



# The convergence of digital finance and green investments: opportunities, risks, energy transitions and regulatory considerations

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## Abstract

The financial industry is transforming due to the confluence of digital finance and green investments, which brings unprecedented potential and problems. This study rigorously examines the consequences of implementing carbon taxes on financial reporting in the corporate sectors of the European Union from 2000 to 2020. We utilize a comprehensive econometric model that includes stable variables, past patterns, and industry-specific differences to examine a dataset of business financial disclosures. Our goal is to determine the magnitude and characteristics of the impact caused by carbon taxes on reporting practices. This presentation highlights the possibilities for speeding up the world's energy transitions as it examines the synergies between sustainable investments and digital finance. The financial industry's growing use of digital technology makes green financing and ecologically responsible investments possible. However, there are also hazards associated with this convergence, which makes a thorough grasp of regulatory structures necessary.

**Keywords** Carbon taxes · Financial reporting · Corporate sectors · Climate change mitigation

## 1 Introduction

Global biodiversity is in grave danger due to the increasing problem of resource depletion and ecological disturbance. Ecosystems have degraded significantly, and biodiversity has declined worldwide due to unsustainable practices and unethical resource extraction (Mohsin et al. 2023). Clean air, water, and temperature control

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are just a few essential ecosystem services in jeopardy due to this catastrophe, threatening Earth's complex web of life. Sustainable development offers a glimmer of optimism (Malghani et al. 2009). Humanity may balance satisfying present demands and protecting resources for future generations by embracing sustainable methods. According to (Liu et al. 2012) responsible management of resources, promotion of renewable energy sources, and support of conservation efforts are essential components of sustainable development. Our planet's diverse and abundant life can be preserved if we work together across borders, change our policies, and educate the public about the need to protect ecosystems and the delicate balance they maintain.

(Yuan et al. 2023a, b) suggest that a multi-faceted strategy is necessary to tackle the problem of green development. Because it considers monetary, social, and ecological factors, green development is not a silver bullet. Policies should be customized to suit the distinct difficulties and possibilities faced by each country due to the unique circumstances in which they are located. In addition to lowering environmental impact and switching to cleaner energy sources, sustainable development also necessitates increasing economic resilience, promoting social inclusion, and developing innovative technologies. According to (Yu et al. 2023) to successfully navigate the intricacies of green development, it is necessary to use various solutions that consider regional circumstances, cultural factors, and economic frameworks. A comprehensive and inclusive vision for long-term prosperity necessitates flexible and evolving policy frameworks. Nations can lead toward a more balanced and harmonious future for people and the Earth by embracing the diverse character of green development.

KPMG (2017) notes a rise in ecological and sustainable development reporting by businesses worldwide, especially in emerging economies. This phenomenon has been studied and attributed to rising stakeholder expectations (Liu et al. 2023a, b), regulatory stresses (Menon and Mohanraj 2016; Puan et al. 2019; Wu et al. 2022), corporate governance standards (Ali 2023; Hajiaghahi-Keshteli et al. 2023; Saputro et al. 2023), and business cases for ecological sustainability. Studies in developing nations tend to reproduce similar linkages established in the Western literature about what influences corporate environmental reporting while ignoring the importance of distinctive settings in developing nations. Corporate responsibility reports are on the increase in developing nations. However, (Alavi et al. 2021) points out that this trend is very contextual and likely to be firmly rooted in a country's social and political institutions rather than blindly following the Western trend. Referring to (Ayough et al. 2023; Koc et al. 2023; Münch et al. 2022). Although the social and political system influences all ecological and social (reporting) activities in developing economies, crucial aspects have been largely overlooked in the existing literature (Demiralay and Paksoy 2022; Sonar et al. 2022). Stronger linkages between the political and economic systems are characteristic of many developing nations compared to the Western system (Mohsin et al. 2020; Waheed et al. 2019). Managers in countries with more centralized political systems, where government officials are more likely to intervene and keep tabs on business operations, are especially motivated to keep close contact with politicians (Aktar et al. 2021). When studying corporate environmental disclosure behavior in developing countries, it is essential to account for this source of political influence. Studies have looked at the correlation

between political ties and the ability to explain a variety of business financial activities, including earnings management and quality (Chang et al. 2022a; Liu et al. 2023a, b); financial reporting (Dilanchiev et al. 2021); corporate governance (Bouzarovski and Tirado Herrero 2017; Chang et al. 2022b); Political influence is valued because it helps businesses decrease risk and achieve a competitive edge via measures such as reduced taxes, easier access to economic and political capital, and lessened regulatory supervision. As (Li and Hu 2012; Mirza et al. 2009; Ntaintasis et al. 2019) point out, this is especially true in developing nations where restrictions regulating government links with industry are often less rigorous. Corporate executives' political relationships/experience may act as a double-edged sword for protecting the environment, making it difficult to investigate the effect of political relationships on ecological operations and reporting.

This paper provides a comprehensive analysis of the relationship between environmental policy and business finance practices in the European Union, a leading region in climate change mitigation. It offers valuable insights into this interface, highlighting its various dimensions and significance. This paper provides new empirical evidence on the impact of carbon taxes on financial reporting behavior over twenty years. It addresses a gap in the current literature, which often needs long-term empirical analysis. First and foremost, the study enhances the comprehension of how fiscal policy tools, such as carbon taxes, can act as drivers for transformation in corporate conduct. It offers solid proof that environmental taxes serve not just as a means of generating public income or lowering emissions but also as mechanisms that might improve the transparency and integrity of financial reporting. The research demonstrates how carbon taxes can impact company strategies by influencing reporting behavior encouraging corporations to incorporate environmental issues into their overall economic perspective. This highlights the more significant influence of fiscal policies on corporate decision-making, extending beyond their immediate financial consequences. Furthermore, the econometric model utilized in this research distinguishes itself by integrating industry-specific variables and fixed effects to account for potential confounding factors. This approach ensures a rigorous examination of the relationship between carbon taxes and financial disclosures, establishing a solid analysis of causality. By employing a fixed-effects model, the study is able to account for unobservable variables that remain constant over time, thereby yielding a more precise understanding of the influence of carbon taxes. The meticulous methodology guarantees that any observed alterations in company reporting may be more convincingly linked to the tax policy rather than any other external variables. Furthermore, this research aids in the development of policies by showcasing the efficacy of carbon prices in attaining broader policy goals. The findings indicate that carbon prices not only incentivize environmentally-conscious behaviors but also foster increased corporate responsibility and proactive financial strategizing. This has substantial ramifications for policymakers seeking to create tax systems that synchronize business conduct with the objectives of sustainable development and environmental stewardship. The study emphasizes the impact of fiscal policy on investor information settings from a corporate governance standpoint. The implementation of carbon taxes has resulted in improved disclosure standards,

indicating that these policies can provide a more comprehensive information landscape for investors. This is particularly important as investors are increasingly considering environmental sustainability when making investment choices. Increased transparency in reporting can enhance the allocation of capital toward sustainable corporate practices, hence promoting a more environmentally friendly economy. Finally, the study's temporal scope and geographic concentration on the European Union offer a contextual contribution. The paper analyzes the period between 2000 and 2020 to observe the early stages of carbon taxing implementation and track its impact on corporate and regulatory development over time. The EU, known for its pioneering efforts in environmental taxation, provides a valuable setting to observe the interaction between rigorous environmental policies and corporate behavior. The acquired insights are especially pertinent for regions considering the implementation or improvement of comparable policies. This study presents a thorough examination of the impact of carbon taxation on financial reporting. It introduces new methodologies, contributes to policy discussions, and improves our understanding of how companies respond to environmental taxation. The study particularly highlights the role of carbon taxation in promoting transparency and sustainability in financial practices.

