ENVIRONMENTAL TAXATION IN THE SUSTAINABLE ECONOMIC TRANSITION

Jyväskylä University
School of Business and Economics

Master's Thesis

2024

Author: Iiris Virokannas
Subject: Economics
Supervisor: Petri Böckerman

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

ABSTRACT

Author Iiris Virokannas	
Title Environmental taxation in the sustainable economic transition	
Subject Economics	Type of work Master´s Thesis
Date 4.1.2024	Number of pages 72

Abstract

This thesis is focusing on how environmental taxes can be used in the sustainable transition that economies are currently facing. The thesis includes a theory part which is focusing on the theory of optimal tax level, and a literature review where earlier results are being shown and discussed. The empirical part of the thesis considers data from 25 European countries between the years 2000 and 2021. The empirical part of the thesis and the research questions set a base for two models that have been established and estimated in this paper. The first research question and the first model focus on how total environmental taxes affect greenhouse gas emissions. In the second research question and in the second model environmental taxes have been separated into energy, transport, and pollution and resource tax and their effect on greenhouse gas emissions has been modelled. The long-run estimation is done with FMOLS and DOLS methods since these methods are also broadly used in the previous literature. Also, necessary preliminary tests and two different causality tests are executed, and the results are provided in this paper. The first results show a positive connection between the taxes and greenhouse gas emissions. These results differ greatly from the previous literature. Further, the connection turns negative when the total environmental tax and the smaller tax groups are connected with primary energy consumption. Dumitrescu-Hurlin panel causality test results reveal a negative causal relationship between environmental taxes and primary energy consumption. This supports the argument that environmental taxes affect greenhouse gas emissions especially through energy consumption. The results are quite similar when environmental taxes are divided into smaller categories. From the smaller environmental tax groups energy tax is found to have the largest effect on greenhouse gas emissions and this tax is also greater revenue-wise than the transport tax and pollution and resource tax in all of the study countries.

Key words
Environmental tax, energy tax, transport tax, pollution and resource tax

Place of storage
Jyväskylä University Library

TIIVISTELMÄ

Tekijä
Iiris Virokannas

Työn nimi
Ympäristöverojen rooli kansantalouden kestävässä siirtymässä

Oppiaine
Taloustiede

Työn laji
Pro gradu

Päivämäärä
4.1.2024

Sivumäärä
72

Tiivistelmä

Tämä tutkielma tarkastelee ympäristöverojen roolia ja mahdollisuuksia kansantalouksien kestävässä siirtymässä. Tutkielman teoriaosio keskittyy optimaaliseen veroasteeseen ja kirjallisuuskatsauksessa esitetään ja keskustellaan aikaisemman tutkimuskirjallisuuden tuloksista. Tutkielman empiirisessä osassa käytetään tietoa 25 Euroopan valtiosta vuosilta 2000-2021. Ympäristöveroja tarkastellaan ensimmäisessä mallissa kokonaisuutena, mutta toisessa mallissa vero jaetaan energiaveroon, liikenneveroon ja saaste- ja luonnonvaraveroon. Keskeisimpänä tutkimuskysymyksenä on tarkastella miten nämä eri veroryhmät, joita usein tutkimuksessa tarkastellaan vain kokonaisuutena, vaikuttavat kasvihuonekaasupäästöihin. Pitkän aikavälin tarkastelussa hyödynnetään FMOLS ja DOLS metodeja, joita on käytetty laajasti myös aikaisemmassa tutkimuskirjallisuudessa samankaltaisissa tutkimuksissa. Tutkielma sisältää myös tarvittavien testien tulokset sekä tulokset kahdesta eri kausaalisuustestistä. Keskeisimmät tulokset ovat, että ilman interaktiotermin lisäystä ympäristöverojen ja kasvihuonekaasupäästöjen välillä näyttää olevan positiivinen yhteys. Tämä tulos on vastoin aikaisemman tutkimuskirjallisuuden tuloksia. Toisaalta tarkasteltaessa ympäristöverojen ja energiakulutuksen yhteisvaikutusta kasvihuonekaasupäästöihin huomataan, että yhteys kääntyy negatiiviseksi. Dumitrescu-Hurlin paneelikausaalisuustestin tulosten perusteella ympäristöverojen ja energiankulutuksen välillä on negatiivinen kausaalisuhde, mikä tukee päätelmää siitä, että ympäristöverot näyttävät vaikuttavat kasvihuonekaasupäästöihin etenkin energiankulutuksen kautta. Tulokset ovat samansuuntaiset myös silloin, kun ympäristöverot on jaettu pienempiin luokkiin. Näistä luokista energiaverolla ja sen muutoksilla näyttää olevan suurin vaikutus kasvihuonekaasupäästöihin. Toisaalta energiaverot on myös suurin erillinen ympäristöveroluokka kaikissa tutkittavissa valtioissa.

Asiasanat
Ympäristövero, energiavero, liikennevero, saaste- ja luonnonvaravero

Säilytyspaikka
Jyväskylän yliopiston kirjasto

CONTENTS

1 INTRODUCTION

Environmental damages, land use, deforestation, decreasing biodiversity, and global warming are not new concerns in societies and the field of economics. Environmental economists have for a long time pointed out that in addition to seeking and aiming for economic growth, we also have to be aware of externalities production may cause. Generally, many economists at least in the neoclassical field which is in many cases dominating economic thinking are arguing the less we intervene the markets the better. For example, according to Wolff and Resnick (2012), the fundamental idea in economics is that the more we consume the better off we are. Also, it is thought that well-functioning markets are dividing the limited resources in the most optimal way. However, in many cases, economically and socially efficient resource distribution and use does not occur without market intervenience. (Wolff & Resnick, 2012. p. 52; 55–57; 101–104; 258–260.)

The externalities of production are occurring if production is causing effects on the third party in addition to the producer and consumer. The third party can also be the environment. (Wolff & Resnick, 2012. p. 258–260). The externalities are especially problematic if there has not been set a price for causing those externalities and if the externalities fall upon the public good. In this case, it has been said that there is market failure in the economy. This means that markets fail to set prices for the use of public goods which leads to their overuse. (Perman, Ma, Common, Maddison & McGilvray, 2011. p. 118–119; 123–124.)

According to Perman et al. (2011), in a perfect world individuals could bargain over pollution decisions, and if the bargaining succeeds governmental decisions are not needed. This would naturally create savings when different instruments do not have to be introduced. However, the global world is full of interests that overlap especially when it comes to the use of public goods. The bargaining process also takes time and thus also creates costs. Thus, bargaining is very rarely possible and some kind of instruments are needed to limit the use of limited resources. (Perman et al., 2011. p. 177; 181–186; 223.) Environmental economic literature offers many possible instruments to affect the environmental problems in societies.

Perman et al. (2011) are dividing instruments into command and control instruments and economic incentive-based instruments. Command and control instruments create a situation where firms and other operators must adapt their production and behaviour under certain criteria. For example, laws are an example of command and control instruments. Economic incentive-based instruments are attempting to change relative prices of production and therefore create incentives to change production and consuming behaviour towards cleaner manufacture and consumption. Usually, economic-based instruments are more cost-effective than command and control instruments meaning that they are economically more beneficial to society compared to the costs of the instrument. On the other hand, under economic incentive-based instruments adapting is completely voluntary. (Perman et al., 2011. p. 188; 195–196; 218.)

Economic incentive-based instruments can be further divided into 1) taxes and subsidies and 2) tradable emission permit systems (Perman et al., 2011. p. 195–196). An example of a tradable emission permit system is an emission trading system in the European Union. Unlike the tradable emission permit system, the European Union does not have collective environmental taxes or subsidies. Each country can set its own levels for taxes and subsidies and leave some production sectors out of the tax reform. Figure 1 shows the development of total environmental taxes in Europe. In the figure we can see that the total environmental tax revenues have increased quite steadily between 2000 and 2021. This indicates that either more sectors have been taken under environmental taxation, environmental tax levels have been increased or more European countries have implemented environmental taxes.

Figure 1. Total environmental tax development in Europe.

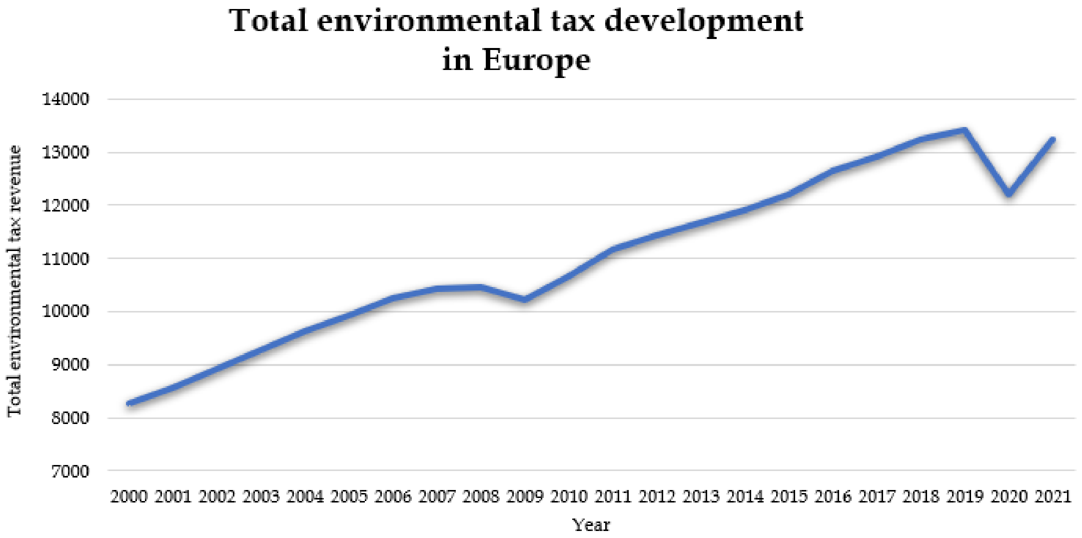


Fig 1. This figure includes data from 25 European countries that are included in this study. The figure shows the total environmental tax revenue development in these countries.

Since there is no collective environmental tax level, environmental taxes can be set with also other purposes than improving the state of the environment. Another incentive would for example be to increase the government´s funds (Sumner, Bird & Dobos, 2011). Further, when environmental tax levels are not bound to any collective agreements, countries can also decide to leave some sectors out of the area that is being taxed. This has often been the case when countries try to protect some of their essential production sectors under the hard competition of the global markets. For example, in Sweden where the environmental tax level is the highest one in the world the coverage of environmental tax is around 40% of the overall greenhouse gas emissions, and according to Jonsson, Ydstedt, and Asen (2020) it could be possible to cut down more emissions with a wider taxing sector.

According to the World Bank (2022), 23% of the global greenhouse gas (GHG) emissions are controlled by some carbon pricing instrument. In total, there are 68 implemented carbon pricing instruments in the world that on the other hand try to decrease the amount of emissions and on the other hand create tax revenues (World Bank, 2022). In other words, 77% of the global GHG emissions are not controlled by any carbon pricing instrument. 77% meant roughly 37 million kt of CO_2 equivalent in 2019 calculated by using the data provided by the World Bank (2023a). CO_2 equivalent is a way to measure all greenhouse gas emissions and their global warming potential on the same scale (Eurostat, 2023). At the same time, the level of emissions does not seem to decrease globally. For example, according to Crippa et al. (2022), CO_2 emissions were only 0,36% smaller in 2021 than in 2019. From the COVID year 2020 CO_2 emissions increased by 5,3 percent in 2021 (Crippa et al., 2022). If societies procrastinate sustainable transition and fail to decrease greenhouse gas emissions before a certain point, the change will be enormously more difficult and costly to execute in the future (Stern, 2015, p. 4–11). This makes carbon pricing instruments and their possible use and extension extremely essential to study.

Compared to the whole world, in Europe the situation is a bit better and there are many environmental goals that try to lead to decreasing levels of emissions. According to the European Environment Agency (2023), total net greenhouse gas emissions are decreasing in the European Union. However, more actions need to be taken if we want to achieve the environmental goals in time (European Environment Agency, 2023). Also, it needs to be pointed out that many European countries are producing much more emissions compared for example to developing countries if we are measuring emissions per capita. In Figure 2 we can see that overall greenhouse gas emissions per capita have decreased in the whole period between 2000 and 2021 but for example between 2013 and 2018 the emissions per capita have been increasing. Also, between 2020 and 2021 the per capita emissions have been increasing again. The figure is summarizing data from 25 European countries used in this study.

This thesis is focusing only on the environmental taxes that are part of economic incentive-based instruments. Subsidies and tradable emission permit systems are left out of the study together with command and control instruments. The reason why exactly environmental taxes have been chosen from all incentive-based instruments is that unlike tradable emission permit systems and subsidies, environmental taxes create tax revenues in addition to the decreasing amount of emissions and other negative externalities. This is an interesting aspect since tax revenues can further be redistributed in the economy (Distefano & D'Alessandro, 2023) and this can optimize the national tax structure and reduce social welfare costs that overall taxation is causing (e.g., Xie, Dai, Xie & Hong, 2018b). Further, it has also been studied already in the 1970th century that environmental taxes could help to achieve the wanted environmental improvement with minimum costs to society (Baumol & Oates, 1971).

Figure 2. Greenhouse gas emissions per capita in Europe.

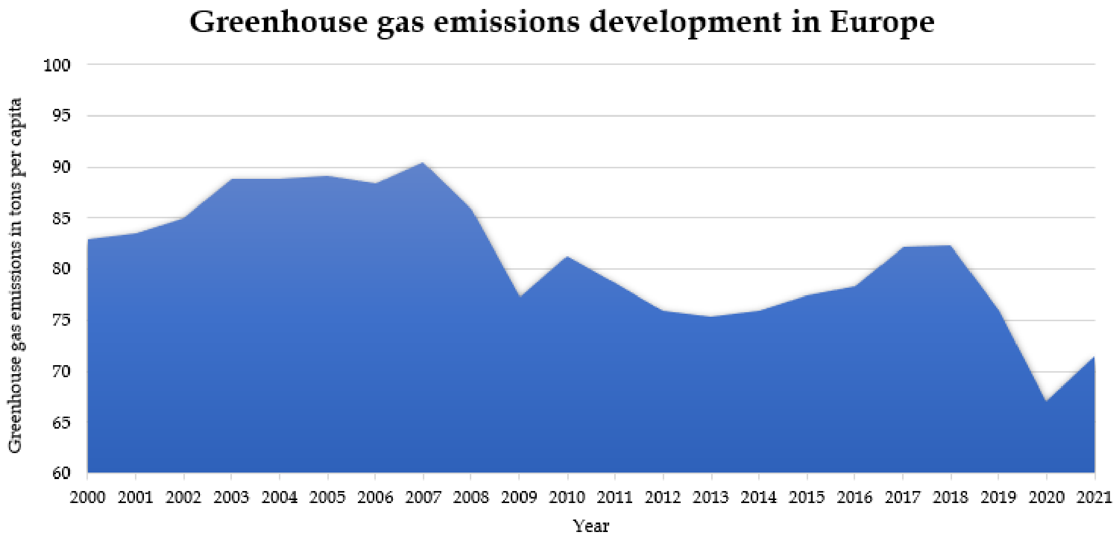


Fig 2. This figure includes data from 25 European countries and shows the overall development of greenhouse gas emissions in tons per capita in these countries.

In this thesis, environmental taxes are divided into smaller categories: energy taxes, transport taxes, and pollution and resource taxes. The environmental tax separation is made because earlier literature focuses mainly on studying how total environmental taxes affect greenhouse gas emissions. However, as we can see for example from Appendix 2 the tax levels are quite different in the study countries between these smaller environmental tax groups. Later we can see that also the results are different for these groups. Thus, it is important to look at these tax groups separately. It is slightly peculiar that a major part of the previous literature is not taking this into account in the models even though there is available data for separated groups of environmental taxes and not only for total environmental tax. However, this kind of separated data is harder to get when the study is focused outside of Europe. Thus, this study is concentrating only on countries in Europe.

This study includes 25 European countries. All of the countries except Norway are also part of the European Union. The country selection has been done based on available data and some European countries are left out of the study due to unavailable data for key variables that are part of the model. The study countries are Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Latvia, Lithuania, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, and Norway. The study period is from 2000 to 2021 and this period has been chosen because some data before this period is not available for all the variables. Further, this thesis is focusing on the following research questions:

(1) How do the total environmental taxes affect the level of greenhouse gas emissions in selected European countries?

(2) How does the effect change when total environmental taxes are separated into energy tax, transport tax, and pollution and resource tax?

These research questions are studied with FMOLS (fully modified OLS) and DOLS (dynamic OLS) methods. According to previous literature, these econometric methods are superior when modelling environmental variables that include cross-sectional dependence. For example, Bashir, MA, Shahbaz, Shahzad, and Vo (2021), Ghazouani, Jebli, and Shahzad (2021), and Doğan, Chu, Ghosh, Truong, and Balsalobre-Lorente (2022) have been using these methods successfully in their studies.

The thesis is organized as follows: the next chapter is focusing on the theoretical framework of environmental taxes and the theory of the optimal tax rate. In the third chapter previous literature is being studied. This chapter focuses on studying what kind of positive and negative effects environmental taxes can have and how different tax revenue distribution systems can affect these outcomes. The second part of the third chapter (3.2) is presenting what kind of models and methodologies have been used in the earlier literature. The fourth chapter presents the data that is used and explains how it has been gathered. This chapter also shows the chosen methodology and model and provides short mathematical explanations of the tests that are used in the study. The fifth chapter presents the results and discussion of the study. The fifth chapter has been further divided into two parts: the first part presents the preliminary test results and the second part the long-run test results. The sixth and final chapter presents what kind of conclusions can be drawn from the study.

2 THEORETICAL CONSIDERATIONS

As stated in the introduction, externalities of production can create market failure, which means that policy tools are needed to set prices for harmful economic activities, for example pollution. Environmental tax is one of the most important policy tools to answer this need. This theory chapter is divided into three parts. The first part (2.1) is focusing shortly on the background of environmental taxes and especially in sub-chapter 2.1.2 to upper-level criteria that pollution control instruments face. These criteria are considered on the side of taxation leaving command and control, subsidy, and tradable emission permit system out of the focus. The second part (2.2) is presenting more specifically the theory of how the optimal rate of environmental tax can be found. However, policymakers are usually lacking some information considering for example the damage of pollution, so the optimal tax rate is hard or impossible to find. This aspect is discussed shortly in the third chapter (2.3).

2.1 Background for environmental taxes

2.1.1 Environmental taxes are part of mitigation strategies

Roughly environmental economic strategies to tackle climate change and global warming can be divided into two different groups: mitigation and adaptation strategies (Asmi, Anwar, Zhou, Wang & Sajjad, 2019). Mitigation strategies focus on reducing emission flow to the atmosphere and limiting the earth´s middle temperature rise (Bayramoglu, Finus & Jacques, 2018). Environmental taxes are one example of a mitigation strategy. By imposing an environmental tax, the country is trying to decrease for example the fossil fuels emissions that are produced in the economy. Other examples of mitigation strategies are avoiding deforestation, investing in new technologies, and trying to change the behaviour of consumers (Breton & Sbragia, 2017).

In recent years, it has become clear that limiting global warming to 1,5 degrees or below 2 degrees will be extremely hard. In recent studies, it has been predicted that with current climate actions, the earth will warm about 2,7 degrees (Climate Action Tracker, 2023). Global warming is already affecting countries and influencing their way of life. This leads to the second group of strategies which are adaptation strategies. According to Bayramoglu, Finus, and Jacques (2018), adaptation strategies focus on keeping the earth suitable for humans while the rise in the middle temperature will create changes in the surrounding environment for example through weather changes. Therefore, adaptation strategies can for example include supporting dyke building sectors or air-conditioning companies that help reduce the damages and discomfort caused by changing environment. According to Breton and Sbragia (2017), other examples of adaptation are for example early warning systems, sea walls, and irrigation systems. In some research terms abatement and self-protection have also been used to describe in the first case mitigation strategies and in the latter adaptation strategies (e.g., Zehaie, 2009). This thesis is focusing only on mitigation strategies and more specifically environmental taxes.

The development of environmental taxes started at the beginning of the 20th century. The tax for polluters and creators of the negative externalities, also known as the Pigouvian tax, was first invented by British economist Pigou in 1920. The idea is that the tax creates an incentive for firms or consumers to change their behaviour voluntarily toward more acceptable behaviour. Environmental taxes are naturally an example of a Pigouvian tax, but also taxes on sugar or alcohol are examples of Pigouvian taxes. (Pigou, 1920; e.g., Distefano & D'Alessandro, 2023.) In other words, the Pigouvian tax and more precisely environmental tax measure the social cost per ton emitted from different pollutants (Mardones & Cabello, 2019). It is also important to point out that directing the environmental tax already to the inputs of the production (for example energy) is more effective than setting the tax on final products (Perman et al., 2011, p. 179).

