	Absolute decoupling
1995-1996	-0,026	0,093	-0,283	Strong dec.	0,109	Absolute decoupling
1996-1997	-0,005	0,112	-0,043	Strong dec.	0,105	Absolute decoupling
1997-1998	-0,005	0,089	-0,051	Strong dec.	0,086	Absolute decoupling
1998-1999	-0,009	0,108	-0,087	Strong dec.	0,106	Absolute decoupling
1999-2000	-0,076	0,102	-0,739	Strong dec.	0,161	Absolute decoupling
2000-2001	0,041	0,058	0,698	Weak dec.	0,017	Relative decoupling
2001-2002	-0,050	0,059	-0,841	Strong dec.	0,103	Absolute decoupling

2002-2003	-0,057	0,038	-1,494	Strong dec.	0,092	Absolute decoupling
2003-2004	-0,040	0,044	-0,911	Strong dec.	0,081	Absolute decoupling
2004-2005	0,015	0,063	0,239	Weak dec.	0,045	Relative decoupling
2005-2006	-0,082	0,063	-1,304	Strong dec.	0,137	Absolute decoupling
2006-2007	-0,049	0,055	-0,886	Strong dec.	0,099	Absolute decoupling
2007-2008	-0,078	-0,022	3,612	Recessive dec.	0,058	0
2008-2009	-0,042	-0,056	0,747	Weak neg. dec.	-0,015	Non-decoupling
2009-2010	0,012	0,004	3,065	Expansive neg. dec.	-0,008	Non-decoupling
2010-2011	-0,070	0,026	-2,692	Strong dec.	0,093	Absolute decoupling
2011-2012	0,076	0,002	49,577	Expansive neg. dec.	-0,074	Non-decoupling
2012-2013	-0,056	0,014	-3,907	Strong dec.	0,069	Absolute decoupling
2013-2014	-0,023	0,052	-0,438	Strong dec.	0,071	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

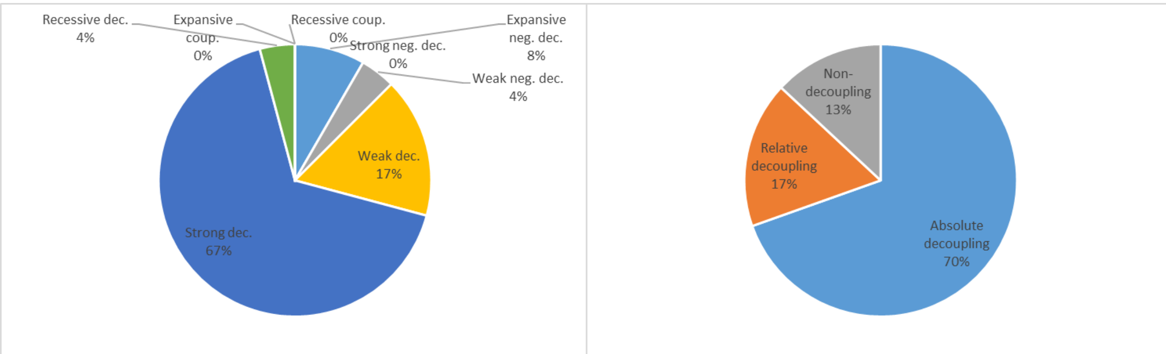

Figure 4.24. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Ireland

Portugal achieved compliance with GHGs emission reduction target under the Kyoto Protocol for the period 2008-2012. Under Kyoto Protocol, it was allowed for Portugal to increase its GHG emissions up to 28% compared to 1990 levels. The GDP of country rose by 34.4% during the entire study period (Figure 4.25). At the same time, the CO_2 emission intensity had irregular decline trend. Therefore, the decoupling states varying along with fluctuation in CO_2 emission intensities. Strong decoupling relationship was in 38% of cases between GDP and CO_2 emission intensity. The longest and continuous period of strong decoupling relationship was between 2005 and 2008 (Table 4.16). After this period, we can observe the effect of financial crisis which deteriorated the decoupling state to recessive decoupling. The sharp decline in 2003 in CO_2 emission intensity (Figure4.25) was due to the high portion (31%) of renewable electricity in final electricity consumption.

This portion was varied in the rest of the study period and reached its peak (46.5%) in 2011[107]. However, for this year results of decoupling analysis showed that the decoupling state between GDP and CO_2 emission intensity was strong negative decoupling (Table 4.16).

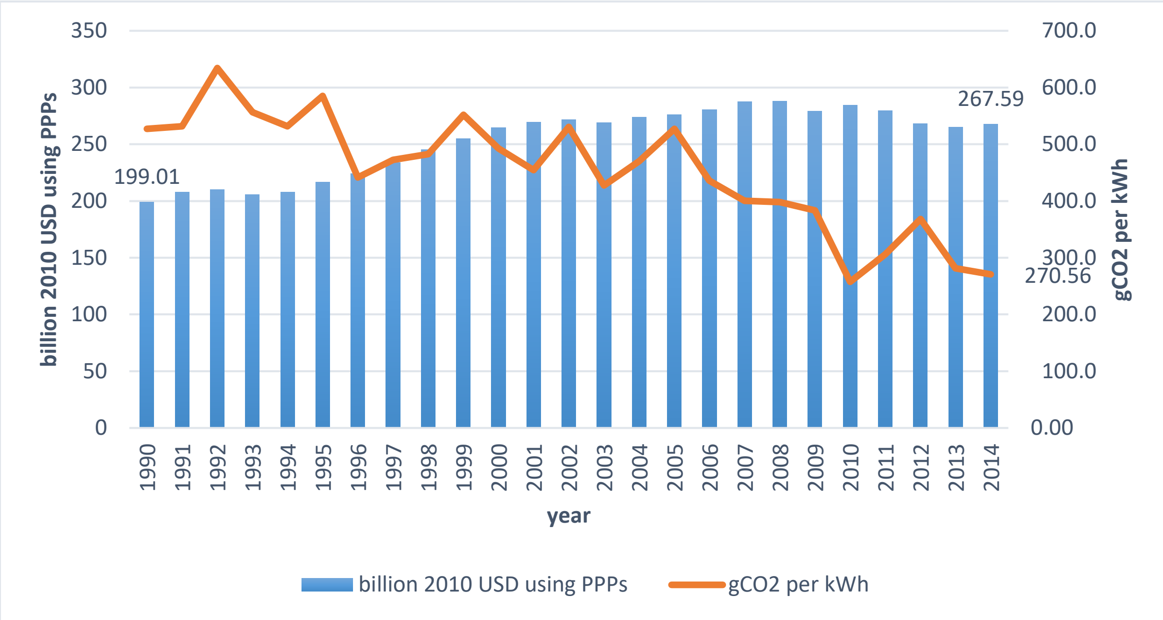

Figure 4.25. GDP and CO_2 emission intensity in Portugal for 1990-2014

Table 4.16. Decoupling analysis results for CO2 emission intensity and GDP Portugal between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,008	0,044	0,182	Weak dec.	0,034	Relative decoupling
1991-1992	0,194	0,011	17,707	Expansive neg. dec.	-0,181	Non-decoupling
1992-1993	-0,123	-0,020	6,020	Recessive dec.	0,105	0
1993-1994	-0,045	0,010	-4,637	Strong dec.	0,054	Absolute decoupling
1994-1995	0,101	0,043	2,353	Expansive neg. dec.	-0,056	Non-decoupling
1995-1996	-0,245	0,035	-7,012	Strong dec.	0,271	Absolute decoupling
1996-1997	0,071	0,044	1,601	Expansive neg. dec.	-0,025	Non-decoupling
1997-1998	0,020	0,048	0,428	Weak dec.	0,026	Relative decoupling
1998-1999	0,144	0,039	3,705	Expansive neg. dec.	-0,101	Non-decoupling
1999-2000	-0,107	0,038	-2,826	Strong dec.	0,140	Absolute decoupling
2000-2001	-0,078	0,019	-4,023	Strong dec.	0,096	Absolute decoupling
2001-2002	0,168	0,008	21,925	Expansive neg. dec.	-0,159	Non-decoupling
2002-2003	-0,195	-0,009	20,833	Recessive dec.	0,187	0
2003-2004	0,100	0,018	5,542	Expansive neg. dec.	-0,081	Non-decoupling
2004-2005	0,121	0,008	15,735	Expansive neg. dec.	-0,112	Non-decoupling

2005-2006	-0,173	0,016	-11,107	Strong dec.	0,185	Absolute decoupling
2006-2007	-0,082	0,025	-3,298	Strong dec.	0,104	Absolute decoupling
2007-2008	-0,005	0,002	-2,414	Strong dec.	0,007	Absolute decoupling
2008-2009	-0,038	-0,030	1,276	Recessive dec.	0,008	0
2009-2010	-0,328	0,019	-17,260	Strong dec.	0,341	Absolute decoupling
2010-2011	0,190	-0,018	-10,360	Strong neg. dec.	-0,212	Non-decoupling
2011-2012	0,202	-0,040	-5,028	Strong neg. dec.	-0,253	Non-decoupling
2012-2013	-0,236	-0,011	20,898	Recessive dec.	0,227	0
2013-2014	-0,038	0,009	-4,241	Strong dec.	0,047	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

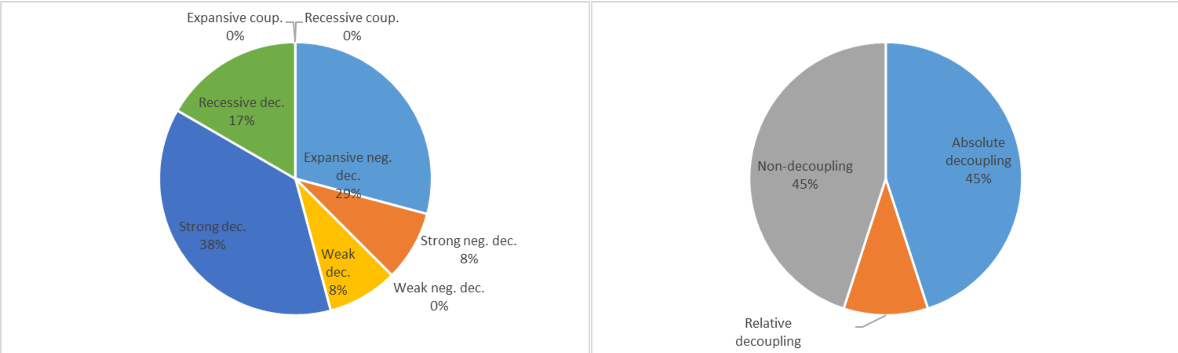

Figure 4.26. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Portugal

In Spain, the GHG emission reached the same reduction level with the upper limit (+15%) which was assigned by first commitment period of Kyoto Protocol (Table 2.3). In Spain, electricity consumption and heat production were main drivers of GHG emissions increase between 1990 and 2008 [93]. In Spain, gradual increase in GDP was occurred between 1990 and 2008 (Figure 4.27). However, the decline trend of CO_2 emission intensity was not smooth, which resulted in nonuniform distribution of decoupling states during the entire study period (Table 4.17). Figure 4.28 shows that the negative expansive decoupling was observed in about one third of total cases during 1990-2014. The proportion of renewable energy in final consumption of electricity has increased by 67% during 2005-2011[108]. Thus, we can see significant decrease in CO_2 emissions from electricity production sector during 2005-2011. However, there was decoupling relationship between GDP and CO_2 emission intensity for that period, but strong negative decoupling happened 2010-2011 implies that there were another factor influencing decoupling states (Table 4.17). Figure 4.21a shows that the population of Spain had been increased by approximately 6 million from

2000 to 2010. The effect of this increase in population may justify increases in CO_2 emissions after 2010. This observation is in accordance with Moutinho et al. [19], which found that the highest effect of population on CO_2 emissions was in Spain among EU-15 member countries. Thus, relatively large increase in population affected decoupling states after 2010 in Spain.