## 2 Literature review

The research emphasizes the importance of financial systems in promoting a sustainable and environmentally friendly future throughout the energy transition. It is crucial to place the intersection of digital finance and green investments within the more extensive discussion on energy transformation. Researchers have highlighted the crucial impact of financial innovation on promoting renewable energy sources (Li and Umair 2023a, b). Digital finance, with its real-time data analytics and efficient resource allocation capabilities, accelerates the adoption of sustainable energy solutions. The literature also mentions possible hazards of using digital money in green investments, including cybersecurity issues and market instability (Author3, Year). The worldwide transition to renewable energy requires thoroughly comprehending the obstacles and possibilities in meeting sustainability objectives. (Wu et al. 2023a, b) highlights that a sustainable energy transition requires significant expenditures in renewable energy initiatives. Digital finance offers a way to raise cash and channel it toward environmentally beneficial projects effectively. Studies show that digital finance technologies like blockchain and smart contracts may improve transparency, traceability, and accountability in sustainable energy projects (Zhang and Umair 2023). Regulatory concerns are crucial for adequately merging digital finance with green investments. Scholars advocate for flexible regulatory systems that promote innovation while mitigating possible hazards (Cui et al. 2023). (Li and Umair 2023a, b) emphasizes the crucial role of regulatory agencies in setting precise standards for sustainable finance to promote the integration of digital financial methods with environmental goals.

## 2.1 Carbon financing and the future of energy

Scholars and academics have advocated for and recognized the phenomena known as "green finance" for the last several decades. Green finance is seen as financial products being given to solve environmental challenges such as "industrial pollution prevention, managing waste, sanitary and clean environments, and environmental protection" (Li and Wang 2023; Wang et al. 2023a, b) and acting as a tool to reduce greenhouse gasses. In this setting (Boucenna et al. 2021; Natividad and Benalcazar 2023), we looked at how much of an impact investing in RE transition resources would have on carbon finance. Investments in renewable energy, renewable power production, and carbon finance were shown to be more volatile than GDP and private sector energy investment. Investments in renewable energy have been shown to have a significant positive effect on renewable energy power production and a negative effect on carbon financing (Lee et al. 2006; Owen et al. 2022). The causal relationship between these factors changes across the short and long runs. Furthermore, there was no proof that the private sector's investment in energy was related to RE investments. Moreover, policies should be created to lessen the volatility of investments in RE and carbon finance and to increase expenditure on these sectors to accomplish healthy economic growth, protection of the environment, and RE manufacturing. Also, (Bartolini and Bonatti 2008; Laboissiere et al. 2015) worked on carbon financing, also known as the ecological fiancée and renewable energy. To investigate the various aspects of sustainable finance, this research used a bibliometric approach on a sample of 223 relevant papers from Scopus databases. The research found that carbon financing, often known as green money, benefits global RE transformation. On top of that, green financing is among the best carbon emission.

## 2.2 Tax on carbon and the new energy economy

Authorities in all countries generate various forms of money to meet their financial obligations. Taxation is the primary means through which states earn revenue. Income tax, sales tax, carbon tax, and environmental taxes are only a few examples. Natural resources such as water and energy are said to be subject to ecological levies. The most common carbon tax, often known as an ecological tax, is the charge placed on the generation and use of energy. When making decisions about natural resource projects or policies, the government continues to rely heavily on these taxes (Li et al. 2022; Sun and Liu 2022; Wu et al. 2023a, b). The reasoning for this is that even a minor adjustment in these taxes may significantly impact the project's outcome. The exchange of energy is almost the same. Ecological costs, such as carbon taxes, affect the nation's energy transition. Related to this topic (34), I worked on carbon taxes, ecological fees, and energy transformation. Spain was the site of the study's research. According to the research results, changes in carbon pricing or other ecological levies influenced the energy transformation in the country. Therefore, carbon taxes, or ecological taxes, and the energy transition in the country are intertwined.

### 2.3 Innovative sustainability and the new energy economy

Because of the risks associated with burning fossil fuels and exploiting natural resources, countries worldwide are shifting their attention to low-carbon development, renewable energy, and other eco-friendly methods. In this respect, solar energy is the option to look forward to in the following years since it does not damage the environment (Chen et al. 2019; Edwards 2021; Greenwood and Tao 2021). From a low-carbon energy transition perspective, i.e., RE, (Hatefi & Torabi 2010; Rovinaru et al. 2023; Rüstemoğlu and Andrés, 2016; Xu et al. 2023) have worked on solar energy. The results demonstrate the urgent need for affordable, practical solutions to environmental problems, such as substituting fossil fuels. There is an opportunity to use solar electricity because of the expected drop in costs due to technical advancements. However, concerns and risks associated with using solar power must be discussed (Nguyen et al. 2022; Shah 2019; Yong et al. 2022). The requirement for energy storage, high startup costs, and poor efficiency are only a few problems. However, switching to solar technologies can be challenging due to the possibility of encountering resistance from limited resources. The European Union was the focus of (Yi et al. 2023) research, and they approached RE from a solar energy perspective. The results showed that over the chosen period, the percentage of electricity coming from the low-carbon energy transition, i.e., renewable energies, in total electricity consumption increased most in Estonia (2315%), Belgium (805%), and the United Kingdom (540%). In addition, renewable energy (RE) usage for HVAC increased by almost one thousand percent in Malta, the United Kingdom, and Luxembourg, respectively (284, 684, and 1184). The percentage of low-carbon energy transition, i.e., RE sources utilized for heating and cooling, increased the least in Portugal (2.7%), Latvia (22%), and Croatia (31%). More than 16.6 percent of the electricity in more than 160 countries comes from hydropower, making it the largest renewable energy source worldwide. In 2017, an additional 24 GW of hydroelectric capacity was installed, bringing the total to about 1096 GW. With a 215 TWh yearly producing capacity, hydropower in Turkey is Europe's most promising. In 2017, Turkey was rated number seven globally for its increased installed capacity of hydroelectric power (Akalpler and Hove 2019; Cui et al. 2022), with an annual installed capacity of 1.8 GW. Turkey was chosen as a case study for research on hydroelectric energy generation from the perspective of sustainable energy development (Leask and Barron 2021; Oehlmann et al. 2021; Wang et al. 2023a, b; Yuan et al. 2023a, b).

### 2.4 Urbanization, energy, and industrialization

The planet is expanding at a lightning rate as time goes on. The growth of this globe is the result of several reasons, including population rise and globalization. This growth increases the need for shelter, furnishings, and clothing throughout the globe. As a consequence, the market becomes unbalanced (Gilal et al. 2020; Lin et al. 2021; Xu et al. 2019). In addition, with the rapid progress of technology came

a rise in demand for manufactured goods. Countries increase their production capacity to keep up with increased demand and boost their national GDP. More energy was needed as industrialization spread. The increased use of traditional energy sources, such as petroleum and coal, has been linked to ecological damage (Capurso et al. 2022; Dangelico 2016).

