Università di Foggia

Doctoral Course in Economics and Finance of Territorial sustainability and Well-being

---

XXXVIII ciclo

Environmental and Financial Performance of Renewable Energy Production under Energy Transition Policy: Empirical Evidence of International Petroleum Companies

Tutor
Prof. Nicola Faccilongo

Co-tutor
Prof. Roberto Rana

Dottorando
Ridha Ali Ben Saleh

Anno Accademico 2025/2026

Environmental and Financial Performance of Renewable Energy Production under Energy Transition Policy: Empirical Evidence of International Petroleum Companies

Ridha Ali Mohamed Ben Saleh

Submitted to the Department of Economics members at the University of Foggia
in the fulfilment of the requirements for the degree of

Doctor of philosophy
in
ECONOMICS AND FINANCE OF TERRITORIAL SUSTAINABILITY AND WELL-BEING

The University of Foggia
February, 2026
Università degli studi di Foggia

ABSTRACT

This thesis centres its attention on exploring empirically the impact of Renewable Energy Production (REP) on the environmental and financial performance in a panel of 27 international petroleum companies under energy transition policy. I utilize the second-generation econometrics methods, namely: generalised method of momentum, quasi-maximum likelihood in the framework of Porter Hypothesis and Natural Resource-Based View over the period from 2015 to 2023. Environmental performance is proxied by GHG emissions, while financial performance is assessed using both accounting-based (ROA and ROE) and market-based metrics (Tobin's Q and stock price). I found strong evidence that renewable energy production positively impacts GHG emissions reduction in both the short and long terms, exhibiting an inverted U-shaped trend. As for financial performance, results reveal that renewable energy production exerts a significantly positive impact on financial performance measured by accounting-based metrics, while this impact is found to be neutral on market-based measures. Furthermore, the results also provide evidence that research and development play a fundamental role in reducing GHG emissions, both directly and by enhancing the effectiveness of REP. This beneficial role of R&D, however, does not extend to the relationship between renewable energy production and financial performance. Finally, the effect of REP on GHG emissions and accounting base metrics is found to be more pronounced in EU international petroleum companies relatively to non-EU international petroleum companies. These findings add an original contribution to the relevant literature, in particular the role of renewable energy production on environmental and financial performance under energy transition policy in petroleum industry. Consequently, these findings provide a valuable guideline for managers at petroleum companies to strategically realigning their capital allocation for improved corporate environmental and financial performance.

Keywords: Renewable energy production, research and development, GHG emissions, Porter Hypothesis and GMM approach.

ABSTRACT

Questa tesi si concentra sull'esplorazione empirica dell'impatto della Produzione di Energia Rinnovabile (PER) sulla performance ambientale e finanziaria in un panel di 27 compagnie petrolifere internazionali sotto politiche di transizione energetica. Utilizzo metodi econometrici di seconda generazione, in particolare: metodo generalizzato dei momenti (GMM) e quasi-massima verosimiglianza (QML) nel contesto dell'Ipotesi di Porter e della Natural Resource-Based View, per il periodo dal 2015 al 2023. La performance ambientale è approssimata dalle emissioni di gas serra (GHG), mentre la performance finanziaria è valutata utilizzando sia metriche contabili (ROA e ROE) che metriche basate sul mercato (Q di Tobin e prezzo delle azioni). Ho trovato prove solide che la produzione di energia rinnovabile ha un impatto positivo sulla riduzione delle emissioni di GHG sia nel breve che nel lungo termine, mostrando un andamento a U invertita. Per quanto riguarda la performance finanziaria, i risultati rivelano che la produzione di energia rinnovabile esercita un impatto significativamente positivo sulla performance finanziaria misurata da metriche contabili, mentre questo impatto risulta essere neutrale sulle misure basate sul mercato. Inoltre, i risultati forniscono anche prove che la ricerca e sviluppo (R&S) gioca un ruolo fondamentale nella riduzione delle emissioni di GHG, sia direttamente che migliorando l'efficacia della PER. Questo ruolo benefico della R&S, tuttavia, non si estende alla relazione tra produzione di energia rinnovabile e performance finanziaria. Infine, l'effetto della PER sulle emissioni di GHG e sulle metriche contabili risulta essere più pronunciato nelle compagnie petrolifere internazionali dell'UE rispetto alle compagnie petrolifere internazionali non-UE. Questi risultati aggiungono un contributo originale alla letteratura pertinente, in particolare riguardo al ruolo della produzione di energia rinnovabile sulla performance ambientale e finanziaria nell'industria petrolifera sotto politiche di transizione energetica. Di conseguenza, queste scoperte forniscono una preziosa guida per i manager delle compagnie petrolifere per riallineare strategicamente l'allocazione del loro capitale al fine di migliorare la performance ambientale e finanziaria aziendale.

Parole chiave: Produzione di energia rinnovabile, ricerca e sviluppo, emissioni di gas serra, Ipotesi di Porter e approccio GMM.

DIDICATION

To my father

ACKNOWLEGEMENT

My greatest and most sincere gratitude is to my supervisor and co-supervisor Professor. Nicola Faccilongo and Professor Roberto Rana. I am very much appreciated their excellent supervision, constructive comment, valuable suggestion, and continuous support during writing my PhD thesis and scientific papers times. They have provided me with outstanding and helpful insights and advices on the research idea and presentations.

I would also like to thank my family members, my wife who stand sold with me and caring bout my children during the hardest times of my PhD. A special thanks also to my parents for their support and efforts helping me since I was born till the completion of my PhD. I am grateful for everything you have done for me! You are such treasures in my life.

There is a great thanks to all the post graduate students in the Economics and Finucane of Territorial Sustainability and Well-Being, XXXVIII cycle for their help, friendship, and creating a pleasant working environment throughout my years at the University of Foggia. The memory of their support will be kept in my heart never fade. Gratitude also goes to my Libyan friends for their engorgement and support. Finally, this acknowledgement is not completed without the mention to the all the Department of Economics members at the University of Foggia who have been helping in many ways, knowledge, and moral support throughout the completion of my PhD journey.

Last but not least, this thesis is just the beginning of my research journey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVAIATIONS

REP	Renewable Energy Production
R&D	Research and Development
GHG	Greenhouse gas
PH	Porter Hypothesis
NRBV	Natural Resource-Based View
ROA	Return on Assets
ROE	Return on Equity
ROCE	Return on Capital Employed
IPCs	International Petroleum Companies
GMM	Generalised Method of Momentum
QML	Quasi-Maximum Likelihood
RE	Random Effects
FE	Fixed Effects
PA	Parise Agreement
CO_2eq	Carbon Dioxide-Equivalents
NDCs	Nationally Determined Contributions
GWh	Giga Watt Houre
MWh	Mega Watt Hours
COP	Climate Change Conference
CCUS	Carbon Capture, Utilization and Storage
IEA	International Energy Agency
EU	European Union
SLR	Systematic Literature Review

Introduction

Global warming has been increasingly affecting each aspect of our live (IPCC, 2023; Pereira et al., 2010; World economic forum, 2025). Undoubtedly, the drastic increase in GHG emissions coming from economic activities which use fossil fuels to provide energy, have been the prime driver of global warming (Al-Ghussain, 2019; Yoro & Daramola, 2020). To prove, the global GHG emissions has been growing remarkably since the beginning of last century and it records the highest quantity ever in 2023 with approximately 54 billion tonnes of carbon dioxide-equivalents (CO_2eq), (figure 1). Recently, the total cumulative emissions from the ratification of Parise Agreement (PA) in 2015 to 2023 were 471 billion tonnes of CO_2eq. Of which, fossil fuels account for over 75 percent and more than 90 percent was CO_2 emission (Our global in data, 2025). For this reason, the global goal of net zero emission by 2050 was declared at the UN Climate Change Conference (COP21) in Paris, in 2015. To achieve this goal, the Nationally Determined Contributions (NDCs), which outline country-specific commandments in order to reduce national emissions, has been officially introduced. Subsequently, climate initiatives and strategies have been adopted within economic sectors around the world. In this context, petroleum sector, which provide over 80% of the world's energy needs (ÓhAiseadha et al., 2020), is considered one of the most polluted industries on earth, as it is responsible for 37% of global GHG emissions due to high oil and gas[1] extraction (IEA, 2020b). For example, in 2023, about 100 million barrels of oil per day and 4,159 billion cubic metre of oil and natural gas were extracted by petroleum companies (IEA, 2023e). Of course, this extraction and use of this resources is accompanied by a concomitant pollution in the forum of GHG emission, which have an adverse effect on agriculture, heath and many more (U.S. Energy Information Administration, 2020). GHG emissions consist of two main categories under the classification of the GHG Protocol, that is, scope 1, scope 2 and scope 3. More specifically, scope 1 includes the direct GHG emissions from sources that are owned or controlled by IPCs. These are emissions that are directly attributed to a company's operations such as flaring, fugitive, leakage and the combustion needed on drilling. While Scope 2 is the indirect GHG emissions associated with the generation of purchased energy consumed by a company. Thus, 20 international petroleum companies such as Chevron, Exxon, BP, Shell, Aramco and Gazprom etc, were behind a third of all carbon emissions with total equal to 480 billion tonnes of CO_2eq since 1965 (Gardian, 2019). In the same vein, Climate Disclosure Project, 2017, reported that 25 major petroleum companies (IPCs) are behind more than 50 % of global industrial GHG emissions since 1998 to 2017. The report also stated that if these

[1] In this thesis, the terms 'oil and gas' and 'petroleum' is used interchangeably.

companies continue to extract fossil fuels at the same rate over the next 28 years, then global average temperatures would increase to 4°C by the end of the century. Based on these alarming statements, in its updated report, the IEA (2023) stated that there should be no new investments or extension of existing investments in petroleum to achieve net-zero emissions by the mid of this century. This underscores the crucial role that IPCs can play in achieving positive environmental outcomes. Their actions across production, operations, and innovation, particularly in developing renewable energy, are essential to underpin the implementation of NDCs and thereby addressing the pressing global challenge (Hart, 1995; Porter & Linde, 1995).

Recently, the increase awareness from the stakeholders such as civil society, managers and investors vis-a-vis the adverse impact of GHG emissions on environment (Calculli et al., 2021) coupled with the tightening of regulatory frameworks such as the PA and supported by The European Green Deal policy, made some national and international companies to recognise the importance of environmental protection and a low-carbon emission transition (Lu et al., 2019). As a consequences, some large oil and gas companies have adopted net zero emission goal by 2050 in line with the PA, see figure 2 (Midttun et al., 2022) (IEA, 2020a). But what is a net zero emission in petroleum industry? It is the reduction of GHG emissions from across all stage of petroleum life cycle, including the stages of exploration, extraction, refining, combustion and transportation. The origin of the net zero has its roots in earlier ideas and insights about carbon neutrality, cumulative emission and carbon budget. Yet, it was the PA in 2015 that instigated the internationalization and institutionalization of net zero as a key policy objective by emphasising on the long term climate action (Berger-Schmitz et al., 2023). The concept of net zero emission was given further impetus by the IPCC, 2018 special report, which affirmed the necessity of reaching net zero emission around the mid of this century so as to limit warming to 1.5.

The core of global net zero-emission goal is Renewable Energy Production (REP). It includes solar photovoltaic, wind, hydro, biofuel hydroelectric, geothermal, biomass, hydrogin and other renewables. REP increased significantly by more than 120 % from 153 gigawatts (GW) in 2015 to almost 340 GW in 2022 (IEA, 2016, 2023c). In view of this, IPCs have started immensely diversifying their business models by deploying renewable energy in order to meet the timeline of net zero emission by 2050. For example, at the beginning of 2016, Equinor launched a new venture capital of $ 200 million to invest in renewable energy, wind power particularly (Statoil Sustainability Report, 2016). One year later, Equinor has a Dudgeon wind farm off the coast of Norfolk in England, and Hywind wind farm in Scotland. As a result, the self-generation of REP production was 830 and 1,251 Giga Watt Hours (GWh) in 2017 and 2018 respectively (Annual sustainability report, 2018). In the time being, more than one million European homes are powered by Statoil's renewable electricity from offshore wind farms in German and UK. Likewise, the Canadian Suncor's renewable energy business includes investments in five operating wind facilities and ethanol plant production with the capacity to generate 187 migawatts of electricity in 2016. In the same vein, the annual sustainability reports 2015 and 2017 of Hellenic Energy showed that the initial production of renewable energy from the operation of photovoltaic stations exceeded 27 GWh in 2015, while the wind energy produced in Messinia exceeded 89 GWh, resulting in the avoidance of over 115, 000 tons of CO_2 emissions in 2017. In 2019, Hellenic Energy also builds the photovoltaic park in Kozani, one of the largest renewable energy projects in the EU, with a capacity of 350 GWh of energy production per year, capable of providing clean zero emission energy to 750,000 household. This resulted in avoiding 300,000 tons of CO_2 emissions. Repsol had started the investment on renewables, mainly for offshore wind projects in 2015 and it aimed to reduce GHG emission by 1,900,000 tonnes in 2020 (Annual sustainability report, 2015). Also, Oil India Limited invested approximately 135 million $ in renewable energy projects in 2015 aiming to become a net zero emission company by 2040 (Annual sustainability report, 2015).

Research and Development (R&D) is another crucial element of IPCs to achieve the global goal of the PA because it involves the use of new technology capable of not only controlling GHG emissions but also boosting REP, thereby accelerating the energy transition path (Alfalih, 2025; Hailemariam et al., 2022; Jiang et al., 2024; Lobov & Rybin, 2022; Muhammad & Hoffmann, 2024). For instance, Eni S.p.A' R&D expenditure amounted to 197.2 million € in 2018 which resulted in 43 patents, out of this 13 was related to renewable energy sources (Annual report, 2018). OMV Aktiengesellschaft R&D expenses were 61 million € in 2020, part of it was attributed to hydrogen, advanced fuel, co-processing, Carbon Capture, Utilization and Storage (CCUS) and energy storage. IndianOil Corporation in 2016, spent about 9.34 million $ on R&D resulted in 105 patents in cutting edge technology of low carbon technology with specific concentration on renewables such as solar, bio-energy, thermal and hydrogen (Sustainability report, 2016). Oil and Natural Gas Corporation spent about 74 million $ to upscale the digitalization across the business process and has filed 14 patents through its seed fund to 19 start-ups in 2019 (annual sustainability report, 2019). R&D include also energy efficiency projects which result in emerging of new environment-friendly technologies (Maradana et al., 2017). For instant, to achieve the goal of becoming a net-zero emission, Repsol spent about 84 million € in projects includes CCUS, e-fuel, green hydrogen and natural carbon sink, which led to about 20 patents at the end of 2018 (Repsol integrated report, 2018).

Based on the forgoing, it is clear that since 2015, many petroleum companies have evolved their business models from a fossil fuel paradigm to a new model that incorporates REP and invest in R&D to achieve net-zero emissions by 2050. However, many uncertainties remain about the progress of the energy transition in these companies and whether it will be sufficiently rapid to prevent the growing severe impacts of global warning.

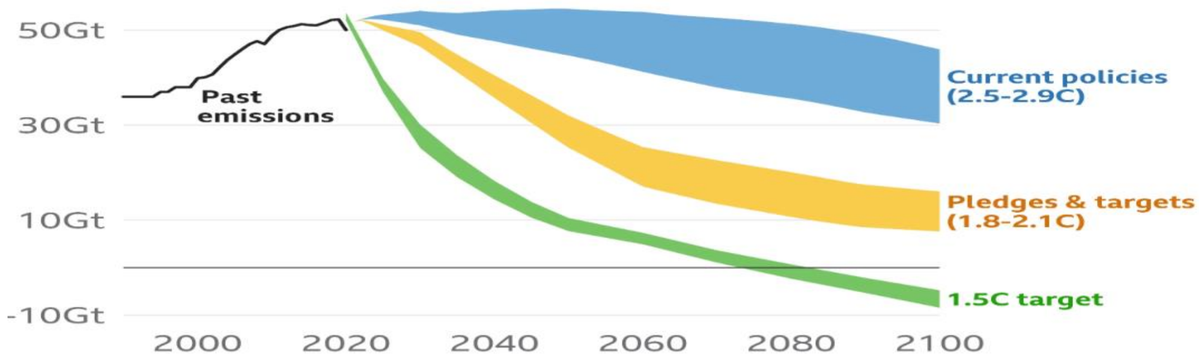

Fig1. Global GHG emissions from Pledges and Targets during the period of 2000 to 2100, Climate Action Tracker, 2024.

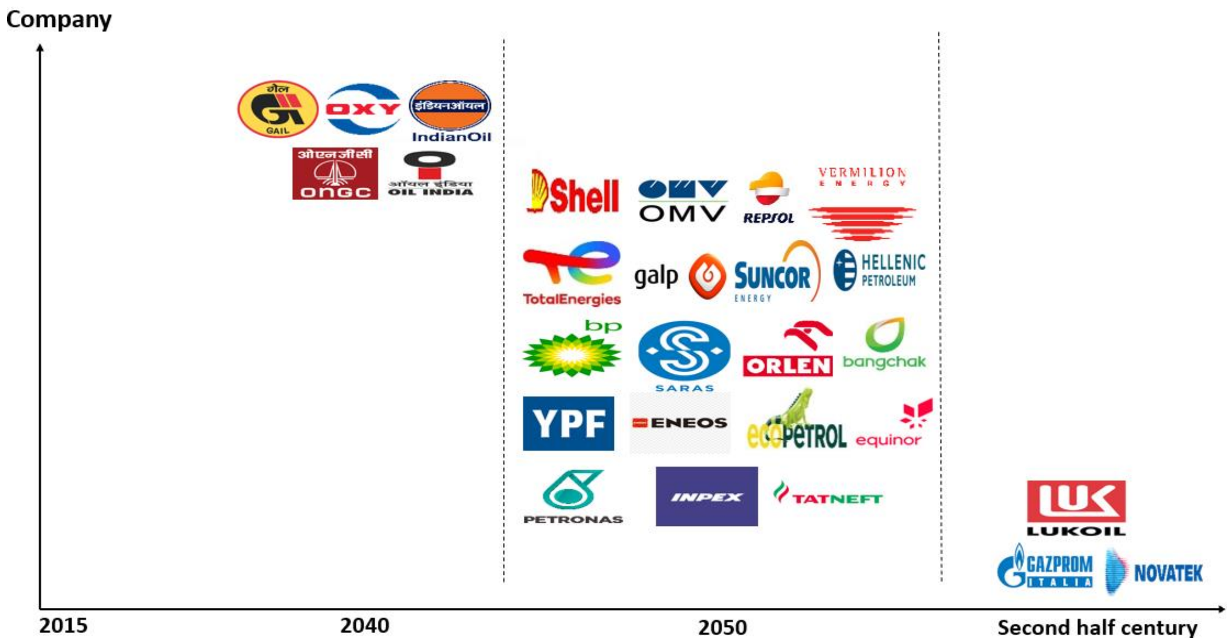

Fig. 2. Net zero emission of international petroleum companies, Author elaboration

Historically, the environmental investment and expenditure such as renewable projects and R&D were conceived merely an additional cost that comes at the expenses of profitability (Ambec & Lanoie, 2008; King & Lenox, 2002; Palmer et al., 1995; Preston & O'Bannon Douglas P, 1997; Walley & Whitehead, 1994). Albeit , this paradigm was revolutionized by Hart, (1995) and Porter & Linde(1995) who hypothesized that environmental activities of a company will not only result in improving the environmental performance but also the FP i.e., a win-win situation. From this perspective, companies neglecting their environmental performance are more prone to fines and taxes for their polluting activities, which managers and investors perceive as a loss. Certainly, when IPCs started producing renewable energy and raise its percentages gradually against conventional petroleum, tax carbon, penalties and fines will be avoided accordingly. A good example for the latter is Eni gas which avoided about 500 Gt of GHG emissions as a result of REP in 2017.

In the same vein, Porter, 1991 postulated that strengthen environmental regulations advocate technological innovation, leading to subsequent improvements in financial performance. The porter hypothesis can be used to comprehend how companies utilize REP and R&D expenditure to decrease their adverse impact on the environment and improve their business performance tandemly. Hence, evaluating companies' performance can be measured based on environmental performance. Having a net zero emission goal for the energy transition is not enough to be successful because this depends on some factor such as the mount of REP and R&D expenditure, and whether the targets goals and milestone in terms of GHG reduction are met (Dai et al., 2017) or it is simply a manifestation of corporate greenwashing otherwise (Christiansen et al., 2023; Biksey & Cowan-Ellsberry, 2002; de Freitas Netto et al., 2020). Given this scenario, the net zero emission goal, which based on REP and R&D, must be evaluated because the strategy failing has an adverse impact on a company in the short and long term (Aragón-Correa & A. Rubio-López, 2007). Energy transformation and increasing REP are crucial for all petroleum companies at present because the energy transition becomes irreversible. Having said that, is the impact of REP on environmental performance positive or negative? What is the impact of REP on financial performance bearing in mind the initial cost of REP? To clarify the latter, according to International Renewable Energy Agency (IRENA) report 2023, a one GW installation of solar PV, hydropower, offshore wind, and onshore wind cost about 758, 2 806, 1 260 and 2 800 million USD, respectively in 2023. In petroleum sector, INPEX's 396,390 Mega Watt Hours (MWh) costed about 45 USD billion in 2021 (Annual sustainability report, 2023). Therefore, measuring the impact of REP on environmental performance and financial performance in IPCs has to consider the initial cost of renewables into the equation so that results can reflect this impact.