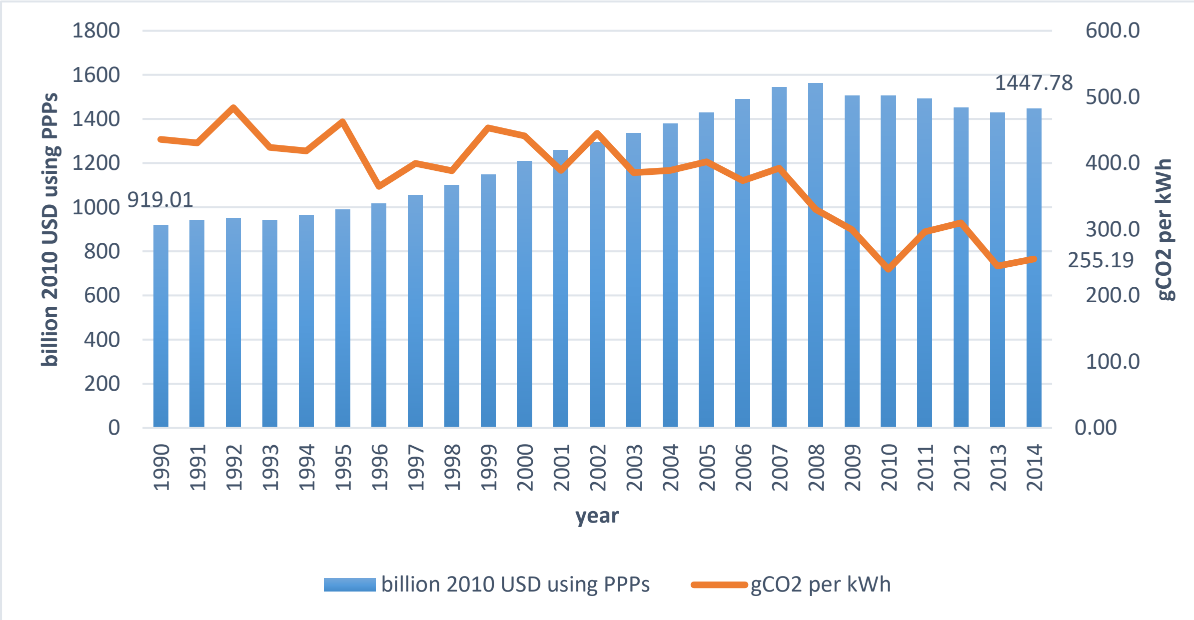

Figure 4.27. GDP and CO_2 emission intensity in Spain for 1990-2014

Table 4.17. Decoupling analysis results for CO_2 emission intensity and GDP Spain between 1990-2014

Time	$\Delta CO_2/CO_2$	$\Delta GDP/GDP$	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	-0,013	0,025	-0,491	Strong dec.	0,037	Absolute decoupling
1991-1992	0,124	0,009	13,348	Expansive neg. dec.	-0,114	Non-decoupling
1992-1993	-0,123	-0,010	11,957	Recessive dec.	0,114	0
1993-1994	-0,013	0,024	-0,537	Strong dec.	0,036	Absolute decoupling
1994-1995	0,104	0,028	3,778	Expansive neg. dec.	-0,075	Non-decoupling
1995-1996	-0,211	0,027	-7,893	Strong dec.	0,232	Absolute decoupling
1996-1997	0,096	0,037	2,599	Expansive neg. dec.	-0,057	Non-decoupling
1997-1998	-0,028	0,043	-0,640	Strong dec.	0,068	Absolute decoupling
1998-1999	0,166	0,045	3,699	Expansive neg. dec.	-0,116	Non-decoupling
1999-2000	-0,027	0,053	-0,507	Strong dec.	0,076	Absolute decoupling
2000-2001	-0,118	0,040	-2,957	Strong dec.	0,152	Absolute decoupling
2001-2002	0,144	0,029	5,007	Expansive neg. dec.	-0,112	Non-decoupling
2002-2003	-0,133	0,032	-4,169	Strong dec.	0,160	Absolute decoupling
2003-2004	0,008	0,032	0,254	Weak dec.	0,023	Relative decoupling
2004-2005	0,034	0,037	0,917	Expansive coup.	0,003	Relative decoupling
2005-2006	-0,071	0,042	-1,697	Strong dec.	0,108	Absolute decoupling
2006-2007	0,050	0,038	1,326	Expansive neg. dec.	-0,012	Non-decoupling
2007-2008	-0,159	0,011	-14,201	Strong dec.	0,168	Absolute decoupling

2008-2009	-0,093	-0,036	2,599	Recessive dec.	0,059	0
2009-2010	-0,200	0,000	-1431,6	Strong dec.	0,200	Absolute decoupling
2010-2011	0,236	-0,010	-23,575	Strong neg. dec.	-0,248	Non-decoupling
2011-2012	0,045	-0,026	-1,722	Strong neg. dec.	-0,073	Non-decoupling
2012-2013	-0,209	-0,017	12,515	Recessive dec.	0,196	0
2013-2014	0,042	0,014	3,115	Expansive neg. dec.	-0,028	Non-decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

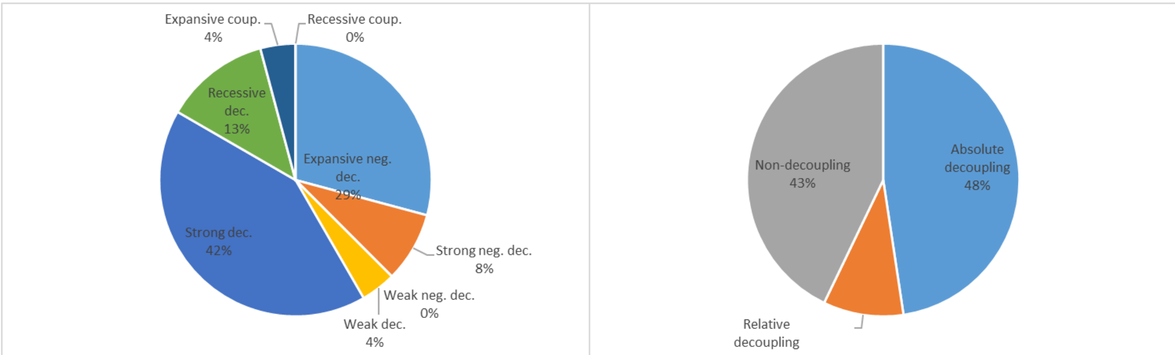

Figure 4.28. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Spain

As shown in Figure 4.29, in Sweden the emissions from electricity and heat production were very low during the entire study period. This was attributed to the fact that the share of nuclear power and hydropower in electricity generation was very high. For example, in 1990s nuclear power and hydropower formed 90% of electricity generation in Sweden [98]. Sweden had the largest share of energy from renewable sources in the EU during 2004-2014 [109]. However, the electricity generation were still utilized coal and fossil fuel as a source of energy. Thus, changes in consumption of electricity caused changes in the level of GHGs emitted from electricity and power plants. For example, proportion of energy use of industry in Sweden's total final energy use was 38% (148.3 TWh) in 2010 [110]. When the energy use in industry shifted from oil to electricity the use of electricity increased during 1970 to 2010 as expected. Depending on oil price there were fluctuations in proportion of oil and electricity use which may be reason for the sharp changes in CO_2 emission intensities. Finally, a decrease in CO_2 emission intensity in 2013-2014 could be due to the mild winter conditions which led to less electricity consumptions [46]. Thus, we observe strong decoupling state in 2013-2014 (Table 4.18). From Figure 4.30 we can notice that strong decoupling state and expansive negative decoupling state were detected at the same frequencies with 38% and 33%, respectively.

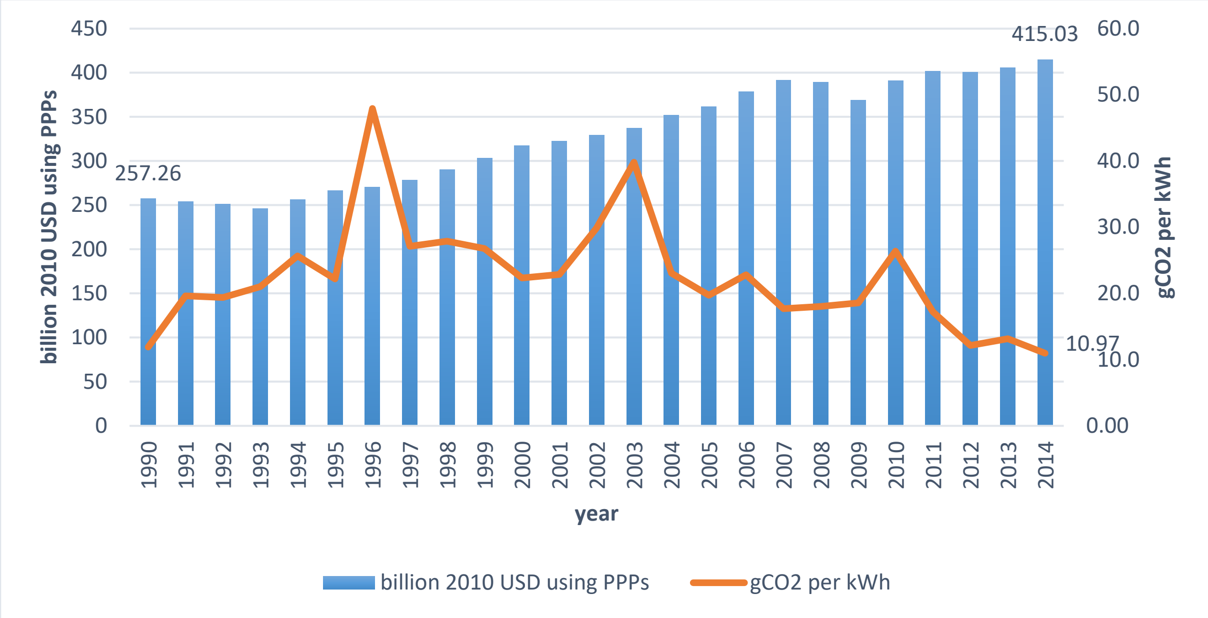

Figure 4.29. GDP and CO_2 emission intensity in Sweden for 1990-2014

Table 4.17. Decoupling analysis results for CO_2 emission intensity and GDP Sweden between 1990-2014

Time	$\Delta CO_2/CO_2$	ΔGDP/GDP	ɣ	Decoupling Condition (Tapio)	D_f	Decoupling Condition (OECD)
1990-1991	0,652	-0,011	-56,817	Strong neg. dec.	-0,671	Non-decoupling
1991-1992	-0,011	-0,012	0,926	Recessive coup.	-0,001	Non-decoupling
1992-1993	0,083	-0,021	-4,017	Strong neg. dec.	-0,106	Non-decoupling
1993-1994	0,222	0,041	5,425	Expansive neg. dec.	-0,174	Non-decoupling
1994-1995	-0,136	0,040	-3,387	Strong dec.	0,170	Absolute decoupling
1995-1996	1,161	0,015	76,438	Expansive neg. dec.	-1,129	Non-decoupling
1996-1997	-0,434	0,029	-14,971	Strong dec.	0,450	Absolute decoupling
1997-1998	0,028	0,042	0,664	Weak dec.	0,014	Relative decoupling
1998-1999	-0,040	0,045	-0,887	Strong dec.	0,082	Absolute decoupling
1999-2000	-0,164	0,047	-3,471	Strong dec.	0,202	Absolute decoupling
2000-2001	0,023	0,016	1,490	Expansive neg. dec.	-0,008	Non-decoupling
2001-2002	0,306	0,021	14,714	Expansive neg. dec.	-0,279	Non-decoupling
2002-2003	0,333	0,024	13,992	Expansive neg. dec.	-0,302	Non-decoupling
2003-2004	-0,421	0,043	-9,751	Strong dec.	0,445	Absolute decoupling
2004-2005	-0,144	0,028	-5,108	Strong dec.	0,168	Absolute decoupling
2005-2006	0,158	0,047	3,362	Expansive neg. dec.	-0,106	Non-decoupling
2006-2007	-0,225	0,034	-6,624	Strong dec.	0,251	Absolute decoupling
2007-2008	0,019	-0,006	-3,452	Strong neg. dec.	-0,025	Non-decoupling
2008-2009	0,029	-0,052	-0,556	Strong neg. dec.	-0,085	Non-decoupling
2009-2010	0,423	0,060	7,058	Expansive neg. dec.	-0,342	Non-decoupling
2010-2011	-0,348	0,027	-13,051	Strong dec.	0,365	Absolute decoupling

2011-2012	-0,296	-0,003	103,323	Recessive dec.	0,294	0
2012-2013	0,084	0,012	6,783	Expansive neg. dec.	-0,071	Non-decoupling
2013-2014	-0,165	0,023	-7,080	Strong dec.	0,184	Absolute decoupling

Notes: Expansive neg. dec. = expansive negative decoupling; Strong. neg. dec.= strong negative decoupling; Weak neg. dec. = weak negative decoupling; Weak dec.= weak decoupling; Strong dec. = strong decoupling; Recessive dec. recessive decoupling; Expansive coup. = expansive coupling; Recessive coup. = recessive coupling. For the D_f calculation details see Appendix A.