The globe is turning to RE to slow down environmental destruction. The authors of (Guan et al. 2019; Lu et al. 2019) studied the adverse effects of industrialization on the environment. Africa was chosen as the study's location. The findings demonstrated how industrialization's progress has hastened ecological decline. Therefore, it is suggested that Africa make the change to RE. A low-cost, reliable energy supply is crucial to a country's capacity to expand and develop responsibly. The need for energy to power that growth grows when the economy grows. The expanding commercialization of the globe has pros and cons for the economy and the natural world. The increased demand for energy caused by industrialization can only be met by utilizing conventional resources, which negatively affects the environment. This is why (Carvalho et al. 2019; Zhang et al. 2021) has also contributed to studying EC, EG, and industrialization in Asia. Energy utilization and carbon emissions were shown to be direct effects of industrialization. This has other environmental effects since the countries above were suggested for the RE transformation. In addition to contributing to unemployed people, diminishing resources, carbon emissions, and adverse environmental effects (Feldman and Kelley 2006; Maghyereh et al. 2016), population growth is one of the world's most pressing problems. It's one of the reasons why the globe has to make the shift to renewable energy.

### 3 Methodology and data

#### 3.1 Theoretical background

This research examines the effects of carbon tax implementation on financial reporting in the EU's business sectors between 2000 and 2020. The idea of carbon pricing, a tool for a policy intended to internalize externalities related to carbon emissions, is the theoretical basis of this study. Economically sound, carbon pricing reflects the actual costs of environmental degradation and encourages companies to recognize and reduce their carbon footprint (Liu et al. 2023a, b). In this regard, financial reporting becomes an essential tool for communicating the economic effects of carbon prices on businesses. Based on the disclosure principle, the research emphasizes the critical role that financial reporting plays in giving stakeholders transparent and trustworthy information about businesses' environmental and economic performance (Xiuzhen et al. 2022). Using a thorough econometric model that accounts for stable variables, historical trends, and industry-specific variations, the study is consistent with economic theories that emphasize the modeling of complex systems to comprehend the complex relationship that exists between financial reporting outcomes and carbon taxes (Umair and Dilanchiev 2022). Additionally, by looking at the years 2000 to 2020, the study recognizes the temporal aspect of environmental policies and economic responses, consistent with theories highlighting how

corporate strategies and practices change over time in response to shifting regulatory environments (Aguila-Almanza et al. 2021). Furthermore, the study acknowledges the significance of industry-specific variations, basing its methodology on industrial organization theory, which postulates that companies operating in the same sector may react to shocks from the outside world in various ways because of structural differences (Borpatragohain et al. 2016). This theoretical framework aims to comprehensively comprehend the complex effects of carbon taxes on the dynamics of financial reporting in the European Union's business environment.

### 3.2 Objective

The primary aim of this article is to examine the effectiveness of a carbon tax on the oil and gas sectors from an environmental perspective, while the secondary aim is to examine the impact of other variables on the release of greenhouse gases in the nations under consideration. The following are the primary theories of the study:

Countries implementing a carbon price on the oil and gas industries have seen a drop in atmospheric CO<sub>2</sub> levels.

Nations implementing a carbon price see reduced emissions partly because of the EU ETS framework (Table 1).

Contributions by businesses can cut carbon dioxide production.

Five advanced EU members (those with GDPs above the EU average)—Denmark, Ireland, Finland, Sweden, and Slovenia—have their carbon taxing systems dissected and analyzed in depth below. Supporters for ecological taxation chose the Nordic nations (Denmark, Estonia, and Swedish) as representations since they were the first to implement a carbon tax and had been doing so since the early 1990s (Table 2). However, unlike in Finland, where it was designed specifically for the energy industry, in Slovenia (the first post-communist member of the EU), the carbon tax had other goals in mind. According to the Environment Protection Agency of Ireland (2019), Ireland is a model of the Anglo-Saxon world in which protecting our environment is a top concern. Countries like France and Portugal, which just instituted their carbon taxes in 2014 and 2015, accordingly, were left out of the analysis because their taxes do not apply to the power sector or because they are not EU members.

### 3.3 Data

Multiple additive effects contribute to the atmospheric concentration of gases that cause climate change. On the one hand, it results from the actions of economic actors like households and businesses. It can be quantified through indicators like final consumption expenditure, gross capital formation (investments by businesses), and utilization of solid fuels industries and clean energy sources. It results from national environmental rules and economic instruments to safeguard the natural world and the climate (Khoshroo et al. 2018; McCamley and Gilmore 2017; Mimica et al. 2022).



**Table 1** List of variables

Variable	Abbreviation	Units	Role	Individual's potential impact
Carbon dioxide equivalent output	ghge	Tons of CO2 equivalent per capital	Dependent	
carbon dioxide tax	co2t	Euro per tons	Key explanatory	Negative
Cost of emissions permits	eap	Euro per allowance	Control explanatory	Negative
Maximum consumption expenditures of households	hfce	Euro per capita	Control explanatory	Positive
Investments by Corporations	ci	Euro per capita	Control explanatory	Negative
Use of solid fuels	sfc	Tons per capita	Control explanatory	Positive
Renewable energy consumption	rec	Tons of oil equivalent per capital	Control explanatory	Negative

**Table 2** Carbon-taxed EU member states as of May 2018

Country	Year of tax introduction	Current tax commodities
Denmark	1993	Primitive gasoline and diesel
Estonia	2001	Generation of heat and power
Finland	1991	Fuels for electric generators, vehicles, and homes
France	2015	Fuel for vehicles and homes
Ireland	2011	Primitive gasoline and diesel
Portugal	2016	Generation of Power
Slovenia	1997	Use of petroleum and natural gas in transportation and heating
Sweden	1090	Primitive gasoline and diesel
Great Britain	2012	Generators that rely on petroleum or coal