With regard to financial performance measurements, metrics such as Return On Assets (ROA), Return On Equity (ROE), and Return on Capital employed (ROCE) are frequently used in the literature as an operation performance for the short run benefit of EP (Gallego-Álvarez et al., 2015). Along with these operation performance, market based measures, namely: Tobin's Q, stock price and Market capitalization are the most popular indicators are used to measure the long term benefit of financial performance (Dorigoni & Anzalone, 2024; Gozgor et al., 2024; Martí-Ballester, 2017). Serval scholars have mentioned that because accounting based and market-based metrics have a difference focuses, this may lead to different results. To illustrate, on one hand, accounting base metrics express a company's efficiency in creating values from its assets as well as the company's internal capabilities performance, but theses metrics are inappropriate in measuring long term and the intangible benefits associated with a better environmental performance (Delmas et al., 2011). On the other hand, REP is considered a competitive advantage for IPCs that started their self-production of renewable energy since the med of last century. This competitive advantage reflects the external perception of a company's performance and thereby it can be measured by market-based metrics (Ruggiero & Lehkonen, 2017). Clearly, measuring only the impact of REP on financial performance in the short run will create a gap in this evaluation. Therefore, integrating both accounting and market metrics for the short and the long run performance will provide a more comprehensive picture of the financial performance benefits associated with environmental performance enhancements in IPCs.

Since the ratification of PA, there have been few studies at micro level with modest evidence to guide IPCs in perusing net-zero emissions by 2050 (Abraham-Dukuma, 2021; Boon, 2019; Salygin & Lobov, 2021). To be specific, most studies conducted on the impact of REP on environmental and financial performance in petroleum companies are survey or analysed the reports and documents on one hand (Abraham-Dukuma, 2021; Boon, 2019; Canal Vieira et al., 2022; Graham, 2019; Lobov & Rybin, 2022; Lu et al., 2019; Morgunova & Shaton, 2022; Nilsen, 2017; Salygin & Lobov, 2021; Toghyani & Saadat, 2024; Zhong & Bazilian, 2018). On the other hand, the majority of empirical studies in this subject were conducted at the macroeconomic level (Saleh et al, 2024; Qudrat-Ullah & Nevo, 2021). To date, previous studies do not provide clear evidence that petroleum companies, adopted net zero emission, improve both environmental and financial performance. In other words, utilizing the actual environmental indicators, namely renewable energy and R&D to measure their impact on environmental and financial performance is still missing in the literature. Thus, it is unclear whether the investment in renewables and R&D improve the environmental and financial performance at micro level which requires more investigation studies (Abraham-Dukuma et al., 2021; Graham, 2019; N. Li et al., 2023). This thesis is motivated by the urgent need for petroleum companies to adopt sustainable energy practice to address the adverse effects caused by GHG emission. To prove, the total GHG emissions of the studies sample during the period of study was about 6 billion tonnes of CO_2eq. Given this scenario, the main purpose of this thesis is to bridge this gap in research literature by measuring the impact of renewables on environmental and financial performance under energy transition policy.

Thesis' objectives, purpose and contribute

This thesis intends, first, to explore the impact of REP on both, environmental and financial performance since the ratification of PA in upstream sector of petroleum industry. Generalized Method of Momentum and QML are computed during the period from 2015 to 2023 in the frame work of PH and NRBV. Moreover, this empirical measurement has been conducted on twenty-seven international petroleum companies[2] in upstream sector during the period from the ratification of PA to 2023 based on Porter Hypothesis (PH) and Natural Resource Based View (NRBV). The second objective is to gage the impact of R&D also on both, environmental and financial performance during the same period. While the third objective is to define the role of R&D on the relationship between REP and environmental performance and between REP and financial performance. To achieve these purposes, first, identifying the IPCs that adopted net zero emission by the mid of this century based on PA ratification to set the preliminary sample of the study. Second, extrapolation IPCs' annual and sustainability reporters are utilized to collect data of the study and to comprehend the actual procedures, activities in terms of REP and R&D and their association with GHG emissions. Third, based on PH and NRBV, environmental data are integrated into empirical models. Finally, the impact of REP and R&D on environmental and financial performance will be measured empirically according to the casual and affect assumption.

Accordingly, this thesis aims to answer the following questions:

Q1 - What is the impact of REP on environmental performance in international petroleum companies?

Q2 - What is the impact of REP on financial performance in international petroleum companies?

Q3 - What is the impact of R&D on environmental performance in international petroleum companies?

Q4 - What is the impact of R&D on financial performance in international petroleum companies?

Q5 - What is the role of R&D on the relationship between REP and environmental performance in international petroleum companies?

Q6 - What is the role of R&D on the relationship between REP and financial performance in international petroleum companies?

Despite the fact that it is a decade since the ratification of PA, 25 years to net-zero emissions and only 5 years to SDGs deadlines, studies into the impact of REP on environmental and financial performance in petroleum industry, which regarded one of the largest pollution industries, remains uninvestigated. Some IPCs are currently transforming and restructuring their business model from fossil fuels to renewables to sustains their financial health and growth trajectory amidst dynamic energy transition. Therefore, it is of remarkable contemporary importance to explore the impact of REP incorporation on environmental and financial performance. As a result, this exploration will clarify IPCs' commitment to net-zero emissions and their contribution to UN SDG 7 and 13, i.e., the affordable clean energy and climate action. Furthermore, for petroleum companies yet to adopt net-zero targets, embracing this goal presents a strategic opportunity to enhance their business model. By incorporating renewables and

[2] Shell, Eni SpA, Total, Repsol, Gazprom, Equinor, Hellenic Petroleum, Eneos, Inpex, OMV Aktiengesellschaft, BP, Ecopetrol, Rosneft, Petrobras, Galp, Lukoil, Novatek, Suncor Energy, Vermilion Energy, Saras, Occidental, Petroleum National Berhad, YPF Sociedad, Bangchak, Gail NS, Indiaoil Corporation Limited e Oil India Limited.

increasing investment in R&D, this transition promises not only improved financial returns but also a stronger reputation with customers and in the market. Moreover, this thesis offers valuable information for investors, portfolio managers, and traders, guiding them to invest in IPCs that have adopted net-zero emissions and invested in renewables to monetize their profit.

Empirical studies in the impact of REP on environmental and financial performance at micro level is scant due to data limitation, particularly environmental data. i.e., REP and GHG emissions. The unique, hand-collected dataset on IPCs enable to fill this gap. Thus, as far as the literature is concerned, this thesis is the first to measure empirically the impact of REP on environmental and financial performance for the short and long term in petroleum industry based on the PA ratification. Therefore, the contribution of this thesis to the extant literature will be significant in several aspects. First and foremost, findings significant empirical results by measuring empirically the impact of REP on environmental and financial performance may encourage petroleum companies to consider not only the investment on renewables but also the energy transition path to global net zero emission in their strategy by the med of this century. Related literature have focussed only on survey studies, in addition to analysing the reports and documents of petroleum companies. (Nilsen, 2017) Hansen and Steen (2015) Zhong and Bazilian (2018) Graham (2019). A second contribution is to shed light on the drivers of net zero emissions and energy transition in petroleum industry since the ratification of PA with a sample consist of 27 IPCs from upstream sector. Thus, understanding the complexity and opportunities of energy transition in petroleum industry since the ratification of PA provides the necessity of innovative sector-specific policies for police makers to advocate this transition and reducing GHG emissions. While previous empirical literature have concentrated only on how environmental strategy in petroleum companies succeeded in reducing emissions and increase profitability (Fethi & Rahuma, 2020; Rahuma & Fethi, 2022). A third contribution is to provides new evidence concerning the role of R&D on boosting the impact of REP on environmental performance, as well as, its moderating role of enhancing the impact of REP on environmental performance. Previous literature have concentrated remarkably on the direct impact of R&D on environmental and financial performance (Gao et al., 2025)(K. H. Lee & Min, 2015) (Fethi & Rahuma, 2020; Rahuma & Fethi, 2022). (Martí-Ballester, 2017) (Ruggiero & Lehkonen, 2017). Last, because in previous literature CO_2 is the common variable used as a proxy of environmental performance (Hao, 2022; Justice et al., 2024; Saidi & Omri, 2020; Trimech, 2024) in this thesis has been utilized all GHG emission as a proxy of environmental performance, which consists of five elements such as, in addition to CO_2, namely: Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6). Hence, the results of this thesis will reflect the effort of the said sample to control and curtail other pollution elements such as CH_4 leakage and fugitive. CH_4 is a potent GHG 80 of times more powerful than CO_2 and its concentration in the atmosphere is around two-and-half times greater than pre-industrial levels (IPCC, 2021).

Following the introductory, which introduces this research, this thesis is structured as follows. Chapter 1 bases the theoretical foundation of this thesis, offering a deep discussion of the emergence and philosophy of PA and NRBV theory. Chapter 2 classifies and discusses the relevant literature concerning the impact of REP and R&D on environmental and financial performance since the ratification of PA. Chapter 3 presents in more detail the data collection process and illuminates the characteristic of IPCs chosen in this thesis. In addition, it thoroughly explains the evolution of the methodology utilized to measure the impact of REP on environmental and financial performance. Chapter 4 contains the analysis and results of this thesis. More specifically, the first part of this chapter addresses the impact of REP on environmental performance, while its second part addresses the impact of REP on financial performance. In chapter 5, I employ the robustness tests to substantiates the original findings at three levels, namely: heterogeneity effect, utilizing other methodology and replacing dependent and control variables. Conclusions are drawn, policy implications are discussed, and limitations are identified.

Chapter 1

1. Theoretical foundation.

It must be remembered that economic growth was the first and foremost issue that the focus of governments and economists revolved around. Historically, Adam Smith, in his famous book 'the wealth of nation' introduced what is known as a classical theory where the natural resources were the driving force behind economic growth. This theory was refined by (Solow, 1956) and (Nelson, 1981) who claimed that material capital and workforce are the driving forces of economic growth. But the emergence of knowledge-based economy conception at the beginning of the 21 century, revolutionized economic theory and shifted the focus of policymakers and economists from tangible asset to tacit asset where the latter is regarded as the driving force of the long run growth (Say, 1803; (Romer, 1986) (Lucas, 1988). Notably, Schumpeter's innovation theory postulated that innovation is the driving force of economic growth and this theory is referred to as Schumpeters' shock (Schumpeter, 1934). Schumpeter also coined the terminology of (creative destruction) in his capitalism, socialism and democracy book to underline the importance of innovation in achieving economic growth and prosperity (Schumpeter, 2013).

The critical turning point on the track of economic growth occurred when its damage on the environment was recognized as one of the most serious problems. (Meadow et al., 1972) in their seminal work "Limit to growth discussed deeply how population growth and exponential economic growth leads to the depletion of finite resources and increased pollution, straining planetary boundaries. Limit to growth concluded that we have to act early to secure the environment, otherwise, the planet could experience serious adverse effects because of climate change. Their work concluded that without early action to manage these limits, the global system risked experiencing systemic adverse effects, including resource scarcity, widespread pollution, and the lack of daily essential life. Equally important the Brundtland – Report which was published in 1987 by the World Commission on Environment and Development (WCED, 1987). It analysed deeply the global environmental problems due to human activities. This report clearly called for 'sustainable development' by adopting climate strategy to secure the environment and ecosystem. Since then, the environment became the cornerstone of most policies and strategies at the level of macroeconomic and microeconomic worldwide.

This growing recognition of environmental costs and damage, often termed negative externalities in environmental economics, underscored the inadequacy of traditional economic models to fully capture the societal impact of production and consumption. These externalities, such as pollution and resource degradation, are not typically reflected in market prices, leading to a misallocation of resources and inefficient outcomes. Consequently, new theories emerged at the microeconomic level to address environmental challenges within business strategy, primarily the PH and the NRBV, each of which will be in the next paragraph discussed next.

1.1 Porter Hypothesis.

This hypothesis had first introduced by (Porter, 1991) and subsequently developed and deeply elaborated by (Porter & Linde, 1995). The hypothesis challenges the conventional wisdom that strengthen the environmental regulations will result in only an additional cost at the expenses of profits. Alternately, PH suggested that rigorous and thoughtfully crafted environmental regulation can spur firms to develop cleaner products and more efficient processes, leading to offset the cost of environment expenditure and ultimately result in a better environmental and business performance. This hypothesis sparked a significant paradigm shift on the conception of environmental regulation and its consequences on environment and financial performance.

In the current era, PH resonates with the ambitious global goal of achieving net-zero emissions because this goal is based on PA, which has its impact on environmental regulation among counties adopted this global goal. Put it differently, petroleum industry has been facing an immense pressure stemming from stringent climate policy through NDCs which each country should introduce at the level of its sectors to achieve the global decarbonization goal. In this regard, petroleum companies have started the investing in renewable energy so that they can meet the decarbonization targets aligned with the PA's 2050 net-zero goal. Clearly, instead of perceiving the shift towards renewable energy production solely as a compliance cost due to the environmental regulation, the PH postulate that stringent environmental regulation can catalyse petroleum companies not only for meeting regulatory requirements but also for investing in clean enrgy, redesigning the operation process to be more efficient, promote efficient use of current assets, avoiding costs and risks through low GHG emissions, creating environmental leadership in the energy sector and investment in new technology for low GHG emission which result to what is called (innovation offsets). Innovation offsets include developing new energy technology like green hydrogen, leveraging their existing infrastructure for new energy vectors, developing new expertise in renewables. Ultimately, all of this lead to the enhancement not only the environmental performance of these companies but also the financial performance in the long-term.

Natural Resource Based view theory.

NRBV theory (Hart, 1995) was an extension of the Resource-Based View (RBV) theory (Barney, 1991). While the latter did not focus on the environment, the former claimed that a company's unique environmental capabilities and natural resource management can be a crucial source of sustained competitive advantage. Particularly, when these capabilities are valuable, rare, inimitable, and non-substitutable (VRIN). Furthermore, it emphasizes that proactive engagement in areas such as pollution prevention, product stewardship, and sustainable development can yield strategic benefits beyond mere compliance, embedding environmental excellence as a core strength. As stated earlier, with the ratification of the PA in 2015, global commitment to mitigating climate change solidified, establishing an ambitious framework towards achieving net-zero emissions by mid-century. This has intensified pressure on all industries, especially the traditionally carbon-intensive like petroleum sector.

For these companies, the NRBV provides a vital lens through which to understand their strategic imperative: achieving net-zero by 2050 is not solely a regulatory burden but a profound opportunity to cultivate new VRIN environmental capabilities, particularly through renewable energy production. By strategically investing in and scaling renewable energy projects (e.g., solar, wind, green hydrogen), these petroleum firms are not only decarbonizing their operations, thus internalizing the environmental costs of GHG emissions, but are also developing distinct expertise, securing access to crucial new energy markets, and building a more resilient, future-proof business model. This direct engagement in renewable energy creates a competitive advantage by reducing exposure to fossil fuel price volatility, enhancing their brand reputation, and positioning them as leaders in the burgeoning green economy, ultimately facilitating their transformation from fossil fuel leaders to sustainable energy providers and securing their long-term relevance.

To this end, the theoretical foundation of this thesis is that the expected impact from the side of REP and R&D on GHG emission is negative, implying a decrease in GHG emissions. In the meantime, the expected impact from the side of REP and R&D on financial performance is positive, indicating an increase in profits. Framing the relationship this way, I therefore faithfully follow Porter and Van (1995) PH, as well as, Hart (1995) NRBV theory to build and develop the main two following models for this thesis:

Model 1: Environmental performance = F (Renewable energy production + research and development + Total assets)

Model 2: Financial performance = F (Renewable energy production + research and development + Total assets).

Where in the first model, environmental performance is proxied by GHG emissions. In the second model, financial performance is proxied by accounting base (ROA, ROE), and market base metrics (Tobin's Q and market price). In addition, total assets are included in both models to control for firm size in order to detect the scale effects.

Chapter 2

2. Literature review

This chapter reviews the literature pertaining to the subject of this thesis. Its aim is to trace the evolution of the topic and the key conclusions that have emerged. Based on this chapter, the impact of REP on environmental and financial performance will be clear. To achieve this, the chapter is divided into several sections. The first section outlines the material and method employed in the literature review. The discussion is presented in the second sector, while the results are reported in section three.

2.1 Material and methods

The PH lays the theoretical foundation of this paper. It postulates that "companies must start to recognize the environment as a competitive opportunity-not as an annoying cost or a postponable threat" (Porter & Linde, 1995). Put it succinctly, adopting global net zero emission leads to improved performance in both the environment and business, representing a win–win scenario. Thus, a Systematic Literature Review (SLR) was conducted to collect and examine studies on the impacts of renewable energy and R&D on the environmental and financial performance of petroleum companies. An SRL is a quantitative methodology used to explore the major important studies on a topic to develop knowledge in a certain domain of research (Miklautsch & Woschank, 2022). Furthermore, current literature emphasizes that valid SLRs help scholars generate and evaluate new knowledge because it minimizes various judgement biases because it involves the systematic assessment of relevant insights from recent research studies (Ali & Usman, 2018).

In line with the SRL methodology, the author performed an explicit, transparent and reproducible analysis by applying the following steps: (1) define the aims and scope of the work, as well as its boundaries (e.g., time frame, keywords, subject areas, document type, and language), (2) identify suitable research strings using Boolean logical operators (e.g., AND) and select keywords, (3) synthesize the collected data according to the PRISMA standard guidelines (Page et al., 2021) and (4) analyse the data. The author conducted a structured TITLE-ABS-KEY search in three main databases because of their positive reputations in the field of academic research, namely the Scopus (Elsevier indexed database), Web of Science (Calvairate indexed database) and Science Direct databases.

Due to the huge body of literature on the environment, in the SLR, we concentrated on how renewable energy and R&D affect the environmental and financial performance of petroleum companies. Importantly, we used eco innovation as a proxy of R&D to get extensive result related to R&D expenditure in environment in line with (Ahmad & Zheng, 2021) (S. Khan et al., 2022) (Feng, 2022) (Fethi & Rahuma, 2020). Accordingly, *Renewable energy,* which is the first independent variable, was used as a search term in addition to the following keywords *CO_2, finance, petroleum, finance, company*. Similarly, the second independent variable was defined using the following keywords: *eco, and innovation,* Table 1 summarizes the selection string.

Table. 1. Databases used in the selection of literature

Keywords	Scopus	Web of Science Clarivate	Science Direct
Renewable AND energy:	231,433	296,808	391,410
Renewable AND energy AND CO_2:	12,254	17,638	24,186
Renewable AND energy AND CO_2 AND finance:	113	1,292	3,441
Renewable AND energy AND CO_2 AND finance AND petroleum:	5	44	951
Renewable AND energy AND CO_2 AND finance AND petroleum AND company:	0	2	422
Eco AND innovation:	4,560	15,929	42,938
Eco AND innovation AND CO_2:	109	779	2,537
Eco AND innovation AND CO_2 AND finance:	2	65	690
Eco AND innovation AND CO_2 AND finance AND petroleum:	0	2	159
Eco AND innovation AND CO_2 AND finance AND petroleum AND company:	0	1	78

Source: Author elaboration.

The plethora of literature brings the author to implement further limitations on the string. Consequently, the string was limited to the period of study between January 2015 and December 2023 because this paper endeavours to investigate the impact of REP on environmental and financial performance in addition to its policy implications for petroleum companies since the ratification of the PA. Furthermore, the string was limited to English language and research articles and review articles to shed light on global and relevant literature. Moreover, the string was limited to six subject areas based on the characteristics of this paper: (1) Economics, econometrics and finance, (2) environmental science, (3) business, management and accounting, (4) social science and energy and (5) engineering. The final selection of article review was carried out based on the PRISMA model. Figure 3 illustrates the steps in this model(Page et al., 2021).