Generally, it is also necessary to point out that environmental taxes usually only work when the emissions are uniformly mixing. This means that the effects of polluting are not dependent on location. (Perman et al. 2011. p. 191; 210–218.) An example of uniformly mixing pollutants is burning fossil fuels and creating greenhouse gas emissions. GHG emissions migrate to the atmosphere and create global warming. This global warming is affecting everywhere in the world, not only in the location where the emissions have been created. According to Perman et al. (2011) when pollution is affecting only certain locations, many advantages of the tax instruments are lost, and they are no longer good and efficient instruments. One reason for this is that location-based pollution would require knowing the marginal abatement cost function for every firm. This would also lead to a situation where the tax level should be different for different locations and firms. (Perman et al., 2011. p. 191; 210–218.) It is not hard to see why this creates inefficiencies in the instrument use. Because this thesis is focusing directly on greenhouse gas emissions which are uniformly mixing pollutants, the location does not play a role in this study. Thus, location-based pollution and the economic theory considering this group of pollutants are left out of the study.

2.1.2 Upper-level criteria for environmental taxes

As briefly stated already in the introduction, a well-designed environmental tax can be the most cost-efficient way to decrease environmental damage and also minimize the social welfare costs that taxation creates. Perman et al. (2011) list criteria for all pollution control instruments and therefore these criteria also apply to environmental tax instruments. The criteria are showing what are the aspects that policymakers have to consider when designing a new tax. The requirements include cost-effectiveness, long-run effects, dynamic efficiency, ancillary benefits, equity, dependability, flexibility, costs of use under uncertainty, and information. The policy maker and regulator have to choose the best instrument based on these criteria which tend to contain trade-offs and conflicts with each other. It is essential to notice that the best instrument and for example the best tax level varies over different circumstances. The one optimal tax level for GHG emissions may not create for example the best outcome for the use of synthetic pesticides. (Perman et al., 2011. p. 178–179.)

Many researchers have been focusing especially on the criteria for cost-efficiency and ancillary benefits. Setting a price on carbon has broadly been stated to be the most important policy tool to achieve cost-effectiveness and a carbon tax is a good way to put carbon pricing into practice (Sen & Vollebergh, 2018). According to Ghazouani, Jebli, and Shahzad (2021), environmental taxes are also seen as the best tool to achieve economic efficiency. Xie, Dai, Xie, and Hong (2018b) argue that carbon tax is one of the most cost-effective instruments when it comes to reducing carbon emissions. According to Perman et al. (2011), cost-efficiency means that the wanted target is being reached with the lowest possible costs. Only if the cost efficiency has been reached, can the instrument achieve economic efficiency. Economic efficiency can also be defined as allocative efficiency or Pareto optimality. The basic idea of economics since Adam Smith is that under certain conditions economic efficiency will be reached through competitive markets. From the other point of view, economic efficiency means that the markets are Pareto optimal or in other words Pareto efficient. This means that Pareto improvement, making someone´s position better without making anyone else's position worse, cannot be made. (Perman et al., 2011. p. 7–8; 94; 178–180.) Reaching cost-efficiency also creates some good solutions that are explained later in this chapter.

Ancillary benefits consider situations where the instrument use enables ending up in the "double dividend" solution. This means that by introducing for example an environmental tax, society can reduce some other taxes meanwhile also pollution is being decreased. If these old taxes have had a distortionary effect, the economy will achieve better efficiency by introducing a new environmental tax that brings environmental benefits but also enables the reduction of ineffective taxes. Thus, with the double dividend hypothesis it is possible to achieve negative real costs if it is managed to weaken deadweight inefficiencies. (Perman et al., 2011. p. 140; 165–168; 178.) For example, Hassan, Oueslati, and Rousselière (2020) present the idea that the tax burden of income, employment, and investment could be transferred to pollution and waste which would mean achieving the double dividend solution. According to Bhat and Mishra (2020), a properly designed carbon tax includes double dividend property and thus can encourage the transition from carbon production towards cleaner production and investments towards new technology. Distefano and D´Alessandro (2023) are presenting the terms triple-dividend and quadruple-dividend hypothesis. According to the writers, the triple-dividend solution takes also long-term employment, GDP growth, and public indebtedness improvements into consideration and the quadruple-dividend hypothesis adds income inequality to the list as well.

Further, the criterion for long-run effects indicates how the instrument and its effects change over time and does the effect for example weaken in the future. Also, dynamic efficiency focuses on the duration and studies, are the effects of the instrument continual or does the effect for example last for only a certain amount of time. The equity criterion focuses on the effects that the instrument has on the allocation of income and wealth. Dependability indicates how reliable it is to achieve a certain target with the instrument in question. Flexibility is an important criterion which is considering how easy it is to change the instrument when we get new information or the conditions in the economy change. (Perman et al., 2011. p. 178.) For example, according to Ghazouani, Jebli, and Shahzad (2021), one advantage of environmental taxes is that they can usually be added to already existing systems which makes environmental taxes more flexible instrument. Costs of the use under the uncertainty criterion is considering the losses that the economy can face if the instrument is used under imperfect information. Information criterion refers to the question of how much information a certain instrument requires. (Perman et al., 2011. p. 178.)

2.2 Theory of optimal environmental tax rate

As pointed out in the earlier chapter, to be economically efficient the new environmental tax has to achieve emission reduction with the lowest possible costs. This means that a new tax system has to be cheaper than for example a new tradable emission permit system and reduce emissions that is needed. However, there are also other requirements for the tax. The optimal tax level is greatly influenced by the marginal damage and marginal abatement costs. According to

Hsiang, Oliva, and Walker (2019), damage function refers to negative benefits and environmental externality, and can be divided into two components. These are the effect to environmental conditions and a vector of socioeconomic attributes that tell how exposure to certain damage affects economic well-being (Hsiang, Oliva & Walker, 2019). The abatement cost function refers to the costs that reduction of certain negative externality for example pollution costs (Perman et al., 2011. p. 180).

It is quite easy to think that the more we can reduce emissions the better. According to economic theory, the case is however not that simple, for the optimal environmental tax level is determined at the point where the marginal abatement cost function equals the marginal damage function (e.g., Perman et al., 2011. p.148; Sumner, Bird & Dobos, 2011; Ghazouani, Jebli & Shahzad, 2021). This can be seen in Figure 3 below. According to Perman et al (2011), before the tax is introduced firms have no incentive to do abatement because that brings extra costs for the firm. Thus, before the tax has been set up the abatement level is zero and the emission level is $\widehat{M}$. After the tax level has been set up to μ*, the firms are adjusting their pollution level to equal M* by doing more abatement. (Perman et al., 2011. p. 196–197.) According to Ghazouani et al. (2011), firms are reducing their emissions as far as the marginal cost of abating CO_2 is lower than the tax level. When that critical point where marginal abatement costs and marginal damage functions equal is reached, the firm pays the tax and is not abating anymore. There is no economic incentive for profit-maximizing firms to do more abatement than to get to level M*. (Ghazouani et al., 2021.) The optimal tax level

Figure 3. The socially efficient level of emissions.

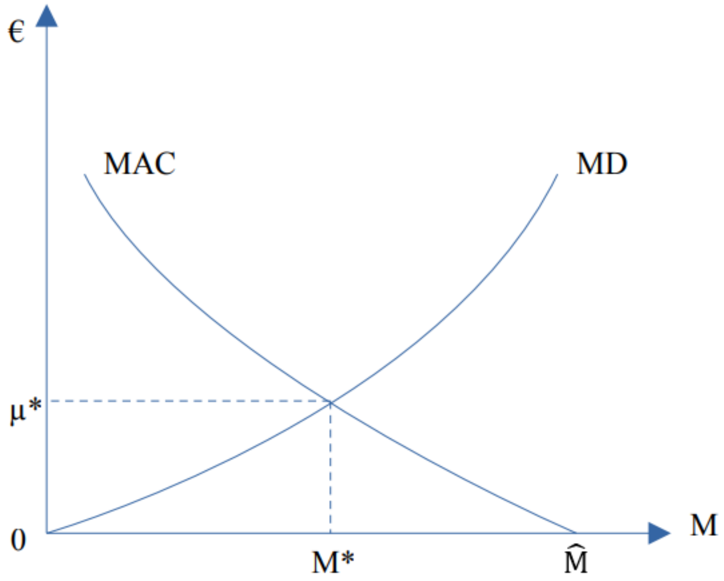


Fig 3. shows the optimal level of emissions and the optimal level of the tax level. These are determined by the marginal abatement costs (MAC) and marginal damage (MD) functions. M stands for the quantity of emission pollution and μ. M* and μ* are showing the socially efficient level of emissions and tax. (e.g., Perman et al., 2011.)

is at the point where marginal abatement costs equal marginal damage because reducing more emissions i.e., abating more, costs more on the left side of M* than taking the occurring marginal damage. On the other hand, on the right side of M* marginal damages cause greater costs so it is cheaper to abate more to get to the level M*.

The same can be demonstrated more mathematically. It is assumed that damage (D) depends only on the magnitude of the emission level (M). Further, it is also assumed that there are some benefits of pollution (B) which also depend on M. This refers to cost savings that society gets when not all the pollution needs to be restricted. NB refers to social net benefits from a given level of emissions. Thus, we have the following equations:

$$D = D(M) \tag{1}$$
$$B = B(M) \tag{2}$$
$$NB = B(M) - D(M) \tag{3}$$

To maximize net benefits the level of M needs to be chosen so that,

$$\frac{\delta NB(M)}{\delta M} = \frac{\delta B(M)}{\delta M} - \frac{\delta D(M)}{\delta M} \tag{4}$$

and when that function is set up to equal zero, we get:

$$\frac{\delta B(M)}{\delta M} = \frac{\delta D(M)}{\delta M} \tag{5}$$

which is the point where the two curves equal. (Perman et al., 2011. p. 146–148.) In Figure 3 marginal net benefits have been renamed as marginal abatement costs.

Thus, the socially efficient level of emissions is depending on how marginal abatement cost and marginal damage functions are shaped. According to Perman et al. (2011), a special case is a situation where marginal damage is so great that there should be no pollution at all. This case is shown in Figure 4, and it illustrates well the argument that the socially efficient level of emissions and tax depends on the two functions and therefore can be different for different pollutants.

It is also possible that the marginal damage and marginal abatement cost functions change. For example, if the marginal damage function would become steeper like in Figure 5 on the left-hand side meaning the damage that emissions cause is now greater than in the earlier case, then the socially efficient solution would be to reduce the emissions from M^1 level to the new M^2 target level (Perman et al., 2011. p. 197–200). This means that society has to do more abatement to keep the pollution level at the optimal M* level. This costs more to society while the optimal level shifts more up in the marginal abatement cost function. Also, the optimal tax level changes from μ^1 to μ^2 meaning that a higher tax level is preferable. On the other hand, also the marginal abatement cost function can change. For example, with new technology it can be possible to abate more easily and cheaply than before. In this case, the marginal abatement cost function shifts to the left and the same amount of emission level is now possible to achieve with less costs. This kind of change also changes the optimal emission and tax level which is shown in Figure 5 on the right-hand side.

Figure 4. The shape of marginal abatement cost and marginal damage functions can change between pollutants.

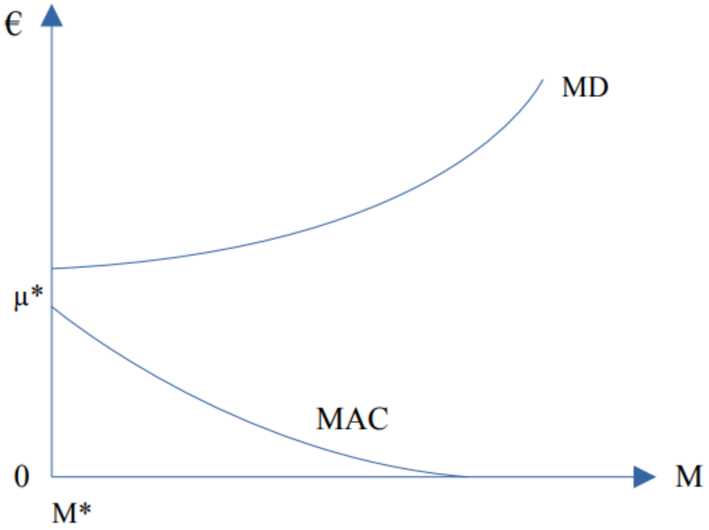


Fig 4. illustrates a special case where at the socially optimal level all abatement should be done and in other words, zero pollution should be made (e.g., Perman et al., 2011).

Figure 5. The socially efficient level of emissions when marginal damage function and marginal abatement cost function change.

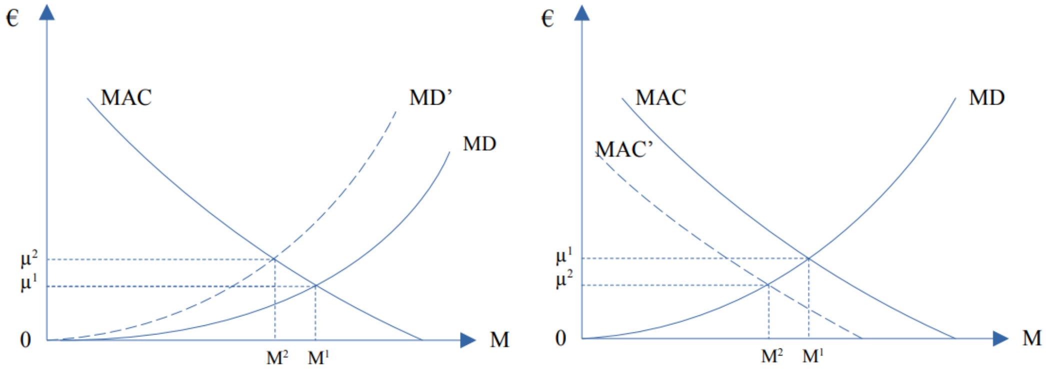


Fig 5. The figure on the left-hand side shows a situation where the marginal damage function changes. This means that the earlier level of emissions is now creating greater damage to society and thus more abatement is needed. The figure on the right-hand side is demonstrating what happens when the marginal abatement cost function changes. The shift to the left shows a situation where abating becomes cheaper for example due to technological improvements. (e.g., Perman et al., 2011.)

Environmental tax achieves cost-effectiveness when the tax is set up to the level of μ^*. This can be seen in Figure 6. Areas a_3 and a_4 form the total damage costs that are paid in the equilibrium. Area a_5 represents the total abatement costs and on the other hand, the abatement that is made in the equilibrium. Therefore, $a_3 + a_4 + a_5$ is the minimum cost and any other level of M is leading to increasing costs. For example, if there is too much abatement, or in other words too little pollution, and the level of emissions is at M_A, then this creates efficiency loss that equals areas $a_1 + a_2$, as seen in Figure 6. In the same way also too much pollution and too little abatement would create efficiency loss to the economy. (Perman et al., 2011. p. 148.)

Figure 6. Reaching the efficient level of pollution and tax leads to cost-effective solution.

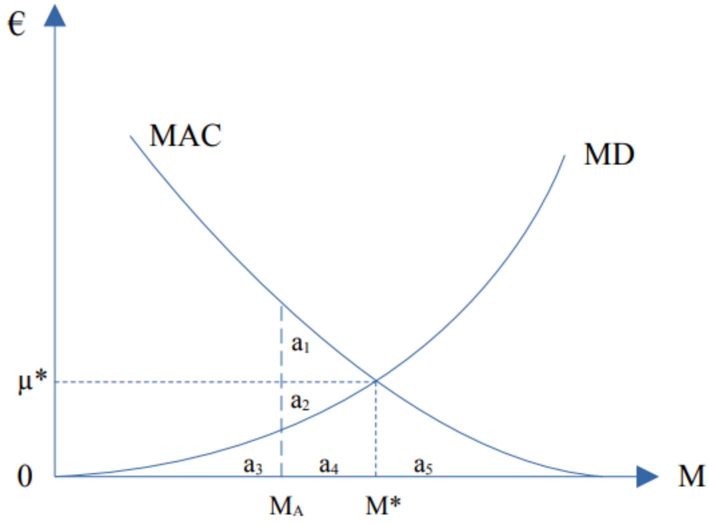


Fig 6. Areas a_1 and a_2 represent the efficiency loss that follows if the optimal level of M^* and μ^* is not reached. (e.g., Perman et al, 2011.)

In Figure 6 it is shown that environmental tax achieves cost-effectiveness. Achieving this least-cost theorem means that the marginal cost of abatement is similar for all firms. When a certain tax level is introduced in an economy, firms set their abatement levels so that their marginal abatement cost is at the same level as the tax. Since the tax rate is similar for all firms also their marginal costs are identical. The total abatement effort firms make are different and firms with relatively low costs to abate will abate more than the firms which have higher relative abatement costs. However, the marginal cost of abatement is similar to all firms under the least-cost theorem. This brings enormous advantages for policymakers. It is still necessary to know the aggregate marginal damage function and the aggregate abatement cost function when searching the socially efficient target of emissions. However, it is not necessary to know the marginal abatement cost function for each firm. (Perman et al., 2011. p. 178–180; 198.) With environmental tax it is possible to avoid deadweight loss and additional welfare costs that for example command and control instruments are creating. These instruments do not consider the differences in marginal abatement costs and marginal damages between firms. (Muller & Mendelsohn, 2009.) Because command and control instruments do not achieve cost-effectiveness, it would be necessary to know different marginal abatement cost functions for each firm. As stated before, this is not necessary in the environmental tax case, where cost-effectiveness is achieved.

2.3 Finding an environmental tax rate in practice can differ from the theory

Despite the good outcome of the least-cost theorem of pollution, finding the optimal tax level is much more straightforward in theory than in practice. Even though it is not necessary to know each firm´s own marginal abatement cost function policymakers who are designing the new tax should know the universal marginal abatement cost function and the marginal demand function. Usually, we do not know what these functions look like. According to Ghazouani et al. (2021), knowing the damage function would require knowing how pollution affects the whole Earth and all the life in it. Further, it is also difficult or almost impossible to set a monetary value for things like biodiversity for instance. This is why in practice the tax is set to a lower level that would be optimal for limiting global warming (Ghazouani et al., 2021).

Despite the difficulties, there are some attempts to calculate marginal damage functions in the economic literature. Muller and Mendelsohn (2009) calculate marginal damages for all air pollution sources in the United States. The researchers are taking for example air quality, exposure, and dose-response into account in their integrated assessment modelling for each six different pollutants. In the end, the experiment covers the whole US and is repeated 60 000 times. The results show that the marginal damage of emissions can be over 150 times larger in bigger cities compared to rural areas. This is why greater abatement would be needed especially in the bigger cities. One advantage of this finding is that it could allow policymakers to choose different environmental tax rates depending on the location, for example in this case in bigger cities. (Muller and Mendelsohn, 2009.) On the other hand, as stated before, one benefit of environmental tax is that it is relatively easy to control since the tax level can be similar to all. If there are many different environmental tax levels for different regions this is more difficult for policymakers to control. However, if the differences between regions are as large as stated in Muller´s and Mendelsohn´s (2009) study, this can be a rational option.

Hsiang, Oliva, and Walker (2019) also point out that marginal damages are usually heterogeneous which means that environmental policy will have different benefits or harms to different people. This can mean that if marginal damage is positively correlated for example with income, the reduction of the damage will benefit more people with higher income levels. On the other hand, if the correlation is negative, then the effect will likely have progressive benefits. The writers point out that this connection is hard to consider in the econometric models since the predictors for heterogeneity in damage functions are not randomly assigned. The solution to this problem would however be essential because that would help us to understand what kind of welfare impacts heterogeneity in environmental benefits and damages can have. (Hsiang, Oliva & Walker, 2019.)

It has to be also pointed out that policymakers can implement an environmental tax without trying to find an optimal level to decrease emissions and other damages. According to Sumner, Bird, and Dobos (2011), environmental tax critics are often arguing that carbon taxes and other environmental taxes are a way to raise tax revenues for governments rather than to decrease environmental damages. In these cases where environmental tax is implemented merely to raise tax revenues, tax cannot be economically efficient (Sumner, Bird & Dobos, 2011). As stated before, good environmental taxes enable double dividend solutions where it is possible to change the tax burden from cleaner producers to more emitting producers. If the other tax levels are left similar after the new environmental tax has been implemented, this can raise a question about the real purpose of the implemented tax. However, it is also essential to search how the tax revenues are being distributed. Chapter 3.1.3 is focusing more on this matter.