OECD and EEA (2018): internal analysis as the source

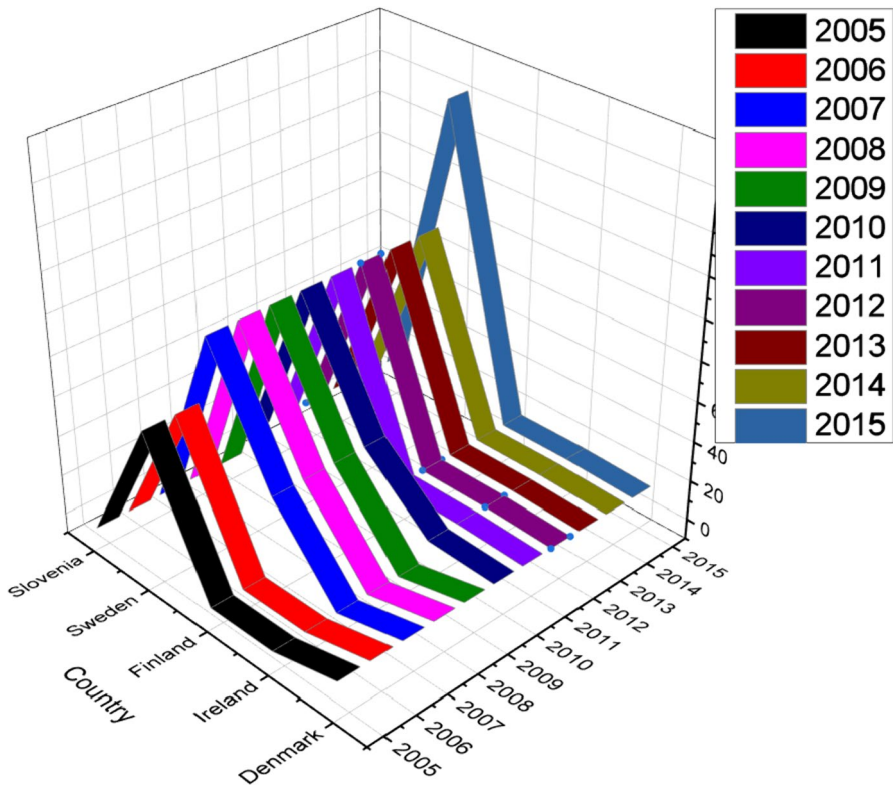
Below, we describe the relevant variables and the reasoning behind their inclusion in the presented models. Oil and gas are given as CO<sub>2</sub> equivalent tons per person and year to represent the fundamental dependent variable. The Eurostat database was mined for information for this study. According to the first study hypothesis, the CO<sub>2</sub> tax rate is an important independent variable in the model of multiple panel regression. This study will examine the impact of carbon taxes on the financial statements of oil and gas businesses in the European Union (EU). By using the multiple-panel regression method to analyze the accounting records of oil and gas companies and controlling for the relevant factors, we look at the link between the carbon price and financial reporting. According to our findings, carbon taxes greatly enhance the reliability of companies' financial reports. In particular, companies subject to greater carbon taxes are more likely to disclose their carbon emissions and environmental hazards in their financial statements. Since the "EU ETS" system is active in all nations selected for evaluation (see the second research premise), the valuing of production allowances figures as a "control explanatory variable" in the study. The "European Energy Exchange and the Energy Regulatory Office databases" provided the information used in this study. The average yearly cost of an emission permit in Euros is the statistical unit. Allowance price increases were predicted to lead to a decrease in greenhouse gas emissions. The GDP is correlated with a metric called the final consumption expenditure of households (HFCE). Once again, data came from Eurostat. It was reasonable to infer that if HFCE rose, so too would GHG emissions; hence that metric was used to measure progress. Several studies have addressed this issue (Samitas et al. 2022; Sarkar and Kumar 2010; Wentworth and Oji 2013) and come to the same conclusion: an increase in consumption by households can lead to an increase in emissions. Another explanatory control variable linked to the aforementioned third study assumption is the business investment indicator. (Without further information, expenditures in oil and gas technology for manufacturing and environmental management were left out of the study.)

The statistics were collected using the Eurostat data set. According to the Porter hypothesis and the research of (Jiakui et al. 2023; Liu et al. 2022; Lombardi and

Schwabe 2017; Nazirul Islam Sarker et al. 2018), it was hypothesized that increasing corporate investment would reduce GHG emissions by funding the development of cutting-edge green technology. It was also considered within the current study that burning fossil fuels was a major contributor to the rising levels of atmospheric CO<sub>2</sub>. The Eurostat database covered normal gas and coal usage (and its byproducts) (changed per capita and yearly) well. The use of oil and gas usage as a controlling explanatory variable is connected to the study's fourth hypothesis. Investments in the oil and gas sector and policy support for the sector's growth go hand in hand. In line with the current pessimistic assumption that the growing ingesting of renewables would be reproduced in a decreased quantity of conservatory gasses, the substitution of "dirty" power from coal oils with "clean" non-combustion foundations outcomes in the reduction of carbon releases. Again, the essential data (translated into tons of lubricant equivalent per capita and yearly) may be found in the Eurostat statistics. The study utilized all the variables mentioned earlier as annual time series from 2005 to 2015. Sub Sect. 2.3 below elaborates on the considerations that led to the selected time frame. The following is a brief synopsis of the rationale behind the study's choice of variables and time frame: The selected explanatory factors have been shown to affect the variable of interest theoretically or empirically. • are based on high-quality data sources; have the greatest impact on greenhouse gas emissions (leading to a decrease, as indicated in the upper-left chart of Fig. 1). The variables evaluated did not include preferences and education about the environment, which are difficult to quantify, or statistics on environmental investments from 2005 to 2015, which are not currently accessible. The averages of every factor across the analyzed period, the time sequence growth for each nation, and the pair-by-pair connections among each factor are all shown in Fig. 1 and Table 3. (The following two examples show how to read the visual symbols of information in the explanatory charts in Fig. 1: Household final consumption expenditures (HFCE) in Finland, for example, peaked in 2005 at around 15,000 euros per capita and have since steadily risen to around 30,000 euros per capita in 2014, while in Ireland, "HFCE" drawn at around 19,000 euros per capita in 2004 and has since method the price of 15,000 euros per capita after a slight fluctuation.

### 3.4 Methods

An example of a cause and effect is the impact of the CO<sub>2</sub> tax on greenhouse gas releases. Causal-explanatory modeling is an exceptionally comprehensive and "appealing" method for analyzing relationships between factors. Simply put, it is one of the three types of regression-based modeling (the others being descriptive and inferential, both of which can be used for prediction; for details, see Ifa and Guetat 2018; Tian and Feng 2022), with any severe causal interpreting necessitating an initial evaluation of all suppositions and prospective limitations. In theory, investigators can only be sure their causal models and interpretations are suitable if they know how the underlying data was generated. When a reliable model is used, only then can accurate causal interpretations be made, leading to conclusive results. When the data generation method is unknown, as in this analysis, only



**Fig. 1** Pairings of countries (with the up and down triangles representing the years 2005 and 2015, correspondingly)

descriptive and inferential statistics can provide a solid foundation for interpreting the framework used. As a result, the suggested causal links invariably guide subsequent discourse. For the sake of this investigation, it is assumed that the method by which the information for the dependent factor is generated looks like this (for each  $i$ ):

$$ghge_{it} = \beta_1 co2t_{it} + \beta_2 eap_{it} + \beta_3 hfce_{it} + \beta_4 ci_{it} + \beta_5 sfc_{it} + \beta_6 rec_{it} + a_i + u_{it} \quad (1)$$

where “ $ghge_{it}$ ,  $co2t_{it}$ ,  $eap_{it}$ ,  $hfce_{it}$ ,  $ci_{it}$ ,  $sfc_{it}$  and  $rec_{it}$ ” are “stochastic processes” of the selected values,  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$  and  $\beta_6$  are “unknown partial regression” constants,  $a_i$  are “time-constant country-specific unobserved effects”,  $u_{it}$  is the process commonly called “idiosyncratic error”,  $t$  is the time index ( $t = 1, 2, \dots, 11$ ) and  $i$  is the cross-section (country) index ( $i = 1, 2, 3, 4, 5$ ). The time-denominated information is used to eliminate  $a_i$  in the fixed effects approach:

$$gh\hat{g}e_{it} = \beta_1 c\hat{o}2t_{it} + \beta_2 e\hat{a}p_{it} + \beta_3 h\hat{f}c_{it} + \beta_4 c\hat{i}_{it} + \beta_5 s\hat{f}c_{it} + \beta_6 r\hat{e}c_{it} + \hat{u}_{it} \quad (2)$$

where

**Table 3** Mix of financial instruments for reducing Carbon dioxide in selected EU nations

EU member state	EU ETS	Fees	Carbon dioxide taxes	The energy consumption tax	Pollutants, in general being taxed
Denmark	Yes	Yes	Primitive combustion	Taxes on the sale of energy sources	Charges for chemicals that deplete the ozone layer and contribute to pollutants in the air
Finland	Yes	Yes	Fuels for electric generators, vehicles, and homes	Taxes on the sale of energy sources	Increase in the Cost of Emitting GHGs
Ireland	Yes	Yes	Primitive gasoline and diesel	Taxes on the sale of energy sources	No
Slovenia	Yes	Yes	Use of petroleum and coal in transportation and heating	Energy conservation tax and renewable items sales charge	NOX and SO2 Releases
Sweden	Yes	Yes	Primitive gasoline and diesel	Electrical consumption taxes	Nuclear energy and sulfur taxes on emissions