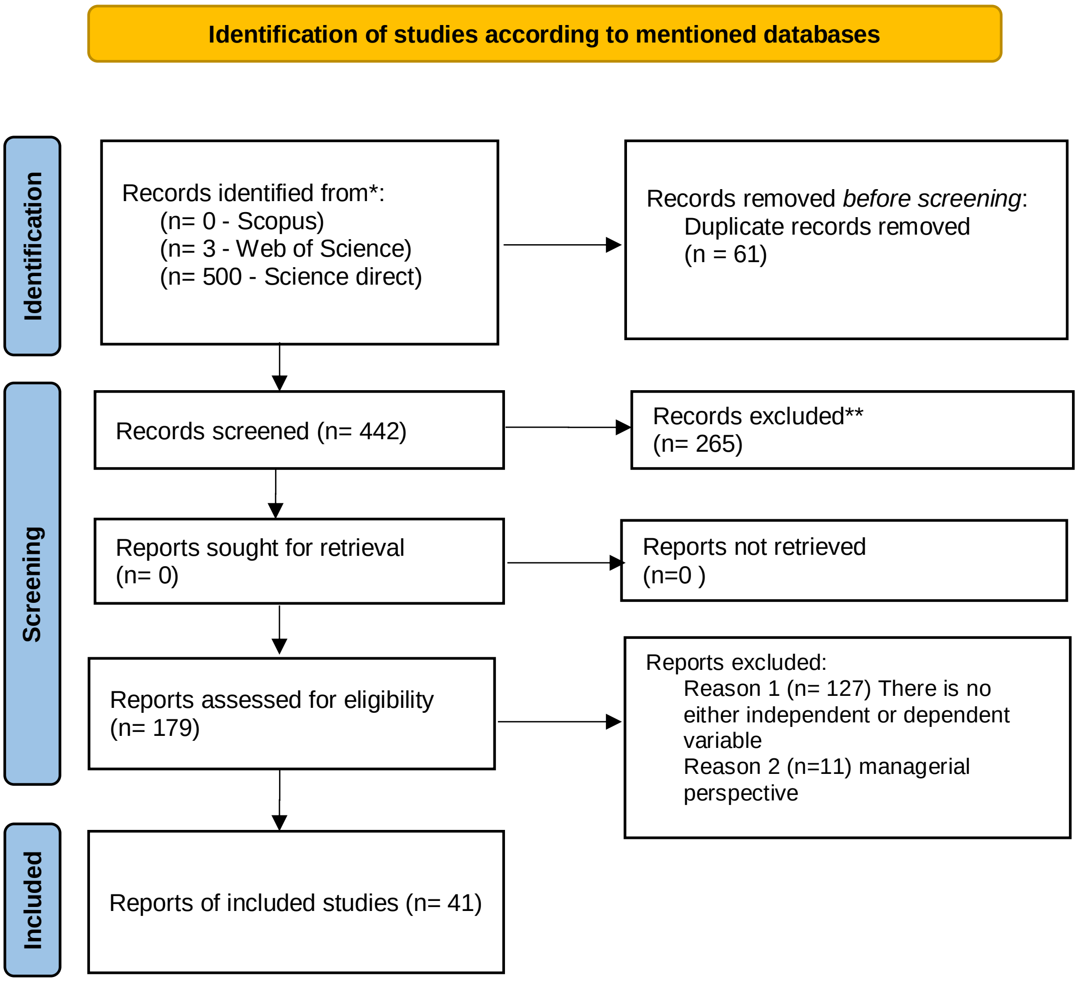

Fig. 3. Selection process according to PRISMA model.

2.2 Result

Table 1 shows the results of the TITLE-ABS-KEY analysis. According to the main scientific database used in this SLR, the results indicate that there is much interest in the concepts of renewable energy and eco innovation. This is manifested in the exponential growing trend of the related literature, as figure 4 shows. Among that literature, renewable energy and eco innovation account for 93.5% and 6.5%, respectively. This different percentage could be linked to the fact that interest in renewable energy started about half a century ago, around the first international environmental summit in Stockholm, Sweden, in 1972, while eco innovation started at the beginning of this decade. Notably, about 70% of the literature identified in the SLR were published after the ratification of the PA in 2015, and about 35% of that literature were published only in the last three years. Moreover, research articles and review articles account for around 86% of the literature that has been published since the middle of the previous century. Finally, most of the literature was published in China and the United States (i.e., around 28% and 11%, respectively based on the Scopus and Clarivate databases). Figure 4 illustrates the evolution of renewable energy and eco innovation literature.

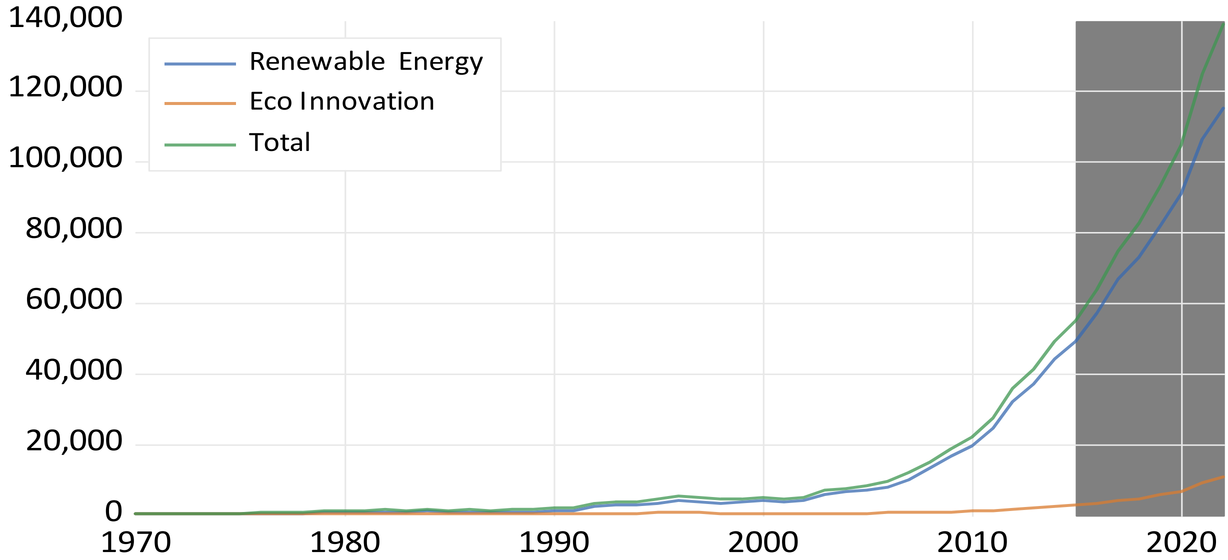

Fig. 4. Evolution of RE and eco innovation literature during the period of 1970-2022.

According to Figure 3, in total, 503 papers were identified using the search string, but most of them were excluded by the authors according to the selection criteria. Thus, 61 papers were eliminated due to duplicate records. Furthermore, 442 articles were subjected to title or abstract screening. In this stage, articles that seemed to have a promising relationship to the framework of eco innovation and RE were selected for a full-text review. The inclusion and exclusion criteria for articles were introduced by Thomé et al. (2016). Accordingly, at this stage, we ended up with 179 articles.

In the final stage, these 179 studies were further analysed by the authors. The next inclusion criterion was the presence of at least one of the dependent variables (i.e., environmental or financial performance) and at least one of the independent variables (i.e., renewable energy or eco innovation). Consequently, 139 of the articles were further excluded because they did not meet the aforementioned criterion.

Finally, 41 articles were identified to be relevant to the research and met the inclusion criteria. This number of articles is considered reasonable when compared to other studies that have utilized the same framework as this thesis. For instance, (n = 47 in Xin et al., 2021, n = 19 in Wang et al., 2019, n = 27 in Ahmad& Zheng, 2021, n = 16 Ulucak, 2021 and n = 27 in Zoundi, 2017). The 41 articles were evaluated in additional depth. Figure 5 shows the steps used to define the gaps in this theme.

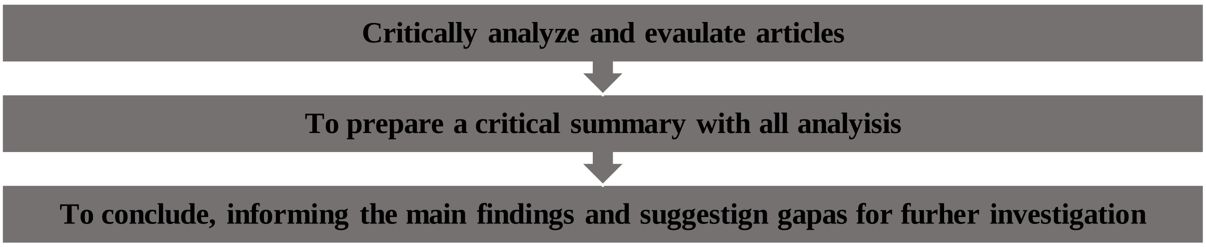

Fig. 5. Steps of defining the gaps.

For constructing and visualize bibliometric networks from previous scientific literature has been used the software VOSviewer. This tool enables researchers to analyse and map data based on the co-authorship relationships, citation networks, and term co-occurrences, displaying them as interactive visualizations. Fig. 6 shows a network visualization of 10 research clusters related to the impact of climate strategy, as identified by the articols author' keywords. The weights of the circles signal the frequency of the topics according to the co-occurrence amount. The data indicated that excluding common terms like *carbon dioxide emissions*, *renewable* and *biodiesel* from the search terms led four major research clusters to stand out. In Figure 6, GHG (purple) is linked to studies related to modelling and power sectors like the petroleum sector, liquefied petroleum gas (red) is linked to studies pertaining to diesel, waste and cement, policy (blue) is linked to studies involving renewable energy, biomass and humans and biodiesel (orange) is connected to studies on topics such as electronic chemistry and hydrogen.

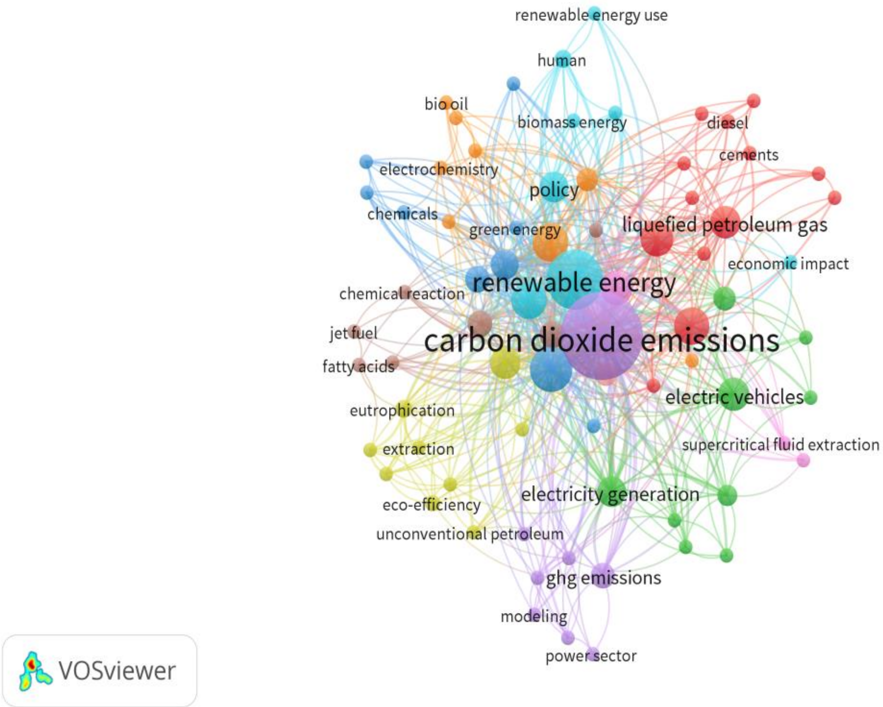

Fig. 6. Overlay Visualization of Authors' Keywords.

2.4. Discussion

This section classifies the literature according to the full-text analysis. To guarantee coherence, the 41 identified studies were divided into two main segments, namely, macroeconomic and microeconomic, each of which was divided into two strands, group economics studies and individual economic studies. Figure 7 shows how the literature is classified.

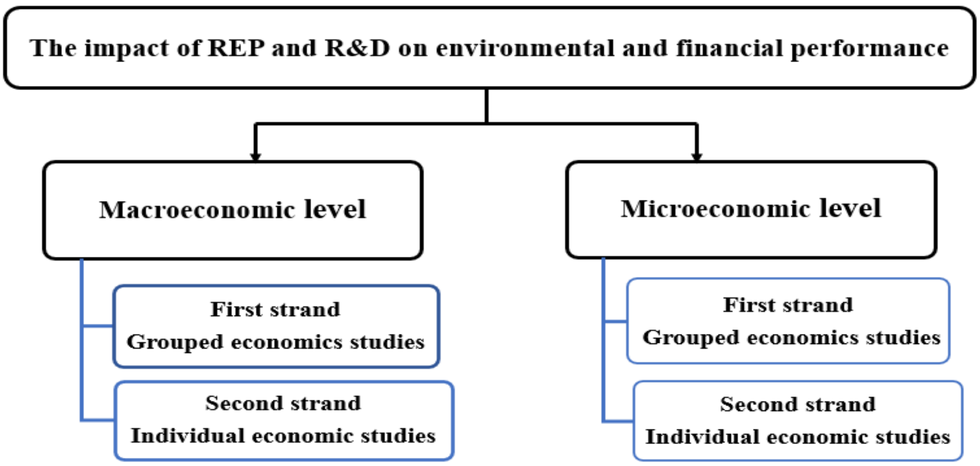

Fig. 7. Literature classification.

4.1 the Effect of renewable energy and eco innovation on environmental and financial performance.

In recent studies, the effects of renewable energy and eco innovation on CO_2 emissions have drawn much attention (Su et al., 2022; Zaidi et al., 2018). As mentioned, the literature on this topic can be categorized into macroeconomic and microeconomic levels.

2.4.1Macroeconomic level.

The first strand of macroeconomics literature is group economics studies, such as three research papers conducted in the EU region. (Balsalobre-Lorente et al., 2018) tested the hypothesis of the Environmental Kuznets Curve (EKC)[3] by investigating the nexus between economic growth and environmental degradation in five EU countries (France, Germany, Italy, Spain and the United Kingdom) from 1985 to 2016. By incorporating renewable energy consumption and energy innovation variables into the model, they found that environment quality was improved by renewable energy consumption and energy innovation. Similar results were found by (Töbelmann & Wendler, 2020) who examined the effect of environmental innovation (patents) and renewable energy consumption on CO_2 emissions in EU-27 economies during the period from 1992 to 2014. By utilizing a dynamic panel generalized method of moments, the findings proved that environmental innovation (based on patents) and renewable energy had negative (reduce) impacts on CO_2 emissions. In a follow-up study, (J. he Wang et al., 2022) securitized the effects of renewable energy on CO_2 emission in 36 EU countries covering the period from 2000 to 2018. Utilizing spatial econometric models, findings uncovered that increasing renewable energy sources as a whole result in a reduction of CO_2 emissions. More specifically, finding demonstrated that increasing renewable energy technology such as hydropower and geothermal decrease CO2 emissions. In contrast, increasing renewable energy sources with more advanced technologies such as wind, solar, and bioenergy generation either increase or have no impact on CO_2 emissions. The authors concluded that increasing renewable energy as a whole led to CO_2 emission reductions. In the same fashion, three research papers were conducted in the BRICS countries. (K. Dong et al., 2017) found that increasing renewable energy consumption and natural gas had negative impacts on CO_2 emissions. Specifically, a 1% increase in renewable energy and natural gas consumption led to CO_2 emissions reductions of 0.2601% and 0.1641%. Also, (Cheng, et al., 2019)

evaluated the impact of renewable energy and environmental patents on CO_2 emissions from 2000 to 2013. Their findings revealed that renewable energy negatively impacted CO_2 emissions and that, conversely, environmental patents accelerated carbon emissions. In another vein, (Ahmad & Zheng, 2021) addressed the impact of eco innovation on CO_2 during economic shocks for the period from 1990

---

[3] The EKC hypothesis is that the relationship between economic growth and pollution emission has a positive nexus in the early stages, but beyond some level of economic growth, the trend of pollution emission reverses (turning point) results in an inverted U-shaped pattern.

to 2016. Using green R&D as a proxy for eco innovation, the results revealed that negative shocks in green R&D during the economic downturn led to an increase in CO_2 emission, whereas a positive shock in green R&D during the expansion phase decreased CO_2 emissions. In the same manner, three studies were executed in the context of OECD economies. First, (Petrović & Lobanov, 2020) measured the impact of R&D expenditures on carbon dioxide in 16 OECD economies between 1981 and 2014. Using panel regression, the results indicated a mixed relationship (positive, negative and neutral) relationship from the side of R&D expenditures on CO_2 in the short and long run. The authors also argued that R&D investment is insufficient to have an adverse impact on CO_2 emission. In the second subsequent study, (Cheng et al., 2021) utilized patents as a proxy for eco innovation to gauge its impact on CO_2 emission over the period from 1996 to 2015. Using a panel quantile regression approach, their findings revealed that patents successfully reduced CO2 emissions. A similar effect was found in the third study by (Elheddad et al., 2021), which measured the impact of increasing renewable energy consumption on CO_2 emissions in 29 OECD economies during the period from 2007 to 2016.

The effects of renewable energy and eco innovation were also confirmed for the N-11 economies in studies by (R. Wang et al., 2020) and (Shao et al., 2021). The former study suggested that renewable energy and technological innovation, alongside human capital, played a significant role in CO_2 emissions between 1990 and 2017. Similarly, the latter study modelled the effects of eco innovation and renewable energy on carbon neutrality over the period from 1980 to 2018. Their results confirmed that both eco innovation and renewable energy negatively influence CO_2 emissions in the long run, thereby supporting environmental sustainability. Nevertheless, the impact of eco innovation was found to be insignificant in the short run. In a study of 25 African countries, (Zoundi, 2017) investigated the impact of renewable energy on CO_2 emissions, while also examining the validity of the EKC hypothesis, for the period 1980 - 2012. Utilizing panel cointegration analysis, the results revealed that RE negatively affected CO_2 emissions in the long run, even though a significant nexus between economic growth and environmental degradation was not observed. (Akram et al., 2020) used a wide sample of 66 developing countries to explore the effects of renewable energy, among other variables, on CO_2 emission from 1990 to 2014. Unsing fixed-effect panel, thier results indicated that renewable energy had an adverse effect on CO_2 emissions. (Armeanu et al., 2021) utilized a mixed sample of 106 countries to capture the impact of renewable energy consumption, among other variables, on CO_2 emissions from 1990 to 2014. Using impulse response functions and variance decomposition, the authors found that renewable energy consumption significantly reduced CO_2 emissions. In another study, (S. Khan et al., 2022) examined a geographically diverse sample including, European, Middle Eastern, South Asian, South-East Asian countries and China to investigate the relationship between investment in R&D for environmentally-friendly projects, renewable energy sources and environmental sustainability from 2007 to 2021. Their findings revealed that investment in renewable energy and R&D for eco-friendly projects reduced CO_2 emissions. In the same year, (Fang et al., 2022) examined the impact of R&D on CO_2 emissions in

South Asia from 2008 to 2020. Using a two-step ordinary least square regression, the results confirmed that R&D reduced carbon emissions and profoundly contributed to the green economy. Last in this strand, (Du et al., 2022) explored the impact of renewable energy, among other variables, on consumption-based carbon emissions in the MINT nation (Mexico, Indonesia, Nigeria, Turkey) over the period from 1990 to 2018. After deploying a moment quantile regression model, their results indicated that renewable energy reduced consumption-based carbon emissions across all quantiles.

The second strand of macroeconomic literature is individual economic studies. Three of the included studies were conducted in China—the world's largest polluter economy. In the first work, (Zhou et al., 2016) measured the effectiveness of CCG technology to halt CO_2 emissions in the cement industry. The results showed that CCG technology can reduce 57% of emissions from this industry by 2030. In the second work, (Chen et al., 2022) assessed the impact of green technology on environmental sustainability from 1990 to 2020. The quantile approach findings revealed that green technology innovation significantly mitigates emissions across all quantiles. In China, (Feng, 2022) focused on the impacts of renewable energy and eco innovation, among other variables, on carbon neutrality from 1998 to 2018. Using R&D as a proxy for eco innovation, the results indicated that renewable energy and eco innovation had a negative impact on carbon emission. Two studies were conducted on the U.S. economy—the second-largest carbon-emitting economy. In the first study, (Su et al., 2022) explored whether RE or technological innovation was best at promoting the path to net-zero emissions. Using a wavelet-based quantile-on-quantile approach for monthly data from 2010 to 2021, it was discovered that renewable energy is preferred over technological innovation because it provides feasible paths for mitigating one's carbon footprint. Further empirical research was done in the second work by (Xin et al., 2021) who found that a positive shock in eco innovation during the expansion phase negatively impacted CO_2 emissions, whereas negative shocks in eco innovation during economic contraction exacerbated CO_2 emissions. In addition, the negative impact of renewable energy on CO_2 emissions was captured in the same period. Another important result came from comparing the linkages between eco innovation, renewable energy and carbon emissions in the United States and China from 1980 to 2016. (Danish & Ulucak, 2021), argued that renewable energy reduced CO_2 emission in both countries and that eco innovation reduced CO_2 emission in the United States, but this effect was statistically insignificant in China. In Turkey, (Hao et al., 2023) examined the nexus between eco innovation, renewable energy and CO_2 emissions based on the stochastic impacts by regression on population, affluence and technology (STIRPAT) model from 1990 to 2018. Their findings revealed that both eco innovation and renewable energy reduced CO_2 emissions. In South Africa, (Samour et al., 2022) found that renewable energy consumption had a negative impact on CO_2 emissions by using the autoregressive distributed lag approach (ARDL) on data from the period between 1986 and 2017. The same results were found for the economy of Vietnam by (Tran, 2022), who delved into the relationship between renewable energy consumption and CO_2 emissions. Utilizing cointegration and Granger causality, their findings confirmed the existence of cointegration among the variables. That is, renewable energy consumption and green investment reduced CO_2 emissions. In the same continent, (Raihan et al., 2022) found that renewable energy use and eco innovation, in addition to forest area were conducive to reducing CO_2 emissions in the Bangladesh economy between 1990 and 2019. In a different vein of research, (Olabi et al., 2022) utilized 87 global indicators to assess the effect of CCG technology on the United Nations Sustainable Development Goals (SDGs). Their findings revealed that CCG technology significantly contributed to all 17 SDGs, especially SDG-7 and SDG-13 (i.e., affordable and clean energy and climate action, respectively).