3 LITERATURE REVIEW

This chapter focuses on the previous literature of the connection between emission and environmental taxation. The literature in this field is broad and studies about the relationship between these two variables have been published continuously already from the last decade. The literature review in this thesis is not a systematic review. Instead, the literature has been selected based on different approaches, viewpoints, and results to provide a wide enough picture of the previous studies. Different and sometimes opposite results are naturally a cause of different data from different periods. However, different results can also be caused by different points of view on the subject. This literature review is aiming to point out these differences and the studies are selected based on that aim.

This chapter has been divided into two parts. The first part (3.1) is divided into three smaller chapters focusing on the observed positive effects of environmental taxes, possible negative effects that environmental taxes can create, and how tax revenue distribution can affect the success of environmental taxation. The second part (3.2) focuses on the models and methods that previous researchers have been using in the literature when studying the connection between environmental tax and emission levels.

3.1 Environmental taxes affect the emission levels but also broader in the economy

The literature about mitigation strategies and more specifically environmental taxes is broad and it has been started a long time ago. In one way it can be seen that the mitigation literature started with Pigou (1920) and his early work with Pigouvian taxes. The more recent literature expands from the Pigou-times and divides to study how environmental taxes, environmental quality, emission levels, conventional energy consumption, renewable energy consumption, natural resource rent, trade diversification, and economic complexity have an impact to one another (Doğan, Chu, Ghosh, Truong & Balsalobre-Lorente, 2022). Also, the connection between environmental taxes and economic growth has been studied (e.g., Ghazouani, Jebli & Shahzad, 2021). The following sub-chapters will focus mainly on the connection between environmental tax and emission levels. However, also for example the connection between environmental tax, economic growth, and renewable energy consumption is studied. According to Hassan, Oueslati, and Rousselière (2020), environmental tax regulation affects the economy through international trade, employment, human capital, investments, and innovations. Also, all these factors will be discussed in the following sub-chapters.

3.1.1 Observed positive effects of environmental taxes

In the previous literature, it has been observed that an increase in environmental tax revenue can decrease the level of emissions. According to Sen and Vollebergh (2018), it is possible to achieve 0,73% long-term reduction in fossil fuel consumption if the energy tax is increased by one euro. The reduction in emission levels is a cause of reduction in fossil fuel energy consumption when the energy tax has been implemented in the economy. Researchers also argue that a uniform carbon tax at the level of 45 euros per ton of CO_2 could help countries achieve their Paris Agreement targets. Sen and Vollebergh include 28 OECD countries in their model. It has also been pointed out that emission reduction can be a lot greater in other countries like Mexico, the United States, and Canada compared for example to Scandinavian countries where taxes towards energy are relatively high already. (Sen & Vollebergh, 2018.) The levels of environmental taxes vary already a lot between European countries. For example, in 2021 Sweden had the world´s highest carbon tax with 116,33 euros per ton of CO_2e. At the same time for example Spain had a carbon tax of 15 euros, Estonia 2 euros, and Poland 0,07 euros per ton of CO_2e. (Tax Foundation, 2021.) Therefore, for some countries also in Europe changing the carbon tax level to 45 euros per ton of CO_2 that Sen and Vollebergh (2018) are suggesting would be an enormous change.

Also, Ghazouani et al. (2021) are finding that there is a negative connection between environmental taxes and emission levels. They study 9 leading emitting countries in the European Union and argue that 1% increase in environmental tax decreases the level of GHG emissions by 0,35% with generalized least squares (GLS) estimation and 0,15% with panel quantile regression estimation. Further, they also study how 1% increase in renewable energy consumption, environmental technology, urbanization growth, and income level affect GHG emissions. The results imply that an increase in renewable energy consumption and environmental technology decrease GHG emissions as well as the environmental tax, but the decline is not as strong as in the environmental tax case. An increase in urbanization and income levels on the other hand increase GHG emissions. (Ghazouani et al, 2021.) Similar results about declining emissions due to an increase in renewable energy consumption have got for example Bashir, MA, Shahbaz, and Jiao (2020), Bhattacharya, Churchill, and Paramati (2017) and Simionescu (2021).

Some researchers (e.g., Mardones & Cabello, 2019; Xie, Dai & Don, 2018a) are dividing GHG emissions into smaller categories and study how environmental tax affects for example carbon, particulate matter, sulfur, and nitrogen emissions. Mardones and Cabello (2019) argue that by extending the GHG taxes to a larger sector, Chile would reduce its carbon emissions respectively from 11% to 14%, particulate matter emissions from 48% to 98%, and sulfur emissions from 49% to 66%. Nitrogen emissions would increase respectively from 5% to 7%. Moreover, if the government would change the GHG tax level to the value of the social cost per ton emitted, additional reductions would be 44% with carbon, 96% with particulate matter, 91% with sulfur, and 2% with nitrogen. (Mardones & Cabello, 2019.) Thus, reduction of emissions is quite significant, if the tax level is set on the level of the value of the social cost per ton emitted. Referring to the previous theory chapter (chapters 2.2 and 2.3), it seems that at least in this case the environmental taxes are set too low compared to the socially optimal tax level. On the other hand, according to Ghazouani et al. (2021), it is essential to set environmental tax low enough to be optimal in all sectors. Too high tax level can create problems both for the economy and the environment.

It has also been pointed out in the literature that environmental taxes may create an incentive for developing cleaner technologies. For example, Morley (2012) finds out that environmental taxes lead to decreasing pollution through an increase in cleaner technology and not because of a decrease in energy consumption. Also, for example Hart (2008) argues that environmental taxes create an incentive for firms to invest in cleaner and greener technology. Hart is using the term "emission-saving technology" referring to this kind of technology. The emission-saving investments occur at the expense of production technology but can benefit economic growth. Production technology is referring to technology that allows more efficient use of capital and labour inputs and emission-saving technology to technology that allows more efficient use of fossil fuels. (Hart, 2008.) According to Karmaker, Hosan, Chapman, and Saha (2021), 1% increase in environmental tax in high and middle-income countries is increasing environmental-related technological innovations by approximately 0,6-0,8%.

Bashir et al. (2020) point out that in addition to environmental technology improvements, also financial development improvements are leading to decreasing carbon emissions and better environmental quality. For example, the strength of financial institutions makes them less vulnerable to different market risks and thus more willing to finance for example technological innovations (Bashir et al., 2020).

Probst and Sauter (2015) find out that CO_2 emissions are positively correlated with technological development. However, in their model they do not specify development as green development and therefore it is likely that improvement in technology does not automatically mean an increase in emission levels. A tighter GHG policy decreases overall technological advancement, but it is doing so by restricting the development of emission-intensive technologies. (Probst & Sauter, 2015.) Since in these estimations emissions are positively linked with higher technology levels, tighter GHG policy and decreasing overall technological level are good in terms of emission reduction. Also, Zhao, Yao, Sun, and Pan (2019) are getting similar results with their model. According to them, a carbon tax significantly reduces investments in coal-based power plants and on the other hand encourages investments in cleaner technology. In their model Zhao et al. model the effect of the tax on investments in wind farms. The researchers found out that already 10 Yuan/ton carbon tax can decrease investments in coal-based power plants, but the tax should be over 30 Yuan/ton or more to encourage investments in the wind farm sector. In a situation without tax, the investors will choose to invest in coal-fired power plants since the profits are higher in that sector if there is no implemented tax. (Zhao, et al., 2019.) This is a good example of a situation where one level of tax may lower investments in polluting production, but the same tax level fails to encourage investments into greener production.

This sub-chapter has brought up different positive sides that environmental taxes can cause either directly or indirectly. The estimated percentage values of environmental tax and decreasing emission levels change between studies because naturally every study uses different data from different countries and different years. Also, the estimation methods differ between studies which causes slightly different estimates. Thus, instead of focusing on the exact numeric estimates and results of studies presented above, more important is to recognize the connections between different factors that are linked to environmental taxes. For example, one important link that can be noticed when comparing the results from previous studies is the link between environmental taxes, energy consumption, and environmental technology. Environmental tax can increase renewable energy consumption since it makes fossil fuel energy more expensive than before. In the same way, the new tax level creates incentives to invest more in environmental technology and thus make the production process more energy-saving. It is also worth noting that it seems the decreasing emission levels are not only a cause of decreasing energy consumption but an increase in energy efficiency as well. From this perspective, economic growth should not be disturbed due to environmental tax. However, there are many studies which are presenting the negative relationship between economic growth and environmental taxes. The next sub-chapter focuses on this matter and additionally on some other negative sides that environmental taxes can have.

3.1.2 Possible downsides with environmental taxes

The positive effects of environmental taxation pointed out last sub-chapter seem undeniable. However, implementing an environmental tax can also have negative downsides to the economy. Hassan, Oueslati, and Rousselière (2020) have been studying the interconnection between environmental tax and economic growth. According to their results, there can be a negative correlation between environmental tax revenues and economic growth both in the short and long term. In other words, high environmental taxes can slow down economic growth. However, Hassan et al. (2020) find that the negative effect applies in the case of low-income and developing countries. In countries with higher GDP per capita rate the economy can achieve increasing growth due to the tax. One possible reason for this outcome comes from differences in production sectors. In the developing countries agriculture and industrial sectors are bigger than the service sectors and environmental tax is targeting especially raw material and physical capital use. Because these sectors are usually so important to the economy of developing countries, the environmental tax towards these inputs is decreasing economic growth. In the developed countries the service sector is usually wider than other sectors or at least wider than in developing countries. The most important input in the service sector is human capital and because the environmental tax does not target this input the effect of the tax is not so massive towards the whole economy. The developed countries have also a better capacity to invest in cleaner production and to make the production process more efficient. (Hassan et al., 2020.)

Nguyen and Kakinaka (2018) are modelling the use of renewable energy and carbon emissions, and they are also taking into consideration three different income groups: low-, middle- and high-income groups. The results reveal that for low-income countries renewable energy consumption is positively linked to carbon emissions and negatively linked with output. The results are the opposite for high-income countries. In other words, when low-income countries are using more renewable energy this decreases total output and increases the emissions. In high-income countries increase in renewable energy consumption increases the total output and decreases the emissions. (Nguyen & Kakinaka, 2018.) The results considering the renewable energy use are slightly surprising and according to Nguyen and Kakinaka they also partly differ from previous literature. According to Nguyen and Kakinaka (2018), low-income countries are less developed and thus tend to use less productive production technology. They are also more focused on supporting economic growth and for example getting rid of poverty rather than greenhouse gas emissions (Nguyen & Kakinaka, 2018). In other words, investing in renewable energy is not increasing their output levels and thus economic growth like it does more often in high-income and developed countries. Even though Nguyen's and Kakinada's study does not focus directly on environmental taxes, it could be argued based on the results that environmental taxes might not be so good option for low-income countries since environmental taxes tend to prompt the use of renewable energy like stated in the previous sub-chapter. If the results of Nguyen's and Kakinada's study are correct and consistent, then an increase in renewable energy consumption would not provide smaller emission levels and would impair the economic growth in these countries.

Some researchers point out that renewable energy and its development could help to reduce the negative impact on economic growth that environmental taxes are causing (Xie et al., 2018a). Based on the results of Nguyen and Kakinaka (2018) this could work better in high-income and developed countries than in low-income and developing countries. On the other hand, also technological improvement can have its limits if energy demand increases fast. According to Peng, Wang, Zhang, He, Taketani, Shi, and Zhu (2019), improvements in energy efficiency can lead to higher energy use in the future. In more detail, 4-5% energy efficiency improvement can increase the use of energy even by 140% (Peng et al., 2019). This development requires an enormous improvement also in renewable energy technology and in its capacity. If renewable energy production cannot produce enough energy for the increasing needs of production, there will be a temptation to take it from fossil fuels. This would again lead to increasing emission levels.

Nguyen's and Kakinada's results considering total output are similar to the results Hassan et al. (2020) got in their study. When including the results considering the impact on emission levels, the results of Nguyen and Kakinaka are supporting the environmental Kuznets curve hypothesis. The environmental Kuznets curve (EKC) is a popular hypothesis or an argument in environmental economics. According to the argument, economic growth will increase GHG emissions to some certain point. After this point, GHG emissions start to decrease while the economy and GDP keep growing. In literature, it is normal to speak about an inverted U-curve when referring to the shape of the EKC. (e.g. Mandal & Chakravarty, 2016; Haberl et al., 2020.) Empirical observations of long-lasting and wide environmental Kuznets curves are quite rare and that is why the hypothesis is controversial among researchers. It has also been pointed out that even if a long-lasting U-shape curve is observed, the emissions can increase again in the future and the curve will become so-called N- or S-shape curve. (Haberl et al., 2020.) Unlike Nguyen and Kakinaka (2018), Mandal and Chakravarty (2016) do not agree with the argument that it would be more probable to see EKC in high-income than in low-income countries. They are however pointing out that EKC theory is always depending on the context, and it cannot be generalized globally.

China is an interesting example of a country that is trying to limit its global emissions and minimize the effects on economic growth. According to the World Bank (2023b), China is considered an upper-middle-income country. Therefore, despite its economic power, it cannot fully be considered a developed country. For example, Li, Dai, Sun, Xie, Liu, Wang, and Yabar (2018), Xie, Dai, and Don (2018a), and Xie, Dai, Xie, and Hong (2018b) focus on their case studies on the emissions and economic growth of different regions of China. According to Li et al. (2018) it is possible to cut down 45% of the carbon emissions in the region of Liaoning by 2023 with a carbon tax of 221 USD/ton-CO_2. This would reduce the GDP by 5.5%. Naturally, smaller reductions in carbon emissions do not usually limit economic growth as much. (Li et al., 2018.) Such an increase of a carbon tax (and thus a decrease of GDP) seems however very unlikely to happen since the business-as-usual scenario Li et al. are using in their model refers to a situation without an environmental tax. However, China implemented an environmental protection tax in 2018 but it has been studied that at least now with this level the tax is not able to increase the incentives to invest in green innovation and the green effect of the tax is considered to be weak (Long, Lin & Ge, 2022).

Further, Xie et al (2018b) argue that implementing a carbon tax in the city of Chongqing would cause GDP losses of 1.5% to 2.5% in the same region. Xie et al. (2018a) are showing that the same environmental tax level can affect differently to the GDP in different regions. For example, Tianjin´s and Beijing´s economic growth would decrease more due to an environmental tax than the economic growth in Hebei. (Xie et al. 2018a.) The environmental tax can also affect differently to different sectors of the economy. Some sectors will be winners and some losers due to the tax implementation and in the winning sectors the tax is enabling economic growth (Xie et al., 2018b; Li et al., 2018).

The earlier studies pointed out in this sub-chapter argue that environmental taxes create bigger economic growth losses in developing countries compared to developed countries. However, environmental taxes can have a negative impact on economic growth and country´s competitiveness also in developed countries. Siriwardana, Meng, and McNeill (2011) are modelling the effects of a carbon tax on economic growth in Australia. According to the results, a 23-dollar tax per ton of carbon dioxide emissions, a tax level that was introduced in Australia in 2012, is decreasing economic growth by 0,7% in the short run. One of the greatest reasons for this is the reduction of the export volumes that the tax causes. According to Perman et al. (2011), the loss in competitiveness can cause an incentive to not implement additional environmental taxes. To prevent this kind of behaviour it has been proposed to set penalties for countries who try to avoid decreasing emissions and thus gain an advantage in better competitiveness. On the other hand, it is also possible to decrease for example labour or capital taxation after implementing the environmental tax. This could help to constrain the decrease in competitiveness. (Perman et al., 2011, pp. 220–221.) The switch of a tax burden is studied more in the next sub-chapter.

In addition to the decreasing competitiveness, also consumer prices can increase due to the tax and so household consumption will decrease. However, it has to be pointed out that in Australia´s case the carbon tax is estimated to cut down emissions by 12% in the first year (Siriwardana, Meng & McNeill, 2011) which is a considerable reduction. The long-term effects have not been studied. Also, Peng et al. (2019) are arguing that environmental tax affects people´s income level. According to their study, the tax rate of 5-15% can decrease people´s income level by 0,3-1,1%. This will create social welfare costs to the society.

According to Probst and Sauter (2015) 1% reduction in CO_2 emissions cost in the long run 0,4% of GDP on average. Since their dataset contains data from both developing and developed countries, it is possible to calculate different estimates for developing and developed countries. For developing countries 1% reduction in CO_2 emissions on average costs 0,1% of GDP and for developed countries 0,5% of GDP. Therefore, the costs of emission reduction are almost four times higher for developed countries. (Probst & Sauter, 2015.) Without again paying more attention to the exact percentage numbers, which naturally vary between studies, the results of Probst and Sauter are reverse compared to the results of Hassan, Oueslati, and Rousselière (2020) mentioned earlier in this chapter. The results can vary for many reasons for example due to different countries and study periods or different research methods used in the studies. Probst and Sauter (2015) study 46 low- and high-income countries while Hassan et al. (2020) study is limited to 31 OECD countries. The country selection can in this case cause at least part of the different results. However, the differences in the results are quite significant and thus would require more investigation.

According to Ono (2003), there is a critical tax level and if the environmental tax is set above that critical level, impacts will be harmful to economic growth. On the other hand, if the environmental tax is set below the critical tax level, the impacts will be beneficial to economic growth if the tax is increased. Thus, according to Ono, it is not certain that environmental tax can be harmful to economic growth. This argument is highly linked with the theory of optimal environmental tax rate, which is discussed earlier in Chapter 2.2. However, Ono (2003) points out that even if the optimal level of the tax is found, it is not certain that the tax level in question will be implemented in economies since tax levels are always political decisions.

It has been pointed out earlier that environmental taxes can have different effects on economic growth and GDP. Also, the effects of the environmental tax on the state of the environment are not completely clear. Environmental taxes may also have a negative effect on the state of the environment. This perspective is less mentioned and studied in the previous literature. According to Probst and Sauter (2015), if the environmental regulations are too strict, this can cause emission export to other countries with less strict environmental policies. Kandil, Hammami, and Battaïa (2022) share this result and argue that high environmental tax makes firms favour outsourcing in production. This can lead to a situation where the total GHG emissions are not decreasing globally at all even though environmental tax levels are rising. One problem with outsourcing is that it can cause bias in greenhouse gas accounting by hiding the true source of the emissions. Thus, it would be important also to pay attention to how the country-specific emissions have been calculated. There are at least three ways to calculate emission levels in a country: production-based, consumption-based, and income-based methods (Haberl et al., 2020; Karstensen, Peters & Andrew, 2018; Marques, Rodrigues, Lenzen & Domingos, 2012). If one uses only a production-based accounting method, emission outsourcing will not be seen in the results. In addition to paying attention to the accounting methods, also global environmental agreements limiting GHG emissions jointly are important together with environmental taxes.

3.1.3 Tax revenue distribution

Environmental tax revenue distribution has a significant effect when studying how effective tax is and what are the outcomes to the economy after the tax has been implemented (e.g., Morley, 2012; Xie et al., 2018b; Hassan et al., 2020). When policymakers are implementing a new environmental tax, they have to know the structure of the other taxes and study what the consequences to these tax levels are after the new tax has been implemented (Morley, 2012). Many studies are suggesting a tax revenue system that is channelling tax burden for example from labour, individual income, and social security taxes to activities and processes that cause harm to the environment. This kind of double dividend solution is discussed briefly already in the theory chapter.

Xie et al. (2018b) and Yamazaki (2022) are suggesting neutral tax revenue where the total tax level remains the same. According to Xie et al. (2018b), this means that when environmental tax is implemented in economy, some other taxes are being decreased so that the total tax revenue stays the same. This will optimize the national tax structure but also reduce the social welfare costs of taxation (Xie et al., 2018b) which was shortly mentioned in the last sub-chapter. The tax burden will however change after implementing the environmental tax and usually the tax burden is tried to move from households to the emitting firms.

One way to introduce a neutral tax revenue is to introduce a lump-sum payment at the same time with an environmental tax. It has been argued that a lump-sum system should be introduced with a new tax always when it is possible. Nevertheless, lump-sum payment systems are rather rare. (Perman et al., 2011, pp. 221.) Still, there are some studies and real-life examples of lump-sum payment systems and their possibilities. For example, Siriwardana et al. (2011) suggest an annual lump-sum payment of 685 Australian dollars to every household in the country after implementing the tax of 23 dollars per ton of carbon dioxide emissions. The researchers argue that this sum is likely to be a neutral strategy to compensate the tax revenues and have public support for the carbon tax (Siriwardana et al., 2011).