Source: The database of OECD members' energy stats, raw data

$$ghge_{it} = ghge_{it} - ghge_i, cò2t_{it} = cò2t_{it} - cò2t_i, \text{ etc}$$

Using an “empirical data-based analysis” in place of theoretic general symmetry (“CGE and AGE”) methods, this research expands upon the work of (Deluna et al. 2021; Oriakhi and Osaze 2013; Sims et al. 1982) to uncover the true marginal impact of the carbon price on greenhouse gas emissions. However, as discussed below, there are some problematic (or even mistaken) steps in (Change 2008; Khan et al. 2020; Ndou et al. 2018) approach that the current study attempts to avoid. Given carbon tax rates and emissions of greenhouse gasses in tons of CO<sub>2</sub> equivalent per capita and year, an analysis can be made. A multiple-panel regression framework (containing various explanatory factors) was selected as the most suitable technique to evaluate how the carbon tax level influences atmospheric GHG reduction about other economic mix instruments. Considering that greenhouse gas emissions stand in for the dependent (response) factor, and the carbon tax stands in as the significant independent (explanatory) factor, there are apparent restrictions on the types of information that may be used and the research methods that can be used. Table 3 shows that in 2005, only two of the five nations studied (Denmark and Sweden) had non-zero taxes on carbon dioxide.

Additionally, the time series show slight variation due to carbon taxes changing very slowly over time, except Denmark’s carbon dioxide tax time sequences, which shows no difference at all, and the others feature one (“Ireland, Slovenia, Finland, Sweden”). Researching how a carbon price will affect the production of greenhouse gasses is complicated by these factors. However, since CO<sub>2</sub> taxes have only been implemented relatively recently, it was decided to begin the study in 2005 as a middle ground between the requirements for a large sample size and a large amount of variation (i.e., a longer time sequence and a large number of variations). In contrast, “Finland and Slovenia” introduced carbon taxes in 1990 and 1996 but didn’t start enforcing them on the power sector until 2007 and 2010, respectively (for further information, see Hamilton et al. 2016; Naser 2016). Since the EU release Trading System pilot ran from 2005 to 2007, most of the relevant macroeconomic data for each country has become publicly available. Table 4 summarizes, from 2005 to 2015, the fundamental linear trends of GHG emission time series per nation. Figures 2 and 3 (upper-left chart) displays time series for all nations with a comparable adverse “linear trend”, enabling them to be combined into one panel of information to determine what factors contributed to a decrease in greenhouse gas emissions.

**Table 4** Energy sector carbon dioxide emission tax evolution (in euros per metric ton)

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Denmark	9	9	9	9	9	9	9	9	9	9	9
Ireland	1	1	1	1	1	10.4	10.4	10.4	10.4	10.4	10.4
Finland	1	1	39	39	39	39	10.4	10.4	10.4	10.4	10.4
Sweden	69	69	99	99	99	99	99	99	99	99	159
Slovenia	1	1	1	1	1	10.4	10.4	10.4	10.4	10.4	10.4

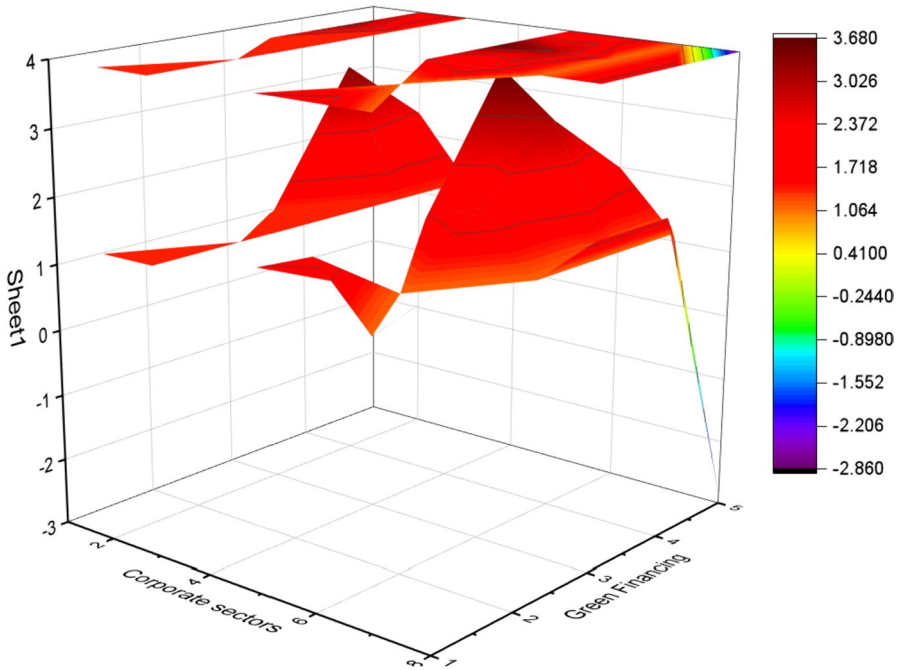
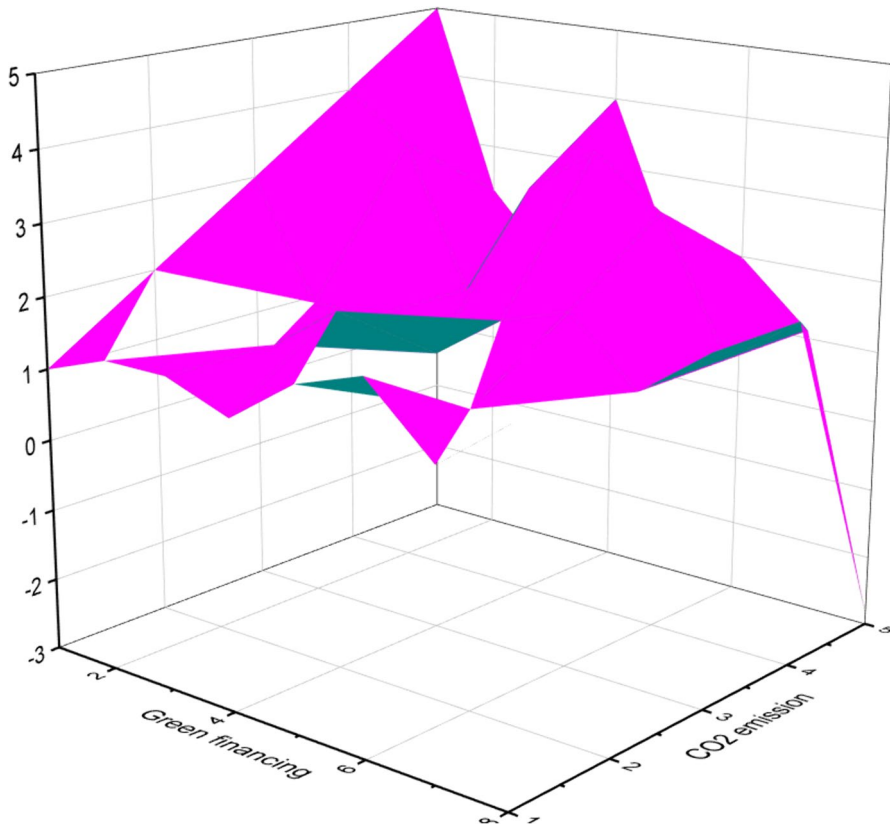