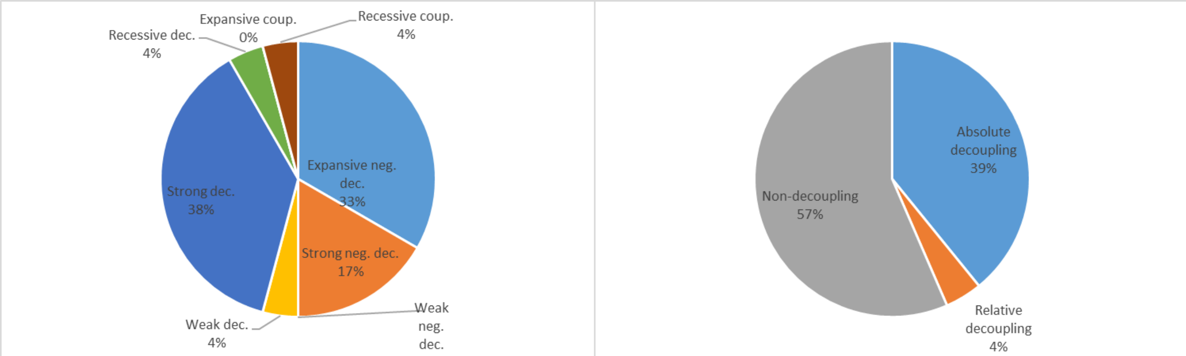

Figure 4.30. The percentage of each decoupling state by Tapio (left) method and OECD method (right). Sweden

Table 4.18. total sum of 3 decoupling states

	Strong decoupling, %	**Weak decoupling, %**	**Recessive decoupling, %**	**Total sum, %**
Sweden	38	4	4	**46**
Spain	42	4	13	**59**
Portugal	38	8	17	**63**
Ireland	67	17	4	**88**
Greece	46	4	12	**62**
Netherlands	63	8	4	**75**
Italy	58	4	21	**83**
France	50	0	4	**54**
Finland	46	17	8	**71**
Belguim	58	13	4	**75**
United Kingdom	58	8	13	**79**
Luxemburg	75	9	4	**88**
Germany	61	9	4	**74**
Denmark	32	10	11	**53**
Austria	59	4	4	**67**

The Tapio decoupling elasticity method subdivides decoupling state further into three states: strong decoupling, weak decoupling and recessive decoupling. Table 4.18 shows the sum of percentage of occurrence of those three decoupling states. Based on this table, we can roughly estimate general state of decoupling between GDP and CO_2 emission intensity for each member country of the EU-15 aggregate in the period 1990-2014. Luxemburg, Ireland and Italy showed above 80% of cases decoupling state. Thus, these three countries were close to desired planned decrease of CO_2 emissions.

4.4 Comparison of the Tapio decoupling elasticity method and OECD decoupling factor method

Firstly, the Tapio method offers eight possible decoupling states: expansive negative decoupling, strong negative decoupling, weak negative decoupling, weak decoupling, strong decoupling, recessive decoupling, expansive coupling and recessive coupling. These decoupling states carry comprehensive information about the current decoupling state between two indicators. For example, expansive negative decoupling state implies that the rate of change of both of environmental pressure ($\Delta CO_2/CO_2$) and economic growth ($\Delta GDP/GDP$) are higher than zero, which means both of indicators are increasing. But the ratio of $\Delta CO_2/CO_2$ to $\Delta GDP/GDP$ is higher than 1.2, which means numerator ($\Delta CO_2/CO_2$) is larger than denominator($\Delta GDP/GDP$).

As for OECD method, only four decoupling states are possible: absolute decoupling, relative decoupling, non-decoupling and perfect decoupling. The perfect decoupling state almost impossible to reach. Absolute decoupling and relative decoupling state in OECD method are equivalent to the strong decoupling and weak decoupling state in the Tapio method, respectively (e.g. Table 4.2). Expansive negative decoupling and strong negative in OECD method are equivalent to non-decoupling state in the Tapio method (e.g. Table 4.2). The recessive decoupling state of the Tapio method does not have analogue in OECD method. Thus, when there was recessive decoupling between two indicators OECD method shows zero, which means it couldn't assign decoupling state (e.g. Table 4.17). Expansive coupling state in the Tapio method has two possible analogues in OECD method depending on the sign of decoupling factor value. If decoupling factor is positive, it corresponds to relative decoupling state in OECD method, otherwise, it is non-decoupling in OECD (e.g. Table 4.14). The same situation with recessive decoupling state of the Tapio method. Depending on the sign of decoupling factor it could be non-decoupling state if a sign negative (e.g. Table 4.9), otherwise, OECD method cannot assign decoupling state (e.g. Table 4.11) for recessive coupling state of the Tapio method.

In general, availability of different decoupling states in the Tapio method can describe more detailed picture of not only decoupling relationship, but also the situations happening during the analyzing period. For example, in Table 4.4 we can see how decoupling state changes during the financial crises period and post-crises period. In Table 4.2 we can see that GDP strongly decoupled from CO_2 emissions from public electricity and heat production during pre-crisis period (2007-2008). During crisis period 2008-2009, the decoupling state deteriorated to recessive decoupling state, which means financial significantly caused recession of the economic sector. In subsequent year from 2009 to 2011 the economy begun to recover along with an increase in emissions from public electricity and heat production sector which is due to the rapid increase in the activity of industries. Then, from 2011 to 2014 decoupling states were improved to strong decoupling state. OECD method failed to assign the decoupling state for the period of financial crisis in a reasonable way. As for post crisis-period, it showed just non-decoupling state (Table 4.2). In case of OECD method, non-decoupling state could not be further classified, which was the main reason for why we encountered undefined states fairly often during the decoupling analysis. Therefore, it is easier to handle the Tapio method than OECD method. This finding was consistent with Liu et al [56] that the Tapio model easy to understand and use. Many researchers highlighted predominance of the Tapio method over OECD method [32], [58].

Nevertheless, there was a case where Tapio decoupling index was not able to assign decoupling state (Table 4.4, in 2001-2002). The reason might be that the most developed countries may show nearly stable trends of GDP and CO_2 emissions. For example, the net change of GDP in Germany between 2001 and 2002 was zero (Table 4.4). Consequently, as GDP is in denominator in the formula of the Tapio decoupling elasticity, we could not calculate the decoupling elasticity because of division by zero is undefined. Therefore, the Tapio method may not be suitable for short-term analysis where net change of any indicator is zero.

Chapter 5- Conclusion

To conclude, decoupling elasticities (Tapio method) and factors (OECD) were calculated to evaluate the decoupling relationship between economic growth in terms of GDP and environmental pressure in terms of CO_2 emission intensity for EU-15 countries between 1990 and 2014. Based on calculation results, the decoupling states were assigned for each period based on describing two methods. Regarding the decoupling states, they highly diverged during the entire study period, which means that no clear trend of decoupling states was observed. Therefore, we were not able to give a specific decoupling state for a relationship between GDP and CO_2 emission intensity for the EU-15 as a group for the entire study period. Luxemburg was only country which showed decoupling (strong, weak and recessive decoupling) state for the relationship between GDP and CO_2 emissions from public energy and heat production sector for almost the entire period from 1990 to 2014. In contrast, Luxemburg did not meet its target under Kyoto Protocol agreement. This implies that sectoral performance of country in CO_2 reduction does not depend on total performance of country. Ireland and Italy were other countries which showed decoupling quite often with more than 80% of the entire study period. It is difficult to conclude that the EU-15 have reached their aggregate target by fully decoupling the economic growth from environmental pressure. Nevertheless, strong decoupling state and weak decoupling state were most prevalent decoupling states between GDP and CO_2 emission intensity for EU-15 countries. Generally, decreasing the use of solid and liquid fuels, shifting to more efficient technologies and growing shares of renewable energy sources in public electricity and heat production accounted for decoupling of GDP from CO_2 emission intensity in EU-15 member countries. We observed that the global financial crisis had serious effect on economy of countries and their GHG emissions. This resulted in deterioration of decoupling state to negative decoupling almost in all 15 countries of EU during 2008-2009.

The Kyoto Protocol agreement was the main tool in the reduction of GHG emissions in EU-15. Furthermore, it served as a basis for consecutive national strategies and policies to cut GHG emissions within 15 countries of EU-15. The EU-15 targeted to reduce their GHG emissions by 8 % below 1990 levels during the first commitment period 2008–2012 of Kyoto Protocol. EU-28+Iceland as an aggregate reduced GHG emission by 24% first commitment period of Kyoto Protocol. Almost all countries complied with the emission levels set out by the Kyoto Protocol first commitment period. The countries that emitted higher levels of GHGs than committed under the first commitment period 2008–2012 Kyoto Protocol respect to 1990 levels were Austria, Denmark, Luxembourg and Spain. The possible reason for this might be that the large amount of emissions of GHGs from transport sector, which did not allow or needed additional efforts for those three countries to reach their reduction targets under Kyoto Protocol. The rest countries showed overachievements in GHGs reductions at the end of the first Kyoto Protocol commitment period. At a broader level, those overachievements contributed to offset the countries which did not surpassed the reduction commitments.

Generally, it has been found that CO_2 emissions from public energy and heat production sectors have been significantly decreasing for the period from 1990 to 2014. The opposite situation occurred with GDP. Thus, we observed decoupling of GDP from CO_2 emission intensity to some extent. The main factors contributing to GHGs emissions reduction are climate mitigation, renewable energy or energy efficiency. The countries with higher percentage of renewable energy (Sweden, Finland and Denmark) had more potential to reduce CO_2 emissions from public electricity and heat production sectors. However, promoting renewable energy is not always bring to positive outputs. The reason is that extensive use of renewables can constrict economic growth of a country because of high cost production and operation. Therefore, for countries with a high share of renewable energy such as Sweden, we noticed the opposite effect in decoupling states than expected. Other factor that may have minor effects on CO_2 emissions level was a weather condition in EU-15. In addition, since the population had not been changed noticeably during the entire study period its influence on decoupling was considered as negligible for all countries except France and Spain. All these factors coming together resulted in nonuniform distribution of decoupling states.

Through the comparisons, results from the Tapio decoupling elasticity method were more persuasive than the OECD methods' results. Its higher number of possible decoupling states provides more detailed picture of decoupling processes in the studying period. As for OECD method, its evaluation of decoupling states seems less accurate compared to the Tapio method. Also, OECD method could not assign decoupling states in most cases.

In the future, it will be beneficial if decoupling analysis is performed along with decomposition of CO_2 emissions to determine the main drivers of CO_2 emissions in EU-15 which have effects on decoupling trends.