Tax revenue-recycling and lump-sum payment systems have already been introduced in Canada. According to Yamazaki (2022), environmental taxes are lowering productivity but a revenue-recycling system can compensate otherwise decreasing productivity. The system implemented in British Columbia is recycling the tax revenues by reducing the rate of income taxes at both personal and corporate levels and further setting a lump-sum transfer to low-income households. It has been estimated that the carbon tax of 50 Canadian dollars/t CO_2 equivalent is reducing the productivity in British Columbia by 1,2%, but the revenue-recycling system is compensating for the loss of productivity by 0,2%. Thus, the net loss of productivity is 1%, which is rather a small reduction according to the paper. The 50 Canadian dollar tax was introduced in British Columbia in 2022 and the earlier level of the tax was 35 Canadian dollars. (Yamazaki, 2022.) Also, Jonsson, Ydstedt, and Asen (2020) are studying Canada´s revenue-recycling system and arguing that its features should be considered also in Scandinavia. However, some studies also argue that lump-sum payment is not as good a revenue distribution system as a system that cuts down some taxes while environmental tax is being raised. According to Sumner, Bird, and Dobos (2011), cost saving is greater in the tax rate shifting case compared to the lump-sum system. However, this can also be a very country-bound issue since countries have very different ways what it comes to for example transferring income between high- and low-income households. It is highly possible that a lump-sum payment system would work better in some other countries compared to different countries. Further, researchers also have to know each system very well to be truly able to compare different approaches.

An additional possibility for tax revenue distribution is not to give the revenues straight to the consumers as lump-sum payments or decrease other taxes but to invest the additional tax revenues. Some studies suggest that the most efficient way to further affect the state of the environment is to direct the revenues for example to research and development in energy saving and environmental protection sectors. According to Xie et al. (2018b), tax revenue distribution to subsidize environmentally cleaner production is as important as making the environmental tax in a way that the total tax revenues are neutral. According to Bhat and Mishra (2019), India is using this strategy and investing carbon tax revenues in research and development on low-carbon emitting technologies. Revenues can be directed straight to environmental programs or first to the government. However, the latter case can be problematic if the public sees this as an attempt to only raise revenue for governments and not as an attempt to decrease overall emissions and improve the state of the environment. (Sumner et al., 2011.)

Environmental tax revenue distribution can also influence how much economic growth or welfare will be affected by the environmental tax. According to Hassan et al. (2020), the reduced tax burden on labour and income can lead to a positive effect on labour supply and saving and investing decisions. Oueslati (2015) compares systems where tax revenues go to further emission reduction through investments for example to education and abatement, and a system where tax revenues are used to reduce wage tax or profit tax. According to Oueslati, redistributing tax systems can improve economic growth and social welfare in the long term but the welfare costs are relatively high, and economic growth slower in the transition period. The results also show that regardless of the public spending policy, it is more efficient for economic growth to reduce wage tax than to reduce profit tax (Oueslati, 2015).

Hassan et al. (2020) argue that in economies where environmental tax revenue is being redistributed to other sectors of the economy, the link between environmentally related tax revenues and the economic growth rate is statistically significant and negative both in the short and in the long term. The link is not statistically significant in economies without a redistributing system. (Hassan et al., 2020.) In other words when there is a lot of emitting production in the economy, the tax revenues are higher and economic growth slower. When production is changing towards cleaner production, the tax revenues are decreasing, and economic growth is faster. According to Hassan et al. (2020), the results show that if a country has a revenue recycling system, it seems that in those countries the environmental tax level has a stronger effect on economic growth than in countries without a redistributing system. This could mean that if a revenue recycling system is implemented, this would give the country more control over how much GDP is affected by the environmental tax. However, drawing more conclusions from these results would require more investigation and this matter is not studied further in this thesis.

3.2 Models and methodologies used in environmental tax literature

As the literature on environmental taxes and their effects is broad, it is quite natural that also the number of methods and models used in the literature is broad. Ghazouani et al. (2021) point out that the chosen methodology and variables as well as the studied period affect the results. Table 1 shows example studies where different methodological and variable choices have been made between different researchers. As one can see, results between these studies however seem to lean in the same direction. As the results have been introduced earlier in this chapter, this sub-chapter is focusing on the models and methodologies used in the studies.

Probst and Sauter (2015) use both economy-wide and sector-level data sets in their study when modelling both developed and developing countries´ emissions between 1990-2010. The researchers are using structural spatial VAR (vector autoregressive) methodology. According to the researchers, their model uses a lot of interdependent variables which would need several instrumental variables in the modelling. With the VAR approach they can use their full dataset without losing the data and without having to create a large number of instrumental variables. In their model anthropogenic CO_2 emissions, GHG policy stringency, technology, energy prices, and GDP are endogenous variables in the model. Further, the model includes dummies for panel-specific fixed effects, period-specific common shocks, and error term. (Probst & Sauter, 2015.)

Sen and Vollebergh (2018) use both ordinary least square (OLS) and instrumental variable (IV) estimations in their model and they argue that their OLS estimation results can include bias towards zero. According to the researchers, the exogeneity of energy tax might not be a good assumption in the model. This means that countries might have different preferences over different tax rates and these characteristics are not observed and therefore not considered in the model. In the IV estimation Sen and Vollebergh use the energy taxes of the neighbour countries as an instrument variable. Sen´s and Vollebergh´s IV estimation results show a stronger effect between energy tax and emission reduction than OLS estimation results.

Loganathan, Mursitama, Pillai, Khan, and Taha (2020) use quantile estimation based on data from four decades instead of OLS estimation in their model where they study Malaysian environmental tax and its effect on GHG emissions. Like Sen and Vollebergh (2018) also Loganathan et al. (2020) argue that OLS regression is facing bias estimation results. One reason for this is that socioeconomic factors are usually not random, and they contain some similar patterns. In other words, used variables are not normally distributed. Due to this reason, the identically disturbance (i.i.d) condition that OLS would require does not hold. Also, Nguyen and Kakinaka (2018) argue that the OLS estimator is asymptotically biased and creates endogeneity and serial correlation problems. A better alternative for OLS according to Nguyen and Kakinaka is to use the FMOLS estimator.

Also, Bashir, MA, Shahbaz, and Jiao (2020) are using quantile estimation in their study. They are also using system-GMM and pooled OLS methods. The system-GMM (Generalized Method of Moments) is a good method if the growth model has a lot of countries and fewer periods. It can also help if there is endogeneity between control variables and problems with fixed effects. In this study pooled OLS and quantile estimation are being used to test the robustness of the results. (Bashir et al., 2020.) Doğan, Chu, Ghosh, Truong, and Balsalobre-Lorente (2022) argue that the GMM method will create inconsistent estimates because this method does not assume cointegration among environmental quality variables. Because previous literature finds cross-sectional dependence and cointegration among environmental quality variables, modelling requires other estimation methods like DOLS and FMOLS (Doğan et al., 2022).

FMOLS (fully modified OLS) and DOLS (dynamic OLS) methodologies seem to form a small majority in environmental tax and carbon emission modelling. Table 1 summarizes the studies of Doğan et al. (2022), Ghazouani et al. (2021) and Bashir, MA, Shahbaz, Shahzad, and Vo (2021) but also for example Bhattacharya, Churchill, and Paramati (2017), Wang, Jebli, Madaleno, Doğan, and Shahzad (2021), and Doğan, Driha, Balsalobre-Lorente, and Shahzad (2020) have used these methodologies in their studies. According to Ghazouani et al. (2021), FMOLS and DOLS are suitable long-run techniques, and they are able to correct possible endogeneity bias and residual serial correlations. According to Bashir et al. (2021), DOLS is good for studies with cross-sectional and country-specific coefficients because this technique includes independent variables´ lags and removes the concerns by taking a parametric approach. It does so by adding past and future values of the first difference of the independent variables (Doğan et al., 2022). On the other hand, FMOLS is a non-parametric method, and it controls the problems of autocorrelation and endogeneity (Bashir et al., 2021). It also limits the lags and is suitable for relatively short study periods which is in the study of Doğan et al. 21 years in total (Doğan et al., 2022).

Also, the computable general equilibrium (CGE) method has been used in several previous studies. For example, Li et al. (2018), Xie et al. (2018a), Xie et al. (2018b), Benavente (2016), and Siriwardana et al. (2011) are using this methodology in their studies. All of these studies focus only either on one country or one region within one country. According to Xie et al. (2018a), CGE models are broadly used when studying for example taxes, subsidies, quotas, transfer instruments, and overall long-term economic implications of climate change policy. According to Benavente (2016), the general equilibrium method has three assumptions: zero profit condition, market clearance, and balanced budget. The basic idea of the method is to estimate the equilibrium prices that allow substitution between goods and primary factors. The production and consumption can be modelled for example with Leontief, Cobb-Douglas, and Constant Elasticity of Substitution (CES). The computable general equilibrium method needs also a benchmark data set, to which the results are being compared to. (Benavente, 2016.)

Table 1. Example studies.

Study	**Data**	**Methodology**	**Variables**	**Main results**
(1) Probst & Sauter, (2015)	Economy-wide dataset: 46 developed and developing countries, 1990-2010. Sector-level dataset: 34 sectors and 35 countries, 1995-2009	Structural spatial VAR	Anthropogenic CO2 emissions, GHG policy stringency, GDP, technology, energy prices, corruption, cooling degree days, heating degree days	Policy stringency reduces GHG emissions, and the reduction can be 15% in countries without earlier regulation. Policy stringency also improves sectoral CO2 efficiency and decreases the dirtiest production sector by 25%. CO_2 reduction costs are large, but 4 times more to developed countries than developing countries.
(2) Sen & Vollebergh, (2018)	35 OECD and non-OECD countries, cross sectional data sets	IV-regression (and OLS)	Energy demand, tax inclusive fuel prices, GDP level, population, long-run responsiveness of energy demand to taxes, fuel-specific effects (oil, natural gas, coal, and peat), control for sectoral differences, own tax, neighbours´ tax (instrument variable), user (sector) dummy, fuel (resource) dummy	In the long run 0,73% carbon emission reduction from fossil fuel consumption is possible with one euro increase in energy taxes.
(3) Loganathan et. al., (2020)	Malaysia, 1970-2018	Quantile estimation	Per capita carbon emissions from the energy consumption, total factor of production, total natural resource rents, petroleum tax revenues	Green taxation is reducing carbon emissions in the upper quantiles. However, the effect is negative in lower and upper quantile levels. Natural resource stocks doesn´t have effect on carbon emissions. The results reject EKC hypothesis.
(4) Bashir et. al., (2020)	OECD countries, 1995-2015	System-GMM, pooled OLS and quantile regression	Carbon emissions, renewable energy, economic growth, environmental taxation, the development of environmental technology, financial intermediation efficiency, financial system´s size, financial globalization	Environmental tax has a negative effect and economic growth has a positive effect on carbon emissions. Renewable energy consumption, environmental technology, and financial development decrease carbon emissions.
(5) Doğan et. al., (2022)	G7 countries, 1994-2014	FMOLS, DOLS	Carbon emissions, energy consumption, renewable energy consumption, natural resources rent, GDP per capita, economic complexity, environmental tax	Strict environmental taxes shift production towards cleaner production and reduce CO2 emissions. The marginal effects of the environmental taxes on energy consumption, natural resources, and renewable energy consumption rise as the tax level rises.

Table 1. (continued)

Study	**Data**	**Methodology**	**Variables**	**Main results**
(6) Ghazouani et. al., (2021)	9 leading European economies, 1994-2018.	FMOLS, DOLS and quantile regression	Greenhouse gas, environmental taxes, renewable energy, environmental technology, urban population, GDP per capita	Increase in environmental tax, renewable energy consumption, and environmental technology reduces GHG emissions. The estimated reduction is varying between used methods. Urbanization and income level growth increase overall GHG emissions.
(7) Bashir et. al., (2021)	29 OECD countries, 1994-2018	FMOLS; DOLS and panel quantile regression	Energy consumption, energy intensity, taxes, urbanization, financial development, trade, growth	Environmental taxes reduce energy consumption and energy intensity. They create incentives for manufacturers to invest in environmentally friendly and energy-saving equipment. Urbanization is increasing energy consumption and energy intensity on medium and high quantiles. Trade openness has a decreasing effect on energy consumption and energy intensity on low quantiles.
(8) Benavente, (2016)	Chile, 2010. The economy is divided into 111 industries and 177 commodities.	CGE	Armington supply of commodity i, aggregate household consumption, household demand for commodity i, domestic demand for commodity i, aggregate exports, export demand for commodity i, aggregate public good, government demand for commodity i, government budget surplus, household savings, aggregate investment, investment demand for commodity i, intermediate demand for commodity i by industry j, capital demand industry j, labour demand industry j, lump sum tax rebatement multiplier, imports of commodity i, international trade deficit, lump sum transfer from government to household, production of commodity i by industry j	20% reduction of GHG emissions due to a carbon tax of 26 USD/t CO_2. The carbon tax reduces Chile´s GDP by 2,3% if both consumers and producers are being taxed, and 2% if only producers are being taxed. The carbon tax affects the renewable sector which increases by 43,3%. The price of electricity will increase by 8%.

4 EMPIRICAL ANALYSIS

4.1 Data

This study analyses the impact of environmental taxes on countries´ pollution levels. The panel data used in this study has been derived from annual observations from 2000 to 2021, and includes variables for the state of the environment, total environmental tax revenues, energy tax revenues, transport tax revenues, pollution and resource tax revenues, economic power, economic complexity, renewable energy consumption, primary energy consumption, urban population, and corruption. The chosen variables are based on which variables have been used in the earlier literature. This literature and list of variables can also be seen in Table 2 below.

The period from 2000 to 2021 has been chosen because some data before this period is not available. For example, there is no available data in Eurostat for tax revenues in Europe before the year 1995. Further, in many countries renewable energy consumption does not have observations before the year 2000. This lack of data could cause problems in the estimation and thus the study period starts from the year 2000 and not from 1995. The renewable energy consumption variable has some missing values also in the chosen study period, but the number of these cases is considerably lower and more random than if the years 1995-1999 were included in the data.

The overall data includes 25 European countries of which 24 belong to the European Union. From countries in the European Union Malta, Luxembourg, and Cyprus have been left out of the study due to unavailable data. All of these countries are missing data either in economic complexity, renewable energy consumption, or primary energy consumption variables. Further, Island, Switzerland, and the UK are left out of the study also due to unavailable data.

However, Norway has been added to the study, being the only country outside of the European Union that is included in the dataset.

The variable data has been taken from many different sources and the sources are listed in Table 2. The data for environmental tax revenues (total, energy, transport, and pollution and resource) has been retrieved from Eurostat. Also, the way environmental taxes have been divided and classified in this data source has formed the basis of how these taxes are also classified and separated in this study. Many earlier studies are taking environmental tax into the model

Table 2. Summary of the variables and their data sources.

Variable	**Symbol**	**Measurement**	**Source**	**Papers supporting variable use**
State of environment	GHG	Greenhouse gas emissions in tons per capita	Eurostat, database (2023)	Probst & Sauter, (2015), Loganathan et al., (2020), Bashir et al., (2020), Doğan et al., (2022), Ghazouani et al., (2021)
Total environmental tax	TET	Tax revenues, % in GDP	Eurostat, database (2023)	Sen & Vollebergh, (2018), Bashir et al., (2020), Doğan et al., (2022), Ghazouani et al., (2021), Bashir et al., (2021)
Energy tax	ET	Tax revenues, % in GDP	Eurostat, database (2023)	Sen & Vollebergh, (2018)
Transport tax	TT	Tax revenues, % in GDP	Eurostat, database (2023)	Aydin & Bozatli (2022)
Pollution/resource tax	PRT	Tax revenues, % in GDP	Eurostat, database (2023)	Durst (2016)
Economic power	GDP	GDP per capita, Constant 2015 US$	World Bank, DataBank (2023)	Doğan et al. (2022), Ghazouani et al. (2021), Probst & Sauter, (2015), Sen & Vollebergh, (2018)
Economic complexity	CPL	Index computed using SITC product classification	The Growth Lab at Harvard University, (2019)	Doğan et al., (2022)
Renewable energy consumption	RC	Exajoules, input-equivalent	Energy Institute, (2023)	Bashir et al., (2020), Doğan et al., (2022), Ghazouani et al., (2021)
Primary energy consumption	PEC	Exajoules, primary energy consumption	Energy Institute, (2023)	Doğan et al., (2022), Bashir et al., (2021)
Urban population	UPOP	Total urban population	World Bank, DataBank (2023)	Ghazouani et al., (2021), Bashir et al., (2021)
Corruption	COR	Control of Corruption: Estimate (ranging from approximately -2.5 to 2.5, where -2.5 is the worst)	World Bank, DataBank (2023)	Probst & Sauter, (2015)

as one variable measuring the effect of the total environmental tax level on the state of the environment or for example on the energy consumption. There are also studies that focus on one of the smaller tax groups and examples of these studies have been listed in the table above. However, it is quite rare that all of the smaller tax categories have been taken into the study. For this reason, this study is separating different environmental taxes based on the data separation in Eurostat´s data and focuses on studying are there differences between energy tax, transport tax, and pollution and resource tax on how they affect the pollution levels.

The data for variables of economic power, urban population, and corruption has been retrieved from the World Bank´s data sources. The economic power includes the data for GDP per capita, urban population the total population that lives in urban areas, and corruption the estimates for control of corruption. For example, Probst and Sauter (2015), Ghazouani et al. (2021), and Doğan et al. (2022) use GDP in their model to measure economic power. Another option for this would be to use economic growth which for example Bashir et al. (2021) are using. Data for economic complexity has been retrieved from The Growth Lab at Harvard University (2019). For example, Doğan et al. (2022) are taking the economic complexity as part of their model. Further, for example Bashir et al. (2021) and Ghazouani et al. (2021) include urbanization or urban population as a control variable in their model to avoid data biases. In addition, urbanization is in their model considered as an indicator of social and economic transformation and thus describes socioeconomic activities. Finally, data for renewable energy consumption and primary energy consumption is retrieved from the database of the Energy Institute and is measured as exajoules. For example, Doğan et al. (2022), Ghazouani et al. (2021), Bashir et al. (2021), and Bashir et al. (2020) are taking at least one of these two variables into their model.

4.2 Methodology and model

The empirical study follows the existing literature by Bashir et al. (2021), Doğan et al. (2022), and Ghazouani et al. (2021), and specifies the following model specification that is being tested empirically:

$$\begin{aligned}\ln(GHG)_{i,t} = {} & \beta_0 + \beta_1 \ln(TET)_{i,t} + \beta_2 \ln(GDP)_{i,t} + \beta_3 CPL_{i,t} + \beta_4 \ln(RC)_{i,t} + \beta_5 \ln(PEC)_{i,t} \\ & + \beta_6 \ln(UPOP)_{i,t} + \beta_7 COR_{i,t} + \beta_8 lnTET_{i,t} \times lnPEC_{i,t} + \varepsilon_{i,t} \qquad (6)\end{aligned}$$

$$\begin{aligned}\ln(GHG)_{i,t} = {} & \beta_0 + \beta_1 \ln(ET)_{i,t} + \beta_2 \ln(TT)_{i,t} + \beta_3 \ln(PRT)_{i,t} + \beta_4 \ln(GDP)_{i,t} + \beta_5 CPL_{i,t} \\ & + \beta_6 \ln(RC)_{i,t} + \beta_7 \ln(PEC)_{i,t} + \beta_8 \ln(UPOP)_{i,t} + \beta_9 COR_{i,t} \\ & + \beta_{10} lnET_{i,t} \times lnPEC_{i,t} + \beta_{11} lnTT_{i,t} \times lnPEC_{i,t} + \beta_{12} lnPRT_{i,t} \times lnPEC_{i,t} \\ & + \varepsilon_{i,t} \qquad (7)\end{aligned}$$

The first of these two equations (equation 6) includes a variable for the total environmental tax revenues (TET) and in the latter equation (equation 7) total environmental tax revenues are separated into three different variables: energy tax revenues (ET), transport tax revenues (TT), and pollution and resource tax revenues (PRT). The explained variable is the state of environment (GHG), and the other variables are economic power (GDP), economic complexity (CPL), renewable energy consumption (RC), primary energy consumption (PEC), urban population (UPOP), and corruption (COR). Both equations include also interaction terms that combine environmental taxes and primary energy consumption and measure their combined effect. The natural logarithm is taken for all of the other variables except economic complexity and corruption which are index variables. Adding logarithms allows percentage interpretation of the results and normalizes the distribution of the variables and thus it is possible to avoid scaling problems (Doğan et al. 2022).