Fig. 2 Time- and variable-specific (excluding CO2 tax) residuals from a fixed effects model

## 4 Results

### 4.1 Modeling for description

With no aim to draw statistical conclusions or “causal interpretations”, Eq. (1) and the symbols in Eq. (1) have a different meaning in descriptive modeling than “inferential or causal modeling”. In this way, we may express the number of greenhouse gasses released by nation  $I$  in year  $t$  as  $get$ . Like the partial regression coefficients, the other signs do not represent “stochastic processes” but prices from the provided information set that must be determined. Descriptive statistics have the benefit of not requiring any elaborate theoretical assumptions to guarantee accurate and reliable results. Descriptive models, which do not attempt to generalize their findings, are accurate representations of reality within the context of the data set under study. Using Fig. 1 as an example, we can infer that the relationships between greenhouse gas emissions and the final consumption expenditures of households in Finland [green] and Denmark [blue] are incredibly comparable since the patterns presented for these two nations are highly close to one another. Using the appropriately stated model in terms of functional forms is recommended for defining the relationship between the dependent and explanatory variables in descriptive regression modeling. A linear model keeps things simple since there is no theoretical justification to deviate from it. GHG emissions show similar trends but different amounts for respective nations, likely due to the countries’ deliberate selection (rather than a



**Fig. 3** “Normal Q-Q plot” for the “fixed effects model residuals”

random sampling). “The fixed effects linear panel model” was used to normalize the researched connections from the “unobserved country-specific time-constant effects”, like different “sectoral structures or levels” of ecological consciousness (Dai et al. 2020; Shin et al. 2013). In addition, regression models were built for each nation to ensure the correct specification of the panel data framework. The estimated partial regression values for every approach are shown in Table 5. “Regression coefficients” are “calculated” rather than “estimated” in statistical analysis.

The partial correlations (changed from those distributed with in Table 6 and Fig. 1) are reflected in the coefficients reported in Table 5. Since Denmark’s CO2 tax was fixed at 13 percent throughout the study period, the corresponding coefficient in the country’s model is zero. The partial regression coefficients have the same sign across all five nations only for the solid-fuel-consumption variable. Carbon tax in Finland (positive), environmental allowance price in Finland (negative), and business investments in Slovenia (negative) all have fractional regression constants that are the closest to zero, but their signs are different. Coefficients in Ireland vary significantly from those in other nations. In line with the Ireland-specific trends



**Table 5** Some time series exhibit linear trends throughout 2005–2015

Variable	Country	Linear tendency	Other
Production of greenhouse gasses	All	Negative	Atypical year 2007
Value of emission permits	All	Negative	
Investment in final usage by households	All except Ireland	Positive	
	Ireland	None	
Investing by Corporations	All except Sweden	None	
	Sweden	Positive	
Use of solid fuels	All except Sweden	Negative	
	Sweden	None	Atypical years 2008 and 2009
Use of alternative energy sources	All	Positive	

in paired connections shown in Fig. 1 (see the four bottom charts), the partial connections in the case of “Ireland” are expressively different from those in the other selected EU member states. The partial connections are the smallest (“co2t, sfc, rec”), “greatest (EAP)”, and second maximum (face, ci) of all. The variation in the partial regression coefficients may be attributed to two main factors.

The models developed for each nation are either. The connections in question may be either • • appropriately stated, therefore sufficiently characterizing the relationships that are different in various nations, or poorly specified, thus inadequately expressing the relationships that are the same in various nations. Whether one or both of these explanations holds water, questions remain as to whether or not a panel data model has been correctly specified. Partial regression coefficients may still be appropriately interpreted with the help of a descriptive regression model. It is possible to think of the partial regression coefficients in a panel model as the “averages” of the partial regression coefficients for each nation. Table 5’s last two columns provide the estimated values for the two-panel models (pooled data and fixed effects), the latter created using time-demeaned data to remove the unobserved effects that vary among countries over time. This paper’s most important discovery is the partial regression coefficient for the carbon tax variable in the fixed effects panel model. For a given value of the other five control explanatory variables, a yearly reduction in greenhouse gas emissions per capita of 0.01158 tons (i.e., 11.58 kg) is associated with a CO2 tax rate improvement of one euro per tons (coefficient = 0.01158).

## 4.2 Modeling inference

Inference modeling is more complex than descriptive modeling because numerous theoretical hypotheses are required to draw reliable statistical conclusions. Only one meaningful application of statistical inference tools is possible, given that the current information file is not a random sample from a population (such as every nation with a carbon tax): the information set is to be interpreted as the product of a data-generating process that existed before and would continue to exist after the period under study 2005–2015. Assuming the aforementioned data-generating

**Table 6** Panel methods with fixed effects and partial linear regression parameters

Variable	Denmark	Ireland	Finland	Sweden	Slovenia	Panel (pooled)	Panel (fixed effect)
Intercept	11.88772	11.3369	9.99847	5.33641	1.22544	7.33211	
CO2 tax		-1.6654	1.11224	-1.3321	-1.99641	-1.3321	-1.33214
Value of emission permits	1.33214	1.336521	-1.11478	1.66547	1.987521	1.11231	1.848487
Investment in final use by households	-1.12354	1.33654	-1.11214	-1.33654	1.112444	-1.33214	-1.11124
Funding from Businesses	1.33214	1.336521	-1.11478	1.66547	1.987521	1.11231	1.848487
Use of solid fuels	3.33214	1.336521	-3.11478	3.66547	2.987521	1.11231	1.848487
Use of alternative energy sources	2.33214	1.336500	-1.11477	1.66555	1.98765	1.11231	-2.848487

process (rather than "general" correlations between variables in the global population), statistical inference is derived. Due to the "Bonferroni correction", we evaluated respectively of the theories ("partial-coefficient tests" in the "fixed effects panel model") at a importance level of  $ind = 0.05/6 = 0.00833$  (for the method with 6 "explanatory variables") that was tested simultaneously. Seven conceptual hypotheses are listed by Wooldridge (2003) about acceptable statistical inference for regression coefficients when using the fixed effects framework. Table 7 provides a summary of these requirements and an analysis of their satisfaction.

The hypotheses listed in Table 7 are usually considered when interpreting partial t-tests. Table 8's p-values should be explained with caution due to questions about the reliability of the partial t-tests (see Table 7). Evidence for statistically important partial associations with greenhouse gas releases was discovered for company expenditures and solid energy use factors at the 5% simultaneous significance level, assuming that the partial t-tests are valid.