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Appendix

Appendix A

COUNTRY: Austria	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	24,88	26,48	25,45	25,74	25,67	26,81	28,5	28,29	28,77	28,71	28,61	30,23	30,5	32,27	32,75	33,62	33,73	33,34	33,55	31,69	33,88	32,91	32,77	33,23	32,16
GDP (billion 2010 USD using PPPs)	232,76	240,77	245,81	247,11	253,04	259,79	266,02	271,89	281,57	291,68	301,5	305,57	310,63	312,98	321,45	328,33	339,34	351,62	357,07	343,5	350,12	359,96	362,68	363,85	365,13
CO2 kWh	244,55	252,06	196,9	183,7	201,51	211,27	232,99	228,64	203,76	189,91	174,84	196,01	197,03	244,69	232,93	225,27	224,1	210,91	192,72	168,3	200,27	217,79	168,14	165,32	151,44
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0643	-0,0389	0,0114	-0,0027	0,0444	0,0630	-0,0074	0,0170	-0,0021	-0,0035	0,0566	0,0089	0,0580	0,0149	0,0266	0,0033	-0,0116	0,0063	-0,0554	0,0691	-0,0286	-0,0043	0,0140	-0,0322	
ΔGDP/GDP -2	0,0344	0,0209	0,0053	0,0240	0,0267	0,0240	0,0221	0,0356	0,0359	0,0337	0,0135	0,0166	0,0076	0,0271	0,0214	0,0335	0,0362	0,0155	-0,0380	0,0193	0,0281	0,0076	0,0032	0,0035	
Tapio decoupling index-3	1,8687	-1,8582	2,1546	-0,1133	1,6648	2,6286	-0,3339	0,4766	-0,0581	-0,1035	4,1946	0,5394	7,6709	0,5496	1,2412	0,0976	-0,3195	0,4064	1,4588	3,5858	-1,0187	-0,5630	4,3513	-9,1531	
ΔCO2/CO2	0,030709	-0,21884	-0,06704	0,096952	0,048434	0,102807	-0,01867	-0,10882	-0,06797	-0,07935	0,121082	0,005204	0,241892	-0,04806	-0,03289	-0,00519	-0,05886	-0,08625	-0,12671	0,189958	0,087482	-0,22797	-0,01677	-0,08396	
Tapio decoupling index	0,892376	-10,4542	-12,6761	4,040084	1,815677	4,287029	-0,84611	-3,05644	-1,89307	-2,35701	8,969598	0,314255	31,97402	-1,77592	-1,53649	-0,15488	-1,62645	-5,56433	3,334206	9,856603	3,11272	-30,1694	-5,19895	-23,8658	
OECD decoupling index TPES vs GDP	1,0289	0,9414	1,0061	0,9739	1,0173	1,0381	0,9712	0,9820	0,9633	0,9641	1,0425	0,9925	1,0501	0,9881	1,0051	0,9707	0,9539	0,9909	0,9819	1,0489	0,9448	0,9883	1,0108	0,9644	
OECD decoupling factor TPES vs GDP	-0,0289	0,0586	-0,0061	0,0261	-0,0173	-0,0381	0,0288	0,0180	0,0367	0,0359	-0,0425	0,0075	-0,0501	0,0119	-0,0051	0,0293	0,0461	0,0091	0,0181	-0,0489	0,0552	0,0117	-0,0108	0,0356	
OECD decoupling index CO2 vs GDP	0,99642	0,765147	0,928053	1,071244	1,021193	1,07698	0,960143	0,860545	0,899723	0,890661	1,10615	0,98883	1,232567	0,926856	0,946849	0,962529	0,908274	0,899808	0,907787	1,167459	1,057754	0,766238	0,980067	0,91283	
OECD decoupling factor CO2 vs GDP	0,00358	0,234853	0,071947	-0,07124	-0,02119	-0,07698	0,039857	0,139455	0,100277	0,109339	-0,10615	0,01117	-0,23257	0,073144	0,053151	0,037471	0,091726	0,100192	0,092213	-0,16746	-0,05775	0,233762	0,019933	0,08717	
	Expansive co	Strong dec.	nsive neg.	nsive neg.	Strong dec.	nsive neg.	Strong dec.	Strong dec.	pansive co	Strong dec.	nsive neg.	nsive neg.	nsive neg.	Strong dec.	Strong dec.	nsive neg.	Strong dec.	Strong dec.	ong neg. d	nsive neg.	Strong dec.	Strong dec.	nsive neg.	Strong dec.	1960

Figure A.1 The raw data for Austria and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Austria	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	47,94	50,08	50,63	49,44	52,46	53,4	56,23	56,24	57,17	57,4	58,12	57,96	55,7	58	58,29	58,22	57,7	56,71	58,42	56,1	60,36	56,21	53,82	55,77	52,77
GDP (billion 2010 USD using PPPs)	292,19	297,55	302,1	299,19	308,85	316,21	321,25	333,17	339,75	351,86	364,65	367,61	374,15	377,05	390,75	398,94	408,91	422,8	425,96	416,23	427,44	435,12	435,78	435,85	441,73
CO2 kWh	357,56	354,91	344,91	359,7	380,12	372,88	352,26	321,58	328,69	290,99	298,82	288,15	282,74	283,81	276,95	281,35	268,05	258,27	254,91	214,67	222,15	197,31	216,55	197,97	206,84
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0446	0,0110	-0,0235	0,0611	0,0179	0,0530	0,0002	0,0165	0,0040	0,0125	-0,0028	-0,0390	0,0413	0,0050	-0,0012	-0,0089	-0,0172	0,0302	-0,0397	0,0759	-0,0688	-0,0425	0,0362	-0,0538	
ΔGDP/GDP -2	0,0183	0,0153	-0,0096	0,0323	0,0238	0,0159	0,0371	0,0197	0,0356	0,0363	0,0081	0,0178	0,0078	0,0363	0,0210	0,0250	0,0340	0,0075	-0,0228	0,0269	0,0180	0,0015	0,0002	0,0135	
Tapio decoupling index-3	2,4334	0,7182	2,4400	1,8919	0,7519	3,3250	0,0048	0,8373	0,1129	0,3451	-0,3391	-2,1917	5,3275	0,1376	-0,0573	-0,3574	-0,5051	4,0345	1,7385	2,8195	-3,8266	-28,0317	225,5590	-3,9873	
ΔCO2/CO2	-0,00741	-0,02818	0,042881	0,05677	-0,01905	-0,0553	-0,08709	0,02211	-0,1147	0,026908	-0,03571	-0,01877	0,003784	-0,02417	0,015887	-0,04727	-0,03649	-0,01301	-0,15786	0,034844	-0,11182	0,097512	-0,0858	0,044805	
Tapio decoupling index	-0,40402	-1,8426	-4,45164	1,758269	-0,79926	-3,46948	-2,34725	1,119491	-3,21788	0,740258	-4,39885	-1,05533	0,488252	-0,66523	0,757995	-1,89155	-1,07411	-1,74066	6,91078	1,293773	-6,22328	64,28669	-534,142	3,321115	
OECD decoupling index TPES vs GDP	1,0258	0,9958	0,9860	1,0279	0,9942	1,0365	0,9644	0,9968	0,9695	0,9770	0,9892	0,9442	1,0333	0,9698	0,9783	0,9669	0,9506	1,0225	0,9827	1,0477	0,9148	0,9560	1,0361	0,9336	
OECD decoupling factor TPES vs GDP	-0,0258	0,0042	0,0140	-0,0279	0,0058	-0,0365	0,0356	0,0032	0,0305	0,0230	0,0108	0,0558	-0,0333	0,0302	0,0217	0,0331	0,0494	-0,0225	0,0173	-0,0477	0,0852	0,0440	-0,0361	0,0664	
OECD decoupling index CO2 vs GDP	0,974708	0,957187	1,053024	1,023717	0,958121	0,92988	0,880244	1,002314	0,854833	0,99089	0,956528	0,964074	0,996064	0,941616	0,995032	0,929499	0,931861	0,979668	0,861827	1,007704	0,872507	1,095849	0,914053	1,030897	
OECD decoupling factor CO2 vs GDP	0,025292	0,042813	-0,05302	-0,02372	0,041879	0,07012	0,119756	-0,00231	0,145167	0,00911	0,043472	0,035926	0,003936	0,058384	0,004968	0,070501	0,068139	0,020332	0,138173	-0,0077	0,127493	-0,09585	0,085947	-0,0309	

Figure A.2 The raw data for Belgium and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Denmark	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	17,36	19,25	18,42	18,92	19,58	19,4	21,95	20,34	20,01	19,17	18,63	19,21	19	20,1	19,44	18,9	20,27	19,78	19,24	18,39	19,48	17,99	17,29	17,55	16,21
GDP (billion 2010 USD using PPPs)	166,23	168,4	171,72	171,57	181,05	186,6	192,01	198,27	202,67	208,64	216,46	218,24	219,26	220,11	225,92	231,43	240,22	242,2	240,46	228,22	231,93	234,6	233,07	231,93	234,46
CO2 kWh	681,6	701,33	672,26	637,93	639,1	595,59	622,92	565,77	523,49	482,93	451,54	446,53	441,79	481,18	408,83	373,8	465,69	431,1	403,49	403,93	362,42	318,2	259,07	300,03	254,54
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,1089	-0,0431	0,0271	0,0349	-0,0092	0,1314	-0,0733	-0,0162	-0,0420	-0,0282	0,0311	-0,0109	0,0579	-0,0328	-0,0278	0,0725	-0,0242	-0,0273	-0,0442	0,0593	-0,0765	-0,0389	0,0150	-0,0764	
ΔGDP/GDP -2	0,0131	0,0197	-0,0009	0,0553	0,0307	0,0290	0,0326	0,0222	0,0295	0,0375	0,0082	0,0047	0,0039	0,0264	0,0244	0,0380	0,0082	-0,0072	-0,0509	0,0163	0,0115	-0,0065	-0,0049	0,0109	
Tapio decoupling index-3	8,3399	-2,1870	-31,0749	0,6313	-0,2999	4,5337	-2,2498	-0,7311	-1,4251	-0,7516	3,7859	-2,3390	14,9341	-1,2440	-1,1389	1,9085	-2,9328	3,8001	0,8679	3,6461	-6,6442	5,9663	-3,0744	-6,9995	
ΔCO2/CO2	0,028947	-0,04145	-0,05107	0,001834	-0,06808	0,045887	-0,09175	-0,07473	-0,07748	-0,065	-0,0111	-0,01062	0,08916	-0,15036	-0,08568	0,245827	-0,07428	-0,06405	0,00109	-0,10277	-0,12201	-0,18583	0,158104	-0,15162	
Tapio decoupling index	2,217416	-2,10245	58,46099	0,033193	-2,22088	1,582729	-2,81406	-3,36744	-2,6303	-1,7342	-1,34927	-2,27123	22,99909	-5,69632	-3,51318	6,472316	-9,01151	8,914834	-0,02142	-6,32159	-10,5987	28,4934	-32,3239	-13,8991	
OECD decoupling index TPES vs GDP	1,0946	0,9384	1,0280	0,9807	0,9613	1,0996	0,8974	0,9624	0,9306	0,9367	1,0227	0,9845	1,0538	0,9423	0,9491	1,0332	0,9678	0,9797	1,0071	1,0423	0,9130	0,9674	1,0200	0,9137	
OECD decoupling factor TPES vs GDP	-0,0946	0,0616	-0,0280	0,0193	0,0387	-0,0996	0,1026	0,0376	0,0694	0,0633	-0,0227	0,0155	-0,0538	0,0577	0,0509	-0,0332	0,0322	0,0203	-0,0071	-0,0423	0,0870	0,0326	-0,0200	0,0863	
OECD decoupling index CO2 vs GDP	1,015688	0,940018	0,949763	0,949377	0,904202	1,016419	0,879578	0,905182	0,896123	0,901222	0,980839	0,984782	1,084954	0,82779	0,892548	1,20024	0,918155	0,942727	1,054781	0,882882	0,867994	0,819518	1,163796	0,839227	
OECD decoupling factor CO2 vs GDP	-0,01569	0,059982	0,050237	0,050623	0,095798	-0,01642	0,120422	0,094818	0,103877	0,098778	0,019161	0,015218	-0,08495	0,17221	0,107452	-0,20024	0,081845	0,057273	-0,05478	0,117118	0,132006	0,180482	-0,1638	0,160773	