As stated earlier in Chapter 3.2, FMOLS and DOLS are chosen as methodological approaches in this study. FMOLS and DOLS methods avoid the problem of endogeneity bias and serial correlation of residuals and are good methods for studying long-run relationships (Ghazouani et al., 2021; Bashir et al., 2021; Doğan et al., 2022). According to Doğan et al. (2022), these methods are considered superior when it comes to studying the cointegrating relationship between variables. Because earlier literature shows that this kind of cointegration and cross-sectional dependence can exist between environmental quality variables, FMOLS and DOLS are the best approaches with models that include these kinds of variables. For example, the Generalized Method of Moments (GMM) and Two-Stage Least Squares (2SLS) would lead to bias in results with variables that are cointegrated and cross-sectional dependent, since they are not assuming these qualities in variables. Since FMOLS is a non-parametric method, it needs a parametric method to be used with it. DOLS suits well to be used with FMOLS, as it considers the cointegration between variables. (Doğan et al., 2022.) To be sure that FMOLS and DOLS are suitable methodologies, it is necessary to test if the variables truly are cointegrated and cross-sectional dependent. The next paragraphs present three different preliminary tests that are computed before starting the long-run analysis. The FMOLS and DOLS functions can be seen in the Appendix 4.

Cross-sectional dependence test:

Like in Bashir´s et al. (2021), Doğan´s et al. (2022), and Ghazouani´s et al. (2021) studies, the analysis starts with several preliminary tests to make sure that the estimation method used in the study is appropriate. The preliminary analysis starts with checking cross-sectional dependence. According to Bashir et al. (2021), Doğan et al. (2022), and Ghazouani et al. (2021), cross-sectional dependence is an important statistical tool that tests is there cross-sectional dependence in the panel data. If the data includes cross-sectional dependence, and this is not considered when choosing the methodology in the study, this can create inefficient estimators and bias the standard errors (Doğan et al., 2022). The cross-sectional dependence test was introduced in Pesaran's (2004) study, where he presented an alternative test for the Lagrange multiplier (LM) test introduced by Breusch and Pagan in 1980. According to De Hoyos and Sarafidis (2006), the cross-sectional dependence test is suitable for cases where T is small when N → ∞. The empirical form of the cross-sectional dependence test (CD) is presented in the following equation:

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right)} \tag{8}$$

where N is the size of the sample, T is the time and ρ_{ij} is the estimation of cross-sectional correlation of residuals for the countries i and j (De Hoyos & Sarafidis, 2006).

Unit root test:

According to Ghazouani et al. (2021), the cross-sectional dependence test needs to be supplemented with a unit root test. Doğan et al. (2022) and Bashir et al. (2021) are both using Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) panel unit root tests that are based on the Dickey-Fuller (ADF) procedure. According to Bashir et al., the difference between these tests is that the LLC test assumes that autoregressive parameters are common between cross-sections, and on the other hand, the IPS test assumes that autoregressive parameters vary between cross-sections. Ghazouani et al. (2021) use a cross-sectional augmented IPS (CIPS) unit root test in their study. This belongs to the group of two generations of panel root tests and the aim of these tests is to take cross-sectional dependencies into account (Hurlin & Mignon, 2007). The empirical form for testing unit root for cross-sectional augmented IPS (CIPS) is:

$$\Delta x_{i,t} = \alpha_{i,t} + \beta_i x_{i,t-1} + \rho_i T + \textstyle\sum_{j=1}^{n} \theta_{i,j} \Delta x_{i,t-j} + \varepsilon_{i,t} \tag{9}$$

where Δ is the difference operator, $x_{i,t}$ is the independent variable, α is the individual intercept, T is the time, and ε refers to the error term (Ghazouani et al., 2021). In this study unit root test is carried out with the CIPS test because variables most likely include cross-sectional dependency. However, the test results of LLC and IPS unit root tests are also presented making it possible to compare the test results.

Cointegration test:

Finally, before the long-run analysis, in all three studies a panel cointegration test is implemented which according to Ghazouani et al. (2021) checks the long-run empirical nexus between the variables. Ghazouani et al. (2021) and Bashir et al. (2021) are using both the Westerlund and Pedroni cointegration methods. Doğan et al. (2022) are using Pedroni´s cointegration test. Instead of using the Pedroni or Westerlund test, in this study it has been chosen to use the Kao cointegration test which also for example Kasperowicz, Bilan, and Štreimikienė (2020) are using in their study beside Westerlund and Pedroni tests. The Kao cointegration test is the third option from the cointegration tests. This approach has been chosen because, in Pedroni and Westerlund tests, there cannot be more than seven covariates in $X'_{i,t}$, in other words, regressors in the model. According to Kasperowicz, Bilan, and Štreimikienė (2020), all three cointegration tests (Kao, Westerlund, and Pedroni) are based on the same equation which is presented below:

$$y_{i,t} = X'_{i,t}\beta_i + z'_{i,t}\delta_i + \varepsilon_{i,t} \tag{10}$$

where $X_{i,t}$ indicates covariates, β_i indicates the cointegrating vector and δ_i indicates the vector of coefficients on $z_{i,t}$. Finally, $\varepsilon_{i,t}$ is the error term. The null hypothesis is the same for all Kao, Westerlund, and Pedroni cointegration methods which is that $y_{i,t}$ and $X_{i,t}$ have no cointegration relationship. Further, all tests also require that covariates are not cointegrated between themselves. (Kasperowicz et al., 2020.) In this study $y_{i,t}$ stands for the state of the environment and $X_{i,t}$ for all the covariates. Thus, rejecting the null hypothesis means that there is a cointegration relationship between the variables in the long run (Ghazouani et al., 2021).

Causality test:

Many earlier studies also provide causality test results after the long-term analysis to check the robustness of the results. Both Doğan et al. (2022) and Karmaker et al. (2021) use the Dumitrescu-Hurlin causality test for heterogenous panel data. This test was developed by Dumitrescu and Hurlin (2012) and it also enables the use of heterogenous panel data and accepts the presence of cross-sectional dependence. In comparison to the Dumitrescu-Hurlin causality test, there is another and newer causality test that also allows cross-sectional dependence and cross-sectional heteroskedasticity. This has been developed by Juodis, Karavias, and Sarafidis (2021) and is called a bias-corrected test for Granger non-causality or Half-Panel Jackknife (HPJ) non-causality test. Because the test has been developed very recently, there are not yet a lot of studies using this approach. However, for example Nwani, Usman, Okere, and Bekun (2023) use the test successfully in their research paper where they study the effect of energy and carbon intensity on emission levels. According to Xiao, Juodis, Karavias, and Sarafidis (2021), the Half-Panel Jackknife non-causality test follows the following equation:

$$y_{i,t} = \emptyset_{0,i} + \sum_{p=1}^{P} \emptyset_{p,i} y_{i,t-p} + \sum_{p=1}^{P} \beta_{p,i} x_{i,t-p} + \varepsilon_{i,t} \tag{11}$$

Where parameter $\emptyset_{0,i}$ indicates the individual-specific effects, $\emptyset_{p,i}$ indicates the heterogeneous autoregressive coefficients, and $\beta_{p,i}$ indicates the heterogeneous feedback coefficients or Granger causality parameters. $\varepsilon_{i,t}$ is the error term and i = 1, …, N and t = 1, …, T and p = 1, …, P. The null hypothesis of the test is that $x_{i,t}$ does not Granger-cause $y_{i,t}$. In other words, the null hypothesis can be written as:

$$H_0: \quad \beta_{p,i} = 0, \qquad \text{for all } i \text{ and } p. \tag{12}$$

In the alternative hypothesis $\beta_{p,i}$ does not equal zero. (Xiao, Juodis, Karavias & Sarafidis, 2021.) In this thesis, both the Dumitrescu-Hurlin causality test and the Half-Panel Jackknife non-causality test are being used. Both of these tests fail to give results for some variables or models but together it is possible to draw conclusions from the results of these two tests.

5 RESULTS AND DISCUSSION

The chapter is divided into two parts. Chapter 5.1 presents the results from preliminary analysis and more precisely results for the cross-sectional dependence test, unit root tests, and cointegration test. Chapter 5.2 presents the results for long-term analysis including FMOLS and DOLS modelling and causality tests. In the end, the weaknesses of the study are also discussed briefly.

5.1 Preliminary analysis

The descriptive statistics

Table 3 presents descriptive statistics of the variables used in the empirical analysis. As we can see from the table, the differences between different countries are relatively large. For example, the minimum and maximum values for the state of the environment vary from -11,4 to 159,2 GHG in tons per capita and Latvia is the only country with negative values. The explanation for these negative values is unknown. From the table, it is also possible to see that overall energy taxes bring more revenues to countries than transport tax and especially pollution and resource tax. The values for pollution and resource tax are small for all countries and for example Germany has zero revenues from pollution and resource tax during the whole study period.

There are also many countries with different economic backgrounds. The GDP per capita changes from 3721 euros to 88 967 euros and economic complexity from 0,018 to 2,45 while the means for these variables are 28 566 euros and 1,17. There are also differences in renewable energy and primary energy consumption. Especially eastern and south-eastern European countries like Estonia, Latvia, Lithuania, Bulgaria, Croatia, Hungary, and Romania are consuming quite little renewable energy. On the other hand, primary energy consumption is greater in bigger countries like Germany, Spain, France, and Italy, and in these countries also the consumption of renewable energy is bigger. Also, corruption variable statistics vary between countries even though all the countries included in the study are in Europe and, all except Norway, in the European Union. Romania, Greece, Croatia, and Bulgaria get negative values for the corruption variable during the study period.

Table 3. Descriptive statistics.

Variable	Observations	Mean	Std. dev.	Min	Max
GHG	550	80.987	27.913	-11.4	159.2
TET	550	2.618	0.614	1.16	5
ET	550	1.956	0.466	0.74	3.3
TT	550	0.560	0.394	0.04	2.15
PRT	550	0.102	0.111	0	0.49
GDP	550	28566	17959	3721	88967
CPL	550	1.174	0.512	0.018	2.445
RC	539	0.161	0.314	0	2.446
PEC	550	2.628	3.343	0.136	14.626
UPOP	550	13 000 000	16 400 000	897 427	64 500 000
COR	525	1.004	0.822	-0.511	2.460

Cross-sectional dependency test

The preliminary tests are started with the cross-sectional dependency test. The null hypothesis is that there is cross-sectional independence in the data. Table 4 below shows the results of the cross-section dependence test. From the table we can see that other variables except economic complexity and corruption are getting p-values close to zero. With all other variables null hypothesis can be rejected at 1% level of significance except with pollution and resource tax null hypothesis can be rejected at 5% level of significance. This result supports the use

Table 4. Results of the cross-section dependence test.

Variable	CD-test	p-value
GHG	25.978	0.000
TET	7.157	0.000
ET	4.038	0.000
TT	9.92	0.000
PRT	2.797	0.005
GDP	56.131	0.000
CPL	-0.906	0.365
RC	74.25	0.000
PEC	31.046	0.000
UPOP	9.355	0.000
COR	-1.101	0.271

Notes: Under the null hypothesis of cross-section independence, CD ~ N(0,1). P-values close to zero indicate data is correlated across panel groups.

of FMOLS and DOLS which are methods that take cross-sectional dependence into account. For economic complexity and corruption, the null hypothesis cannot be rejected. Economic complexity and corruption are both index variables.

Unit root test

Thus, earlier results of the cross-section dependence test indicate that there is dependency between panel groups, the panel unit root test is prosecuted with the cross-sectional augmented IPS (CIPS) approach. The results from this test can be seen in Table 5. Also, first-generation panel unit root test results with the IPS and LLC tests can be seen in Table 6. According to Ghazouani et al. (2021) and Doğan et al. (2022), to have unit roots in the same order and thus prove cointegration relationship, variables should be stationary at least after the first difference. It can be seen from Tables 5 and 6 that for most variables the null hypothesis can be rejected at 1% level of significance at first difference with all three tests. The null hypothesis in the unit root test is that all panels contain unit roots. Rejecting a null hypothesis means that some panels in the data are stationary.

The most interesting variables according to the tests are pollution and resource tax, renewable energy consumption, urban population, and corruption. These variables and their results have to be examined carefully. According to CIPS and LLC, the pollution and resource tax variable is stationary, and the null hypothesis can be rejected at 1% level of significance. IPS test does not give a result for this variable because the test needs at least 6 observations per panel with balanced data. The data for pollution and resource tax variable includes more zero values within the study period than other tax revenue variables. For example, for Germany and Greece, the revenues from pollution and resource tax have been zero for the whole or almost the whole study period referring to that in these countries such tax has not been implemented in most of the study period. Because the other tests are rejecting the null hypothesis and it can be assumed that the problems with the IPS test arise from the missing observations, it is concluded that with the variable pollution and resource tax the null hypothesis can be rejected.

The CIPS and LLC tests do not give results for renewable energy consumption variable because the data contains gaps for these variables and is not strongly balanced. However, the missing values for this variable appear occasionally and not for example in some specific year. On the other hand, with the IPS test the null hypothesis can be rejected at 1% level of significance. Again, it can be assumed that missing observations cause the technical problems, and it is concluded that with the renewable energy consumption variable the null hypothesis can be rejected. However, this rejection is not so strong than others since two of the three tests do not provide results for the variable.

The values for urban population are the most interesting ones because according to CIPS the null hypothesis cannot be rejected for this variable and with IPS only at 10% level of significance. The LLC test is the only test that would allow rejecting the null hypothesis at 1% level of significance. In this case, missing values cannot explain the test results and the reasons for inconsistency in the results are unknown. On the other hand, the results from other variables are quite clear and there is stationary in the data. This is why inconsistency in the results of one variable does not cause changes to the methodology that has been chosen to use. Also, the earlier cross-section dependency test revealed that there is cross-sectional dependence also in the urban population variable indicating that the use of FMOLS and DOLS is possible. With the corruption variable it can be stated that even though the CIPS test does not give results for the variable in levels due to gaps in data, all three tests give results in the first difference that the null hypothesis can be rejected.

Table 5. Results of CIPS unit root test.

	Specification without trend		*Specification with trend*	
Variable	Level	First difference	Level	First difference
GHG	-2.057	-4.608***	-2.434	-4.786***
TET	-1.412	-4.368***	-2.418	-4.378***
ET	-1.569	-4.265***	-2.697**	-4.263***
TT	-2.101*	-4.028***	-2.495	-4.155***
PRT	-1.798	-3.749***	-1.970	-4.396***
GDP	-1.558	-2.961***	-1.315	-3.210***
CPL	-1.974	-4.939***	-2.763**	-4.992***
RC	-	-	-	-
PEC	-2.369***	-4.864***	-3.123***	-4.752***
UPOP	-2.371***	-1.846	-2.085	-1.977
COR	-	-4.159***	-	-4.126***

The symbols ***, **, and * refer to level of significance at 1%, 5%, and 10% respectively.

Table 6. Results of LLC and IPS unit root tests.

	LLC unit root test statistic		*IPS unit root test statistic*	
Variable	Level	First difference	Level	First difference
GHG	-0.567	-9.120***	1.204	-11.510***
TET	0.345	-6.576***	2.231	-10.221***
ET	-0.932	-7.946***	0.568	-10.029***
TT	-2.717**	-9.226***	-0.107	-10.467***
PRT	-4.072***	-7.221***	-	-
GDP	-0.743	-5.862***	3.346	-10.456***
CPL	-3.690***	-9.667***	-1.852**	-12.737***
RC	-	-	15.284	-7.251***
PEC	-0.095	-9.340***	-1.912**	-12.782***
UPOP	-5.329***	-9.794***	1.022	-1.613*
COR	-1.024	-6.797***	-0.268	-10.435***

The symbols ***, **, and * refer to level of significance at 1%, 5%, and 10% respectively.

Cointegration test

As stated before, the cointegration test is made for data that is noticed to be stationary and to find out if there is a long-run empirical relationship between the explained variable and control variables. In this study, the Kao test is being used to test cointegration since in Pedroni and Westerlund tests there cannot be more than seven regressors in the model. The null hypothesis in the Kao test is that there is no cointegration. The results of the Kao test for cointegration can be seen in Table 7. As we can see, all other tests except the augmented Dickey-Fuller test give a result that the null hypothesis can be rejected at least at 5% level of significance. According to the augmented Dickey-Fuller test, the null hypothesis can be rejected at 10% level of significance, but the value is closer to the level 5% than 10%. The results suggest that there is most likely a long-run cointegrated relationship between the explained variable and control variables, although the augmented Dickey-Fuller t-test is a bit above the 5% statistical significance level.

Table 7. Results of the Kao test for cointegration.

Cointegration test	**Statistic**	**p-value**
Modified Dickey-Fuller t	-1.687	0.046
Dickey-Fuller t	-2.551	0.005
Augmented Dickey-Fuller t	-1.571	0.058
Unadjusted modified Dickey-Fuller t	-4.567	0.000
Unadjusted Dickey-Fuller, t	-4.016	0.000

After completing all three preliminary tests, it can be confirmed that the data includes cross-sectional dependence and stationery and that there is long-run cointegration between the explained variable and control variables. This allows FMOLS and DOLS to be used in the long-run analysis which is presented in the next section. In addition, also correlations between all the variables have been listed in Appendix 5.

5.2 Long-run analysis

The long-run analysis is done with FMOLS and DOLS methods and the results for heterogeneous cointegrated panels are reported in Tables 8 and 9. In the first two models with both FMOLS and DOLS techniques, only environmental taxes and renewable energy consumption have been included in the models as control variables. In the third and fourth models, gross domestic product (to measure economic power) and economic complexity have been added to the model. Further, in the fifth and sixth models also primary energy consumption, urban population, and corruption have been added to the model. The seventh and

Table 8. Long-run estimates using FMOLS.

	FMOLS (1)	FMOLS (2)	FMOLS (3)	FMOLS (4)	FMOLS (5)	FMOLS (6)	FMOLS (7)	FMOLS (8)
lnTET	0.483*** (0.146)		0.632*** (0.14)		0.408*** (0.064)		0.396*** (0.057)	
lnET		0.75*** (0.136)		0.687*** (0.098)		0.471*** (0.055)		0.324*** (0.043)
lnTT		0.093* (0.049)		0.16*** (0.036)		0.054*** (0.019)		-0.026 (0.022)
lnPRT		-0.002 (0.037)		0.052* (0.028)		0.043*** (0.015)		-0.02 (0.015)
lnGDP			0.941*** (0.195)	0.947*** (0.149)	0.554*** (0.098)	0.62*** (0.058)	0.54*** (0.085)	0.424*** (0.058)
CPL			0.342*** (0.086)	0.434*** (0.076)	0.071 (0.084)	0.169*** (0.065)	0.196** (0.076)	0.314*** (0.055)
lnRC	-0.029*** (0.011)	-0.026** (0.013)	-0.109*** (0.013)	-0.102*** (0.012)	-0.039*** (0.012)	-0.043*** (0.008)	-0.052*** (0.012)	-0.047*** (0.006)
lnPEC					1.235*** (0.095)	1.157*** (0.068)	1.28*** (0.095)	1.105*** (0.078)
lnUPOP					-0.731*** (0.219)	-0.649*** (0.153)	-0.577*** (0.202)	-0.726*** (0.149)
COR					0.029 (0.041)	0.025 (0.03)	0.004 (0.037)	0.096*** (0.029)
lnTETxlnPEC							-0.278*** (0.044)	
lnETxlnPEC								-0.273*** (0.037)
lnTTxlnPEC								-0.129*** (0.019)
lnPRTxlnPEC								0.076*** (0.016)
Adjusted R-squared	0.67	0.66	0.72	0.71	0.83	0.82	0.83	0.83
Sum squared residuals	30.64	28.3	25.68	23.95	12.08	11.22	11.7	10.5

The symbols ***, **, and * refer to level of significance at 1%, 5%, and 10% respectively.

Table 9. Long-run estimates using DOLS.