### 4.3 Causal modeling

To draw valid conclusions about what's causing what, it's necessary to believe that the model accurately represents the method by which the data was generated. In addition, the framework must incorporate all (or the vast majority of) significant explanatory factors that affect the dependent variable (in this case, GHG emissions). Each cross-section of a panel data set must be able to be explained by the same model. However, while conducting the analysis, it became clear that the latter expectation still needed to be fulfilled. There is also another facet of the contested statistical connections to consider. To reduce the overall complexity of the model, this research focuses only on simultaneously occurring effects. The need for caution when making causal generalizations is highlighted by the ease with which compelling arguments concerning time-lagged effects may be presented. (One variable that may have an immediate and delayed impact on greenhouse gas (GHG) emission reduction efforts and long-term business environmental investment decisions is the market price of tradable emission permits in Fig. 4.

Private home spending has both short-term and long-term effects [the latter being consistent with the equilibrium framework for general supply and demand]. Environmental policy and regulations are another area with far-reaching consequences for the environment. In addition, it is a prerequisite for any credible causal interpretations to make different manipulations of variables doable. The interaction effects of explanatory factors are not readily apparent during a short period. However, the long-term effects of economic mechanisms like taxation on the environment and investments become clear. The long-term environmental effect of carbon tax rates and the cost of emission allowances is reflected, for instance, in the rising use of renewable energy and decreasing reliance on fossil fuels. While the suggested study's outcomes do not "provide evidence" of any kind, they do raise some doubts about the assumptions required to interpret the results of the present study causally. According to the calculated partial coefficient of regression for the CO<sub>2</sub> tax explanatory variable, the reduction in yearly the production of greenhouse gasses

**Table 7** The academic requirements for partial t-test reliability

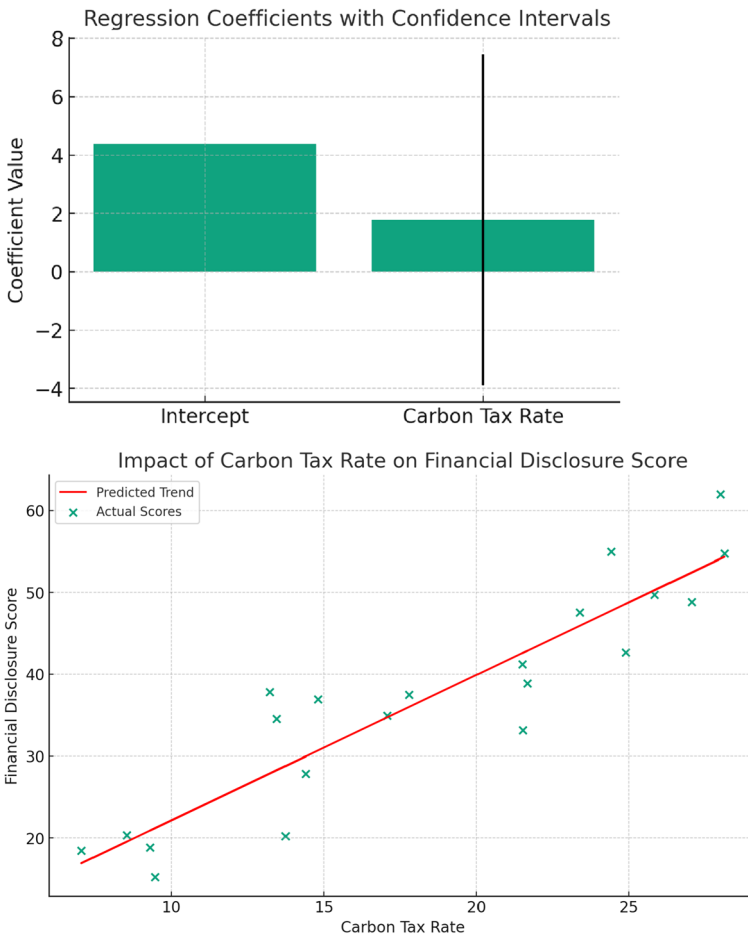
Assumption	Discussion	Conclusion
1. The model specifications are valid	<p>Here, we assume that the model for each nation (each <math>i</math>) is (1). It may be probable to draw charts with up to three measurements; with six factors, conducting a comprehensive data-based check of the satisfaction of this hypothesis (from the viewpoint of effectively selected functional forms) is complicated. However, data against the hypothesis was found, as the partial regression coefficients in country-specific regressions significantly differ from each other (see Table 6), even under the assumption of a correct functional form</p>	Some arguments in favor of
2. Taking a Chance in the Cross-Section	<p>The nations included in the study were not chosen randomly from the populations of every nation with a non-zero CO2 tax; instead, they were chosen specifically for this research. To get around this issue, one possible solution is to infer statistically from the (assumed) data-generating process rather than the general population</p>	Infringed upon but evadable
3. Explanatory variables must be completely exogenous	<p>The predicted value of the characteristic error given the explanatory factors over all periods and the unobserved impacts is zero for each <math>t</math>; there is no practical method to "find out" this from the information at hand</p>	Unclear/unknown
4. Explanatory factors change throughout time, and no perfect linear correlations exist	<p>There are no perfectly linear relationships between the explanatory variables in the current panel data set, and each of them varies with time (for at least some <math>i</math>)</p>	Fulfilled
5. Differences in the total number of errors made	<p>There is almost no data-based technique to confirm that the variance of the idiosyncratic error is constant (i.e., the same) for each <math>t</math>, dependent on all the explanatory factors over every period and the unobserved effects. Figure 2 below shows a scatter plot of the residuals from the fixed effects models against time and each explanatory factor. As one would need to draw identical diagrams of remainders about any possible combination of the variables that explain the result, the lack of evidence for the change in the variance of the remaining variables (concerning x-axis values) is far from acceptable for determining that this supposition is fulfilled. The most that can be charted is in three dimensions. Hence this is impossible</p>	There is insufficient evidence to

**Table 7** (continued)

Assumption	Discussion	Conclusion
6. Individual mistakes are not linked to one another	Residuals in Fig. 2 don't indicate systematic behavior concerning any explanatory variable, as with assumption no. 5	Unclear/no evidence against
7. Irregularities stand alone and follow a normal distribution	Again, there is no data-based way to determine whether or not the pre- sumption no. 7 (additionally affected by all explanatory variables and unobserved effects) is fulfilled, even though the "Q-Q plot" (cf. Figure 3 below) suggests that the distribution of the "fixed effects model residuals" is close to the "normal distribution"	There is insufficient evidence to

**Table 8** “Fixed effects model” – partial *t*-tests

Variable	Estimate	Std.error	<i>t</i> -value	Pr(>   <i>t</i>  )
CO2tax	- 1.3214	11.77991-18	- 3.2233	1.1141
Valueofemissionpermits	1.3212	10.77991-15	3.2232	1.1121
Investmentinfinalusagebyhouseholds	- 1.3213	13.77991-13	- 3.2239	1.3321
InvestmentsbyCorporations	- 1.3218	14.77991-21	- 3.2237	3.225e-12
Useofsolidfuels	1.3219	12.77991-1	3.2238	2.221e-12
Useofalternativeenergysources	- 1.3215	11.77991-12	- 3.2236	1.774155



**Fig. 4** Impact of carbon tax on financial disclouser

is 11.58 kgs per capita for every one-euro increase in the carbon tax rate. Careful analysis reveals that the inverse correlation between the carbon tax and the emission of greenhouse gasses is indicated by the value's negative indicator.