Figure A.3 The raw data for Denmark and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Finland	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	28,38	28,79	27,13	28,46	30,39	28,92	31,11	32,26	32,57	32,46	32,41	33,26	34,99	36,89	37,3	34,42	37,45	36,89	35,44	33,47	36,63	35,23	33,98	33,28	33,95
GDP (billion 2010 USD using PPPs)	138,52	130,33	126	125,07	130	135,47	140,43	149,2	157,3	164,29	173,55	178,03	181,02	184,63	191,88	197,22	205,21	215,85	217,41	199,43	205,4	210,68	207,67	205,35	204,51
CO2 kWh	357,56	354,91	344,91	359,7	380,12	372,88	352,26	321,58	328,69	290,99	298,82	288,15	282,74	283,81	276,95	281,35	268,05	258,27	254,91	214,67	222,15	197,31	216,55	197,97	206,84
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0144	-0,0577	0,0490	0,0678	-0,0484	0,0757	0,0370	0,0096	-0,0034	-0,0015	0,0262	0,0520	0,0543	0,0111	-0,0772	0,0880	-0,0150	-0,0393	-0,0556	0,0944	-0,0382	-0,0355	-0,0206	0,0201	
ΔGDP/GDP -2	-0,0591	-0,0332	-0,0074	0,0394	0,0421	0,0366	0,0625	0,0543	0,0444	0,0564	0,0258	0,0168	0,0199	0,0393	0,0278	0,0405	0,0518	0,0072	-0,0827	0,0299	0,0257	-0,0143	-0,0112	-0,0041	
Tapio decoupling index-3	-0,2443	1,7355	-6,6419	1,7204	-1,1496	2,0683	0,5919	0,1770	-0,0760	-0,0273	1,0160	3,0970	2,7229	0,2830	-2,7744	2,1729	-0,2884	-5,4386	0,6721	3,1539	-1,4868	2,4834	1,8440	-4,9216	
ΔCO2/CO2	-0,00741	-0,02818	0,042881	0,05677	-0,01905	-0,0553	-0,08709	0,02211	-0,1147	0,026908	-0,03571	-0,01877	0,003784	-0,02417	0,015887	-0,04727	-0,03649	-0,01301	-0,15786	0,034844	-0,11182	0,097512	-0,0858	0,044805	
Tapio decoupling index	0,12535	0,848083	-5,80965	1,440196	-0,45266	-1,51036	-1,39461	0,407253	-2,58111	0,477402	-1,38325	-1,11789	0,189765	-0,61555	0,570873	-1,16683	-0,70369	-1,80008	1,908802	1,163982	-4,34983	-6,82516	7,680214	-10,9532	
OECD decoupling index TPES vs GDP	1,0782	0,9747	1,0568	1,0273	0,9132	1,0377	0,9760	0,9576	0,9542	0,9452	1,0004	1,0346	1,0337	0,9729	0,8978	1,0457	0,9365	0,9538	1,0296	1,0626	0,9377	0,9785	0,9905	1,0243	
OECD decoupling factor TPES vs GDP	-0,0782	0,0253	-0,0568	-0,0273	0,0868	-0,0377	0,0240	0,0424	0,0458	0,0548	-0,0004	-0,0346	-0,0337	0,0271	0,1022	-0,0457	0,0635	0,0462	-0,0296	-0,0626	0,0623	0,0215	0,0095	-0,0243	
OECD decoupling index CO2 vs GDP	1,054963	1,005221	1,050635	1,016694	0,941345	0,911334	0,859245	0,969477	0,847636	0,972116	0,940027	0,965018	0,984158	0,938958	0,988381	0,915633	0,916019	0,979908	0,918065	1,004766	0,865924	1,113419	0,924528	1,049096	
OECD decoupling factor CO2 vs GDP	-0,05496	-0,00522	-0,05064	-0,01669	0,058655	0,088666	0,140755	0,030523	0,152364	0,027884	0,059973	0,034982	0,015842	0,061042	0,011619	0,084367	0,083981	0,020092	0,081935	-0,00477	0,134076	-0,11342	0,075472	-0,0491	

Figure A.4 The raw data for Finland and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: France																									
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total primary energy supply (TPES) (Mtoe)	224,01	236,76	232,7	236,54	227,59	237,06	250,48	242,81	249,87	249,46	251,9	260,52	261,16	265,84	269,74	270,86	266,5	263,46	264,62	253,23	261,21	251,38	251,91	253,01	242,64
GDP (billion 2010 USD using PPPs)	1680,64	1698,1	1725,27	1714,7	1754,91	1791,51	1816,37	1858,83	1924,93	1990,52	2067,65	2108,06	2131,64	2149,11	2208,99	2244,51	2297,81	2352,08	2356,67	2287,35	2332,31	2380,81	2385,16	2400,81	2405,13
CO2 kWh	108,16	122	96,25	68,65	65,88	74,31	77,95	71,75	99,71	85,8	77,17	62,14	67,53	70,8	68,41	80,72	74,78	78,11	70,58	76,61	79,84	61,88	65,72	63,85	40,9
	1990-1991	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	
ΔTPES/TPES -1	0,0569	-0,0171	0,0165	-0,0378	0,0416	0,0566	-0,0306	0,0291	-0,0016	0,0098	0,0342	0,0025	0,0179	0,0147	0,0042	-0,0161	-0,0114	0,0044	-0,0430	0,0315	-0,0376	0,0021	0,0044	-0,0410	
ΔGDP/GDP -2	0,0104	0,0160	-0,0061	0,0235	0,0209	0,0139	0,0234	0,0356	0,0341	0,0387	0,0195	0,0112	0,0082	0,0279	0,0161	0,0237	0,0236	0,0020	-0,0294	0,0197	0,0208	0,0018	0,0066	0,0018	
Tapio decoupling index-3	5,4786	-1,0717	-2,6935	-1,6135	1,9951	4,0796	-1,3099	0,8177	-0,0482	0,2524	1,7509	0,2196	2,1866	0,5265	0,2582	-0,6779	-0,4830	2,2562	1,4633	1,6032	-1,8097	1,1539	0,6655	-22,7780	
ΔCO2/CO2	0,127959	-0,21107	-0,28675	-0,04035	0,12796	0,048984	-0,07954	0,389686	-0,1395	-0,10058	-0,19476	0,08674	0,048423	-0,03376	0,179944	-0,07359	0,044531	-0,0964	0,085435	0,042162	-0,22495	0,062056	-0,02845	-0,35944	
Tapio decoupling index	12,31686	-13,1914	46,8048	-1,72065	6,135469	3,52998	-3,40251	10,95856	-4,09417	-2,59577	-9,96549	7,754551	5,908428	-1,21155	11,19075	-3,09884	1,885442	-49,4001	-2,90453	2,144981	-10,8176	33,96381	-4,33658	-199,754	
OECD decoupling index TPES vs GDP	1,0460	0,9674	1,0228	0,9401	1,0203	1,0421	0,9472	0,9937	0,9655	0,9721	1,0144	0,9914	1,0096	0,9872	0,9883	0,9611	0,9658	1,0024	0,9860	1,0116	0,9428	1,0003	0,9978	0,9573	
OECD decoupling factor TPES vs GDP	-0,0460	0,0326	-0,0228	0,0599	-0,0203	-0,0421	0,0528	0,0063	0,0345	0,0279	-0,0144	0,0086	-0,0096	0,0128	0,0117	0,0389	0,0342	-0,0024	0,0140	-0,0116	0,0572	-0,0003	0,0022	0,0427	
OECD decoupling index CO2 vs GDP	1,116361	0,77651	0,717643	0,937662	1,104916	1,034627	0,899436	1,341966	0,832141	0,865866	0,789799	1,074718	1,0399	0,940051	1,161272	0,904923	1,02043	0,901838	1,11833	1,022072	0,759261	1,060119	0,965213	0,639413	
OECD decoupling factor CO2 vs GDP	-0,11636	0,22349	0,282357	0,062338	-0,10492	-0,03463	0,100564	-0,34197	0,167859	0,134134	0,210201	-0,07472	-0,0399	0,059949	-0,16127	0,095077	-0,02043	0,098162	-0,11833	-0,02207	0,240739	-0,06012	0,034787	0,360587	

Figure A.5 The raw data for France and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

Germany																									
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total primary energy supply (TPES) (Mtoe)	351,2	344,29	337,9	334,58	332,98	336,49	347,86	344,82	342,74	334,96	336,58	346,68	338,9	337,11	339,5	337,01	346,36	327,9	331,46	310,45	326,87	310,65	311,81	317,71	306,75
GDP (billion 2010 USD using PPPs)	2435,03	2559,42	2608,66	2583,71	2647,2	2693,2	2715,23	2765,44	2820,19	2876,23	2961,42	3011,63	3011,63	2990,25	3025,24	3046,62	3159,35	3262,36	3297,67	3112,38	3239,36	3357,92	3371,53	3381,57	3435,66
CO2 kWh	624,24	640,17	621,22	619,61	616,15	600,51	598,06	577,41	570,17	546,92	542,06	561,22	561,85	525,64	511,86	506,31	500,63	522,42	488,73	480,47	474,9	482,94	485,63	488,67	473,58
	1990-1991	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	
ΔTPES/TPES -1	-0,0197	-0,0186	-0,0098	-0,0048	0,0105	0,0338	-0,0087	-0,0060	-0,0227	0,0048	0,0300	-0,0224	-0,0053	0,0071	-0,0073	0,0277	-0,0533	0,0109	-0,0634	0,0529	-0,0496	0,0037	0,0189	-0,0345	
ΔGDP/GDP -2	0,0511	0,0192	-0,0096	0,0246	0,0174	0,0082	0,0185	0,0198	0,0199	0,0296	0,0170	0,0000	-0,0071	0,0117	0,0071	0,0370	0,0326	0,0108	-0,0562	0,0408	0,0366	0,0041	0,0030	0,0160	
Tapio decoupling index-3	-0,3852	-0,9647	1,0273	-0,1946	0,6066	4,1309	-0,4726	-0,3047	-1,1423	0,1633	1,7699	#DIV/0!	0,7440	0,6059	-1,0378	0,7498	-1,6346	1,0031	1,1281	1,2964	-1,3558	0,9213	6,3541	-2,1567	
ΔCO2/CO2	0,025519	-0,0296	-0,00259	-0,00558	-0,02538	-0,00408	-0,03453	-0,01254	-0,04078	-0,00889	0,035347	0,001123	-0,06445	-0,02622	-0,01084	-0,01122	0,043525	-0,06449	-0,0169	-0,01159	0,01693	0,00557	0,00626	-0,03088	
Tapio decoupling index	0,499555	-1,53864	0,270974	-0,22725	-1,46076	-0,49877	-1,8672	-0,63334	-2,0521	-0,30002	2,084769	#DIV/0!	9,078248	-2,24039	-1,53424	-0,30319	1,334931	-5,9582	0,300792	-0,28415	0,462567	1,374268	2,102139	-1,93052	
OECD decoupling index TPES vs GDP	0,9327	0,9629	0,9997	0,9713	0,9933	1,0254	0,9733	0,9747	0,9583	0,9759	1,0128	0,9776	1,0018	0,9954	0,9857	0,9911	0,9168	1,0000	0,9924	1,0116	0,9168	0,9997	1,0159	0,9503	
OECD decoupling factor TPES vs GDP	0,0673	0,0371	0,0003	0,0287	0,0067	-0,0254	0,0267	0,0253	0,0417	0,0241	-0,0128	0,0224	-0,0018	0,0046	0,0143	0,0089	0,0832	0,0000	0,0076	-0,0116	0,0832	0,0003	-0,0159	0,0497	
OECD decoupling index CO2 vs GDP	0,975678	0,952082	1,00704	0,970566	0,95797	0,98784	0,947942	0,968291	0,940533	0,962603	1,018085	1,001123	0,942241	0,962522	0,982216	0,9535	1,010576	0,925495	1,041626	0,949663	0,981025	1,001511	1,003272	0,953863	
OECD decoupling factor CO2 vs GDP	0,024322	0,047918	-0,00704	0,029434	0,04203	0,01216	0,052058	0,031709	0,059467	0,037397	-0,01809	-0,00112	0,057759	0,037478	0,017784	0,0465	-0,01058	0,074505	-0,04163	0,050337	0,018975	-0,00151	-0,00327	0,046137	