	DOLS (1)	DOLS (2)	DOLS (3)	DOLS (4)	DOLS (5)	DOLS (6)	DOLS (7)	DOLS (8)
lnTET	0.391** (0.162)		0.542*** (0.161)		0.398*** (0.132)		0.371*** (0.12)	
lnET		0.575*** (0.177)		0.547*** (0.16)		0.416*** (0.148)		0.272** (0.118)
lnTT		0.073 (0.059)		0.137** (0.062)		0.076 (0.054)		0.005 (0.056)
lnPRT		-0.0008 (0.044)		0.042 (0.043)		0.039 (0.044)		-0.034 (0.046)
lnGDP			0.863*** (0.22)	0.877*** (0.249)	0.576*** (0.214)	0.65*** (0.241)	0.581*** (0.206)	0.536*** (0.207)
CPL			0.276** (0.112)	0.333*** (0.122)	0.025 (0.15)	0.064 (0.172)	0.111 (0.138)	0.17 (0.146)
lnRC	-0.024** (0.011)	-0.019 (0.014)	-0.097*** (0.015)	-0.09*** (0.017)	-0.035** (0.017)	-0.037** (0.019)	-0.046*** (0.017)	-0.041** (0.017)
lnPEC					1.193*** (0.173)	1.103*** (0.195)	1.305*** (0.189)	1.343*** (0.285)
lnUPOP					-0.932** (0.375)	-1.001** (0.43)	-0.862** (0.354)	-1.22*** (0.421)
COR					0.038 (0.074)	0.031 (0.089)	-0.001 (0.076)	0.102 (0.088)
lnTETxlnPEC							-0.306** (0.156)	
lnETxlnPEC								-0.319** (0.148)
lnTTxlnPEC								-0.152** (0.061)
lnPRTxlnPEC								0.141** (0.056)
Adjusted R-squared	0.67	0.67	0.72	0.71	0.75	0.74	0.76	0.77
Sum squared residuals	31.03	28.64	26.69	24.86	22.46	21.32	21.64	18.49

The symbols ***, **, and * refer to level of significance at 1%, 5%, and 10% respectively.

eighth models take into the model interaction term for environmental tax and primary energy consumption.

As can be seen in Tables 8 and 9, total environmental tax has a positive coefficient with all the models to where it has been added. These models are the first, third, fifth, and seventh models. These are very surprising results since this indicates that a raise in total environmental tax would also increase greenhouse gas emissions. The results for this control variable are similar regardless is the model estimated with FMOLS or DOLS. The results are also statistically significant at the level of 1% or 5%. In the previous literature, the results in similar studies and with similar models are opposite. For example, all Doğan et al. (2022), Bashir et al. (2021), Ghazouani et al. (2021), Bashir et al. (2020), and Doğan et al. (2020), are getting results where an increase in total environmental tax has a negative impact to greenhouse gas emissions. The results are also against intuition.

Similar kinds of results continue in the second, fourth, sixth, and eighth models with energy tax. The coefficient for the transport tax variable seems to be positive in all the other models except in the eighth model with FMOLS. However, the results are only statistically significant at least at the level of 5% with FMOLS in the fourth and sixth models and with DOLS in the fourth model. The pollution and resource tax variable gets also negative values for the coefficients with both FMOLS and DOLS methods, but these values are not statistically significant. The pollution and resource tax variable gets the least statistically significant values compared to other tax variables. Only the sixth model with FMOLS provides statistically significant value for the pollution and resource tax variable.

It is hard to say a specific reason why the results differ from previous literature. Naturally, the study period and the countries included in the study differ from previous literature. However, it is hard to believe that countries in the European Union plus Norway would differ so much for example from G7 countries that Doğan et al. (2022) are using or from OECD countries that Bashir et al. (2021) are using. Ghazouani et al. (2021) are even using also European Union countries in their study like it is mostly done in this study. Thus, country selection cannot be the reason behind the different results. Another reason for differences can be that the models include variables for which change is quite difficult to estimate. Not all the reasons that lead to the variable change can be controlled in the model. For example, environmental tax levels are always political decisions and therefore they can change for example due to elections. This is a challenge with this kind of variables and data.

One challenge can also be that tax levels might not change so much between countries. If we look at Appendix 2, we can see that there are differences between the tax levels in different countries but sometimes the differences are not that great. Also, pollution and resource tax seem to be quite constant and low in all of the countries. This could be one reason why the estimated coefficients for pollution and resource tax fail to be statistically significant with both FMOLS and DOLS methods. Further, small differences in other environmental taxes between study countries can cause statistical significance problems also to their coefficients. However, this cannot explain why the estimated coefficients show a positive correlation between environmental taxes and greenhouse gas emissions.

In the seventh and eighth models, the interaction term between the environmental tax and primary energy consumption is added to the model. The interaction term shows what kind of effect these two variables have on greenhouse gas emissions together. The interaction terms are negative and statistically significant at the level of 1% with FMOLS and at the level of 5% with DOLS for total environmental tax, energy tax, and transport tax. The results suggest that 1% increase in the interaction term of total environmental tax and primary energy consumption decreases greenhouse gas emissions by 0,28% (FMOLS) or 0,31% (DOLS). Similar estimates for energy tax are 0,27%(FMOLS) or 0,32% (DOLS) and for transport tax 0,13% (FMOLS) or 0,15% (DOLS). Only the interaction term for pollution and resource tax and primary energy consumption has a positive and statistically significant coefficient with both FMOLS and DOLS. These results indicate that 1% increase in the interaction term of pollution and resource tax and primary energy consumption would increase greenhouse gas emissions by 0,08% (FMOLS) or 0,14% (DOLS).

The results suggest that total environmental tax, energy tax, and transport tax decrease primary energy consumption, and this leads to decreasing greenhouse gas emissions. We can see in models 5-8 that a one percent increase in primary energy consumption leads to a multiple times larger increase in greenhouse gas emissions. When the interaction term and its coefficients are negative this gives a signal that environmental taxes are restricting the increase in primary energy consumption which has a decreasing effect on greenhouse gas emissions. On the other hand, pollution and resource tax is so low in all study countries that this could explain why it does not have enough power to restrict primary energy consumption as much as the other environmental taxes. These results are consistent with earlier literature. For example, Doğan et al. (2022) also add an interaction term between total environmental tax and energy consumption variables. The results are similar to this study and the researchers find that the interaction term has a negative effect on greenhouse gas emissions. In one of the models that Doğan et al. (2022) are estimating, the coefficient for total environmental tax is positive while the interaction term is negative. The results of this particular model are completely similar to this study. However, other models in the study of Doğan et al. (2022) show a negative coefficient for interaction term but also for the coefficient of total environmental tax.

Unlike results for environmental taxes, the results for renewable energy consumption are consistent with the previous literature and much more straightforward. The models indicate that a one percent increase in renewable energy consumption would decrease greenhouse gas emissions by 0,03%-0,12% (FMOLS) or 0,02%-0,1% (DOLS) depending on the model. The coefficient for the renewable energy consumption variable is negative in all of the eight models and is statistically significant at the level of 1% or 5% in all the models estimated with the FMOLS method and in all of the models except in the second model estimated with DOLS. The results for renewable energy consumption are also logical and follow intuition – increasing the level of renewable energy consumption leads to decreasing greenhouse gas emissions. For example, Bhattacharya et al. (2017), Doğan et al. (2020), Bashir et al. (2020), Wang et al. (2021), Ghazouani et al. (2021), and Doğan et al. (2021) present similar results. Some of these studies are also continuing the research by investigating how renewable energy can also affect the other explaining variables. For example, Doğan et al. (2020) argue that economic complexity affects renewable energy consumption and they both, together and separately, have negative and decreasing affection to greenhouse gas emissions.

Also, results for primary energy consumption, gross domestic product, and corruption are consistent with previous literature. An increase in these variables also increases the greenhouse gas emissions. Similar results for gross domestic product and economic growth get for example Doğan et al. (2020), Bashir et al. (2020), Bashir et al. (2021), Doğan et al. (2022), and Ghazouani et al. (2021). Results for primary energy consumption are similar to what Doğan et al. (2022) estimate in their model. In this study, results for both GDP and primary energy consumption are statistically significant at the level of 1% with all the models they are included in and with both methods.

Economic complexity seems to have a positive relation to greenhouse gas emissions. For example, according to the results of the fourth model, an increase in economic complexity leads also to increasing greenhouse gas emissions at the statistically significant level of 1%. Economic complexity is statistically significant at least at the level of 5% in all other models except the fifth one with FMOLS but with DOLS only in the third and fourth models. In models 5-8 the estimated coefficients are not statistically significant. The reason for this is not clear. The variable does not include any missing values so this cannot be the cause behind the results. One reason can be that the variation of this variable is not very large between the study countries which could make it much more difficult to find the causal connection. If the data also include data from outside of Europe, this variable could have more statistically significant results also with DOLS. The previous literature is not consequent when considering how this variable affects greenhouse gas emissions. Doğan et al. (2022) present similar results that have been obtained in this study. However, Doğan et al. (2020) argue that economic complexity has a decreasing relation to greenhouse gas emissions. It is difficult to say why the results differ this much. Like in this study, also in the other two studies FMOLS and DOLS are used when estimating the models. Doğan et al. (2020) use different interaction terms in the study, and they do not take environmental tax into their model as an explaining variable. This could be one reason for the different results. However, it would require more investigation to be able to say why the results are different.

Although the results for the corruption variable are similar to previous literature, the estimated coefficients have the same problem as economic complexity with statistical significance. The coefficient is only statistically significant in the eighth model with FMOLS and never significant with DOLS. The reasons for this can be similar to the economic complexity although the corruption variable also includes some missing values. The missing values can be one reason why the corruption variable fails to produce statistically significant values more than economic complexity. Also, differences in corruption levels within the study countries are relatively small although there are exceptions. For example, Bulgaria, Greece, Croatia, and Romania stand out from the data with their negative values. However, the differences would be greater if the data would include countries outside of Europe. On the other hand, in the model where the coefficient for corruption is statistically significant, the results are consistent with the results of Probst and Sauter (2015), who also include corruption in their model to explain greenhouse gas emissions.

Urban population is another interesting variable that gets different estimated coefficients in this model compared to the earlier literature. Both Bashir et al. (2021) and Ghazouani et al. (2021) are adding urban population into their model and argue that an increase in urban population also increases greenhouse gas emissions. Also, Doğan et al. (2020) and Wang et al. (2021) present similar results compared to these studies. The results in this study are the opposite and the estimated negative and statistically significant coefficients indicate that a one percent increase in urban population would decrease the greenhouse gas emissions by 0,65%-0,73% (FMOLS) or 0,86%-1,22% (DOLS) depending a bit on which model is examined. Again, it cannot be said for sure what causes the different results. The reasons can be similar to what has already been reflected earlier in this chapter when considering the different results for environmental taxes. Bashir et al. (2021) argue that urban population can affect negatively the state of the environment by increasing the demand for limited resources and increasing energy consumption in urban areas. On the other hand, it can also promote economic development and innovations (Bashir et al., 2021). One other possible explanation can be found in the unit root test results. As stated earlier in this chapter, only the LLC unit root test provides statistically significant estimates for urban population. The same reasons that affect the results of IPS and CIPS unit root tests could possibly also explain different results in FMOLS and DOLS estimations.

The adjusted R-squared, in other terms coefficient of determination, increases when more explaining variables are added into the model. The adjusted R-squared value is the highest in the seventh and eighth models with FMOLS and in the eighth model with DOLS. Overall, it can be said that FMOLS provides on average more statistically significant values than DOLS. This can also be seen in the values of the coefficient of determination. The adjusted R-squared values suggest that for example, the seventh and eighth models can explain about 83% (FMOLS) or 76-77% (DOLS) of the greenhouse gas emissions. The rest of the variation in the explained variable is included in the error term and cannot be explained with these models. The values for the adjusted R-squared are quite modest when comparing for example to Doğan et al. (2022) but on the other hand more rewarding compared to Bashir et al. (2021). However, as said many times in this thesis, sometimes comparing actual estimated values too precisely is not meaningful since the data and included variables are always a bit different.

Causality test

Like in some earlier studies, also in this study causality test is provided to identify causal relationships between variables and to ensure robustness of the results. This study provides two different causality tests. The reason for this is that both tests fail to estimate some aspects of the models but together they can provide more reliable results than alone. The results of the Dumitrescu-Hurlin causality test are shown in Table 10 and the Half-Panel Jackknife causality test in Table 11.

The Dumitrescu-Hurlin causality test does not provide results for variables that include missing data. This is the reason why the test fails to give results to pollution and resource tax, renewables consumption, and corruption. However, the results that the test manages to estimate for the rest of the variables are also informatic and interesting. Based on the test results there are two kinds of statistically significant causality flow between variables. Between greenhouse gas emissions and GDP and greenhouse gas emissions and economic complexity the causality goes only to one direction. Based on the test results both GDP and economic complexity have a causal relationship to greenhouse gas emissions and changes in these two variables do cause changes in greenhouse gas emission levels. With these parts, the test results are similar to the results of Doğan et al. (2022). Also, total environmental tax, energy tax, transport tax, primary energy consumption, and urban population have a causal effect on greenhouse gas emissions, but the causality flows also in the other direction. Based on the Dumitrescu-Hurlin panel causality test results greenhouse gas emissions also cause changes in all of these variables. These kinds of results where causality flow goes in both directions are not unique. For example, Doğan et al. (2022) also argue that energy consumption and greenhouse gas emissions have a causality flow in both directions. However, Doğan et al. (2022) argue that the causality flow goes only one way from total environmental taxes to greenhouse gas emissions. Again, the reasons for differing results are not clear, but it is reasonable to think that they might be similar to what has already been discussed earlier with some of the results for FMOLS and DOLS estimators.

Thus, the results and interpretation of the FMOLS and DOLS estimators change after the addition of the interaction terms also the connection between environmental taxes and primary energy consumption has been studied with the Dumitrescu-Hurlin panel causality test. The results show that there is a causality flow from total environmental tax and transport tax to primary energy consumption. In other words, changes in total environmental tax and transport tax are causing changes also in primary energy consumption. On the other hand, in the case of the energy tax, the causality goes both ways. This seems quite a logical result; if the primary energy consumption is high the tax revenues that the government would get specifically from energy tax are also higher meaning that it would be an attractive target for politicians to tax. Further, an increase in energy tax is also changing the level of primary energy consumption. This later logic applies also to total environmental tax and transport tax. The connection between primary energy consumption and pollution and resource tax stays unknown due to the missing data and the properties of a Dumitrescu-Hurlin panel causality test.

Table 10. Results of Dumitrescu-Hurlin panel causality test.

Null hypothesis	Z-bar tilde statistics	Causality flow
GHG ≠ TET	3.70***	TET ↔ GHG
TET ≠ GHG	2.92***	
GHG ≠ ET	2.02**	ET ↔ GHG
ET ≠ GHG	3.37***	
GHG ≠ TT	4.28***	TT ↔ GHG
TT ≠ GHG	3.40***	
GHG ≠ PRT	-	-
PRT ≠ GHG	-	
GHG ≠ GDP	7.38***	GDP → GHG
GDP ≠ GHG	1.66*	
GHG ≠ CPL	3.15***	CPL → GHG
CPL ≠ GHG	1.27	
GHG ≠ RC	-	-
RC ≠ GHG	-	
GHG ≠ PEC	5.11***	PEC ↔ GHG
PEC ≠ GHG	8.27***	
GHG ≠ UPOP	10.13***	UPOP ↔ GHG
UPOP ≠ GHG	7.41***	
GHG ≠ COR	-	-
COR ≠ GHG	-	
PEC ≠ TET	4.64***	TET → GHG
TET ≠ PEC	1.82*	
PEC ≠ ET	3.60***	ET ↔ GHG
ET ≠ PEC	3.51***	
PEC ≠ TT	4.86***	TT → GHG
TT ≠ PEC	1.44	
PEC ≠ PRT	-	-
PRT ≠ PEC	-	

The symbols ***, **, and * refer to level of significance at 1%, 5%, and 10% respectively.

The results of the newer Juodis, Karavias, and Sarafidis (2021) bias-corrected test for Granger non-causality test that is also called Half-Panel Jackknife can be seen in Table 11. Also, this test has difficulties in providing results when there is some missing data for some variables. However, the test manages to provide results to the model where total environmental tax is being part of. The test is done for the seventh model that was estimated with FMOLS and DOLS, and which includes all of the explaining variables including the interaction term between total environmental tax and primary energy consumption. According to the results, the null hypothesis that selected variables do not Granger-cause greenhouse gas emissions can be rejected at the 5% level of statistical significance. Also, the eighth model which includes energy tax, transport tax, and pollution and resource tax was tried to test with the Half-Panel

Jackknife non-causality test, but the test failed to give results for this model due to the missing data especially in pollution and resource tax variable. However, it is possible to assume that the results for the eighth model would be quite similar to the results of the seventh model since total environmental tax consists of these three more specific taxes, and nothing else changes between the seventh and eighth models apart from the additional interaction terms. Thus, it can be argued based on the results of both causality test results that the used explaining variables do have a causal effect on greenhouse gas emissions. A more specific and accurate research with a longer data period could however help to provide clearer results also for models where total environmental tax is being separated into smaller tax categories.

Table 11. Results of Half-Panel Jackknife non-causality test.

H_0: Selected covariates do not Granger-cause lnGHG	**HPJ Wald test**	**p-value**	**Decision**	**Conclusion**
Model 7 (with total environmental tax)	18.03**	0.021	Reject H_0	Selected covariates do Granger cause lnGHG

The symbols ***, **, and * refer to level of significance at 1%, 5%, and 10% respectively.

Weaknesses of the study

Despite the findings and merits of the model, this study has also some weaknesses like all studies have. One of these weaknesses is that some of the control variables include missing data. For example, Germany and Greece do not have pollution and resource tax in the whole or almost in the whole study period. This problem could have been solved by deleting Germany and Greece from the model. However, this was not seen appropriate way to handle the problem especially because Germany is the biggest economy in the European Union. Thus, the study would have lost credibility if this kind of country is not included in the study. However, some control variables were deleted in the modelling process, because they included a notable number of missing data. These variables were economic growth and environmental technology. After deleting these variables from the model, the coefficient of determination decreased, but the coefficients of different variables changed to statistically more significant. Another reason for this decision is that environmental technology was seen to be connected to renewable energy consumption and economic growth to economic power (measured with GDP). Some variables including missing data were however left to the model. These variables are pollution and resource tax, renewable energy consumption, and corruption.

Renewable energy consumption and corruption variables include missing data, particularly at the beginning of the study period. However, the variables were seen as so important that it was decided to keep them in the model. The study period is quite short since some of the variable data starts from 2000 and thus the study period cannot be longer with the chosen variables. The shorter the study period the more problematic the lack of data is in the regression. A short study period makes it difficult to see differences between different countries especially when the model consists of variables that are usually quite stable. The variables used in this study can be said to be quite stable and permanent. For example, economic complexity and corruption are good examples of variables that change relatively little in such a short study period that has been used in this study. Also, environmental tax revenues are quite permanent as can be seen in Appendix 2 although in some countries there is more variation in the tax revenues between the years. For example, greenhouse gas emissions per capita seem to be an example of a variable that changes more over the years. The development of greenhouse gas emissions can be seen in Appendix 1 for every country that is included in the model. The variation in greenhouse gas emissions per capita over the years can be good, thus then it could mean that the level of emissions can be changed more easily. On the other hand, this could also mean that some exogenous shocks can more easily change the emission levels.

6 CONCLUSIONS

The study of increasing greenhouse gas emissions and sustainable transition of the economy is not a new topic in the field of economic research, even though sometimes this research seems to leave in the shadow of for example economic growth literature. Also, the use of environmental taxes in the sustainable transition has been studied broadly and many countries have been implementing environmental taxes into their economies. The research on environmental taxes is essential since it has been argued that environmental taxes can achieve greenhouse gas emission reduction in the most cost-effective way. Environmental taxes can also achieve economic and social efficiency in emission reduction if the tax has been set to the right level. However, this can be hard since it is almost impossible to know all the damages increasing emissions and global middle-temperature cause. All of these damages should be included in the damage function as it has been demonstrated in Chapter 2.2.

This thesis has been focusing on total environmental taxes and how they affect greenhouse gas emissions. On the other hand, total environmental taxes have also been divided into energy tax, transport tax, and pollution and resource tax since this classification is possible to do in the Eurostat database where the data for these variables has been collected. Also, there are few studies in the earlier literature where this kind of classification and grouping of different environmental taxes has been made, which makes the topic even more important to study. The long-run estimation methods that have been used in this study are FMOLS and DOLS and these methods allow cross-sectional dependence and cointegration of the variables that earlier literature has suggested that environmental variables normally include.

The main findings to answer the research questions are that alone both total environmental taxes and smaller environmental tax groups (energy tax, transport tax, and pollution and resource tax) seem to have a positive causal connection to greenhouse gas emissions. This result is against both common knowledge and previous literature. The only way that environmental taxes would have a negative effect on the state of the environment is when some of the greenhouse gas emissions are outsourced to countries with less strict environmental policies (e.g. Probst & Sauter, 2015). The models of this study do not include greenhouse gas outsourcing into the model. However, when the interaction term for each environmental tax and primary energy consumption is added to the model the connection turns to negative for all other taxes except for pollution and resource tax. This can imply that environmental taxes (apart from pollution and resource tax) affect greenhouse gas emissions, particularly through primary energy consumption. Thus, when environmental tax is increased that affects decreasingly to primary energy consumption which on the other hand decreases also greenhouse gas emissions. This theory gets support from the Dumitrescu-Hurlin panel causality test where it is shown that environmental tax levels have a causal effect on primary energy consumption. Another result to highlight is that according to the model an increase in renewable energy consumption will decrease greenhouse gas emissions regardless of which method, FMOLS or DOLS, is being used. Also, the results stay quite similar regardless is the model including total environmental tax or energy tax, transport tax, and pollution and resource tax.