2.4.2 Microeconomics level

The first strand of microeconomic literature is group economics studies. To begin, three sundry studies were conducted in the industrial sector. First, (Wurlod & Noailly, 2018) explored the impact of green innovation on energy intensity in 14 industrial sectors in 17 OECD economies from 1975 to 2005. Their results showed that green innovation had a negative impact on energy intensity in 10 industrial sectors, namely food, beverages and tobacco, textiles, textile products, leather and footwear, wood and products of wood and cork, pulp, paper and paper products, printing and publishing, manufacture of coke, refined petroleum products and nuclear fuel, chemicals, rubber and plastics, non-metallic minerals, metals and machinery. Conversely, a positive impact from the side of green innovation on energy intensity existed in four industrial sectors (i.e., office and accounting, electrical engineering, medical, precision, optical industry, transport equipment manufacturing, recycling and last sale, the maintenance and repair of motor vehicles and retail sales of fuel). In the second work, (Alam et al., 2019) used a huge sample of 1,350 firms in G-6 countries to assess the effect of R&D investment on CO_2 emissions between 2004 and 2016. Their regression results revealed that R&D investment enhanced environmental performance. In the third work, (Gyamfi et al., 2022) studied the industrial sector of BRICS economies from 1990 to 2019. They found that both renewable energy and technological innovation reduced CO_2 emissions. In contrast, industrial value-added, natural resources, foreign direct investment and total reserves contributed to the degradation of the environment. In the petroleum sector, two research papers were conducted by Fethi and (Fethi & Rahuma, 2020) and (Rahuma & Fethi, 2022). In the first work, the authors measured the impact of eco innovation on the environment and profitability in a sample of 17 international petroleum companies from 2005 to 2016. Investment, training and R&D were utilized as proxies for eco innovation. The results revealed that eco innovation had a significant impact on environmental and financial performance. In their second work in 2022, the authors used the same sample and the same period to investigate the environmental strategy from the perspectives of both investors and managers. The balanced scorecard and panel dynamic regression analysis findings revealed that using an environmental strategy had a negative impact on CO2 emissions and increased financial performance (as measured based on returns on equity and net income). Last in this strand, (Herzog, 2017)assessed the impact of financing CCG technology projects worldwide. He concluded that financing this kind of project contributes to a sustainable environment.

The second strand of microeconomic literature included individual economic studies. In this regard, China has received huge interest from academicians. For example, (Quader et al., 2015) conducted a metanalysis on the steel and iron sectors and concluded that to reduce CO_2 in the long term, renewable energy (bioenergy) and CCS technology usage, among other technologies, is crucial. (Sun et al., 2018) conducted a qualitative study on projected emission reductions in the Chinese oil and gas industry. Their results revealed that eco innovation and energy efficiency could reduce 16.71 million tons of potential CO_2 in this industry by 2050. Three studies were also conducted at the province level in China. (B. Lin & Zhu, 2019) employed a linear regression model to explore the relationship between renewable energy technological innovation and climate change from 2000 to 2015. Their findings confirmed that renewable technological innovation had a significant negative effect on CO_2 emissions. This result aligned with those of (Bai et al., 2020) , who applied a panel fixed-effect regression model to explore the impact of renewable energy technological innovation on CO_2 emissions. In the third work, (Li et al., 2022) explored the moderating effect of low-carbon innovation on the nexus between green finance and the transition to a low-carbon economy in 30 Chinese provinces from 2001 to 2019. The following proxies were used: patents granted for low-carbon innovation and the Global Malmquist-Luenberger index for CO_2 and green credit, green securities, green insurance and green investment for green finance. Utilizing a panel data model, a moderating effect model and 2SLS, the findings revealed that carbon technology innovation negatively mediated the relationship between green finance and the transition to a low-carbon economy. Nevertheless, green finance played a significant role in the transformation of the low-carbon economy. In the same year, (Y. Lin et al., 2023) analysed the effects of renewable and green finance on emissions in Chinese cities during the period from 2000 to 2020. Using time-series econometric techniques, the findings confirmed the role of investing in renewable energy and green finance in reducing emissions. This empirical evidence is similar to that of (Liguo et al., 2022), who reported that renewable energy and eco innovation were helpful in reducing CO_2 emissions in a study conducted on the USA's marine energy generation sector from 1990 to 2018. Table 2 contains a summary of the literature discussed above (e.g., the macro and micro economic studies).

To summarize, a comprehensive SLR based on the PRISMA standard guidelines was conducted on the subject of the impacts of REP and R&D on the environment and financial performance. Navigating to the Scopus (Elsevier indexed database), Web of Science (Calvairate indexed database) and Science Direct databases, out of 503 articles, 41 were relevant to our deep investigation according to a certain criterion. Furthermore, the literature was divided into two segments, namely: macroeconomic and microeconomic groups, each of which was divided into grouped studies and individual studies.

Generally, the results reveal that the interest in this subject has been growing because 70% of the studied literature was published after the Paris Agreement while about 35% of it was only conducted after the approval of the EU Green Deal 2019. The results also indicate that roughly 74% of the deeply-investigated literature was on macroeconomics while only about 26% was on microeconomics. Importantly, the results showed that the authors of the majority of studies found that eco innovation and renewable energy had statistically significant positive impacts on the environment, but few suggested that the impact of eco innovation on the environment is harmful due to eco innovation negative shocks during the contraction economic cycle and specific characteristic of a country.

Table. 2. Summary of the literature.

Authors	Sample	Time	Method	Results			
				Eco/ CO_2	RE/ CO_2	Eco/ Financial Performance	RE/ Financial performacne
Macroeconomic level							
Balsalobre-Lorente et al. (2018)	EU-5	1985–2016	(EKC)	-	-		
Toebelmann & Wendler (2020)	EU-27 countries	1992 -2014	Generalized Method of Moments	-	-		
Wang et al. (2022)	36 EU countries	2000- 2018	Spatial econometric models		+ -		
Dong (2017)	BRICS	1985-2016	augmented mean group		-		
Cheng et al. (2019)	BRICS	2000-2013	OLS and quantile regression	+	-		
Ahmad & Zheng (2021).	BRICS	1990-2016	(CS-ARDL) model t	+ -			
Petrović & Lobanov (2020)	16 (OECD)	1981- 2014	panel regression	-+			
Elheddad et al. (2021)	29 OECD countries	2007- 2016	fixed and random		-		
Cheng et al. (2021)	OECD	1996-2015	panel quantile	-			
Wang et al. (2020)	N-11	1990-2017	mean group	-	-		
Shao et al. (2021)	N-11	1980- 2018	(CS-ARDL)	-+	-		
Zoundi (2017)	25 African economies	1980-2012	cointegration test		-		
Akram et al. (2020)	66 developing countries	1990-2014	fixed-effect and quantile regression		-		
Armeanu et al. (2021)	106 countries	1990–2014	impulse response functions		-		
Khan et al. (2022)	EU, ME, South Asia, South-East Asia and China	2007-2021		-	-		
Fang & Putra (2022)	South Asian	2008- 2020	least square	-			
Du et al. (2022)	MINT	1990 – 2018	moment quantile regression		-		
Zhou et al. (2016)	China's aviation industry	2015-2030	scenario analysis	insignificant			

Chen et al. (2022)	China	1990- 2020	quantile	-		
Feng (2022)	China	1998-2018		-	-	
Shan et al., 2021)	Turkey	1990 - 2018	STIRPAT model	-	-	
Su et al. (2022)	USA	2010- 2021	Wavelet-Based quantile-on-quantile	ineffective	-	
Xin et al. (2021)	USA	1990- 2016	Econometric models	-+	-	
Ulucak (2021)	United States and China	1980- 2016	dynamic (DARDL)	+ insignificant		
Samour & Tursoy (2022)	South Africa	1986-2017	ARDL		-	
Tran (2022)	Vietnam	1986-2018	cointegration, Granger causality		-	
Raihan et al. (2022)	Bangladesh	1990- 2019	multivariate time-series analysis	-	-	
Olabi et al. (2022)	worldwide indicators			-		
Microeconomic level						
Wurlod & Noailly (2018)	14 industrial sectors in	1975–2005	translog cost function	- +		
Alam et al. (2019)	1350 firms in G-6 countries	2004–2016	Panel regression	-		
Gyamfi et al. (2022)	industrial sector	1990 -2019	Augmented Mean Group	-	-	
Rahuma & Fethi (2022)	17 petroleum companies	2005-2016	panel dynamic regression	-		+
Fethi & Rahuma (2020)	17 Petroleum companies	2005–2016	ARDL	-		+
Herzog (2017)	Worldwide projects	different years	assess impact	-		
Quader et al. (2015)	steel and Iron		Metanalysis	-	-	
Sun et al. (2018)	Petroleum sector	5015-2050	qualitative	-		
Lin & Zhu (2019)	Chinese provinces	2000 to 2015	linear regression		-	
(Bai et al., 2020),	Chinese provinces	2000 to 2015	fixed-effect and threshold		-	
Li et al. (2022)	30 provinces of China	2001- 2019	panel regression	+		
Lin et al. (2022)	Chinese cities	2000 -2020	pooled OLS estimates	-	-	
Liguo (2022)	marine energy	1990 - 2018	QMSA	-	-	

Chapter 3

3. Energy transition

The energy sector is one of the prime drivers of economic growth and social development (Azam et al., 2015; I. Khan et al., 2021; T. H. Le & Nguyen, 2019; Shahzad et al., 2022). Furthermore, the energy demand is on the increase driven by the geopolitical issues, post-pandemic economic growth, the rapid urbanization and rising standard of living and more importantly, the growth of population (Meadows et al., 2018) (Muzayanah et al., 2022; Nepal & Paija, 2019), (IEA, World energy outlook, 2023). Above of this, it must be said that in the time being, more than around 750 million of population without having access to electricity (Statista, 2024). On the flip side, energy sector is responsible for approximately three-quarters of GHG emissions (IEA, 2021) (Frumhoff et al., 2015) (figure 8). Specifically, the emissions of this sector were 37 gigatonnes (Gt) in 2022 – a record high and a 5% increase from 2015 (IEA, 2023b). In response to this, the UN COP 21 (The Paric climate conference) set the off the net zero emission for what we call now the new energy transition. Energy transition is a milestone of tackling the climate crisis, as fossil fuels still supply 60 percent of global energy supply. This transition, which is expected to have a significant consequence on climate change (N. Li et al., 2023), must fit with the framework of international sustainable development goals. It needs to secure the energy demands, while remain economically viable and significantly mitigate GHG emissions. Thus, we can say that energy sector is at a juncture. But what is the energy transition exactly? According to IRENA, energy transition is a regular and steady shift of global energy use from hydrocarbon sources, in particular oil, natural gas and coal to renewable sources like solar (mainly photovoltaic and thermal) and wind by 2050. Energy transition is the prim tool in a comprehensive strategy adopted by governments to curb the intensification of global warming by keeping average Earth's temperature at no more than 1.5°C above pre-industrial levels. Energy transition grounded on renewables is necessary to cut the GHG emissions from fossil fuels, that scientific research approves is a drive factor in the phenomenon of climate change, and thereby alleviate its disruptive impacts. Accelerating the energy transition requires scaling up REP in sectors reliant on fossil fuels. Technology advances such as recycling, hydrogen, electrification, internet of things, energy storage, CCUS are accelerating the energy transition (Aalto et al., 2021) (Gallo et al., 2016) (Shu et al., 2023)(Masoomi et al., 2024).

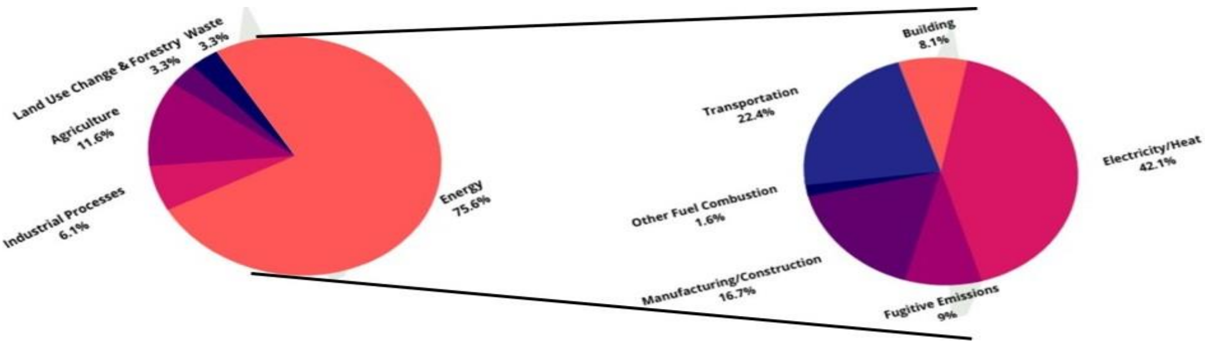

Fig. 8. GHG emissions by source.

In accordance with the forgoing, the Energy Information Administration projected an increase of global energy demand by 46% by the year 2040. Of these, oil and gas demand will account for 50% of energy market and IPCs will provide this demand (EIA, 2023). Figure 9 shows the projection of this demand. To a certain extent, petroleum will play a fundamental role in the energy supply in the future. However, a decrease in GHG emissions will only occur if the growth in renewable energy production surpasses the growth in oil and gas production. In this regard, a survey carried out by the IEA for the purpose of drafting 'The petroleum Industry in Energy Transitions' report among 20 IPCs showed that between 2015 and 2019 energy transition leaders allocate on average up to 5 percent of their total capital expenditure to investment in renewables, biofuels and CCUS technologies (IEA, 2020c). The energy transition forced petroleum companies to start moving away from fossil fuels towards a system centred on renewables sources such as hydropower, solar, wind, and geothermal. In this essence, IPCs' strategic decision of energy transition will have a significant consequence on climate change (N. Li et al., 2023) because this sector's emission due to fossil fuel is too high (see figure 10).

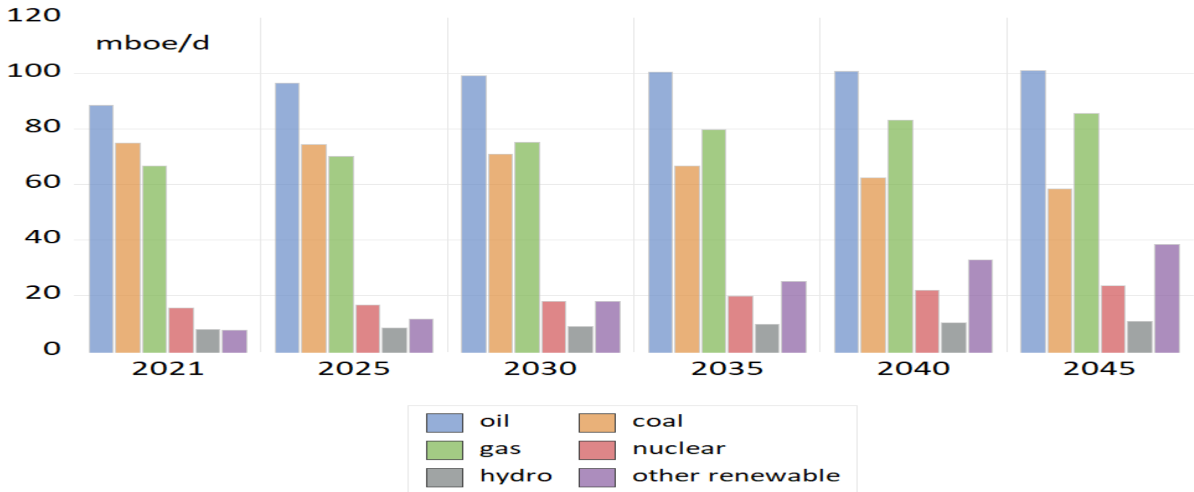

Fig. 9. World primary energy demand by fuel type. OPEC, 2022.

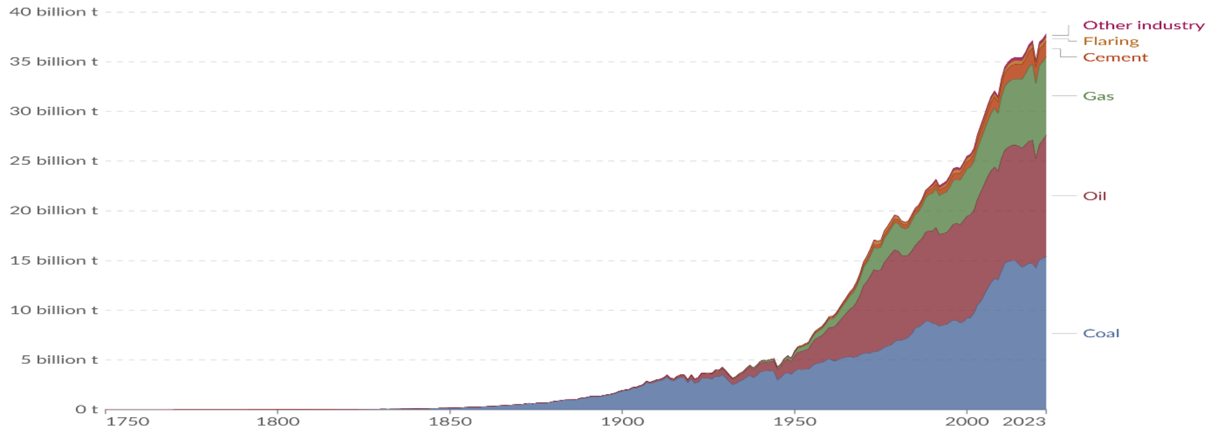

Fig. 10. CO_2 by fuel type, our world in data, 2023

3.1 Petroleum industry:

Since its inception, petroleum industry has contributed significantly to the world economic growth, generating wealth, enhancing living standards, and fostering prosperity (Jahangir & Dural, 2018) (Duch-Brown & Costa-Campi, 2015). Petroleum remains the prime provider to the energy industry followed by natural gas, despite the noteworthy growth of renewable energies in recent decades (IEA, 2023a). For example, petroleum covers nearly all the required energy from the transportation sector, supplies about half of raw material for the petrochemical sector and contribute to 25% of electricity generation worldwide (IEA, 2024). Petroleum industry is commonly divided into three major sectors based on its supply chain namely, upstream, midstream and downstream. Specifically, upstream is the starting point of the supply chain and it is well known as the exploration and production sector. To find and extract crude oil and natural gas from the ground is the core function of this sector. While midstream sector, the second stage of supply chain, handles the primary processing of the unrefined crude oil and natural gas. This sector connects the upstream production fields with the downstream processing facilities. Last, downstream, which is the final stage of the supply chain, transform raw material into finished product such as refining crude oil and manufacturing petrochemical and sold them to the end users (IEA, 2023d).

Daily production of oil was about 88.3 mboe/d in 2021, while it is projected to record 98.9 and 100.6 mboe/d in 2030 and 2045 respectively. Likewise, natural gas demand is estimated to increase significantly by 19 mboe/d between 2022 and 2045 from 66.4 mboe/d in 2021 to 85 mboe/d in 2045 (OPEC, 2022). Probing further, in 2024, the global proven reserve of crude oil and natural gas are estimated to be approximately 1765 billion barrels and 225 trillion cubic meters, respectively (IEA, 2024). This huge reserve fortifies the role of petroleum companies, allowing them to remain the foundation of petroleum industry. Apparently, the production of petroleum is on the increase and will likely last to be used as one of major resource for the energy mix in the world during next decades (Griffiths et al, 2022). With regard to the sample of this thesis, the production of oil and gas was more than 32 mmboed in 2015, while in the third quarter of 2019, this production increased steadily to reach more than 37 mamboed/d in. Nevertheless, after the math of covid-19, the production of oil and gas in the said sample decreased dramatically in a fluctuating trend and it returned back to slightly above the level of 2015, (see figure 11).

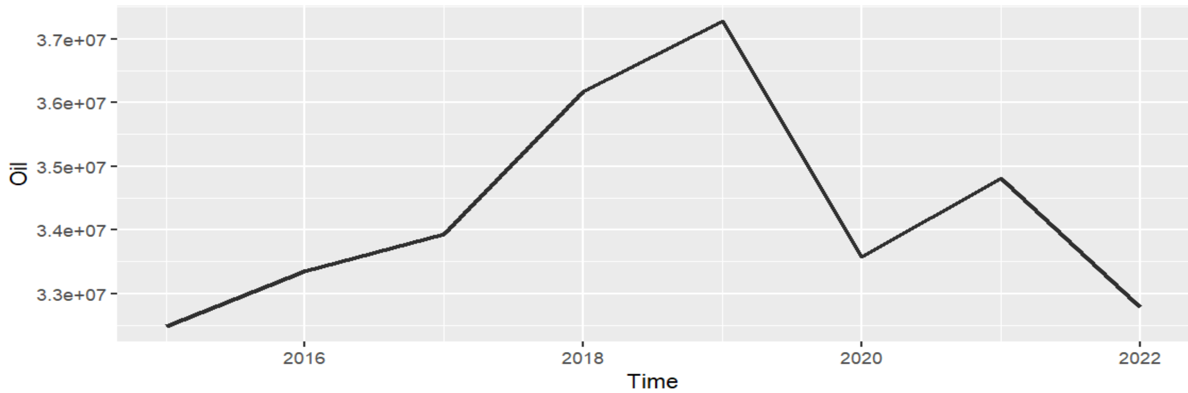

Fig. 11 Total oil and gas production from 2015 to 2023. (Annual sustainability reports, 2015-2023).