Figure A.6 The raw data for Germany and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

Greece																									
Greece	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total primary energy supply (TPES) (Mtoe)	21,44	21,62	22,15	21,87	22,48	22,68	23,4	24,33	25,62	25,72	27,09	28	28,32	29,14	29,7	30,25	30,22	30,21	30,41	29,43	27,6	26,74	26,54	23,33	23,13
GDP (billion 2010 USD using PPPs)	212,67	219,26	220,79	217,26	221,61	226,26	232,74	243,17	252,64	260,41	271,36	281,78	292,84	309,81	325,49	327,44	345,95	357,27	356,07	340,76	322,09	292,68	271,31	262,63	264,35
CO2 kWh	1 007,25	957,29	989,64	966,45	944,20	963,90	858,21	838,11	814,89	796,16	835,59	849,22	831,47	795,02	793,74	793,10	743,17	764,72	759,01	736,92	730,01	718,11	695,23	649,42	670,25
	1990-1991	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	
ΔTPES/TPES -1	0,0084	0,0245	-0,0126	0,0279	0,0089	0,0317	0,0397	0,0530	0,0039	0,0533	0,0336	0,0114	0,0290	0,0192	0,0185	-0,0010	-0,0003	0,0066	-0,0322	-0,0622	-0,0312	-0,0075	-0,1209	-0,0086	
ΔGDP/GDP -2	0,0310	0,0070	-0,0160	0,0200	0,0210	0,0286	0,0448	0,0389	0,0308	0,0420	0,0384	0,0393	0,0579	0,0506	0,0060	0,0565	0,0327	-0,0034	-0,0430	-0,0548	-0,0913	-0,0730	-0,0320	0,0065	
Tapio decoupling index-3	0,2709	3,5131	0,7907	1,3931	0,4240	1,1085	0,8869	1,3615	0,1269	1,2668	0,8748	0,2912	0,4997	0,3797	3,0911	-0,0175	-0,0101	-1,9710	0,7495	1,1349	0,3412	0,1024	3,7805	-1,3090	
ΔCO2/CO2	-0,0496	0,033793	-0,02343	-0,02302	0,020864	-0,10965	-0,02342	-0,02771	-0,02298	0,049525	0,016312	-0,0209	-0,04384	-0,00161	-0,00081	-0,06296	0,028997	-0,00747	-0,0291	-0,00938	-0,0163	-0,03186	-0,06589	0,032075	
Tapio decoupling index	-1,60069	4,842825	1,465643	-1,14985	0,994349	-3,82855	-0,52262	-0,71141	-0,74734	1,177796	0,424796	-0,53252	-0,75648	-0,03181	-0,13459	-1,11368	0,886188	2,223049	0,676875	0,171144	0,178526	0,436369	2,059576	4,897557	
OECD decoupling index TPES vs GDP	0,9781	1,0174	1,0034	1,0077	0,9882	1,0030	0,9951	1,0135	0,9739	1,0108	0,9954	0,9732	0,9726	0,9701	1,0125	0,9456	0,9680	1,0100	1,0113	0,9922	1,0662	1,0707	0,9081	0,9850	
OECD decoupling factor TPES vs GDP	0,0219	-0,0174	-0,0034	-0,0077	0,0118	-0,0030	0,0049	-0,0135	0,0261	-0,0108	0,0046	0,0268	0,0274	0,0299	-0,0125	0,0544	0,0320	-0,0100	-0,0113	0,0078	-0,0662	-0,0707	0,0919	0,0150	
OECD decoupling index CO2 vs GDP	0,921835	1,026629	0,992434	0,9578	0,999884	0,865562	0,934692	0,935849	0,947864	1,007174	0,978729	0,94212	0,903788	0,950294	0,993243	0,886908	0,996394	0,995878	1,014518	1,048045	1,082546	1,044395	0,964981	1,02536	
OECD decoupling factor CO2 vs GDP	0,078165	-0,02663	0,007566	0,0422	0,000116	0,134438	0,065308	0,064151	0,052136	-0,00717	0,021271	0,05788	0,096212	0,049706	0,006757	0,113092	0,003606	0,004122	-0,01452	-0,04804	-0,08255	-0,04439	0,035019	-0,02536	

Figure A.7 The raw data for Greece and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Ireland																									
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total primary energy supply (TPES) (Mtoe)	9,91	9,99	9,88	10,06	10,56	10,65	11,36	11,96	12,69	13,31	13,8	14,36	14,4	14,05	14,48	14,57	14,63	15,03	14,79	14,28	14,37	13,12	13,12	13,02	12,77
GDP (billion 2010 USD using PPPs)	72,37	73,76	76,23	78,28	82,79	90,76	99,18	110,26	120,09	133,01	146,62	155,17	164,39	170,7	178,22	189,51	201,47	212,63	208,04	196,31	197,09	202,19	202,5	205,4	216,08
CO2 kWh	750,11	752,86	758,63	742,26	739,11	735,68	716,37	712,96	709,70	703,08	649,89	676,34	642,53	605,68	581,37	590,18	541,61	515,04	474,88	454,88	460,42	428,35	460,91	435,12	425,20
	1990-1991	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	
ΔTPES/TPES -1	0,0081	-0,0110	0,0182	0,0497	0,0085	0,0667	0,0528	0,0610	0,0489	0,0368	0,0406	0,0028	-0,0243	0,0306	0,0062	0,0041	0,0273	-0,0160	-0,0345	0,0063	-0,0870	0,0000	-0,0076	-0,0192	
ΔGDP/GDP -2	0,0192	0,0335	0,0269	0,0576	0,0963	0,0928	0,1117	0,0892	0,1076	0,1023	0,0583	0,0594	0,0384	0,0441	0,0633	0,0631	0,0554	-0,0216	-0,0564	0,0040	0,0259	0,0015	0,0143	0,0520	
Tapio decoupling index-3	0,4203	-0,3288	0,6775	0,8627	0,0885	0,7186	0,4728	0,6846	0,4541	0,3598	0,6959	0,0469	-0,6332	0,6947	0,0981	0,0653	0,4936	0,7397	0,6116	1,5862	-3,3616	0,0000	-0,5322	-0,3693	
ΔCO2/CO2	0,003666	0,007664	-0,02158	-0,00424	-0,00464	-0,02625	-0,00476	-0,00457	-0,00933	-0,07565	0,040699	-0,04999	-0,05735	-0,04014	0,015154	-0,0823	-0,04906	-0,07797	-0,04212	0,012179	-0,06965	0,076013	-0,05595	-0,0228	
Tapio decoupling index	0,190876	0,228868	-0,8024	-0,07366	-0,04821	-0,28293	-0,04261	-0,05129	-0,0867	-0,73935	0,697932	-0,84131	-1,49414	-0,91108	0,239214	-1,30402	-0,88563	3,61214	0,746956	3,065214	-2,69178	49,57738	-3,90717	-0,43846	
OECD decoupling index TPES vs GDP	0,9891	0,9569	0,9916	0,9925	0,9200	0,9761	0,9470	0,9742	0,9470	0,9406	0,9832	0,9465	0,9396	0,9871	0,9463	0,9445	0,9734	1,0057	1,0232	1,0023	0,8900	0,9985	0,9784	0,9323	
OECD decoupling factor TPES vs GDP	0,0109	0,0431	0,0084	0,0075	0,0800	0,0239	0,0530	0,0258	0,0530	0,0594	0,0168	0,0535	0,0604	0,0129	0,0537	0,0555	0,0266	-0,0057	-0,0232	-0,0023	0,1100	0,0015	0,0216	0,0677	
OECD decoupling index CO2 vs GDP	0,984752	0,975014	0,952799	0,941512	0,907953	0,891084	0,895228	0,913947	0,894443	0,838545	0,983356	0,896728	0,907803	0,919362	0,954676	0,863225	0,901032	0,942368	1,01512	1,008173	0,906879	1,074365	0,930717	0,928902	
OECD decoupling factor CO2 vs GDP	0,015248	0,024986	0,047201	0,058488	0,092047	0,108916	0,104772	0,086053	0,105557	0,161455	0,016644	0,103272	0,092197	0,080638	0,045324	0,136775	0,098968	0,057632	-0,01512	-0,00817	0,093121	-0,07437	0,069283	0,071098	

Figure A.8 The raw data for Ireland and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Italy	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	146,56	150,16	149,23	148,44	146,57	159,13	158,99	161,25	165,77	168,32	171,52	172,1	173,3	181,6	182,86	186,35	184,65	184,06	181,63	169,6	173,72	167,95	161,31	155,37	146,77
GDP (billion 2010 USD using PPPs)	1693,31	1719,36	1733,71	1718,92	1755,9	1806,59	1829,83	1863,43	1893,56	1923,12	1994,47	2029,83	2034,92	2038,03	2070,3	2089,96	2131,89	2163,32	2140,61	2023,27	2057,88	2069,96	2011,63	1976,48	1967,7
CO2 kWh	581,47	554,77	540,14	529,42	520,75	550,75	529,10	519,40	518,45	499,77	502,37	487,18	509,12	516,59	502,31	490,85	484,47	480,40	457,17	414,78	409,85	405,73	392,48	342,80	330,90
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0246	-0,0062	-0,0053	-0,0126	0,0857	-0,0009	0,0142	0,0280	0,0154	0,0190	0,0034	0,0070	0,0479	0,0069	0,0191	-0,0091	-0,0032	-0,0132	-0,0662	0,0243	-0,0332	-0,0395	-0,0368	-0,0554	
ΔGDP/GDP -2	0,0154	0,0083	-0,0085	0,0215	0,0289	0,0129	0,0184	0,0162	0,0156	0,0371	0,0177	0,0025	0,0015	0,0158	0,0095	0,0201	0,0147	-0,0105	-0,0548	0,0171	0,0059	-0,0282	-0,0175	-0,0044	
Tapio decoupling index-3	1,5967	-0,7421	0,6206	-0,5856	2,9684	-0,0684	0,7741	1,7336	0,9854	0,5124	0,1907	2,7806	31,3377	0,4382	2,0098	-0,4547	-0,2167	1,2576	1,2083	1,4201	-5,6582	1,4030	2,1074	12,4603	
ΔCO2/CO2	-0,04592	-0,02637	-0,01985	-0,01638	0,057609	-0,03931	-0,01833	-0,00183	-0,03603	0,005202	-0,03024	0,045035	0,014672	-0,02764	-0,02281	-0,013	-0,0084	-0,04836	-0,09272	-0,01189	-0,01005	-0,03266	-0,12658	-0,03471	
Tapio decoupling index	-2,98478	-3,1597	2,326466	-0,76122	1,995581	-3,05581	-0,9984	-0,11312	-2,30805	0,140222	-1,70549	17,95929	9,600357	-1,7458	-2,4025	-0,64787	-0,56983	4,606275	1,69152	-0,69483	-1,71248	1,158907	7,24414	7,814551	
OECD decoupling index TPES vs GDP	1,0090	0,9856	1,0033	0,9666	1,0552	0,9864	0,9959	1,0117	0,9998	0,9826	0,9859	1,0045	1,0463	0,9912	1,0095	0,9714	0,9823	0,9973	0,9879	1,0071	0,9611	0,9883	0,9803	0,9489	
OECD decoupling factor TPES vs GDP	-0,0090	0,0144	-0,0033	0,0334	-0,0552	0,0136	0,0041	-0,0117	0,0002	0,0174	0,0141	-0,0045	-0,0463	0,0088	-0,0095	0,0286	0,0177	0,0027	0,0121	-0,0071	0,0389	0,0117	0,0197	0,0511	
OECD decoupling index CO2 vs GDP	0,939627	0,96557	0,988587	0,962908	1,027934	0,948489	0,963966	0,982288	0,949152	0,969242	0,95287	1,042421	1,013124	0,957201	0,967993	0,96759	0,977193	0,961741	0,959895	0,971496	0,98417	0,995392	0,888953	0,969593	
OECD decoupling factor CO2 vs GDP	0,060373	0,03443	0,011413	0,037092	-0,02793	0,051511	0,036034	0,017712	0,050848	0,030758	0,04713	-0,04242	-0,01312	0,042799	0,032007	0,03241	0,022807	0,038259	0,040105	0,028504	0,01583	0,004608	0,111047	0,030407	