The cause for differences between the results provided by this study and the results provided by previous literature is unclear. The possible reasons have been discussed more in the previous chapter but as a summary, the differences can be explained for example with missing data, especially in the case of pollution and resource tax. Also, in some parts, there seem to be quite small changes between the tax levels and their development within one country but also compared to other study countries. This can be at least partly explained by the short study period which starts from 2000 and ends in 2021. Another reason can be the fact that some of the variables, for example, economic complexity and corruption are very stable and change slowly. Furthermore, maybe the most logical explanation for the results can be found behind politics. In a perfect world, politicians in all of the study countries would care for the environment equally and set higher environmental taxes if their country produces more greenhouse gas emissions. However, implementing environmental tax and deciding its level is always a political choice. Behind the decision making there can also be other goals for setting environmental tax than improving the environment. The composition of the government changes over time and within countries and thus also the principles of decision-making are always a bit different. Thus, it can also be the case in this model that not all the study countries are raising the environmental taxes when the greenhouse gas emissions per capita are rising. This naturally would affect the results of the model and could explain at least partly why the model shows a positive connection between environmental taxes and greenhouse gas emissions. However, this does not explain why in earlier literature these kinds of results do not exist. This part remains unclear and would be a good topic for future research to study.

This thesis does not take political aspects into account in the model except by including corruption variable in the model. Since politics have a certain effect on environmental tax levels it would be valuable to try to take this aspect better into account in future economic models. Also, dividing the environmental taxes into smaller groups like energy tax, transport tax, and pollution and resource tax is an advantage because by including them it is possible to make more accurate conclusions about the efficiency of each smaller tax group. For example, based on this research energy tax has been noticed to have a greater effect on greenhouse gas emissions than transport tax, and especially pollution and resource tax have. Energy tax revenues are also greater in all of the study countries compared to transport and pollution and resource tax revenues. The third aspect to which future research should pay more attention among with taking politics and separated environmental tax groups into the modelling is to study how large sectors are targeted with environmental taxes and to which sectors the tax is not affecting. As shortly discussed in this thesis many countries are protecting some sectors of their economy from environmental taxes. More specific research on these sectors and how a possible environmental tax extension could affect not only the greenhouse gas emissions but also the economic growth of the country could provide important information for policymakers in the future. Overall, environmental tax research stays important in the future when countries are decreasing their emission levels through decreasing fossil fuel consumption as confirmed in the latest climate change conference in Saudi Arabia.

REFERENCES

Asmi, F., Anwar, M.A., Zhou, R., Wang, D. & Sajjad, A. (2019). Social aspects of `climate change communication´ in the 21st century: a bibliometric view. *Journal of environmental planning and management*, vol. 62 (14), pp. 2393–2417.

Aydin, M. & Bozatli, O. (2022). Do transport taxes reduce air pollution in the top 10 countries with the highest transport tax revenues? A country-specific panel data analysis. *Environmental Science and Pollution Research*, vol. 29, pp. 54181–54192.

Bashir, M. F., MA, B., Shahbaz, M. & Jiao, Z. (2020). The nexus between environmental tax and carbon emissions with the roles of environmental technology and financial development. PLoS ONE, vol. 15 (11): e0242412. Available at: https://doi.org/10.1371/journal.pone.0242412.

Bashir, M. F., MA, B., Shahbaz, M., Shahzad, U. & Vo, X.V. (2021). Unveiling the heterogeneous impacts of environmental taxes on energy consumption and energy intensity: Empirical evidence from OECD countires. *Energy*, vol. 226, 120366.

Baumol, W.J. & Oates, W.E. (1971). The use of standards and prices for protection of the environment. In: Bohm, P., Kneese, A. V. (eds). The Economics of Environment. Palgrave Macmillan, London. Availabe at: https://doi-org.ezproxy.jyu.fi/10.1007/978-1-349-01379-1_4.

Bayramoglu, B., Finus, M. & Jacques, J.F. (2018). Climate agreements in a mitigation-adaptation game. *Journal of public economics*, vol. 165, pp. 101–113.

Benavente, J.M.G. (2016). Impact of a carbon tax on the Chilean economy: A computable general equilibrium analysis. *Energy Economics*, vol 57, pp. 106–127.

Bhat, A.A. & Mishra, P.P. (2020). Evaluating the performance of carbon tax on green technology: evidence from India. *Environmental Science and Pollution Research*, vol. 27, pp. 2226–2237.

Bhattacharya, M., Churchill, S.A. & Paramati, S.R. (2017). The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. *Renewable Energy*, vol. 111, pp. 157–167.

Breton, M. & Sbragia, L. (2017). Adaptation to climate change: commitment and timing issues. *Environmental and resource economics*, vol. 68, pp. 975–995.

Breusch, T.S. & Pagan, A.R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The review of economic studies*, vol. 47(2), pp. 239–253.

Climate Action Tracker. (2023). Temperatures. Retrieved 30.12.2023 from https://climateactiontracker.org/global/temperatures/.

Crippa, M., Guizzardi, D., Banja, M., Solazzo, E., Muntean, M., Schaaf, E., Pagani, F., Monforti-Ferrario, F., Olivier, J., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Jacome Felix Oom, D., Branco, A., San-Miguel-Ayanz, J. & Vignati, E. (2022). CO2 emissions of all world countries. JRC/IEA/PBL 2022 Report, EUR 31182 EN, Publications Office of the European Union, Luxembourg. doi:10.2760/730164.

De Hoyos, R.E. & Sarafidis, V. (2006). Testing for cross-sectional dependence in panel data models. The Stata journal, vol. 6 (4), pp. 482–496.

Distefano, T. & D`Alessandro, S. (2023). Introduction of the carbon tax in Italy: Is there room for a quadruple-dividend effect? *Energy economics*, vol. 120, 106578.

Doğan, B., Driha, O.M, Balsalobre-Lorente, D. & Shahzad, U. (2020). The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. *Sustainable Development*, vol. 29 (1), pp. 1–12.

Doğan, B., Chu, L.K., Ghosh, S., Truong, H.H.D. & Balsalobre-Lorente, D. (2022). How environmental taxes and carbon emissions are related in the G7 economies? *Renewable Energy*, vol. 187, pp. 645–656.

Dumitrescu, E.I. & Hurlin, C. (2012). Testing for Granger non-causality in heterogenous panels. *Economic modelling*, vol. 29(4), pp. 1450–1460.

Durst, M.C. (2016). Improving the performance of natural resource taxation in developing countries. ICTD Working paper 60. Available at SSRN: http://dx.doi.org/10.2139/ssrn.3120472.

Energy Institute. (2023). Statistical review of world energy. Retrieved 29.12.2023 from Home | Statistical Review of World Energy (energyinst.org).

European Environment Agency. (2023). Total net greenhouse gas emission trends and projections in Europe. Retrieved 2.12.2023 from Total net greenhouse gas emission trends and projections in Europe (europa.eu).

Eurostat. (2023). Glossary: Carbon dioxide equivalent. Retrieved 28.12.2023 from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent.

Eurostat, database. (2023). Database. Retrieved 29.12.2023 from https://ec.europa.eu/eurostat/web/main/data/database.

Ghazouani, A., Jebli, M.B. & Shahzad, U. (2021). Impacts of environmental taxes and technologies on greenhouse gas emissions: contextual evidence from leading emitter European countries. *Environmental science and pollution research*, vol. 28, pp. 22758–22767.

Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fisman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., Mayer, A., Pichler, M., Schaffartzik, A., Sousa, T., Streeck, J. & Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: Synthesizing the insights. *Environmental Research Letters, 15*(6), 65003.

Hart, R. (2008). The timing of taxes on CO_2 emissions when technological change is endogenous. *Journal of environmental economics and management*, vol. 55(2), pp. 194–212.

Hassan, M., Oueslati, W. & Rousselière, D. (2020). Environmental taxes, reforms and economic grow analysis of panel data. *Economic Systems,* vol. 44, 100806.

Hsiang, S., Oliva, P. & Walker, R. (2019). The distribution of environmental damages. *Economics and policy*, vol. 13(1), pp. 83–103.

Hurlin, C. & Mignon, V. (2007). Second generation panel unit root tests. Working papers, halshs-00159842. Retrieved 22.10.2023 from https://shs.hal.science/halshs-00159842.

Jonsson, S., Ydstedt, A. & Asen, E. (2020). Looking back on 30 years of carbon taxes in Sweden. Tax foundation. *Fiscal fact*, No. 727.

Juodis, A., Karavias, Y. & Sarafidis,V. (2021). A homogeneous approach to testing for Granger non-causality in heterogeneous panels. *Empirical economics*, vol. 60, pp. 93–112.

Kandil, N., Hammami, R. & Battaïa, O. (2022). Insourcing versus outsourcing under environmental considerations and different contract arrangements. *International journal of production economics*, vol. 253, 108689.

Karmaker, S.C., Hosan, S., Chapman, A.J. & Saha, B.B. (2021). The role of environmental taxes on technological innovation. *Energy*, vol. 232, 121052.

Karstensen, J., Peters, G.P. & Andrew, R.M. (2018). Trends of the EU's territorial and consumption-based emissions from 1990 to 2016. *Climatic Change*, vol. 151(2), pp. 131–142.

Kasperowicz, R., Bilan, Y. & Štreimikienė, D. (2020). The renewable energy and economic growth nexus in European countries. *Sustainable Development*, vol. 28, pp. 1086–1093.

Li, Z., Dai, H., Sun, L., Xie, Y., Liu, Z., Wang, P. & Yabar, H. (2018). Exploring the impacts of regional unbalanced carbon tax on CO2 emissions and industrial competitiveness in Liaoning province of China. *Energy Policy,* vol. 113, pp. 9–19.

Loganathan, N., Mursitama, T.N., Pillai, L.L.K, Khan, A. & Taha, R. (2020). The effects of total factor of productivity, natural resources and green taxation on CO2 emissions in Malaysia. *Environmental science and pollution research*, vol. 27, pp. 45121–45132.

Long, F., Lin, F. & Ge, C. (2022). Impact of China's environmental protection tax on corporate performance: Empirical data from heavily polluting industries. *Environmental impact assessment review*, vol 97, 106892.

Mandal, S.K. & Chakravarty, D. (2016). Is environmental Kuznets curve a universal phenomenon? -an econometric analysis of the existing studies. *Journal of Developing Areas*, vol. 50(6), pp. 261–276. doi:10.1353/jda.2016.0133.

Mardones, C. & Cabello, M. (2019) Effectiveness of local air pollution and GHG taxes: the case of Chilean industrial sources. *Energy Economics*, vol. 83, pp. 491–500.

Marques, A., Rodrigues, J., Lenzen, M. & Domingos, T. (2012). Income-based environmental responsibility. *Ecological Economics*, vol. 84, pp. 57–65.

Masih, R. & Masih, A.M.M. (1996). Stock-Watson dynamic OLS (DOLS) and error-correction modelling approaches to estimating long and short-run elasticities in a demand function: new evidence and methodological implications from an application to the demand for coal in mainland China. *Energy Economics*, vol. 18., pp. 315–334.

Morley, B. (2012). Empirical evidence on the effectiveness of environmental taxes. *Applied economics letters*, vol. 19, pp. 1817–1820.

Muller, N. Z. & Mendelsohn, R. (2009). Efficient pollution regulation: getting the prices right. *American economic review*, vol. 99(5), pp. 1714–1739.

Nguyen, K.H. & Kakinaka, M. (2018). Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. *Renewable Energy*, vol. 132, pp. 1049–1057.

Nwani, C., Usman, O., Okere, K.I. & Bekun, F.V. (2023). Technological pathways to decarbonisation and the role of the renewable energy: A study of European countries using consumption-based metrics. *Resources Policy*, vol. 83, 103738.

Ono, T. (2003). Environmental tax policy and long-run economic growth. *The Japanese economic review*, vol. 54 (2), pp. 203–217.

Oueslati, W. (2015). Growth and welfare effects of environmental tax reform and public spending policy. *Economic modelling*, vol. 45, 1–13.

Pedroni, P. (2000). Fully modified OLS for heterogeneous cointegrated panels. *Department of Economics Working Papers*, Department of Economics, Williams College.

Peng, J.T., Wang, Y., Zhang, X., He, Y., Taketani, M., Shi, R. & Zhu, X.D. (2019). Economic and welfare influences of an energy excise tax in Jiangsu province of China: a computable general equilibrium approach. *Journal of Cleaner Production*, vol. 211, pp. 1403–1411.

Perman, R., Ma, Y., Common, M., Maddison, D. & McGilvray, J. (2011). Natural resource and environmental economics. Fourth edition Pearson Education Limited 2011. ISBN: 978-0-321-41753-4.

Pesaran, M.H. (2004). General diagnostic tests for cross section dependence in panels. University of Cambridge, Cambridge Working Papers in Economics, 435.

Pigou, A.C. (1920). The Economics of Welfare. London: Macmillan. Retrieved 16.6.2023 from https://archive.org/details/dli.bengal.10689.4260/page/n79/mode/2up.

Probst, M. & Sauter, C. (2015). CO2 emissions and greenhouse gas policy stringency: an empirical assessment. IRENE *Institute of Economic Research*, No. 15-03.

Sen, S. & Vollebergh, H. (2018). The effectiveness of taxing the carbon content of energy consumption. *Journal of environmental economics and management*. Vol. 92, pp. 74–99.

Simionescu, M. (2021). The nexus between economic development and pollution in the European Union new member states. The role of renewable energy consumption. *Renewable Energy*, vol. 179, pp. 1767–1780.

Siriwardana, M., Meng, S., McNeill, J., (2011). The impact of a carbon tax on the Australian economy: results from a CGE model. *Business, Economics and Public Policy Working Papers*, 2. Retrieved 7.7.2023 from http://www.une.edu.au/__data/assets/pdf_file/0009/23877/econwp11-2.pdf.

Stern, N. (2015). Why are we waiting? : The logic, urgency, and promise of tackling climate change. Cambridge, MA: MIT Press.

Sumner, J., Bird, L. & Dobos, H. (2011). Carbon taxes: a review of experience and policy design considerations. *Climate Policy*, vol. 11(2), pp. 922–943.

Tax foundation. (2021). Carbon taxes in Europe. Published 3.6.2021. Retrieved 12.12.2023 from https://taxfoundation.org/data/all/eu/carbon-taxes-in-europe-2021/.

The growth lab at Harvard university. (2019). Growth projections and complexity rankings. Harvard Dataverse, V4. Available at: https://doi.org/10.7910/DVN/XTAQMC.

Wang, Z., Jebli, M. B., Madaleno, M., Doğan, B. & Shahzad, U. (2021). Does export product quality and renewable energy include carbon dioxide emissions: Evidence from leading complex and renewable energy economies. *Renewable Energy*, vol. 171, pp. 360–370.

World Bank. (2022). State and Trends of Carbon Pricing 2022. State and Trends of Carbon Pricing;. © Washington, DC: World Bank. Retrieved 14.6.2023 from http://hdl.handle.net/10986/37455.

World Bank. (2023a). Total greenhouse gas emissions (kt of CO2 equivalent). Retrieved 16.6.2023 from https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE.

World Bank. (2023b). The World Bank in China. Retrieved 20.7.2023 from China Overview: Development news, research, data | World Bank.

World Bank, DataBank. (2023). Explore databasis. Retrieved 29.12.2023 from https://databank.worldbank.org/.

Wolff, R.D. & Resnick, S.A. (2012). Contending economic theories: Neoclassical, Keynesian and Marxian. Cambridge, Mass.: MIT Press. E-book.

Xiao, J., Juodis, A., Karavias, Y. & Sarafidis, V. (2021). Improved test for Granger non-causality in panel data. MPRA Paper No. 107180.

Xie, Y., Dai, H. & Dong, H. (2018a). Impacts of SO2 taxations and renewable energy development on CO2, NOx and SO2 emissions in Jing-Jin-Ji region. *Journal of Cleaner Production*, vol. 171, pp. 1386–1395.

Xie, J., Dai, H., Xie, Y. & Hong, L. (2018b). Effect of carbon tax on the industrial competitiveness of Chongqing, China. *Energy for Sustainable Development*, vol. 47, pp. 114–123.

Yamazaki, A. (2022). Environmental taxes and productivity: Lessons from Canadian manufacturing. *Journal of Public Economics*, vol. 205, 104560.

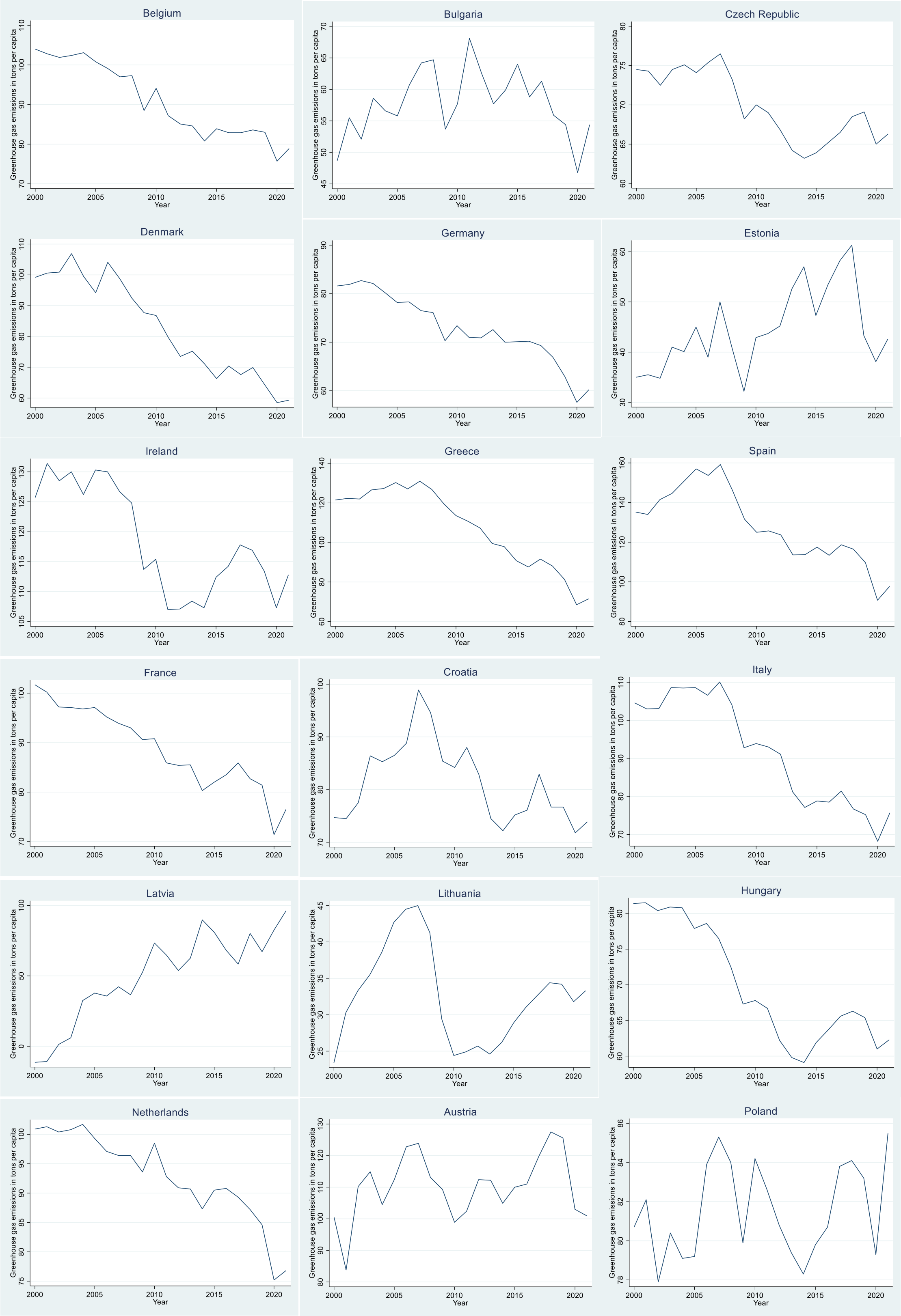
Zehaie, F. (2009). The timing and strategic role of self-protection. *Environmental and resource economics*, vol. 44(3), pp. 337–350.