Logically, the large increase of petroleum extraction and production will be accompanied by more pollution in the forum of GHG emissions (U.S energy information administration, 2020). Petroleum companies heavily engaged in upstream sector are considered one of the largest polluter companies, regardless of their benefits, due to their overall direct emissions of scope 1 GHG emission (Abudu et al., 2022). For example, the 2019 annual reports of Petrobras, Total, Lukoil and Eneos showed that the direct GHG emission due to oil and gas extraction were about 59, 41, 40 and 22 Mt of CO_2eq, respectively in 2019. This sort of emission originates from sources owned and controlled by these companies during the operational process in the exploration and production phase. These direct emissions include the onsite combustion of fossil fuels, routine gas flaring, process related vinting, fugitive emission and methane leakage. All of which occur during the refining, production and transportation of petroleum. Based on data availability, for example, the combustion of fossil fuels, which is usually account for the highest percentage of scope1 GHG emissions, Eni gas, Novatek, Lukoil and Eco petrol composed more than 33, 12, 9 and 8 Mt of CO_2eq respectively in 2019. As for flaring, latest satellite data indicates that approximately 3.5% of natural gas is wastefully burned across petroleum fields globally. For instance, Lukoil's flaring was 2.52 Mt CO_2eq, while in the same year Repsol flared hydrocarbon was 32 Mt CO_2eq. Eni gas' venting and fugitive emission were more than two and one million of CO_2 equivalent, respectively in 2018 (Annual sustainability report, 2018). Shell's venting, flaring and fugitive was 8, 7 and 0.015 Mt CO_2eq in 2021. Indiaoil's flaring and venting was 1.3 Mt of CO_2eq and CH_4 emissions in 2019. Oil and gas leakage accidents are another channel of pollution during the exploration and production stage. For example, Enis' spill of oil due to operation was 427 cases in 2016 (annual report, 2016) and 11 oil and gas leakage occurred in Enquier in 2021 (Annual sustainability report, 2021). In addition to scope 1 GHG emissions, scope 2 GHG emissions which account for a very small percentage of emissions relative to scope 1 emission. In particular, scope 2 GHG emission of the chosen sample did not exceed 2% of the total sample because it is a source of emissions that originates from the purchased electricity by the side of petroleum companies. The following figure shows the said sample's total of GHG emission of scope 1 and 2 during the period of the study.

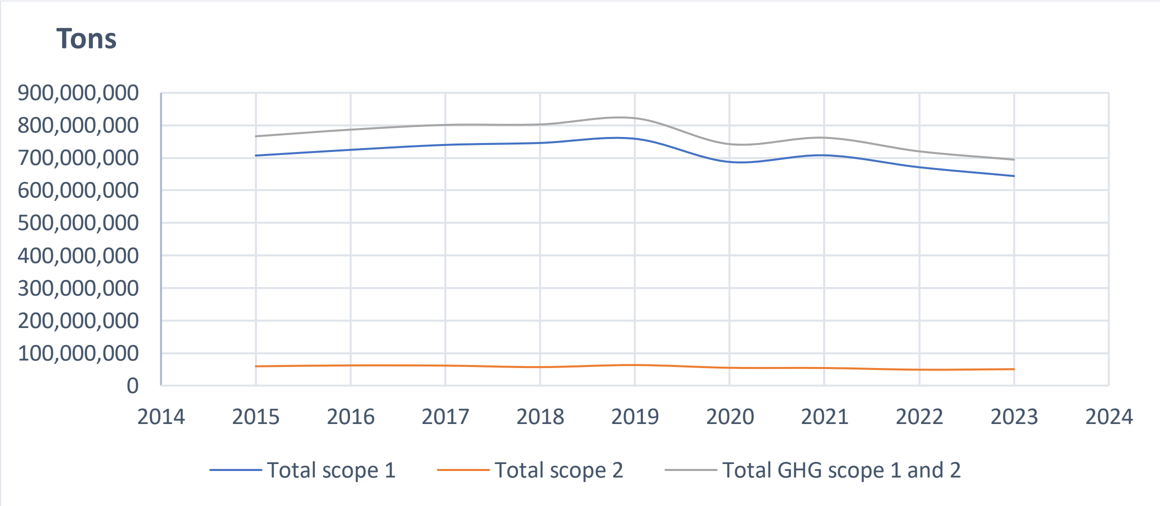

Fig. 12. Total GHG emission for the period of the study. Annual reports 2015-2023.

Overall, the investigated petroleum companies discharged about 6897 Mt of CO_2eq GHG emission (scope 1 and 2) of 2015 to 2023. It is clear that scope 1 account for more than 96% of the total emission, while scope 2 accounts for only about 3%. More specifically, scope 2 GHG emissions was about 700 Mt of CO_2eq in 2015, while it recorded the highest amount in 2019 with a quantity above 800 million of CO_2eq. However, it decreases linearly to record less than 650 million in 2023. Scope 2 remained less than 100 Mt of CO_2eq in the same period. This indicate that the majority of pollution emitted from the chosen sample came from scope 1 GHG emission during the exploration and production of petroleum.

The high amount of GHG emissions of petroleum companies have an advert impact on the environment, which makes the opportunity of increasing production to meet the demand of energy encounter a high level of risk in the future. Environmental charges, fines and penalties on GHG emissions are the best examples of the environmental pertinent regulations impact on companies' operations. For instance. eco-petrol paid a carbon tax equal to about 42,150,741 USD in 2021. In the same avenue, Pb is still paying taxes concerning the Gulf of Mexico oil spill occurred in 2010, in particular it paid 1.4 and 1.3 billion in 2022 and 2023 respectively. More importantly, petroleum companies are obliged to meet net zero emission by 2050. Crucially, the environmental regulations have been increasingly rigours, which expected to cause petroleum price to peak before 2030. Conversely, the cost of renewables continue to decrease, making it an increasingly attractive alternative (IRENA, 2023) (IEA, 2022). All of this will put further presser on petroleum companies to shift their business model from conventional to renewables.

Petroleum companies are faced an extraordinary challenge for meeting the net zero emission goals by 2050, while simultaneously addressing the increasing energy demand. What is more, these companies are positioned to lead the energy transition due to their immense capabilities in terms of expertise, annual returns, technology and innovations. For example, Petrobras is leading the energy transition in Brazil. The capacity of these companies stems from a myriad of factors, first and for most is their capital. In particular, the total asset of the chosen sample was 2607 billion in 2022, (see figure 13). Besides, petroleum companies are ranked among the first in terms of annual profits, for example, Total energies, Shell, Petronas generated 20, 17 and 12 billion USD of net profits, respectively in 2023 (Annual reports, 2023). In addition, the large number of employees in the chosen sample with a good knowledge and experience not only in building and operating mega project but also in developing technology via R&D departments, can be pivoted to work on renewables advancement such as biofuels, green/blue hydrogen production, battery technology and grid stabilization.

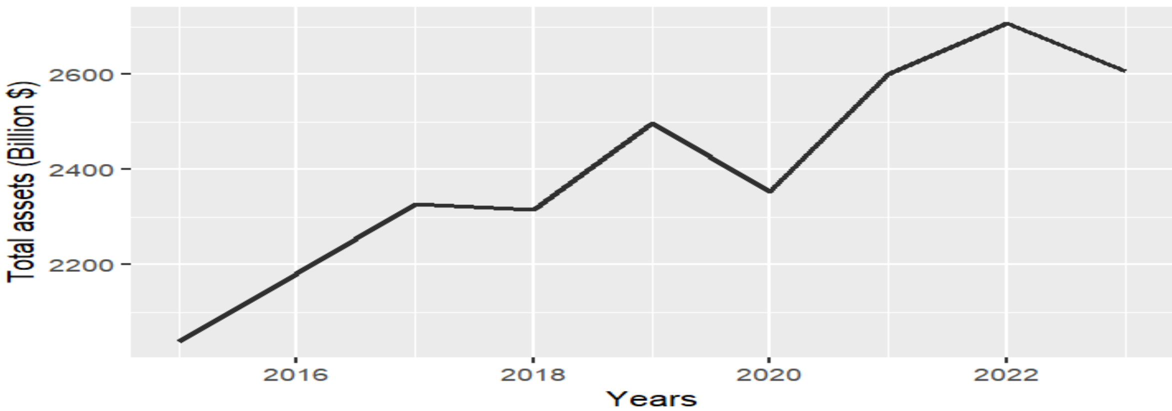

Fig. 13. Total assets for the period 2015-2023, annual financial reports 2015-2023.

3.2 The response of the chosen IPCs to net zero emission.

Since the emergence of PA, the chosen petroleum companies in this thesis have recognized the necessity of developing their business strategy to be aligned with net zero emission by 2050. Accordingly, they developed their visions and environmental goals of their business operation based in the med and long-term indicators. Subsequently, the chosen companies have increased their investment in renewable projects and R&D in renewable and low-carbon technologies, (see figures 14 and 15). Following these ambitions, the chosen companies have established concrete medium-term targets for 2030, focusing on both renewable energy capacity and GHG emissions reduction. For instance, based on the said sample's corporate sustainability reports, announced 2030 renewable installation targets include Eni (15 GW), Repsol (18 GW), Equinor (12

GW), and ONGC (10 GW), INPEX (3), Hellicin petroleum (2) and Saras (1). Concurrently, significant scope 1 and 2 GHG emissions reduction targets have been set. Equinor, Shell, Hellenic Petroleum, Eni, and BP are targeting a 50% reduction by 2030, in the baseline of 2015, 2016, 2017, 2018 and 2019, respectively. Other commitments include a 40% reduction by Total Energies and Galp on the base of 2015 and 2017, respectably, a 30% reduction by OMV, and a 25% reduction by Petronas and Ecopetrol in the baseline year of 2019. Similarly, Lukoil and Repsol aim for a 20% reduction, while Bangkok Oil aims for carbon neutrality by 2030.

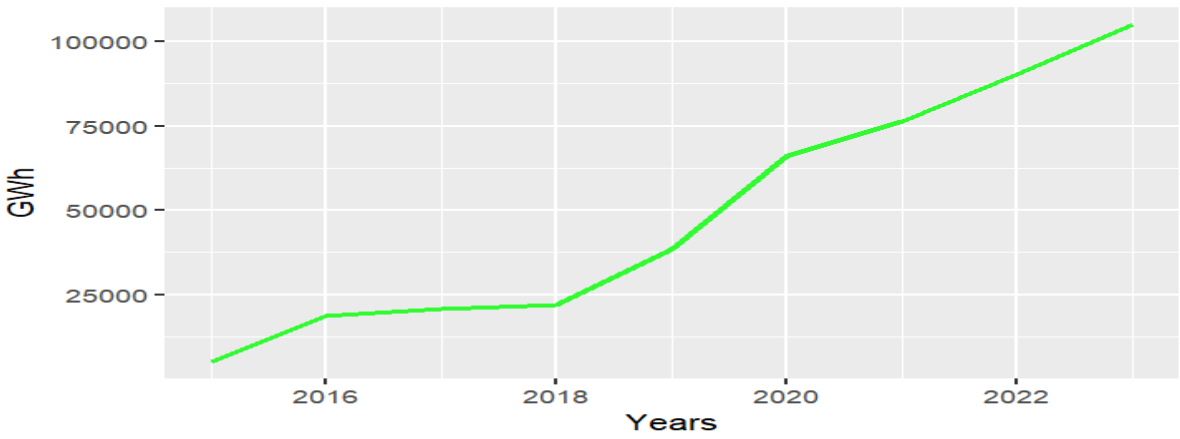

Fig. 14. Total REP for the period 2015-2023, annual reports 2015-2023.

Beyond broad GHG goals, some companies from the said sample have established more granular targets focusing on specific emissions like CH_4 and on carbon intensity metrics. Regarding CH_4, commitments include a 30% reduction by YPF Sociedad, Bangchak (baseline 2019) and a 4% reduction by Novatek (baseline 2021) by 2030. More ambitiously, Occidental Petroleum aims to eliminate routine CH_4 flaring in its upstream operations by 2030. A similar trend is observed in the adoption of intensity-based targets, which measure emissions relative to production. By 2030, Novatek targets a 6% reduction in its upstream GHG intensity (baseline 2019), while Vermilion Energy Inc. aims to decrease its Scope 1 and 2 intensities by 25–30% (baseline 2020). OMV has also committed to reducing the carbon intensity of its energy supply by 15–20% by 2030 and 50% by 2040, relative to a 2019 baseline (Annual sustainability report, 2022).

In the net zero emission future also, twelve leading petroleum companies including PB, Eni, Enqier, OXY, Shell, Repsol, total energy and Petrobras formed the Oil and Gas Climate Initiative (OGCI) in 2014. This initiative aims to accelerate the transition to a low-carbon future by investing in R&D. The OGCI's 2023 Progress Report documented a collective investment of $65.8 billion in low-carbon technologies between 2017 and 2022. This investment has driven significant operational improvements in terms of emissions, including a 45% reduction in routine flaring, a 50% cut in upstream methane emissions, and a 21% decrease in upstream carbon intensity over the same period. Furthermore, the initiative fosters knowledge sharing with non-member companies to amplify global decarbonization efforts achieve net zero emissions. The World Bank's 'Zero Routine Flaring by 2030 is another initiative in the path of net zero emission. IPCs in the said sample, namely YPF, Petronas, Galp, LUKOIL, Shell, and Total Energies, are committed to eliminate routine flaring in their operations by 2030.

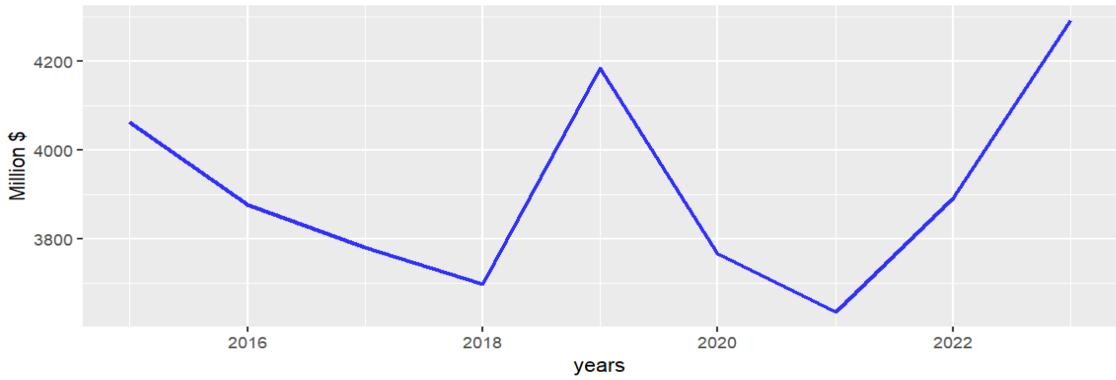

Fig. 15. Total R&D for the period 2015-2023, annual reports 2015-2023.

IPCs have been intensifying their energy transition efforts zero emission target by 2050. But it is crucial to assess the actions and progress with respect to REP of these IPCs rather than solely relying on their stated commitments and words. Energy transition is gridled with uncertainty, especially given the scenario of the global energy demand and energy poverty as mentioned above. To this end, despite the ambitious medium and long-term metrics set by IPCs, whether these companies are doing well in terms of the energy transition or not is what this thesis set out to measure empirically.

Before closing this chapter on energy transition, it is noteworthy that numerous IPCs rebranded their names to manifest their efforts of energy transition. Examples include Hellenic Petroleum transitioning to Hellenic Energy, Repsol Petroleum to Repsol Energy, and BP to Beyond Petroleum, then to integrated energy company. Similarly, the state-owned petroleum company Statoil rebranded to Equinor. These name changes underscore these companies' commitments to diversify their energy portfolios to meet the new energy paradigm which based on innovative business models, see figure 16.

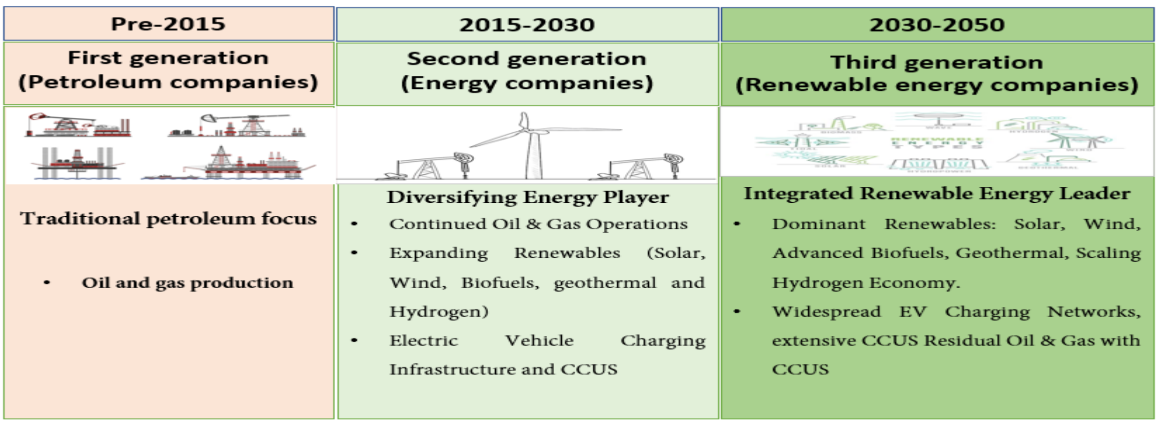

Fig. 16. Evolution of the IPCs on the Path to Net-Zero Emissions.

Chapter 4

4. Materials and Methods

This chapter present data collection, variables description and methodology of this thesis. The first section illustrates data collection and its sources, in addition to the criterion of the chosen sample. Next, the variables of the thesis are introduced. While in the third section, I delve into the model specification, which comprises two models, in particular GMM and MMQ.

4.1 Data collection.

This thesis aims to measure the impact of REP on environmental and financial performance in IPCs in upstream sector over the period from 2015 to 2022. The starting date of the study was selected because of the PA ratification in 2015, when the majority of petroleum companies in the sample had adopted set net-zero emissions goals and started deploying renewables (IEA, 2020a). The analysis is conducting using annual data of twenty-seven IPCs, namely: Shell, Eni S.p.A, Total, Repsol, Gazprom, Equinor, Hellenic Petroleum, Eneos Inpex, OMV Aktiengesellschaft, BP, Ecopetrol, Rosneft, Petrobras, Galp, Lukoil, Novatek, Suncor Energy, Vermilion Energy, Saras, Occidental, Petroleum National Berhad, YPF Sociedad, Bangchak, Gail NS, Indiaoil Corporation limited and Oil India Limited. I selected these IPCs as a sample based on the following inclusion criteria: (i) its market capitalisation must to be more than US$1 billion. (ii) it must be engaged heavily in the upstream sector. (iii) it must have an investment and a self-generation of REP such as solar, wind, hydro, biomass and geothermal. (iv) it must have a vision of net zero emission. (v) it must be listed in a stock exchange.

IPCs is a good choice to start studying petroleum sector because they are a major contributor to global GHG emissions in particular scope 1. For example, Total, Lukoil and Eneos produced about 44, 48.5 and 25.5 Mt of CO_2 equivalent respectively in 2019 (Annual reports, 2019). Furthermore, IPCs gain huge profits annually, which in return, enable them to invest in RE projects. To prove, the net profit of PJSC TATNEFT, Ecopetrol S.A and Etrolian National Berhad were 3,049 3,529 and 11,565 million USD respectively in 2018. Therefore, IPCs' REP likely has an impact on environmental performance. Moreover, Petroleum companies are also obliged to disclose their environmental, social and governance data according to the Non-Financial Reporting Directive (2014/95/EU) and annual sustainability reports (EU 2023/2772). The data is extracted from two main sources, namely: formal reports of IPCs and Orbis dataset. Specifically, I first navigated to the official web sites of IPCs to gather integrated, annual and sustainability reports. In a second step, I identified the petroleum companies that engaged heavily in upstream sector and removed companies that were only engaged in downstream or midstream sectors. Third, I collected the annual data related to REP, R&D and hydrocarbon production from the aforementioned reports. Subsequently, I extracted data related to outcomes variables (financial and market variables) in addition to total assets from Orbis. All data is standardized to avoid the problem of scale measurement (Gujarati & Porter, 2009) (Vestrelli et al., 2024a). Table 3 presents the definition, measurement unit and sources of all variables.

4.2 Variables of the thesis.

4.2.1 Dependent variable

GHG emissions is the dependent varialbel of the first model, which is going to explore the impact of REP Aand R&D on GHG emissions in line with (Hailemariam et al., 2022). As mentioned eliear, GHG emissions consists of scope 1 and scope 2. The latter was included because some IPCs in the sample used electricity from renewables of self-generation, for example occidental Goldsmit solar planet generated 43, 324 MWh of renewable electricity in 2022. Out of this, 33, 845 were consumed on site in the godsmit field, while the rest surplus was send to the gred. The company's renewable electricity generated at Oman and Bolivia facilities was consumed on site also (Annual ustainability report, 2023). I also used scope 1 GHG emissions as a dependent variable for a robustness check. Financial performance is measured by accounting-base and market-base metrics for the short and long run terms and represent the second model proposed in this thesis. Specifically, for accounting-base metric, I use two commonly indicators, namely, ROA and ROE (Dopierała et al., 2022; Gallego-Álvarez et al., 2015; Martí-Ballester, 2017; Ruggiero & Lehkonen, 2017; Schabek, 2020). ROA computed as a ratio of company's net profit to its total assets, while the ROE is computed as a return of a company's net profit to its equity. ROA gauges a profitability of a company in relation to its total assets, whereas ROE metric measures how a company utilize its shareholder's equity to make profit. Both indicators are operation performances and used to measure financial performance in the short-run (Gallego-Álvarez et al., 2015). Return on Capital Employed (ROCE) is also used for a robustness check.