Figure A.9 The raw data for Italy and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Luxembourg	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	3,39	3,62	3,63	3,68	3,56	3,15	3,19	3,11	3	3,13	3,35	3,52	3,66	3,86	4,3	4,39	4,33	4,21	4,21	3,96	4,22	4,18	4,1	3,97	3,82
GDP (billion 2010 USD using PPPs)	20,07	21,8	22,2	23,13	24,01	24,36	24,73	26,19	27,89	30,24	32,8	33,5	34,71	35,2	36,75	37,93	39,87	43,22	42,86	40,55	42,85	43,95	43,58	45,48	47,33
CO2 kWh	2 769,24	2 642,34	2 649,19	2 634,58	2 407,52	1 861,06	1 668,69	1 109,89	434,92	495,09	467,10	427,65	385,18	351,73	349,05	345,23	343,55	344,57	336,15	343,82	340,85	339,22	337,23	306,27	303,66
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0678	0,0028	0,0138	-0,0326	-0,1152	0,0127	-0,0251	-0,0354	0,0433	0,0703	0,0507	0,0398	0,0546	0,1140	0,0209	-0,0137	-0,0277	0,0000	-0,0594	0,0657	-0,0095	-0,0191	-0,0317	-0,0378	
ΔGDP/GDP -2	0,0862	0,0183	0,0419	0,0380	0,0146	0,0152	0,0590	0,0649	0,0843	0,0847	0,0213	0,0361	0,0141	0,0440	0,0321	0,0511	0,0840	-0,0083	-0,0539	0,0567	0,0257	-0,0084	0,0436	0,0407	
Tapio decoupling index-3	0,7871	0,1506	0,3288	-0,8571	-7,9006	0,8360	-0,4248	-0,5449	0,5143	0,8303	2,3778	1,1011	3,8709	2,5887	0,6519	-0,2672	-0,3298	0,0000	1,1018	1,1576	-0,3692	2,2734	-0,7273	-0,9289	
ΔCO2/CO2	-0,04582	0,002592	-0,00551	-0,08618	-0,22698	-0,10337	-0,33487	-0,60814	0,138347	-0,05654	-0,08446	-0,09931	-0,08684	-0,00762	-0,01094	-0,00487	0,002969	-0,02444	0,022817	-0,00864	-0,00478	-0,00587	-0,09181	-0,00852	
Tapio decoupling index	-0,53162	0,141286	-0,13165	-2,26528	-15,5709	-6,80538	-5,67221	-9,36895	1,641917	-0,66782	-3,95743	-2,7495	-6,15164	-0,17304	-0,34084	-0,09514	0,035336	2,933708	-0,42335	-0,1523	-0,18629	0,696833	-2,10576	-0,2095	
OECD decoupling index TPES vs GDP	0,9831	0,9847	0,9730	0,9319	0,8721	0,9975	0,9206	0,9058	0,9623	0,9868	1,0288	1,0035	1,0400	1,0670	0,9892	0,9383	0,8969	1,0084	0,9942	1,0085	0,9657	0,9892	0,9278	0,9246	
OECD decoupling factor TPES vs GDP	0,0169	0,0153	0,0270	0,0681	0,1279	0,0025	0,0794	0,0942	0,0377	0,0132	-0,0288	-0,0035	-0,0400	-0,0670	0,0108	0,0617	0,1031	-0,0084	0,0058	-0,0085	0,0343	0,0108	0,0722	0,0754	
OECD decoupling index CO2 vs GDP	0,878454	0,984528	0,954499	0,880323	0,761913	0,883219	0,628048	0,367973	1,049884	0,869829	0,896412	0,869292	0,900446	0,950525	0,958287	0,946712	0,925228	0,983758	1,081084	0,93815	0,970309	1,002574	0,870252	0,952724	
OECD decoupling factor CO2 vs GDP	0,121546	0,015472	0,045501	0,119677	0,238087	0,116781	0,371952	0,632027	-0,04988	0,130171	0,103588	0,130708	0,099554	0,049475	0,041713	0,053288	0,074772	0,016242	-0,08108	0,06185	0,029691	-0,00257	0,129748	0,047276	

Figure A.10 The raw data for Luxemburg and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Netherlands	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	65,71	69,38	68,37	68,97	69,4	73,9	77,89	75,49	76,06	74,79	75,47	77,65	78,7	81,46	82,81	81,43	80,51	80,42	79,73	78,06	83,5	77,4	77,85	77,3	72,95
GDP (billion 2010 USD using PPPs)	471,56	483,06	491,3	497,48	512,21	528,17	547,01	570,53	596,35	626,48	653,03	666,9	667,59	669,49	683,09	697,84	722,4	749,11	761,84	733,14	743,42	755,79	747,8	744,1	751,62
CO2 kWh	615,64	600,74	591,06	609,91	597,46	561,27	533,72	529,04	514,51	498,22	499,58	514,35	506,93	511,21	494,40	479,21	459,75	468,10	451,95	427,01	420,58	409,45	440,77	444,57	472,51
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0559	-0,0146	0,0088	0,0062	0,0648	0,0540	-0,0308	0,0076	-0,0167	0,0091	0,0289	0,0135	0,0351	0,0166	-0,0167	-0,0113	-0,0011	-0,0086	-0,0209	0,0697	-0,0731	0,0058	-0,0071	-0,0563	
ΔGDP/GDP -2	0,0244	0,0171	0,0126	0,0296	0,0312	0,0357	0,0430	0,0453	0,0505	0,0424	0,0212	0,0010	0,0028	0,0203	0,0216	0,0352	0,0370	0,0170	-0,0377	0,0140	0,0166	-0,0106	-0,0049	0,0101	
Tapio decoupling index-3	2,2902	-0,8534	0,6977	0,2106	2,0810	1,5136	-0,7166	0,1668	-0,3305	0,2145	1,3600	13,0695	12,3223	0,8158	-0,7718	-0,3210	-0,0302	-0,5049	0,5560	4,9701	-4,3904	-0,5500	1,4279	-5,5683	
ΔCO2/CO2	-0,0242	-0,01611	0,031892	-0,02041	-0,06057	-0,04909	-0,00877	-0,02746	-0,03166	0,00273	0,029565	-0,01443	0,008443	-0,03288	-0,03072	-0,04061	0,018162	-0,0345	-0,05518	-0,01506	-0,02646	0,076493	0,008621	0,062847	
Tapio decoupling index	-0,99243	-0,94463	2,535351	-0,68941	-1,94399	-1,37608	-0,20393	-0,60688	-0,62666	0,064411	1,391977	-13,943	2,966552	-1,61873	-1,42287	-1,15384	0,491212	-2,03026	1,464832	-1,07391	-1,59042	-7,23561	-1,74243	6,218702	
OECD decoupling index TPES vs GDP	1,0307	0,9689	0,9962	0,9773	1,0327	1,0177	0,9292	0,9639	0,9360	0,9681	1,0075	1,0125	1,0321	0,9963	0,9626	0,9551	0,9633	0,9749	1,0174	1,0549	0,9118	1,0166	0,9979	0,9343	
OECD decoupling factor TPES vs GDP	-0,0307	0,0311	0,0038	0,0227	-0,0327	-0,0177	0,0708	0,0361	0,0640	0,0319	-0,0075	-0,0125	-0,0321	0,0037	0,0374	0,0449	0,0367	0,0251	-0,0174	-0,0549	0,0882	-0,0166	0,0021	0,0657	
OECD decoupling index CO2 vs GDP	0,952567	0,967385	1,019073	0,951416	0,91104	0,918164	0,950368	0,930428	0,921767	0,961962	1,008152	0,984555	1,005581	0,947862	0,948789	0,926774	0,981859	0,949366	0,981803	0,971322	0,957603	1,087995	1,013637	1,052213	
OECD decoupling factor CO2 vs GDP	0,047433	0,032615	-0,01907	0,048584	0,08896	0,081836	0,049632	0,069572	0,078233	0,038038	-0,00815	0,015445	-0,00558	0,052138	0,051211	0,073226	0,018141	0,050634	0,018197	0,028678	0,042397	-0,08799	-0,01364	-0,05221	

Figure A.11 The raw data for Netherlands and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Portugal	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total primary energy supply (TPES) (Mtoe)	16,78	16,97	18,05	17,8	18,26	20,19	20	21,06	22,76	24,43	24,59	24,78	25,81	25,11	25,82	26,46	25,15	25,33	24,68	24,35	23,5	22,85	21,44	21,52	21,16
GDP (billion 2010 USD using PPPs)	199,01	207,7	209,97	205,68	207,66	216,55	224,13	234,05	245,26	254,8	264,45	269,59	271,66	269,12	274	276,1	280,39	287,37	287,95	279,37	284,68	279,47	268,22	265,19	267,59
CO2 kWh	527,29	531,47	634,32	556,30	531,47	585,01	441,42	472,69	482,38	551,90	492,84	454,30	530,78	427,39	470,34	527,06	436,10	400,30	398,35	383,20	257,49	306,31	368,31	281,36	270,56
	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	
ΔTPES/TPES -1	0,0113	0,0636	-0,0139	0,0258	0,1057	-0,0094	0,0530	0,0807	0,0734	0,0065	0,0077	0,0416	-0,0271	0,0283	0,0248	-0,0495	0,0072	-0,0257	-0,0134	-0,0349	-0,0277	-0,0617	0,0037	-0,0167	
ΔGDP/GDP -2	0,0437	0,0109	-0,0204	0,0096	0,0428	0,0350	0,0443	0,0479	0,0389	0,0379	0,0194	0,0077	-0,0093	0,0181	0,0077	0,0155	0,0249	0,0020	-0,0298	0,0190	-0,0183	-0,0403	-0,0113	0,0091	
Tapio decoupling index-3	0,2593	5,8231	0,6779	2,6845	2,4689	-0,2688	1,1975	1,6854	1,8864	0,1729	0,3975	5,4134	2,9007	1,5593	3,2341	-3,1863	0,2875	-12,7143	0,4487	-1,8366	1,5113	1,5329	-0,3303	-1,8484	
ΔCO2/CO2	0,007927	0,19352	-0,123	-0,04463	0,100739	-0,24545	0,07084	0,0205	0,144119	-0,10701	-0,0782	0,168347	-0,19479	0,100494	0,120594	-0,17258	-0,08209	-0,00487	-0,03803	-0,32805	0,1896	0,202409	-0,23608	-0,03838	
Tapio decoupling index	0,181544	17,70664	6,020014	-4,63655	2,353156	-7,01213	1,600531	0,428007	3,70509	-2,82556	-4,02334	21,92495	20,8332	5,54198	15,7346	-11,1071	-3,29765	-2,41358	1,276373	-17,2596	-10,3599	-5,02821	20,89799	-4,24138	
OECD decoupling index TPES vs GDP	0,9690	1,0521	1,0067	1,0161	1,0603	0,9571	1,0084	1,0313	1,0332	0,9698	0,9885	1,0336	0,9821	1,0100	1,0170	0,9359	0,9827	0,9724	1,0169	0,9471	0,9905	0,9776	1,0152	0,9745	
OECD decoupling factor TPES vs GDP	0,0310	-0,0521	-0,0067	-0,0161	-0,0603	0,0429	-0,0084	-0,0313	-0,0332	0,0302	0,0115	-0,0336	0,0179	-0,0100	-0,0170	0,0641	0,0173	0,0276	-0,0169	0,0529	0,0095	0,0224	-0,0152	0,0255	
OECD decoupling index CO2 vs GDP	0,965756	1,180617	0,895294	0,946257	1,055551	0,729033	1,025453	0,973856	1,101282	0,860402	0,904225	1,159444	0,812811	1,080894	1,11207	0,81476	0,895613	0,993124	0,991512	0,659413	1,211777	1,252842	0,77265	0,95299	
OECD decoupling factor CO2 vs GDP	0,034244	-0,18062	0,104706	0,053743	-0,05555	0,270967	-0,02545	0,026144	-0,10128	0,139598	0,095775	-0,15944	0,187189	-0,08089	-0,11207	0,18524	0,104387	0,006876	0,008488	0,340587	-0,21178	-0,25284	0,22735	0,04701	