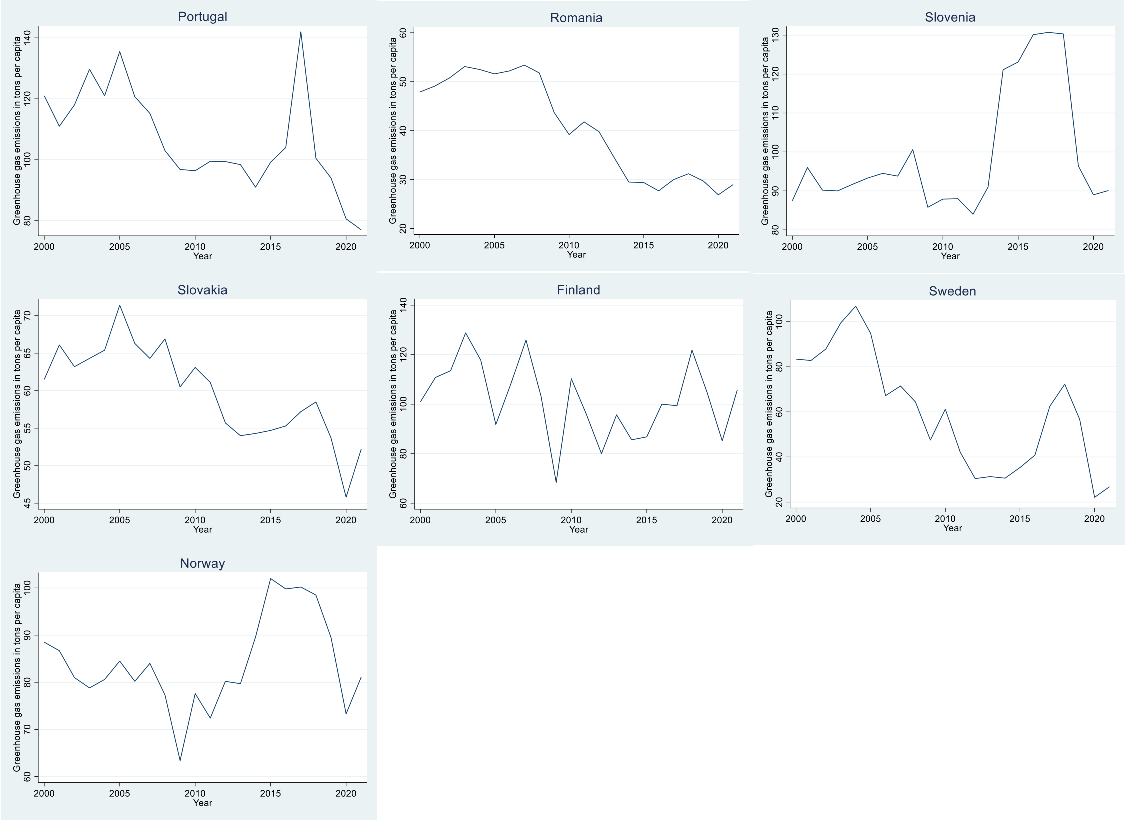
Zhao, X., Yao, J., Sun, C. & Pan, W. (2019). Impacts of carbon tax and tradable permits on investment in China. *Renewable energy*, vol. 135, pp. 1386–1399.

The “Grammarly” artificial intelligence application is used in this thesis to help in finding and correcting spelling errors. The application is available in: https://app.grammarly.com/.

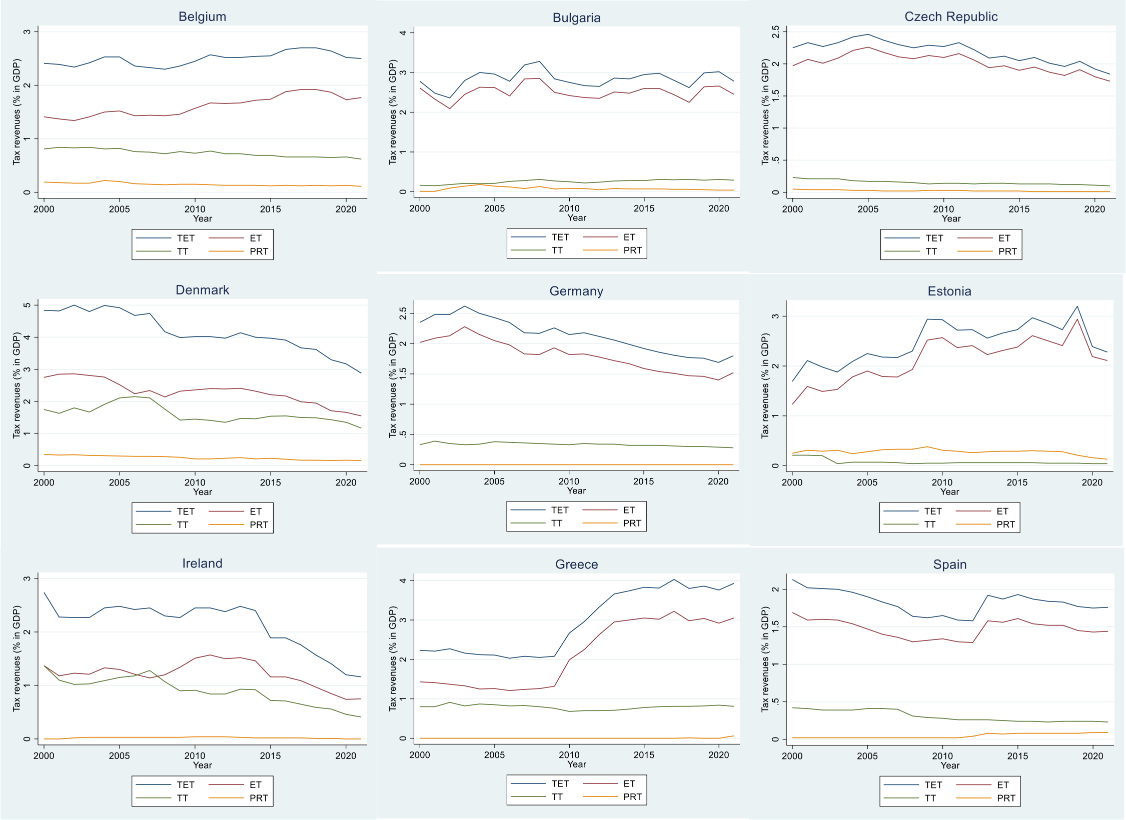
APPENDICES

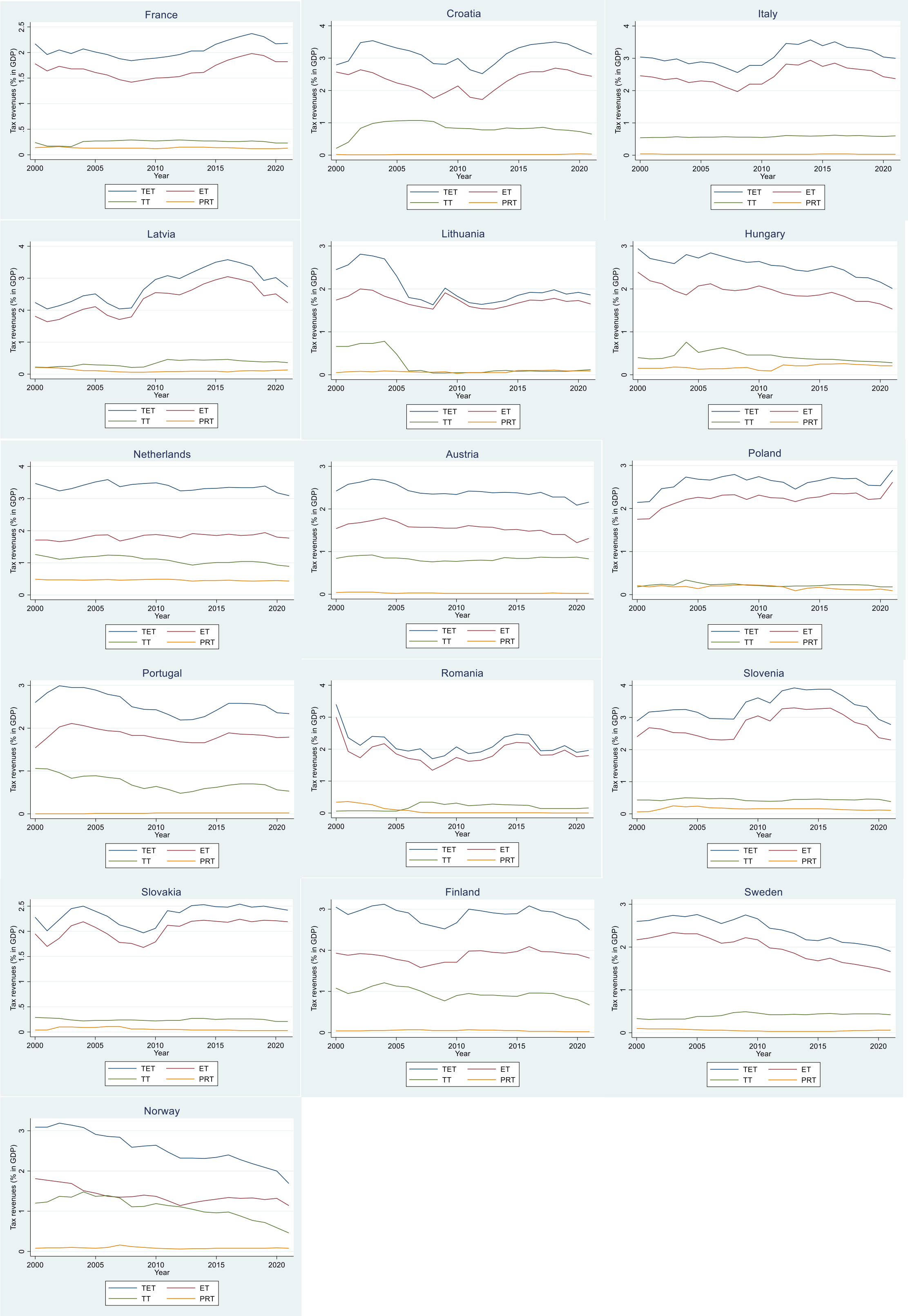
Appendix 1. Greenhouse gas emissions in ton per capita in the study countries



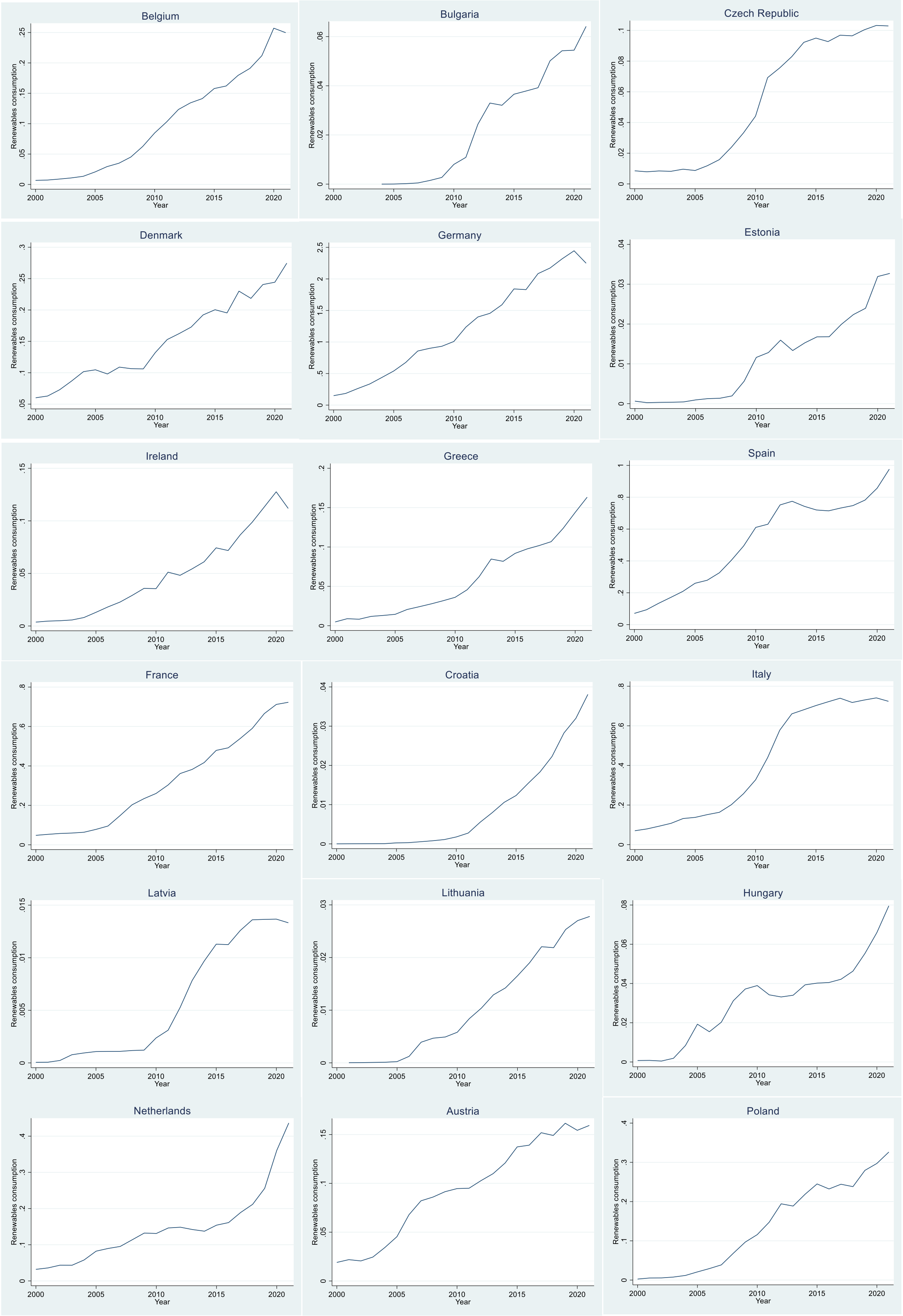


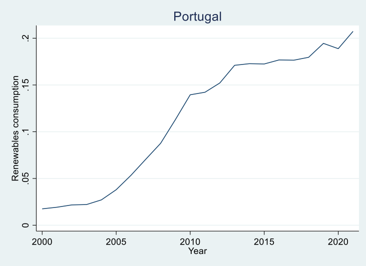
Appendix 2. Total environmental tax, energy, transport, and pollution and resource tax revenues in the study countries

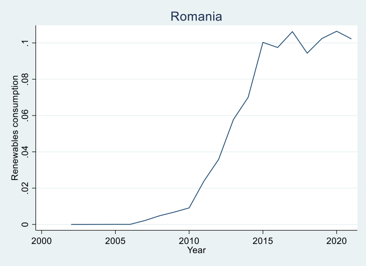


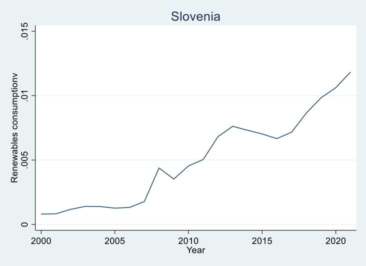

France
Croatia
Italy
Latvia
Lithuania
Hungary
Netherlands
Austria
Poland
Portugal
Romania
Slovenia
Slovakia
Finland
Sweden
Norway
Tax revenues (% in GDP)
Year
2000
2005
2010
2015
2020
0
.5
1
1.5
2
2.5
3
4
TET
ET
TT
PRT

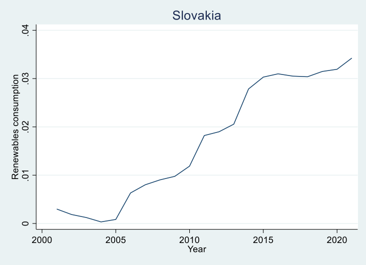
Appendix 3. Renewables consumption (in exajoules) in the study countries

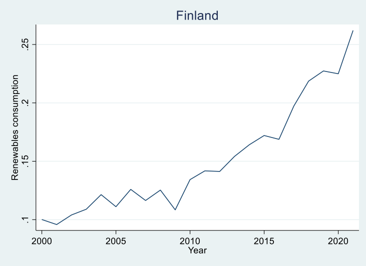


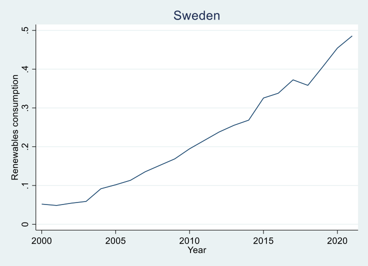

Portugal
Renewables consumption
0
.05
.1
.15
.2
2000
2005
2010
2015
2020
Year

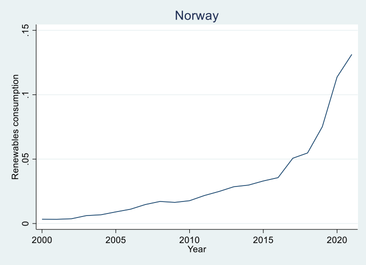

Romania
Renewables consumption
0
.02
.04
.06
.08
.1
2000
2005
2010
2015
2020
Year


Slovenia
Renewables consumptionv
0
.005
.01
.015
2000
2005
2010
2015
2020
Year


Slovakia
Renewables consumption
0
.01
.02
.03
.04
2000
2005
2010
2015
2020
Year


Finland
Renewables consumption
.1
.15
.2
.25
2000
2005
2010
2015
2020
Year


Sweden
Renewables consumption
0
.1
.2
.3
.4
.5
2000
2005
2010
2015
2020
Year


Norway
Renewables consumption
0
.05
.1
.15
2000
2005
2010
2015
2020
Year

Appendix 4. FMOLS and DOLS functions

Asymptotic distribution of the pooled panel FMOLS estimator from Pedroni (2000):

$$\widehat{\beta}^{*}{}_{NT} - \beta = \left(\sum_{i=1}^{N} \hat{L}_{22i}^{-2} \sum_{t=1}^{T} (x_{it} - \bar{x}_i)^2\right)^{-1} \sum_{i=1}^{N} \hat{L}_{11i}^{-1} \hat{L}_{22i}^{-1} \left(\sum_{t=1}^{T} (x_{it} - \bar{x}_i)\mu_{it}^{*} - T\hat{\gamma}_i\right)$$

where $\mu_{it}^{*} = \mu_{it} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \Delta x_{it}$ and $\hat{\gamma}_i = \hat{\Gamma}_{21i} + \widehat{\Omega}_{21i}^{0} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} (\hat{\Gamma}_{22i} + \widehat{\Omega}_{22i}^{0})$.

$\hat{L}_i$ is a lower triangular decomposition of $\widehat{\Omega}_i$:

$$L_{11i} = \left(\Omega_{11i} - \frac{\Omega_{21i}^2}{\Omega_{22i}}\right)^{1/2} , \quad L_{12i} = 0 , \quad L_{21i} = \frac{\Omega_{21i}}{\Omega_{22i}^{1/2}} , \quad L_{22i} = \Omega_{22i}^{1/2}$$

Dynamic OLS (DOLS) from Masih, R and Masih, A (1996):

$$C_t = B'X_t + \sum_{j=-J}^{j=J} \eta_j \Delta P_{t-j} + \sum_{j=-K}^{j=K} \lambda_j \Delta Y_{t-j} + \zeta_t$$

where $B = [c, \alpha, \beta]'$, $X = [1, P_t, Y_t]$, and

$$\eta(\mathrm{u}) = (1/T^2) \sum_{t=1}^{T} \frac{S_t^2}{\sigma_k^2} , \quad S_t = \sum_{i=1}^{t} v_i, \ t = 1, \dots T$$

Appendix 5. Correlation table of the variables used in the model.

	lnGHG	lnTET	lnET	lnTT	lnPRT	lnGDP	CPL	lnRC	lnPEC	lnUPOP	COR
lnGHG	1										
lnTET	0.193	1									
lnET	-0.192	0.694	1								
lnTT	0.603	0.497	-0.165	1							
lnPRT	-0.062	0.385	0.229	-0.052	1						
lnGDP	0.486	0.100	-0.453	0.592	0.074	1					
CPL	0.269	0.014	-0.020	0.164	-0.098	0.387	1				
lnRC	0.359	-0.063	-0.205	0.263	-0.096	0.558	0.390	1			
lnPEC	0.401	-0.188	-0.281	0.187	-0.012	0.371	0.284	0.654	1		
lnUPOP	0.300	-0.207	-0.194	0.113	-0.055	0.173	0.174	0.632	0.950	1	
COR	0.373	0.175	-0.371	0.514	0.256	0.883	0.320	0.428	0.222	0.023	1