As for a market-based performance metrics, I employ Tobin's Q and stock price in line with (Dorigoni & Anzalone, 2024; Martí-Ballester, 2017; Xia & Wang, 2021; Xie et al., 2019). Tobin's Q computed as a share of a company's market value to its total assets (Xie et al., 2019). While, stock market was the price of the stocks at the end of the year. Both indicators used for long-term profitability measurement (Inoue & Lee, 2011; Xueming Luo ; C. B. Bhattacharya, 2006). market capitalization is also used for a robustness check (Ng & Zheng, 2018).

4.2.2 Explanatory variables

The core explanatory variable of this thesis is the renewable energy production (self-generation of renewable energy) expressed in GWh (Dorigoni & Anzalone, 2024; Hulshof & Mulder, 2020; Ruggiero

& Lehkonen, 2017; Schabek, 2020). According to the literature it is expected REP to have a negative impact on GHG emissions because the operations process of the clean energy emits much less emissions than oil and gas. Conversely, REP should have positive impact on financial performance proxied by accounting-base and market-base metrics because IPCs is increasingly avoid fines and taxation of emissions.

R&D expenditure is the second independent variable and it incorporated as a proxy for the technological knowledge being measured in US$1 million to detect its impact on environmental and financial performance (Elsayed & Paton, 2005; Fujii et al., 2013; Hart & Ahuja, 1996; Khanna et al., 1998; Konar & Cohen, 2001; K. H. Lee & Min, 2015; Martí-Ballester, 2017; Ruggiero & Lehkonen, 2017; Trumpp & Guenther, 2017; Xie et al., 2019). Similar to REP, it is expected that R&D to have a negative impact on GHG emissions. Conversely, R&D should have a positive impact on financial performance proxied by accounting-base and market-base metrics. As concluded by different studies (Dincer, 2000; Dkhili & Dhiab, 2020; Y. Zhang et al., 2017) REP and R&D activities enables companies to reduce their ecological footprint and subsequently, enhance the impact on society, environment and economic growth.

4.2.3 Control variables.

In the selection of the control variables and setting their expectations, it follow previous authors in the same area such as (Clarkson et al., 2011; Fujii et al., 2013; Martí-Ballester, 2017; Morina et al., 2021) who have shown which company characteristics could affect environmental performance and financial performance. Accordingly, it use Total Asset (TA) as a proxy for company size in million dollars (Clarkson et al., 2011; Dopierała et al., 2022; Schabek, 2020). Economic scale is considered the central factor that can influence the environmental and financial performance. I assume TA to have a significant positive impact on both, environmental and financial performance (Morina et al., 2021; Xie et al., 2019). For the robustness check, I further use the number of employees (Jarboui, 2021; Xie et al., 2019) and the daily barrel production of oil and gas as control variables (Clarkson et al., 2011; Le & Nguyen-Phung, 2024; Ruggiero & Lehkonen, 2017).

Table 3. Variables, measurements and sources.

Variables	Measurement	Source
GHG emissions	Tons of CO_2 equivalent	Annual sustainability reports
REP	GWh	Annual sustainability reports
R&D	Million dollars	Annual financial reports
Scope 1	Tons of CO_2 equivalent	Annual sustainability reports
Employees	Numeric number	Annual sustainability reports
Oil and gas	Numeric number	Orbis dataset
production ROA	Percentage	Orbis dataset
ROE	Percentage	Orbis dataset
ROCE	Percentage	Orbis dataset
TA	Million dollars	Orbis dataset

4.3 Methodology

To reach the goals of the present thesis, several advanced econometric techniques are employed. The core analysis employs are the GMM and QML estimators to address the endogeneity issues frequently exist in this kind of panel data analysis (Bond, Hoeffler, and Temple, 2001). In plus, novel methods of movement quantile regression and random and fixed effect are utilized in order to provide a robust analysis. The four methods are deeply discussed as follows:

4.3.1 Generalized method of momentum

GMM is the first and foremost approach applied in this thesis to measure the impact of REP on GHG emissions. It was proposed by Holtz-Eakin et al. (1988) and subsequently developed by (Arellano & Bond, 1991; Arellano & Bover, 1995; Roodman, 2009). GMM is a panal dynamic data method estimates parameters in models, and it is used when the number of cross-sectional units is larger than the period of time in a panel (Roodman, 2009). Hence, the number of cross-sections (N) in this thesis is 27 while the period (T) is 9. Besides, this method can be used to control the endogeneity of the lagged independent variable, the bias of omitted variables (Nickell, 1981), measurement errors and unobserved panel heterogeneity.

The GMM method involves utilising the first-differenced estimator to evaluate regression equations in first differences using lagged levels of independent variables as instruments. This method eliminates company-specific fixed effects, thereby addressing the potential exclusion of time-invariant company-specific factors that might impact GHG emissions. Nevertheless, the first-differenced GMM estimator, as introduced by Arellano and Bond in 1991, is not suitable for use when time series are highly persistent and the number of time series observations is limited. In such situations, lagged levels of independent variables are weak instruments for subsequent first differences, resulting in biased outcomes. Arellano and Bover (1995) and Blundell and Bond (1998) recommended using the system-GMM technique to resolve this issue, which combines regression equations for first differences and levels into a single system. The level equations use lagged first differences of the series as instruments. Therefore, we begin with the following general model.

$yit = ayit - 1 + BXit + ni + \varepsilon it$ for i=1,2. . . . , N and t =1. 2, . . . ,T, (1)

Where: i represents the company index, t denotes the time index, y is the dependent variable (GHG emissions), X is a vector of other conditional variables affecting GHG emissions, iη captures unobserved company-specific effect terms while εit indicates the idiosyncratic disturbance term. Arellano and Bond (1991) recommend transforming the model into first differences to eliminate company-specific effects.

$$yit - yi, t_{-1} = a(yit_{-1} - yi, t_{-2}) + B(xit - xit_{-1}) + (\mathcal{E}it - \mathcal{E}i, t_{-1}) \quad (2)$$

GMM estimators are typically used in one-step and two-step variants (Arellano & Bond, 1991). The one-step estimator uses weighting matrices that are independent of the estimated parameters. In contrast, the two-step GMM estimator uses optimal weighting matrices for which the moment conditions are weighted by a consistent estimate of their covariance matrix. Consequently, the two-step estimator is usually more efficient than the one-step estimator., Using the two-step estimator, however, in small samples has notable drawbacks. These drawbacks stem from the proliferation of instruments. Through simulation analysis, (Windmeijer, 2005) demonstrated that employing many instruments in two-step GMM estimation can lead to biased standard errors and parameter estimates. (Roodman, 2009) suggested reducing the dimensionality of the IV matrix to address issues caused by the proliferation of instruments. We adopted this approach in this thesis, employing the moment conditions and using the two-step estimator. We lowered the dimensionality of the IV matrix based on Roodman's recommendations. The prime objective of this thesis is to measure the impact of REP on environmental and financial performance. To do so, we followed PH (i.e., REP improves a company's operations and decreases GHG emissions). Many studies had the same perspective, such as that of (Jarboui, 2021), the results of which suggest that increasing REP improves the quality of the natural environment by reducing GHG emissions. Based on this discussion, we developed the following model for the first part of measurement, that is, the impact of REP on GHE emissions reduction:

$$GHGit = ai + B1GHG_{t-1} + \beta 2(\text{REPit}) + \beta 3(\text{R\&Dit}) + \beta 4(\text{TAit}) + \mu\text{i} + \delta\text{t} + \varepsilon\text{i}, \text{t} \quad (3)$$

Where: GHGit is an indicator for environmental emissions in company i at year t, i is the number of cross-sections (=1, …, N), t is the number of time series (=1, …, T). REPit denoted renewable energy production from solar, wind, hydroelectricity, biogas energy (Baskaya et al., 2022). $R\&D$it denoted research and development expenses, TA represents total assets, μi is the unobserved company-specific fixed effects, δt is the time trend and εi, t is the error term. we expect REP to positively impact GHG emissions reduction attempts.

Equation 1 is for only the short-run effects. Additionally, to align this study with the previous literature on this topic, R&D is added to the model as a second explanatory variable to assess its impact on GHG emissions in line with the method of (Fethi & Rahuma, 2020) who measured the impact of R&D on CO_2 emission within 17 petroleum companies. R&D is related to innovation and technology for patents which are useful to improve the existing technology in order to reduce GHG emissions (Cheng, Ren, & Wang, 2019).

The role of R&D investment in developing REP to enhance the latter's impact on GHG emissions is vital (Hailemariam et al., 2022). Therefore, I expect R&D investment to play a moderating role in the relationship between REP and GHG emissions in line with (C. C. Lee & Wang, 2024).To test the role of interaction variable REP*R&D in moderating the relationship between REP and GHG emissions, I formulate the following equation:

$$GHGit = \alpha i + B1GHG_{t-1} + \beta 2(\text{REPit}) + + \beta 3(\text{REP} * \text{R\&Dit}) + \beta 4(\text{TAit}) + \mu\text{i} + \delta\text{t} + \varepsilon\text{i,t} \quad (4)$$

Where $\text{REP} * \text{R\&Dit}$ is the the interaction variable. i.e., renewable energy production multiplied by research and development.

I formulated the following equation to explore the nonlinear relationship between both REP, R&D on GHG emissions:

$$GHGit = \alpha i + B1GHG_{t-1} + \beta 2(\text{REPit}) + \beta 3(\text{REPit})^2 + \beta 4(\text{R\&Dit}) + \beta 5(\text{R\&Dit})^2 + \beta 6(\text{TAit}) + \mu\text{i} + \delta\text{t} + \varepsilon\text{i,t} \quad (5)$$

Where: $(\text{REPit})^2$ and $(\text{R\&Dit})^2$ are the square terms of REP and R&D respectively. The squared terms of REP and R&D were taken to measure the effect of both variables on GHG emissions at the initial stage and in a later stage. Thus, if the inverted U-shaped holds for REP and R&D, then the signs of B2 and B4 of REP and R&D are positive, whereas B3 and B5 of REP squared and R&D squared are negative.

The first equation was formulated to calculate the short-run parameters. To measure the long-run relationship between variables in Eq. 1, we generated the long-run coefficients by adopting the following equations 5 and 6:

$$\text{REP} \div [1 - \emptyset] \quad (6)$$

$$\text{R\&D} \div [1 - \emptyset] \quad (7)$$

Where: REP and R&D are the coefficients of the short-run parameters and ф is the coefficient of the endogenous variable in the model of Eq. 1.

To further explore the nonlinear impact of the interaction variable REP*R&D in in moderating the relationship between REP and GHG emissions, Eq. 7 is formulated is to capture the interaction between REP and R&D in one hand, and REP squared and R&D on the other hand.

$$D\text{GHGit} = \alpha\text{i} + B1GHG_{t-1} + \beta 2(\text{REPit}) + \beta 3(\text{REPit})^2 + \beta 4(\text{R\&Dit}) + \beta 5(\text{REPit} * \text{R\&D}) + \beta 6\,(\text{REP}^2\text{it} * \text{R\&D}) + (\text{TAit}) + \mu\text{i} + \varepsilon\text{i,t} \quad (8)$$

Where: (REPit*R&D) is REP multiplied by R&D; (REP^2it*R&D) is the exponential of REP multiplied by R&D.

4.3.2 Quasi Maximum Likelihood

As stated earlier, the data set of this study consists of 27 IPCs over 9 years, resulting in 243 company-year observations. Given the short time diminution of T=9, in addition to the fact that the dynamic nature of corporate financial performance necessitates a model that includes a lagged dependent variable to capture persistence and account for potential reverse causality. Albeit, estimating a short panel model in terms of short T using traditional panel models will introduce a few drawbacks due to its inconsistent of cov ($\pi Y_{it-1}, \ \varepsilon_{it}$) ≠ 0, as seen in equation 9. In other words, the lagged of πY_{it-1} and ε_{it} are highly correlated and this corelation cause a bias estimation on a panel with fixed T (Moral-Benito, 2012). Furthermore, Nickell 1981 pointed out that the bias stemming from endogeneity is considerably large and cannot be mitigated by increasing N as the bias in a is of order 1/T. In addition, simulation results from (Soto, 2009) reveal that the bias of ordinary least square estimator highly increase with the persistence of y.

$$Y_{it} = \pi Y_{it-1} + \beta X_{it} + fiY + \varepsilon_{it} \qquad 9$$

To address the above mentioned challenges, I employ the QML of linear dynamic short T panel data estimation introduced by (Hsiao et al., 2002) and subsequently implemented in Stata by (Kripfganz, 2016). QML method is specifically designed for short-T panels because it provides consistent estimates by correctly modelling the initial observation (the first-year value of the dependent variable), thereby resolving the bias issue (Ajide et al., 2025)(Mdaghri & Raghibi, 2025). Equation 10 showes that after removing fixed effects by having the first difference transformation, the lagged variable of the independent variable πY_{it-1} is correlated by construction with the lagged error term $\Delta\, \varepsilon_{it}$. Thus, an estimator that treats the lagged variable as exogenous might be biased. QML method correct for any potential omission variable's biased and endogeneity.

$$\Delta Y_{it} = \pi Y_{it-1} + \Delta\, \beta X_{it} + \Delta\, \varepsilon_{it} \qquad 10$$

To this end, was employed QML method, both fixed effects and random effects to explore the impact of REP on financial performance in IPCs in the frame of dynamic panel data following the previous literature in the same field (Vestrelli et al., 2024b) (Han et al., 2016). To this end, the dynamic panel model estimation of QML used to capture the impact of REP on FP is written in equation 11 as follows:

$$FP_{it} = a + \beta_1 FP_{it-1} + \beta_2 REP_{it} + \beta_3 R\&D_{it} + \beta_4 TA_{it} + ø + \delta t + \varepsilon_{it} \qquad 11$$

Where FP_{it} is the financial performance metrics (i.e. ROA, ROE, ROCE, Tobin's Q, market price and Market capitalization) for company i at time n, pPF_{it-1} is the lagged financial performance to account for reverse causality, REP_{it} is a vector of the primary explanatory variable, $R\&D_{it}$ is a vector of the second explanatory variable, while TA_{it}, the proxy of size, is the control variable. a, β_1, β_2 and β_3 are the vector of coefficients, $ø$ and δt represent the company and time fixed effects respectively, while ε_{it} is the idiosyncratic error term. To address the problem of heteroscedasticity, I employed the robust standard errors. I anticipate a positive and statically relationship from the side of REP and R&D to financial performance. Finally, a Hausman test confirmed that a fixed effects model is more appropriate than random effects mode.

Finally, we calculate the long-run coefficients of financial performance from the short run equations as below:

$$\text{REP} \div [1 - \emptyset] \qquad (12)$$

$$\text{R\&D} \div [1 - \emptyset] \qquad (13)$$

Where: REP and R&D are the coefficients of the short-run parameters in the first equation, while $\emptyset$ is the coefficient of the endogenous variable in the same equation.

4.4 Robustness tests:

To validate the credibility of the empirical findings in this thesis, I further adopt two methods to conduct a robustness test. First, subsampling analysis for heterogeneity. Second, employing other methods, MMQR and Fixed and Random effects models in particular. Third, replacing the control variable by other control variable, namely: the number of employees and daily barrel of petroleum production in boe/d. The methods used in the robustness check were designed on the ground of the objectives of this thesis and they are as follow:

4.4.1 Momentum quantile regression (MMQR)

To explore the impact of REP and R&D on GHG emissions, this thesis moves beyond traditional mean-based models. Methods such as Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS), concentrate on modelling the conditional mean of the outcome variable. These methods can produce misleading estimates if the effects of the covariates are not uniform across the distribution. While more advanced methods such as GMM and QML exist, they also primarily concentrate on average effects. Therefore, I employ the MMQR, an econometric panel method introduced by Machado and Silva (2019) as a robustness test for the first objective in line with (Baskaya et al., 2022). This approach is superior for several reasons. First, it allows to model the entire conditional distribution of GHG emissions, revealing how the effects of REP and R&D differ at various quantiles of GHG emissions. Second, unlike earlier quantile regression techniques, MMQR effectively controls for individual fixed effects, thereby accounting for unobserved time-invariant heterogeneity across the companies in the said sample. Third, the model is inherently robust to outliers and does not rely on restrictive assumptions about the error distribution. Finally, the unique strength of the MMQR framework is its ability to simultaneously estimate how our explanatory variables affect both the central tendency (location) and the dispersion (scale) of GHG emissions. By doing so, a comprehensive understanding of distributional dynamics related to the impact of REP and R&D on GHG emissions can be discovered and whether they are consistent or if they vary significantly for companies with low, medium, and high levels of GHG emissions. According to the literature in questions, many authors have explored the panel quantile framework (Ge & Mehmood, 2024; Song et al., 2024; B. Zhang et al., 2024). and Razzaq, 2022). The modified location-scale definition of conditional quantiles Q(X) is in the following Equation.

$$y_{it} = a_i + X'_{it}\emptyset + (\delta_i + U'_{it}\psi)C_{it} \qquad 14$$

Where y_{it} is the outcome variable, X_{it} is an i.i.d endogenous variable. The terms $(a, \emptyset, \delta, \psi)$ are the parameters to be estimated. The component $(\delta_i + U_{it}\ \psi > 0) = 1. C_{it}$ is an i.i.d unobserved random variable distributed across all individuals and also is orthogonal to X_{it} to satisfy (Machado & Silva, 2019) moment condition. $i = 1,2 \ldots . n$, denotes the individual i fixed effects and U is a k-vector of the known parameters of X. Next, model 14 can be expressed in its quantile based in the following manner in Equation 15.

$$Q_y(\tau/\chi_{it}) = \left(a_i + \delta_i q(\tau)\right) + X'_{it}\emptyset + U'_{it}\psi q(\tau) \qquad 15$$

Where $Q_y(\tau/\chi_{it})$ represent the quantile distribution of the dependent variable, The notation $a_i(\tau)$= $a_i + \delta_i q(\tau)$ is the scalar coefficient, τth is the sample quantile, while U' denotes a k -vector of known components of X'_{it} which is normalized to be in line with the Machado (Machado & Silva, 2019) moment conditions, E(U)=0 and E($|U|$)=1 (Koengkan et al., 2021).

The version of MMQR model, which includes the relevant variable of this thesis, is specified in Equation (16) as follows:

$$Q_{GHG_{it}}(\tau_k/a_i, x_{it}) = a_i + B_{1\tau}\,REP + B_{2\tau}\,R\&D + B_{3\tau}\,TA \qquad 16$$

Where GHG is the dependent variable GHG emissions, REP denotes the renewable energy production and TA is the main control variable of this study.

4.4.2 Robustness test for the second objective: Pooled OLS, fixed-effects and random-effects.

The three basic regression model used commonly in panel static data analysis are pooled Ordinary Least Squares (OLS), fixed-effects and random-effects regressions (Baltagi, 2021; Wooldridge, 2016). Each model provides a distinct approach to treat the intercept and address the potential unobserved heterogeneity across entities. The pooled OLS is the most straightforward specification and serves as an essential baseline for static models. It effectively treats the panel dataset as a single large cross-section by combining all observations across entities (i) and time periods (t), thereby ignoring the panel structure of data. The core assumption in this model is that both, the intercept and slope coefficients are constant for all entities and time periods. This implies that there are no unobserved, individual-specific characteristics that influence the dependent variable. However, this assumption of homogeneity is rarely holds in practice so that the pooled OLS often leads to significant omitted variable bias.

The fixed effects model has the ability to address the issue of unobserved heterogeneity as each entity (i) is given a unique intercept $(\beta 0)$. The individual-specific intercept absorbs the effects of all characteristics of an entity such as the fundamental business culture, geographic location, size and quality management, regardless of whether these factors are correlated with the model's regressors. The primary advantage of the fixed-effects model is its robustness in providing consistent estimates in the presence of such time-invariant omitted variables. However, this robustness comes at the cost of being unable to estimate the coefficients of any time-invariant explanatory variables, as their effects are fully absorbed into the fixed intercepts. Finally, the random-effects model which acknowledges also the presence of individual-specific effects but it treats each entity's individual effect as a combination of a common average intercept $(\beta 0)$ and a random, entity-specific error term $(u\text{i})$.The central assumption of the random-effects model is that these unobserved individual effects are uncorrelated with the explanatory variables. If this assumption holds, the random-effects model is more statistically efficient than the fixed effects model because it utilizes both within-entity and between-entity variation. The following is the functional forms for these three models, showing how they treat the intercept differently:

Pooled OLS models

$$y_{it} = \beta 0 + x'_{it}\beta + \varepsilon_{it} \text{ , } where\ \varepsilon_{it} \sim IID(0, \sigma_v^2) \quad (17)$$

Fixed Effects Model

$$y_{it} = (a_i + u_i) + x'_{it}\beta + \varepsilon_{it} \qquad where\ \varepsilon_{it} \sim IID(0, \sigma_v^2) \quad (18)$$

Random Effects Model

$$y_{it} = \beta 0 + x'_{it}\beta + w_{it} \quad , where\ w_{it} = (u_i + \varepsilon_{it}) \qquad and\ w_{it} \sim IID(0, \sigma_v^2) \tag{19}$$

Where y_{it} is the dependent variable for entity i at time t, x'_{it} is a vector of explanatory variables, β is a vector of coefficients, ε_{it} is the idiosyncratic error term. Models of individual effects in all individuals, so-called heterogeneity might be observed or unobserved. This is a crucial contrast between a pooled OLS model and a model with individual-specific effects. The critical distinction lies in the treatment of the individual-specific effect, denoted as a_i in the fixed effects model and u_i in the random effects model. Specifically, in the fixed effects model specification, see equation 2, a_i is a set of fixed parameters that are permitted to be correlated with the regressors ε_{it}. In contrast, in the random-effects model specification, see equation 3, the individual effect u_i is a component of the error term and is strictly assumed to be uncorrelated with x'_{it}.