Figure A.12 The raw data for Portugal and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

Spain	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014
ΔTPES/TPES -1	0,0373	0,0186	-0,0409	0,0554	0,0461	-0,0147	0,0628	0,0504	0,0484	0,0484	0,0261	0,0298	0,0345	0,0435	0,0211	-0,0008	0,0142	-0,0330	-0,0807	-0,0008	-0,0159	-0,0017	-0,0669	-0,0218
ΔGDP/GDP -2	0,0255	0,0093	-0,0103	0,0238	0,0276	0,0267	0,0369	0,0431	0,0449	0,0529	0,0400	0,0288	0,0319	0,0317	0,0372	0,0417	0,0377	0,0112	-0,0357	0,0001	-0,0100	-0,0262	-0,0167	0,0136
Tapio decoupling index-3	1,4651	2,0035	3,9591	2,3254	1,6711	-0,5492	1,7031	1,1707	1,0799	0,9159	0,6522	1,0330	1,0819	1,3750	0,5661	-0,0203	0,3761	-2,9584	2,2574	-5,6114	1,5888	0,0637	4,0025	-1,5999
ΔCO2/CO2	-0,0125	0,124074	-0,12344	-0,0128	0,104195	-0,21103	0,095884	-0,02757	0,165903	-0,02679	-0,11832	0,144206	-0,13289	0,008036	0,03415	-0,07082	0,049964	-0,15854	-0,0929	-0,19955	0,235785	0,045134	-0,20927	0,0424
Tapio decoupling index	-0,4911	13,34796	11,95665	-0,53714	3,778091	-7,89261	2,598615	-0,64033	3,698673	-0,50659	-2,95712	5,006925	-4,16928	0,253763	0,917204	-1,69676	1,325707	-14,2009	2,599369	-1431,63	-23,5752	-1,72236	12,51511	3,115326
OECD decoupling index TPES vs GDP	1,0115	1,0092	0,9691	1,0309	1,0180	0,9597	1,0250	1,0070	1,0034	0,9958	0,9866	1,0009	1,0025	1,0115	0,9844	0,9591	0,9773	0,9563	0,9534	0,9991	0,9941	1,0252	0,9489	0,9651
OECD decoupling factor TPES vs GDP	-0,0115	-0,0092	0,0309	-0,0309	-0,0180	0,0403	-0,0250	-0,0070	-0,0034	0,0042	0,0134	-0,0009	-0,0025	-0,0115	0,0156	0,0409	0,0227	0,0437	0,0466	0,0009	0,0059	-0,0252	0,0511	0,0349
OECD decoupling index CO2 vs GDP	0,962976	1,113721	0,885702	0,964211	1,07456	0,768426	1,056887	0,932285	1,115852	0,924326	0,847757	1,112174	0,84033	0,977094	0,997028	0,891952	1,01183	0,832174	0,940721	0,800336	1,248269	1,073258	0,804177	1,028403
OECD decoupling factor CO2 vs GDP	0,037024	-0,11372	0,114298	0,035789	-0,07456	0,231574	-0,05689	0,067715	-0,11585	0,075674	0,152243	-0,11217	0,15967	0,022906	0,002972	0,108048	-0,01183	0,167826	0,059279	0,199664	-0,24827	-0,07326	0,195823	-0,0284

Figure A.13 The raw data for Spain and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: Sweden																									
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total primary energy supply (TPES) (Mtoe)	47,2	48,69	46,54	46,51	49,7	50,33	51,5	50,17	51,07	50,15	47,56	50,53	51,78	50,62	52,59	51,57	50,21	50,06	49,6	45,41	50,9	49,84	50,16	49,41	48,16
GDP (billion 2010 USD using PPPs)	257,26	254,31	251,37	246,18	256,24	266,55	270,6	278,45	290,21	303,36	317,73	322,69	329,39	337,24	351,81	361,73	378,69	391,58	389,4	369,21	391,32	401,75	400,6	405,57	415,03
CO2 kWh	11,88	19,62	19,41	21,02	25,68	22,18	47,94	27,12	27,88	26,76	22,36	22,88	29,87	39,83	23,05	19,73	22,84	17,69	18,03	18,55	26,39	17,21	12,12	13,14	10,97
	1990-1991	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	
ΔTPES/TPES -1	0,0316	-0,0442	-0,0006	0,0686	0,0127	0,0232	-0,0258	0,0179	-0,0180	-0,0516	0,0624	0,0247	-0,0224	0,0389	-0,0194	-0,0264	-0,0030	-0,0092	-0,0845	0,1209	-0,0208	0,0064	-0,0150	-0,0253	
ΔGDP/GDP -2	-0,0115	-0,0116	-0,0206	0,0409	0,0402	0,0152	0,0290	0,0422	0,0453	0,0474	0,0156	0,0208	0,0238	0,0432	0,0282	0,0469	0,0340	-0,0056	-0,0518	0,0599	0,0267	-0,0029	0,0124	0,0233	
Tapio decoupling index-3	-2,7529	3,8196	0,0312	1,6784	0,3150	1,5300	-0,8902	0,4248	-0,3976	-1,0903	4,0003	1,1914	-0,9400	0,9008	-0,6878	-0,5625	-0,0878	1,6506	1,6293	2,0189	-0,7813	-2,2430	-1,2052	-1,0846	
ΔCO2/CO2	0,651515	-0,0107	0,082947	0,221694	-0,13629	1,161407	-0,43429	0,028024	-0,04017	-0,16442	0,023256	0,305507	0,333445	-0,42129	-0,14403	0,157628	-0,22548	0,01922	0,028841	0,422642	-0,34786	-0,29576	0,084158	-0,16514	
Tapio decoupling index	-56,8165	0,925841	-4,01741	5,425103	-3,38736	76,43777	-14,9707	0,663535	-0,88657	-3,47111	1,489732	14,71404	13,99152	-9,75127	-5,10815	3,361956	-6,62433	-3,45235	-0,55625	7,057597	-13,0512	103,3225	6,783473	-7,08009	
OECD decoupling index TPES vs GDP	1,0435	0,9670	1,0204	1,0266	0,9735	1,0079	0,9467	0,9767	0,9394	0,9055	1,0461	1,0039	0,9548	0,9959	0,9537	0,9300	0,9642	0,9964	0,9656	1,0576	0,9538	1,0093	0,9730	0,9525	
OECD decoupling factor TPES vs GDP	-0,0435	0,0330	-0,0204	-0,0266	0,0265	-0,0079	0,0533	0,0233	0,0606	0,0945	-0,0461	-0,0039	0,0452	0,0041	0,0463	0,0700	0,0358	0,0036	0,0344	-0,0576	0,0462	-0,0093	0,0270	0,0475	
OECD decoupling index CO2 vs GDP	1,670673	1,000867	1,105778	1,17373	0,830299	2,129057	0,549759	0,986366	0,918221	0,797785	1,007528	1,278952	1,302406	0,554743	0,832491	1,105782	0,749023	1,024926	1,085102	1,342261	0,63521	0,706263	1,070873	0,815826	
OECD decoupling factor CO2 vs GDP	-0,67067	-0,00087	-0,10578	-0,17373	0,169701	-1,12906	0,450241	0,013634	0,081779	0,202215	-0,00753	-0,27895	-0,30241	0,445257	0,167509	-0,10578	0,250977	-0,02493	-0,0851	-0,34226	0,36479	0,293737	-0,07087	0,184174	

Figure A.14 The raw data for Sweden and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.

COUNTRY: United Kingdom																									
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total primary energy supply (TPES) (Mtoe)	205,92	212,93	212,17	214,32	215,99	216,35	225,68	219,31	221,5	222,06	222,95	223,76	218,83	222,58	221,62	222,66	218,98	211,05	207,79	195,9	202,77	188,01	193,83	191,6	179,42
GDP (billion 2010 USD using PPPs)	1475,79	1457,54	1464,06	1502,79	1563,28	1640,18	1683,94	1736,13	1794,75	1850,61	1920,91	1973,89	2023,12	2090,62	2142,65	2206,85	2265,59	2324,18	2313,33	2216,36	2250,49	2294,88	2321,94	2372,09	2441,84
CO2 kWh	685,77	674,65	669,07	592,16	560,18	537,66	525,25	490,24	485,06	455,85	479,71	492,74	477,69	499,79	501,95	501,01	524,84	515,49	497,95	448,14	453,01	443,13	489,50	460,71	413,07
	1990-1991	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**2000-2001**	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	
ΔTPES/TPES -1	0,0340	-0,0036	0,0101	0,0078	0,0017	0,0431	-0,0282	0,0100	0,0025	0,0040	0,0036	-0,0220	0,0171	-0,0043	0,0047	-0,0165	-0,0362	-0,0154	-0,0572	0,0351	-0,0728	0,0310	-0,0115	-0,0636	
ΔGDP/GDP -2	-0,0124	0,0045	0,0265	0,0403	0,0492	0,0267	0,0310	0,0338	0,0311	0,0380	0,0276	0,0249	0,0334	0,0249	0,0300	0,0266	0,0259	-0,0047	-0,0419	0,0154	0,0197	0,0118	0,0216	0,0294	
Tapio decoupling index-3	-2,7528	-0,7979	0,3831	0,1936	0,0339	1,6164	-0,9107	0,2957	0,0812	0,1055	0,1317	-0,8834	0,5136	-0,1733	0,1566	-0,6209	-1,4003	3,3088	1,3651	2,2773	-3,6904	2,6253	-0,5327	-2,1619	
ΔCO2/CO2	-0,01622	-0,00827	-0,11495	-0,05401	-0,0402	-0,02308	-0,06665	-0,01057	-0,06022	0,052342	0,027162	-0,03054	0,046264	0,004322	-0,00187	0,047564	-0,01781	-0,03403	-0,10003	0,010867	-0,02181	0,104642	-0,05882	-0,10341	
Tapio decoupling index	1,311258	-1,84896	-4,34533	-1,3417	-0,81724	-0,86512	-2,15063	-0,31294	-1,93481	1,377869	0,984829	-1,22465	1,386641	0,173655	-0,0625	1,786967	-0,68888	7,288688	2,386333	0,705699	-1,10571	8,874382	-2,72313	-3,51667	
OECD decoupling index TPES vs GDP	1,0470	0,9920	0,9841	0,9688	0,9547	1,0160	0,9426	0,9770	0,9723	0,9673	0,9767	0,9542	0,9843	0,9715	0,9755	0,9580	0,9395	0,9892	0,9840	1,0194	0,9093	1,0189	0,9676	0,9097	
OECD decoupling factor TPES vs GDP	-0,0470	0,0080	0,0159	0,0312	0,0453	-0,0160	0,0574	0,0230	0,0277	0,0327	0,0233	0,0458	0,0157	0,0285	0,0245	0,0420	0,0605	0,0108	0,0160	-0,0194	0,0907	-0,0189	0,0324	0,0903	
OECD decoupling index CO2 vs GDP	0,996103	0,987313	0,86224	0,90939	0,914798	0,951532	0,905289	0,957117	0,911414	1,013829	0,999593	0,945866	1,012484	0,979934	0,969091	1,020404	0,957425	0,970505	0,939345	0,995537	0,959269	1,091768	0,921287	0,870984	
OECD decoupling factor CO2 vs GDP	0,003897	0,012687	0,13776	0,09061	0,085202	0,048468	0,094711	0,042883	0,088586	-0,01383	0,000407	0,054134	-0,01248	0,020066	0,030909	-0,0204	0,042575	0,029495	0,060655	0,004463	0,040731	-0,09177	0,078713	0,129016	

Figure A.15 The raw data for United Kingdom and calculation results by the Tapio decoupling elasticity method and OECD decoupling factor.