## 5 Discussion

This study aimed to investigate the impact that carbon taxes have on the financial statements of oil and gas businesses that are active in countries that are members of the European Union (EU). We used the multiple panel regression technique, with a primary concentration on the degree to which carbon emissions and environmental dangers were declared, to examine carbon taxes' impact on the processes used for financial reporting (Coleman 2012; Dutta et al. 2022). According to the findings of our study, carbon taxes lead to a considerable improvement in the disclosure processes of oil and gas businesses. In particular, we find that companies subjected to higher carbon taxes are more likely to reveal information about their carbon emissions and the environmental dangers linked with them in their financial reports. This is the case regardless of the size of the carbon tax. This finding is consistent with the findings of earlier research, which found that environmental regulations may motivate firms to adopt greener ways. This finding may be explained by the fact that companies are more likely to invest in their reporting infrastructure when faced with rising carbon prices. Businesses could take measures such as hiring specialized staff or putting in place data management solutions to improve their ability to monitor and report on their carbon emissions. Companies wishing to make it simpler for investors to compare their financial statements across nations may adopt new reporting standards or norms. This would make it possible for investors to evaluate companies regardless of location. According to the findings of our study, the various states that make up the EU may respond to the price of carbon in various ways when it comes to financial reporting. Particularly, more substantial benefits are observed in countries with more stringent carbon laws. This underscores the European Union's need to collaborate to unify carbon taxation and reporting regulations. This will provide a level playing field for companies and make comparing financial data from various countries simpler. In addition to the impact that carbon taxes have on the requirements for financial reporting, we discovered that many other factors also influence the degree of disclosure associated with carbon emissions in financial reports.

There are several significant elements, including company size, the kind of industry, and the level of voluntary disclosure. According to the findings of our study, larger companies and those operating in carbon-intensive industries are more likely to give detailed data on their carbon emissions and the environmental concerns linked with those emissions. Businesses that embrace voluntary reporting systems or participate in sector-specific activities are more likely to submit meaningful data on their environmental performance. This is because these businesses are more likely to want to be held accountable for their environmental performance. Our study is noteworthy because it provides real data on how carbon taxes influence the financial reporting of oil and gas corporations, especially in the European Union

member states. This information is particularly relevant to countries that are members of the EU. According to the findings of our study, carbon taxes seem to have the potential as a public policy tool for raising corporations' environmental transparency and accountability. Businesses depend on their being level playing fields, which can only be realized via the worldwide standardization of reporting regulations. Because of this, companies may need to upgrade their reporting systems to keep up with the increased interest shown by the general public in information on the firms' respective carbon footprints. Our research has a few important limitations that participants in future studies of this kind need to remember. To begin, we are just focusing on one business responsible for significant carbon dioxide production, namely, the oil and gas industry. Pricing carbon might influence the accounting practices used by manufacturing and transportation corporations, which could be something that needs to be looked into in the future. Second, we focused entirely on how the accounting sector would be impacted by the introduction of a price on carbon. Additional research might investigate how environmental policies, such as cap-and-trade or voluntary reporting frameworks, influence financial reporting. In conclusion, the scope of this study is restricted to the member nations of the European Union. In the future, carbon taxes may impact the financial reporting systems used in North America and Asia; this topic may be the subject of more research. In conclusion, our study's findings offer insight into how carbon taxes impact the financial reporting of oil and gas businesses in the member states of the European Union. According to the findings of our study, carbon taxes seem to have the potential as a public policy tool for raising corporations' environmental transparency and accountability. Our findings may serve as a resource for decision-makers, investors, and anyone interested in improving environmentally responsible business practices and decreasing the harmful consequences of climate change. Our results may serve as a platform for additional examination into how environmental restrictions impact the financial reporting methods of various industries and locales (Cheng et al. 2023; Hyndman and Khandakar 2008; Tiwari et al. 2020). This line of inquiry may be further upon in the future.

## 6 Conclusion and policy recommendations

### 6.1 Conclusion

This study highlights the complex connection between environmental fiscal regulations and business financial disclosure procedures in the European Union, emphasizing several essential issues. The empirical analysis conducted between 2000 and 2020 demonstrates that the introduction of carbon taxes has a noticeable impact on the financial reporting of firms. It was also noted that enterprises subject to these taxes expanded the scope and detail of their financial statements regarding environmental matters. This signifies an elevated degree of transparency, implying that carbon taxes not only fulfill their primary objective of decreasing emissions but also foster increased corporate disclosure and accountability. The adoption of increased reporting practices indicates that corporations are not solely addressing



the immediate financial consequences of the tax but are also adjusting their long-term strategy and engagement with stakeholders. This behavior demonstrates a broader recognition among businesses of the significance of environmental hazards and opportunities in their financial performance. This realization is likely influenced by the economic indications conveyed by carbon taxes.

From a policy standpoint, the results offer a compelling case for implementing carbon prices as a means to promote both environmental accountability and enhanced corporate governance standards. This has significant ramifications for policymakers who aim to establish a regulatory framework that promotes the achievement of sustainable development goals. Hence, the research implies that the advantages of carbon taxing go beyond environmental effects and have a profound impact on business culture and involvement with stakeholders.

## 6.2 Policy recommendations

At these crossroads in the world's economy, when digital finance and green investments are coming together, there are tremendous possibilities and hazards. A sophisticated strategy is required for policymakers to successfully traverse this junction to promote sustainable growth and solve environmental problems. Robust One important suggestion is robust legislative frameworks encouraging the convergence of green investments and digital finance. Examples include making sustainable finance standards more transparent, providing tax incentives for environmentally friendly initiatives, and encouraging open environmental performance reporting. The shift to a green economy may be facilitated by digital finance with the help of such regulatory measures, which can direct funds toward ecologically conscious projects.

Green investment-focused new financial solutions should be co-created by lawmakers and financial organizations. Green bonds, investment funds, and other eco-friendly financial products might be part of the solution. Public agencies may significantly affect environmental sustainability if they push for private investment in green initiatives. Another way to encourage the creation of digital tools that simplify and ease green investments is to promote cooperation between IT businesses and financial institutions. For example, fintech technologies make investing in environmentally friendly assets easy, while blockchain applications could make supply chains transparent and traceable. Also, lawmakers need to deal with the dangers that can arise from green investments and digital finance coming together. To prevent assaults that might damage green investment platforms, it is necessary to beef up cybersecurity safeguards for the digital financial infrastructure. In addition, countries need to keep a tight eye on the carbon offset industry to avoid "greenwashing," in which investments don't help the environment. The convergence of digital finance and green investments must be supported by a robust regulatory framework to reduce risks and maintain credibility. This convergence relies heavily on energy changes; thus, politicians should work to ease the transition to renewable power. A low-carbon economy may be quickly achieved by implementing research and development funds, incentives for renewable energy projects, and supporting regulations.

Governments may ensure meaningful and coherent sustainable development by coordinating energy transition objectives with digital finance activities.

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## Declarations

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