For the model specification tests, the Hausman test (Hausman, 1978) and the Breusch-Pagan Lagrange Multiplier (BPLM) test (Breausch T. S & Pagan A.R, 1979), in addition to the F-test are employed to assess the specification of the best model mentioned above. By putting those specification tests to the test, one can see whether panel statics models, namely: a pooled OLS, a fixed-effects, or a random-effects model, are appropriate for describing the empirical research model of this thesis. Practically, A random-effects or a pooled OLS model can be employed in the context of the BPLM test. If the null hypothesis of the BPLM test is rejected, a random-effects model is suitable. Otherwise, a pooled OLS model is preferred. If individual effects are captured after the F-test and BPLM test, the Hausman test is used to discover a preferred model, either a fixed effects model or a random effects model. The former will be executed if the alternative hypothesis is accepted and the null hypothesis is rejected. Otherwise, a random effects model would be preferred. In addition to the above empirical steps. Finally, to determine whether the data set is homoscedastic or heteroscedastic, the Breusch-Pagan test is utilized.

Chapter 5

5. Results and discussion

5.1 The impact of Renewable Energy Production on environmental performance

The commercial oil and gas industry took off following the 1859 discovery of Pennsylvania's first viable oil well, and was further boosted by the 1959 Groningen gas field discovery in the Netherlands, which laid the foundation for the modern gas sector. The Seven Sisters played a pivotal role in accelerating oil and gas exploration and extraction during the 20th century, leading to unprecedented production levels for commercial consumption. While this era spurred significant economic development, it also resulted in a dramatic surge of GHG emissions, causing substantial negative impacts on the environment. For this reason, the ratification of PA was signed in 2015 and governments introduced NDCs, which outline country-specific commitments to reduce national emissions. Subsequently, major players in the petroleum sector had adopted the net zero emission goal and begun significantly the investment in renewables, which are proven scientifically to impact positively GHG emissions reduction, particularly at macroeconomic (Deng et al., 2024). At microeconomic level, a few survey studies indicate that increasing REP has a positive impact on environmental Toghyani and Saadat (2024). Albeit, despite the current research literature have broaden our standing of how REP affects GHG emissions, the task of actual reducing GHG emissions by utilizing REP is an undiscovered issue in the petroleum industry. Because of the fact that a majority of these researches are survey studies that concentrate on the policies rather than the actual performance. In this chapter, I attempt to empirically explore the impact of REP on GHG emissions reduction in a panel of 27 IPCs for both the short and long term. To do so, I faithfully followed PH which postulate that inspiring environmental activities such as REP and R&D on company level reduce the negative impact on the environment.

Table 4 shows that the mean value of GHG emissions is -0.037 with a maximum value of 2.199. GHG emissions are calculated by aggregating the values of Scope 1 and Scope 2 GHG emissions. Scope 2 is added to scope 1 in our analysis because many of IPCs consume part of their REP internally, for example Ecopetrol and Bangchak's consumption from self-generated REP was around 54 GWh and 23 MWh respectively in 2021. The mean value of REP is 0.11 with maximum and minimum values of 2.423 and -2.455, respectively. REP is calculated based on the generation of electricity in GWh annually. The data is standardised to minimise heterogeneity that arises from the different sizes of IPCs.

Table 4. Descriptive Statistics for the variables of the first emperical chapter.

Variables	Obs	Mean	Std. Dev.	Min	Max
GHG emissions	243	-0.05	0,95	-3.17	2.52
REP	243	0.05	0.94	-2.64	2.66
R&D	243	-0.01	0.90	-2.22	2.53
TA	243	0.00	0.94	-2.18	2.16

Source: Author's calculation.

Table 5 contains the correlation matrix. The unconditional correlations between the variables are generally low. The highest correlations were observed between REP and TA (0.40) and between R&D and TA (0.25), suggesting that large petroleum companies produce more RE and spend more on R&D. Besides, the amount of REP was found to be law and negatively correlated (-0.21) to GHG emissions. Conversely, the correlation between R&D and GHG emissions was positive and very law. Firms with many employees had higher GHG emissions. For the other correlations, the absolute value of correlation was below 0.40. Thus, multicollinearity was not a problem in our estimations.

Table 5. Corelation Matrix of the first emperical chapter.

Variables	GHG	REP	R&D	TA
GHG	1.000			
REP	-0.211	1.000		
R&D	0.131	0.087	1.000	
TA	-0.056	0.402	0.256	1.000

Source: Author's calculation.

Table 6 presents the two-system GMM estimator and the two-step corrected system-GMM estimator results of Eg 3. First, it is notable that the lagged dependent variable is statistically significant at a 1% level, confirming that a dynamic model is justified in this analysis. The positive and significant singe of the lagged variable (GHG_{t-1}) indicates that a one standard deviation in lagged GHG emission results in a 0.50% rise in GHG emissions. This implies that a rise in previous GHG emissions would heighten current GHG emissions in the studied IPCs. This finding aligns with those in global reports that showed there were rapid increases in GHG emissions in the past few years due to petroleum extraction and production (Climate Disclosure Project, 2017). Secondly, REP, the core variable of this model, was found to have a negative and statistically significant link with GHG emissions at a 1% level, as well as for the system-GMM robust. Precisely, a one standard deviation increase in REP will result in a 0.34 drop in GHG emissions in the short run at the 1% level of significance *ceteris paribus*. The negative coefficient implies that REP is a vital factor in reducing GHG emissions because the production process for RE emits very little GHG emissions. Accordingly, IPCs pursuing REP are likely to improve their environmental performance. This outcome aligns with that of (Jarboui, 2021) who used the true fixed effect model in a sample of 45 USA oil and gas companies. Similar results were also achieved by (Dauda et al., 2021; Deng et al., 2024; Y. Lin et al., 2024; Qudrat-Ullah & Nevo, 2021; Usman et al., 2022; Y. Zhang & Chen, 2023) who used the GMM methodology but at the level of macroeconomics. Importantly, these results serve SDG7 and 13. (i.e., affordable and Clean Energy and climate action. Thirdly, R&D was found to have a statistically significant and negative relationship with GHG emissions. Thus, a one standard deviation in R&D causes a 0.13 drop in GHG emissions in the short run at the 10% level of significance *ceteris paribus*. This outcome is congruent with those of (Alam et al., 2019; Fethi & Rahuma, 2020; K. H. Lee & Min, 2015; Yang et al., 2014) (Y. Zhang et al., 2017) while it contradicts those of (Cheng, Ren, & Wang, 2019) who concluded that the development of a patent did not lead to a significant reduction in CO_2 in 35 OECD countries. Fourth, the IV included in the model posits a positive and statistically significant connection with GHG emissions. As such, a one standard deviation increase of TA leads to a 0.15 increase in GHG emissions. This result is in line with Jarboui, 2021 who reproted a positiv impact of total assets on CO_2 emissions in a sample consist of 45 US oil & gas companies.

To conclude, the results suggest that REP and R&D is essential in reducing GHG emissions in the IPCs. These outcomes resonate with our earlier claims that promoting REP and R&D lower GHG emission. The contributions of REP and R&D to GHG emissions reduction efforts significantly differ, with contributions ranging from -0.34 for REP to -.11 for R&D. The much larger contribution of REP than R&D may be attributed to the fact that the IPCs started greatly investing in renewable energy projects after setting the goal of net-zero emissions after 2015 (Lu et al., 2019). While IPCs was concentrating on R&D before 2015 to control GHG emissions (Fethi & Rahuma, 2020). Hence, our results support the PH that inspiring environmental investment has positive effects on environmental performance by decreasing GHG emissions in the studied sample (Porter & Linde, 1995).

Table 6. The linear impact of REP and R&D on GHG emissions.

Variables	Two-step System GMM	Two-step system-GMM (Robust)
GHGit-1	**.628*****	**.628*****
	(10.34)	(3.49)
REP	**-.361*****	**-.361*****
	(-7.86)	(-3.04)
R&D	**-.134***	**-.134**
	(-1.98)	(-0.79)
TA	.165***	.165
	(3.70)	(1.44)
Constant	-.016	-.016
	(- 0.62)	(-0.24)
Sargan test	0.256	0.256
Hansen test	0.122	0.122
AR (1)	0.003	0.013
AR (2)	0.542	0.610
Number of groups	27	27
Number of instruments	23	23
Observations	189	189

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

The moderating effect of R&D in the linear relationship between REP and GHG emissions is displayed in table 7. The values indicate that R&D have a negative impact on enhancing the restraining effect of REP on GHG emission. Specifically, a one standard deviation in the moderating variable (REP*R&D) leads to 0.7% drop in GHG emissions in the short run at the 10% level of significance *ceteris paribus*. This suggests that higher R&D investment strengthen REP's effectiveness in reducing GHG emissions. These results are consistent with (Hailemariam et al., 2022) who found that R&D investment in renewable energy technology has a positive effect on environmental quality by reducing GHG emissions in a global sample of 27 developed and emerging economies. However, this result contradicts with (Muhammad & Hoffmann, 2024) who found a negative impact from the side of R&D on renewable energy consumption across 16 federal German states.

Table 7. The linear Moderating role of R&D in the relationship between REP and GHG emissions.

Variables	Two-step System GMM	Two-step system-GMM (Robust)
GHGit-1	.501***	.501***
	(9.30)	(4.24)
REP	-.532***	-.532***
	(-10.89)	(-3.06)
R&D	.008	.008
	(.13)	(0.06)
REP×R&D	-.072***	-.072
	(-2.62)	(-1.21)
TA	.272	.272
	(3.42)	(1.51)
Constant	-.032	-.032
	-2.15	-0.85
Sargan test	0.273	0.273
Hansen test	0.468	0.468
AR (1)	0.005	0.011
AR (2)	0.760	0.792
Number of groups	27	27
Number of instruments	24	24
Observations	216	216

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

Table 8 contains the result of the nonlinear relationship of Eq. 5. The result reveals that REP has a positive impact on GHG emission while its quadratic has a negative impact on GHG emission. Of note, the coefficients are the same with regard to the system-GMM robust but at the level of 10%. This means that REP does not affect GHG emissions reduction efforts at the beginning, however, the effect becomes influential in reducing GHG emissions above a certain threshold, indicating that a U-shaped pattern is valid in this relationship. This finding aligns with that of (Cheng, Ren, & Wang, 2019) who found an inverted U-shape from the side of renewable energy on CO_2 in a sample of 35 OECD countries. Also, this result is in line with (F. Dong et al., 2022) who found a threshold effect between renewables and carbon emission efficiency within 32 developed countries. Similarly, R&D has the same trend as REP on GHG emission reductions. Specifically, the impact of R&D on GHG emissions is positive in the initial stages. However, as long as IPCs spend more on R&D, this effect becomes negative above a certain threshold, indicating that a U-shaped relationship exists between the two variables. This outcome resonates with several existing studies concerning the inverted U-shape trend between R&D and GHG emissions (Dauda et al., 2021; Deng et al., 2024; W. Li et al., 2021; Y. Zhang & Chen, 2023).

Table 8. The nonlinear relationship between REP and R&D on GHG Emissions.

Variables	Two-step system-GMM	Two-step system-GMM (Robust)
GHGit-1	**.619*** **	**.619*** **
	(3.55)	(3.50)
REP	**.589*** **	**0.589** **
	(3.55)	(2.61)
REP^2	**-.635** **	**-.635** **

	(-3.17)	(-2.48)
R&D	**.214**	**.214**
	(1.26)	0.93
$R\&D^2$	**-.334****	**-.334****
	(-3.00)	(-2.31)
TA	.143	.143
	1.10	0.93
Constant	.434**	.434**
	(3.59)	2.29
Sargan test	0.744	0.744
Hansen test	0.711	0.711
AR (1)	0.004	0.005
AR (2)	0.831	0.836
Number of groups	27	27
Number of instruments	18	18
Observations	162	162

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

Table 9 shows the long relationship results from the side of REP and R&D on GHG emissions of Eq. 6 and Eq. 7 as it was in the short run. The findings reveal a positive relationship between REP and GHG emission reduction in IPCs in the long run in line with (Subhan et al., 2024). However, the findings also revealed that R&D does not have a long run impact on GHG emission reduction. This findings aligns with that of (Fethi & Rahuma, 2020) who claimed that R&D did not have a long relationship with CO_2 emissions in a sample of 17 IPCs. This finding is also consistent with those of (Qudrat-Ullah & Nevo, 2021) at the macroeconomic level. The most plausible case for the insignificant long impact from the side of R&D on GHG emissions that IPCs might have been investing much more on renewable energy projects than R&D since the ratification of the PA in 2015 (Salygin & Lobov, 2021).

Table 9. Long-run effect of REP on GHG emissions.

Variables	**Two-step System GMM (Robust)**
REP	**-.974 **** (-2.23)
R&D	**-.361** (-0.64)

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

According to the U-shaped relationship between REP and GHG emissions reduction, we proceeded to use Eq. 8 to capture the role of R&D in moderating the nonlinear relationship between REP on GHG emissions reduction.

Table 10. The moderating role of R&D in the nonlinear relationship between REP and GHG Emissions.

Variables	Two-step system-GMM	Two-step system-GMM (Robust)
GHGit-1	**.768*****	**.768*****
	(7.51)	(3.36)
REP	**.238****	**.238**
	(2.45)	(1.16)
REP^2	**-.708*****	**-.708****
	(-5.36)	(-2.68)
REP×R&D	**.7062*****	**.706***
	(3.08)	(1.74)
REP^2×R&D	**-.478*****	**-.478***
	(-2.88)	(-1.71)

R&D	.447*	.447
	(1.70)	(0.84)
TA	.017	.017
	(0.19)	(0.08)
Constant	.488***	.488
	(4.18)	(1.84)
Sargan test	0.850	0.850
Hansen test	0.319	0.319
AR (1)	0.009	0.021
AR (2)	0.384	0.446
Number of groups	27	27
Number of instruments	20	20
Observations	216	216

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

Table 10 present the result of Eq. 8, which incorporates the interaction term between REP and R&D (REP×R&D) and REP squared and R&D (REP^2 × R&D). Based on (Law et al., 2018), it is not of intent to interpret the individual term of the independent variable and its squared and mediator values, so these coefficients are not of interest. Interestingly, results show that the coefficients associated with REP and R&D interaction are positive, and the interaction between REP squared and R&D is negative. Besides, both interaction terms are statistically significant determinants of REP. These empirical results indicate that the inverted U-shaped relationship between both REP and R&D play a vital role in moderating the effect of R&D in the REP nexus. Clearly, when the interaction terms (i.e., (REP × R&D) and (REP^2 × R&D) have positive and negative signs, respectively, and are significant, the effect of REP on GHG emissions increases with R&D, and further REP has a vanishing effect on GHG emission reductions. This result indicates that the effect of REP on GHG emission reduction increases monotonically with R&D. Put differently, the positive effect of REP on GHG emissions reduction declines as R&D decreases. This finding aligns with that of (Hailemariam et al., 2022), who found that R&D investment in renewable technologies has a positive effect on environmental quality by reducing GHG emissions in advanced and emerging economies. Therefore, our findings support the view that R&D embedded within REP is effective tool in reducing GHG emissions.

Before closing the empirical results of this chapter, it is noteworthy to mention that the reliability of the GMM depends on satisfying a few conditions (Arellano & Bond, 1991). Specifically, the two-step system GMM robust indicates that there is no heteroscedasticity problem in the results. Also, there is no autocorrelation for the second-order Auto-regression in the first differences. Besides, the number of groups exceed the number of instruments so that the rules of thumb condition has met in our analysis. Finally, the Sargan and Hansen statistic are more than 0.1. As such, we can conclude that the results of this study are valid and reliable since these conditions have been met.

5.2 The impact of Renewable Energy Production on financial performance

The awareness of climate change and environmental issue has been increasing remarkably, result in the pressure on firms' activity to control emissions (Calculli et al., 2021). Recently, another kind of pressure from broader perspective has emerged since PA ratification, which is well known as energy transition.

Firms in this regard are not only required to control emissions but also shift into renewables. This shift is considered a global dilemma by some firms' managers who perceive renewables as an extra expense which in return has a complex impact on their financial performance, particularly for firms with poor environmental performance (Ghisetti & Rennings, 2014). However, based on the NRBV theory of how a company might enhance its financial performance by gaining a competitive advantage of going green (Berchicci & King, 2007). It is expected that a company's profitability is positively influenced by the competitive advantages generated if the innovations offset the cost of compliance to stringent environmental standards (Hart, 1995). It is just as true as PH postulated that the inclusion of environmental activities in a company's strategy enhance both, the environmental and financial performance (Porter & Linde, 1995). Theoretically, petroleum companies that had adopted net zero emission by 2050 and subsequently started scaling their REP for energy transition should have enhanced their financial performance. Some results of empirical studies indicated that companies can circumvent risk and increase profits by reducing the pollution from source rather than at the end (Toghyani & Saadat, 2024). Building on this, REP is a potential clean energy source which can play a significant role in ameliorating pollution reduction, particularly in petroleum industry. Nevertheless, how REP impacts the financial performance of IPCs is still messing in the relevant literature. Therefore, this chapter aims to investigate the impact of REP on financial performance in the frame work of both, PH and NRBV.

Table 11 presents descriptive statistics. the mean for ROA is 0.00% and the mean of ROE is 0.02. In general, the greater the ROA and ROE, the more effectively the company generates profits. Normally, a ROA and ROE of 5% or above is desirable. With a mean ROA and ROE of 0.00% and 0.02, most of the companies in the dataset seem to be not efficient in generating profit. The mean for Tobin's Q and Market price is 26% and 16% respectively. Tobin's Q above one suggests the stock is overvalued. I may therefore infer the majority of the companies in the dataset are undervalued. Additionally, it can be noticed that the standard deviation for each variable is among the predicted range.

Table 11. Descriptive Statistics for the second empirical chapter.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA	243	0.00	.945	-2.41	2.315
ROE	243	0.02	.945	-2.48	2.038
Market price	243	.162	1.245	-2.265	5.289
Tobins' q	243	.265	1.662	-2.027	9.331
REP	243	.006	.946	-2.645	2.667
R&D	243	-.014	.909	-2.227	2.539
Total assets	243	0.00	.945	-2.186	2.169

Source: Author's calculation.

Unconditional correlations as shown in Table 12 are generally low with a few exceptions. To illustrate, the highest correlations can be observed between ROA and ROE (0.95), between Tobin's Q and Market price (0.84), between ROA and Market price (0.44), between ROE and Market price (0.41). The forgoing coefficients are all explainable as measures of profitability. Additionally, strong corelations were captured between TA and REP (0.42), between TA and ROE (0.34), between TA and ROA (0.31). This can be attributed to the fact that larger companies in terms of total assets have a higher REP and profitability.

Table 12. Correlation matrix for the second empirical chapter.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ROA	1.000						
ROE	0.985	1.000					
Tobin's Q	0.175	0.153	1.000				
Market price	0.342	0.325	0.317	1.000			
REP	0.252	0.264	-0.092	0.042	1.000		
R&D	0.064	0.055	0.019	0.092	0.081	1.000	
Total assets	0.334	0.346	-0.096	0.169	0.402	0.256	1.000

Source: Author's calculation.

Table 13 present the regression results of the dynamic panel model specified in equation 11. Using QML with fixed effect and robust standard error, models 1 and 2 showes the direct effects of REP, R&D and control variables on ROA and ROE, respectively. As shown in table 13, we have several important findings. First, the coefficients associated with the lagged value of ROA and ROE indicators in the mentioned models are positive and significant, which confirms the validity of QML dynamic model. This indicates that the current profitability of the IPCs is affected by the past year profitability, which is line with the results of (Han et al., 2016) who utilized QML methodology to measure the financial performance of firms proxied by ROA, among other market-based metrics.

Table 13. The impact of REP, R&D and control variables on accounting-based metrics (QML Model).

Variables	**Model 1 (ROA)**		**Model 2 (ROE)**	
	Fixed effects robust	**Random effects robust**	**Fixed effects robust**	**Random effects robust**
FP_{it-1}	**0.166*** **	**.079**	**0.148** **	**.027**
	(2.71)	**(1.45)**	2.40	0.49
REP	**0.209*** **	**.181*** **	**.207*** **	**.205*** **
	(2.76)	(2.63)	2.66	2.82
R&D	-0.049	-.033	-0.062	-.042
	(-0.71)	(-0.47)	-0.88	-0.58
TA	0.392***	.344***	0.394***	.365***
	(4.62)	(5.35)	4.32	4.98
Dummy	-.544***	-.439***	-.473***	-.405**
	(-3.72)	(-2.99)	-3.10	-2.59
_cons	0.343 ***	.283***	.294***	.251***
	(4.23)	(3.51)	3.52	2.95

N of groups	27	27	27	27
Observations	216	243	216	243
Hausman test	24.95		11.52	
p-value	0.0001		0.0420	

Note: **** p<.01, ** p<.05, * p<.1*

Second, REP is demonstrated to have a significantly positive impact on accounting-based measures in the both models. Specifically, a one standard deviation increase in REP will lead to about 15 % and 14% growth of ROA and ROE respectively at the 1% level of significance *ceteris paribus*. This findings are consistent with the results of panel from renewable energy companies in emerging markets (Schabek, 2020), Europe electric utilities (Dorigoni & Anzalone, 2024), Chinese manufacturing companies (Zeng et al., 2010), suggesting that accounting-based measures of IPCs will be enhanced as a result of the investment in renewables. The results is also partially in line with Dopierała et al. (2022) who found the increase of solar energy and wind impact positively ROA and ROE, while the investment in hydroelectric power affected negatively ROA and ROE. However, our results contradicts with findings from a panel of large electric utilities covers 26 different countries (Ruggiero & Lehkonen, 2017), and multinational companies from 36 countries (Martí-Ballester, 2017).

Third, the coefficient on R&D expenditure is consistently negative but statistically insignificant across the both models. This suggests that R&D spending have no impact on the firm's accounting-based metrics. These results is in line with samples from manufacturing industries (Maury, 2022), electric utility industry (Trumpp & Guenther, 2017), chemical industry, (Tatsuo, 2010) and manufacturing (Iwata & Okada, 2011; Sueyoshi & Goto, 2009). This results is also partially in line with (Ghisetti & Rennings, 2014; Hart & Ahuja, 1996; Konar & Cohen, 2001; K. H. Lee & Min, 2015; Martí-Ballester, 2017) who found a negative significant relationship between R&D and several of accounting-based metrics. However, this results contradict with (Ghisetti & Rennings, 2014; Hart & Ahuja, 1996; Konar & Cohen, 2001; K. H. Lee & Min, 2015; Martí-Ballester, 2017). In the petroleum industry, this result also contradicts with Rahuma & Fethi (2022) who found that R&D affected positively ROE and net income in a panel of 17 IPCs. This result is also alien with Lee et al. (2016) who found no relationship between R&D and ROA and ROE. The rationales behind this result can be elucidated by the following assertions. First, IPCs may started extensively investing in renewable energy projects since 2015 because the commitment of energy transition which tailed to their vision, while they had concentrated on R&D pre 2015 to control emissions (Rahuma & Fethi, 2022). Second, the benefit of R&D investment on environmentally-friendly technology does not reach a certain level to affect the financial performance of the studied sampled. Last, the sample of this study consists of nine-year panel data and it did not capture the effect of R&D on FP.

Finally, the coefficients associated with control variables (TA) have a positive and significant impact on both models reflecting that company size is a valuable determinant for accounting-based metrics

(Gallego-Álvarez et al., 2015). Precisely, a one standard deviation increase in TA will lead to about 37 % growth of ROA and ROE at the 1% level of significance *ceteris paribus*.

According to the forgoing results and discussions, environmental regulation can advocate firms to adopt environmental policies aims to enhance accounting-based metrics with a potential of a higher profit than the additional cost (Porter & van der Linde, 1995).

According to the significant results of table 13, I proceeded to use Eq. 12 and 13 to capture the long run impact from the side of REP and R&D on accounting-based metrics. The results are reported in Table 14.

Table 14. the long run relationship between EP and accounting-based metrics (QML Model).

variables	Model 1 (ROA) **Fixed effects (robust)**	Model 2 (ROE) **Fixed effects (robust)**
REP	**.251*** **	**.243*** **
R&D	-.058	-.072

**** p<.01, ** p<.05, * p<.1*

It can be seen from the table above that the results suggest the positive long relationship between REP and accounting-based metrics. As such, one standard deviation increase in REP will lead to about 22 % increase in ROA and ROE in the long run at the 1% level of significance *ceteris paribus*. Conversely, there is no long relationship between R&D and accounting-based indicators of the both models. This results contradict the study of Rahuma & Fethi (2022) who founds a positive relationship between R&D and ROA and net income of 17 IPCs.

Table 15 presents the estimated results concerning the impact of REP on market-based measures. It is clearly shown that the coefficients associated with the lagged value of FP indicators in models 1 and 2 are positive and significant. This indicates that the current profitability of the IPCs is affected by the past year profitability concerning market-based metrics, which is line with the results of (Vestrelli et al., 2024a) who used fixed effects model under QML and found the lagged value of Tobin's Q affects its subsequent value. Also, this result is in line with (Martí-Ballester, 2017; Morina et al., 2021) justifying the validity of the dynamic model's usage. Importantly, the impact of REP on market-based metrics is insignificant in the two models. Hence, we can conclude that REP has a positive but insignificant impact on Tobin's Q and market price. These results is in line with Zeng et al (2010). However, these results contradicts with Dorigoni & Anzalone (2024) who found the increase in REP impact positively ROA and Tobin's Q. Similarly, these results contradicts with (Ruggiero & Lehkonen, 2017) who found a negative correlation between the increase in renewable energy investment and Tobin's Q.

As for R&D, it is insignificantly associated with market base indicators in both models. This result is in line with Xie et al. (2019) who did not find a relationship between R&D and market value in a sample consisted of 6,631 firms from 74 countries covered 11 sectors. Finally, TA positively and significantly impacts market base metrics in both models, indicating that IPCs which have more asset is still playing such role in energy sector.

Table 15. The impact of REP, R&D and control variables on market-based metrics (QML Model).

Variables	**Model 1** (Tobin's Q)		**Model 2** (Market price)	
	Fixed effects robust	**Random effects Robust**	**Fixed effects robust**	**Random effects robust**
FP_{it-1}	**.412 *****	**.427*****	**.466 *****	**.589**
	6.14	2.70	5.45	1.46
REP	**.074**	**.081**	**.107**	**.105**
	0.95	1.03	1.22	1.24
R&D	.045	.034	-.010	-.037
	0.73	0.53	-0.15	-0.34
TA	.139*	.153*	.380 ***	.384***
	1.80	1.83	4.44	4.70
Dummy	-.931***	-.935 ***	-.800 ***	-.772 ***
	-8.31	-7.81	-6.78	-5.40
_cons	.713 ***	.659 ***	.622 ***	.592 ***
	3.64	2.86	6.77	7.46
N of groups	27	27	27	27
Observations	216	243	216	243
Hausman test	19.15		13.02	
P value	0.0018		0.01	

**** p<.01, ** p<.05, * p<.1*

In the end, the findings of this chapter emphasize the crucial role that REP can play in the path of net zero emission, which significantly influences the IPCs' ROA and ROE. Almost certainly that avoiding taxes, fines and penalties due to the negative impact on the environment, in addition to enhancing the image of these companies among the stakeholders can contribute positively to the profitability of IPCs. However, REP is still not affecting markets significantly and this can be attributed to the fact that the profitability of hydrocarbon production is still predominant the market on one hand. On the other hand, traders and investors are not recognizing the role of REP's impact on the accounting bases metrics.

Chapter 6

6. Robustness check:

6.1 Heterogeneous effects.

To assess the homogeneity of our results, further empirical analysis is conducted at the regional level concentrating on two subsamples, namely: EU IPCs and non-EU IPCs (H. Le & Nguyen-Phung, 2024). Table 16 presented the results concerning the impact of REP and R&D on GHG emission, which reveals a significant regional disparity. Specifically, in the short run, the impact of REP on GHG emission is most significant for EU IPCs than non-EU IPCs. Similarly, REP's coefficient value is substantially larger for EU IPCs compared to their non-EU counterparts. Interestingly, this pattern persists in the long run, where the impact of REP on GHG emissions reduction remains both more significant and of a greater magnitude for EU IPCs compared to their non-EU counterparts (see table 17). This result alien with (Salygin & Lobov, 2021) Boon (2019) who found that major oil and gas companies in the EU increased their investments in renewable energy and are more likely than others to adapt their businesses to the energy transition as a result of strict environmental regulations.

It attribute the superior effectiveness of EU IPCs concerning the impact of REP on GHG emissions to several facts. First and for most is the stringent regulatory frameworks within the EU like the EU green deal which mandates climate neutrality by 2050 and a minimum 55% reduction in GHG emissions by 2030 based on 1990 levels. Second, EU IPCs have demonstrated a purely concentrated focus on renewable energy, while many of the non-EU IPCs continue to utilize natural gas as a primary component of their decarbonization strategy such as Gail India, Petroliam Nasional Berhad and ONGC. Last, the capacity of REP is generally larger in the EU IPCs. To prove, we further divided the aggregate sample into two groups on the ground of REP scale. It is not only observed that IPCs with higher REP capacity exhibit more pronounced GHG emissions reductions but also the majority of the EU IPCs predominantly constitute the high-capacity group. With respect to the results of R&D, its coefficient is significant only in the short run for both groups. Importantly, the impact of R&D on GHG emission is significantly weaker than the impact of REP on GHG emission both in short and long run.

Table 16. The impact of REP and R&D on GHG emissions (Subsample).

Region variables	**EU IPCs** Two-step System GMM	**EU IPCs** Two-step System GMM (Robust)	**Non-EU IPCs** Two-step System GMM	**Non-EU IPCs** Two-step system-GMM (Robust)
GHGit-1	**.466*****	**.466***	**.434*****	**.434**
	(3.36)	(1.79)	(3.68)	(1.59)
REP	**-.407*****	**-.407*****	**-.168****	**-.168**
	-8.04	(-3.86)	(-2.20)	(-0.87)
R&D	**-.124***	**-.124**	**-.057***	**-.057**
	(-0.94)	(-0.34)	(-0.59)	(-0.22)
TA	**.166**	**.166**	**.175**	**.175**
	(2.05)	(0.96)	(1.30)	0.64
Constant	-.103	-.103	.015	.015
	(-1.93)	(-0.64)	(0.22)	(0.10)
Sargan test	0.621	0.621	0.173	0.173
Hansen test	0.105	0.105	0.170	0.170

AR (1)	0.070	0.106	0.063	0.156
AR (2)	0.842	0.860	0.550	0.638
Number of groups	14	14	13	13
Number of instruments	12	12	12	12
Observations	98	98	91	91

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

Table 17. The long-run effect of REP and R&D on GHG emissions (Subsample).

Variables	**EU IPCs** **Two-step system-GMM (Robust)**	**Non-EU IPCs** **Two-step system-GMM (Robust)**
REP	**-.763*** ** (-4.51)	**-.297** ** (-2.25)
R&D	**-.233** (-0.80)	**-.101** (-0.61)

***p < 0.01, **p < 0.05, *p < 0.1 indicate significance at 1%, 5% and 10% respectively.

6.1.2 Sub sample for the second empirical chapter.

Following the regional level analysis of the two subsamples, it employ GMM also to assess the impact of REP and R&D on financial performance proxied by accounting base metrics. Table 18 and 19 depict the impact of REP and R&D on ROA and ROE. In the short run, the positive impact of REP on ROA and ROE is found to be more significant for EU IPCs than for non-EU IPCs. Correspondingly, REP's coefficient value is substantially larger for EU IPCs compared to their non-EU counterparts. Importantly, this trend persists in the long run, where the impact of REP on ROA and ROE remains both more significant and of a greater magnitude for EU IPCs compared to their non-EU counterparts, as further detailed in tables 20 and 21.

The greater effectiveness of EU IPCs, regarding REP's impact on ROA and ROE, stems from several factors. Firstly, the EU IPCs have benefited from the EU emissions trading system by effectively avoiding the cost associated with carbon pricing for their renewable assets. Secondly, the energy transition from fossil fuels to renewable energy leads to reduce the exposure to accidents such as leakage and spills, inherently associated with fossil fuel extraction and production, particularly in upstream sector. All of these factors contribute to the increase of operational profit. As regards the results of R&D, its coefficient remains highly insignificant in both the short and long run, consistent with the findings from the original model which assessed the impact of REP and R&D on accounting base metrics.

Table 18. The impact of REP and R&D on accounting base metrics (ROA).

Variables	**EU IPCs** **Two-step System GMM**	**EU IPCs** **Two-step System GMM (Robust)**	**Non-EU IPCs** **Two-step System GMM**	**Non-EU IPCs** **Two-step system-GMM (Robust)**
ROAit-1	-.328*	**-.328***	**.138*** **	**.138**
	(-2.67)	(-1.80)	(3.54)	(1.24)
REP	.572***	**.572*** **	**.390*** **	**.390**
	(3.67)	(3.14)	(3.82)	(1.55)
R&D	-.064	**-.064**	**-.102**	**-.102**
	(-0.26)	(-0.43)	(-0.79)	(-0.35)
TA	.850***	**.850*** **	**.867*** **	**.867**
	(3.47)	(3.13)	3.68	1.36
dummy	-1.595***	-1.595***	-2.222***	-2.222*
	(-5.71)	(-3.49)	(-5.12)	(-1.81)
Constant	.830***	.830***	1.248***	1.248*
	5.38	3.30	5.08	1.84
Sargan test	0.075	0.075	0.464	0.464

Hansen test	0.177	0.177	0.282	0.282
AR (1)	0.062	0.136	0.027	0.040
AR (2)	0.018	0.058	0.880	0.896
Number of groups	14	14	13	13
Number of instruments	12	12	12	12
Observations	112	112	104	104

Note: **** p<.01, ** p<.05, * p<.1*

Table 19. The impact of REP and R&D on accounting base metrics (ROE).

Variables	**EU IPCs** Two-step System GMM	**EU IPCs** Two-step System GMM (Robust)	**Non-EU IPCs** Two-step System GMM	**Non-EU IPCs** Two-step system-GMM (Robust)
ROEit-1	**-.259*****	**-.259**	**.191*****	**.191****
	(-3.41)	(-1.68)	(3.88)	(2.28)
REP	**.512****	**.512****	**.286****	**.286**
	(3.62)	(2.68)	(2.83)	(1.51)
R&D	**-.254 ***	**-.254**	**-.115**	**-.115**
	(-1.91)	(-1.24)	(-0.75)	(-0.50)
TA	**.915*****	**.915*****	**.657****	**.657**
	(4.19)	(2.30)	2.82	1.21
dummy	-1.561***	-1.561	-1.726***	-1.726
	-5.87)	(-3.33)	(-4.41)	(-1.52)
Constant	.799***	.799	.980***	.980
	(5.48)	(3.20)	4.44	1.55
Sargan test	0.090	0.090	0.491	0.491
Hansen test	0.255	0.255	0.560	0.560
AR (1)	0.026	0.050	0.007	0.011
AR (2)	0.033	0.128	0.941	0.951
Number of groups	14	14	13	13
Number of instruments	12	12	12	12
Observations	112	112	104	104

Note: **** p<.01, ** p<.05, * p<.1*

Table 20. The long-Run Effect of REP and R&D on GHG Emissions (ROA).

Variables	**EU IPCs** Two-step system-GMM	**Non-EU IPCs** Two-step system-GMM
REP	**.430***** (4.24)	**.452*** (1.68)
R&D	**-.048** (-0.25)	**-.118** (-0.36)

Note: **** p<.01, ** p<.05, * p<.1*

Table 21. The long-Run Effect of REP and R&D on GHG Emissions (ROE).

Variables	**EU IPCs** Two-step system-GMM	**Non-EU IPCs** Two-step system-GMM
REP	**.406***** (3.26)	**.353** (1.52)
R&D	**-.201**(-1.21)	**-.143** (-0.50)

Note: **** p<.01, ** p<.05, * p<.1*

In conclusion, heterogeneous effects' findings underscore the significance of regional characteristics in the relationship between REP and GHG emissions, and between REP and accounting base metrics. Notably, REP's effect on these outcomes is more pronounced in EU IPCs compared to non-EU IPCs. Theses subsample findings align with the earlier results of the aggregate sample.

6.2 Robustness check for the methodology

6.2.1 Robustness check for the first objective's methodology.

Following the comprehensive GMM analysis for the impact of REP, R&D on GHG emissions, it I proceeded to employ the MMQR to corroborate the reliability of this findings. The result of the robustness analysis of MMQR are provided in tables from 22 to 25 and it is going to be compared with the original results of GMM method in tables 6, 7, 8 and 10. Columns (0.10) – (0.90) record the figures for quantitatively regressive amounts of nine quantile (0.1,0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9). It is apparent from the findings that the MMQR results are consistent with the outcomes derived from the GMM models.

Table 22. Panel quantile regression results for the impact of REP and R&D on GHG emissions.

Quantile variable	Location	Scale	Quantiles								
			0.10	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
REP	-.223***	-.079**	-.086	-.129	-.173**	-.200***	-.238***	-.268***	-.283***	-.306***	-.328***
R&D	.157**	-.004	.165	.163*	.160**	.158**	.156**	.154**	.153**	.152**	.150**
TA	-.005	.019	-.039	-.028	-.017	-.011	-.001	.005	.009	.015	.020

Note: *** p<0.01, ** p<0.05, * p<0.1

To illustrate, table 22 presents the impact of REP and R&D on GHG emissions results. As it can be seen, the impact of REP on GHG emissions is negative and it increases across the quantiles (0.10th to 0.90th). However, the relationship between GHG emissions and REP is negative and significant only for higher quantiles (30th to the 90th). This indicates that the impact of REP in reducing GHG emissions is more effective in higher GHG emissions IPCs than in lower GHG emissions IPCs. More deeply, for IPCs with lower GHG emissions (10th and 20th percentiles), the relation between GHG emissions and REP is statistically insignificant. This implies that the impact of REP in mitigating GHG emissions in low emission IPCs is not as effective as in higher emission IPCs. One possible reason for the significant relation between GHG emissions and REP in these higher emission IPCs could be that the investment scale in renewable energy projects may be relatively higher for these IPCs relative to IPCs with low GHG emissions. In other words, the high emission may be due to high oil and gas extraction and production of these companies which allows them to invest more in renewable projects. This evidence of a statistically significant negative relationship between GHG emissions and REP is in line with statistically significant MMQR negative relationship between carbon emissions and renewable energy consumption at the level of macroeconomic found by (Wolde-Rufael & Mulat-Weldemeskel, 2022) and (Alharthi et al., 2021) for the Latin America and Caribbean countries, respectively. In contrast, this results is inconsistent with (Anwar et al., 2021) who used MMQR and found insignificant relationship between carbon dioxide and renewable energy consumption in MENA countries.

Finally, the control variable (TA) shows a negative but insignificant impact on GHG emissions across the first halve of the whole quantiles, while it turned positive and remain insignificant through the second halve of the whole quantiles. These results demonstrate that the impact of TA in reducing GHG emissions is more effective in lower GHG emissions companies than in higher GHG emissions companies. More deeply, for IPCs with higher GHG emissions (60th to 90th percentiles), the relation between GHG emissions and TA is positive and statistically insignificant. This implies that impact of TA in mitigating GHG emissions in higher emission IPCs is not as effective as in lower emission IPCs. The logical reason behind these results in these higher emission IPCs could be that more TA leads to increase the capacity of oil and gas production and this result in a higher GHG emissions. To conclude, the results of MMQR regression in table 22 confirms the result of GMM in table 6. Figure 14 shows the trend of independent variables under MMQR regression.

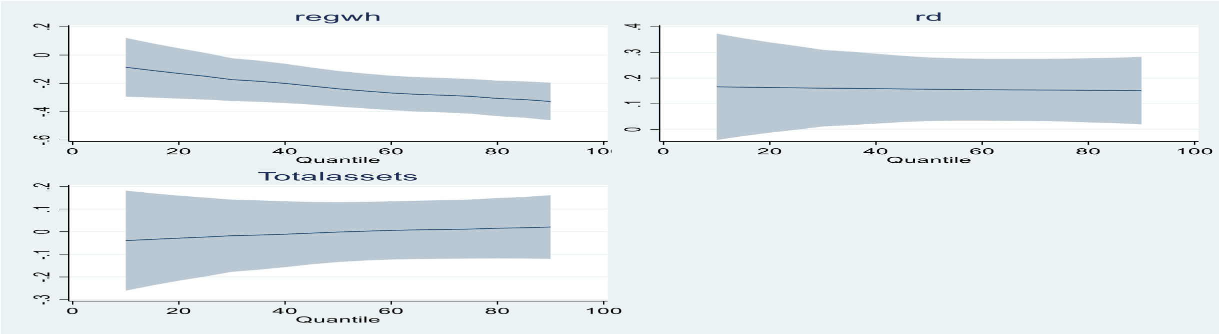

Fig. 17. Change in panel quantile regressions coefficients for REP, R&D and TA over the studied period.

Table 23. The role of R&D in the impact of REP on GHG emissions

Quantile variable	Location	Scale	Quantiles								
			0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
REP	-.221***	-.074**	-.098	-.138	-.176**	-.201***	-.233***	-.262***	-.278***	-.299***	-.325***
R&D	.185***	-.019	.216*	.206**	.197**	.190***	.182***	.174**	.170**	.165**	.158**
REP*R&D	-.096*	.023	-.135	-.122	-.110*	-.102*	-.092*	-.084	-.079	-.072	-.064
TA	-.012	.034	-.070	-.051	-.033	-.022	-.007	.006	.013	.023	.035

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 23 shows the result of the interaction variable between renewable energy and research and development. i.e., REP*R&D. The results amplify that the impact of REP*R&D on GHG emissions is negatively across all quantiles, see figure 15. Manifestly, this impact is only significant at quantiles from 3th to 0.50. In the aggregate, these results confirm the role of R&D on enhancing the impact of REP on GHG emissions similar to the GMM results in table 7.

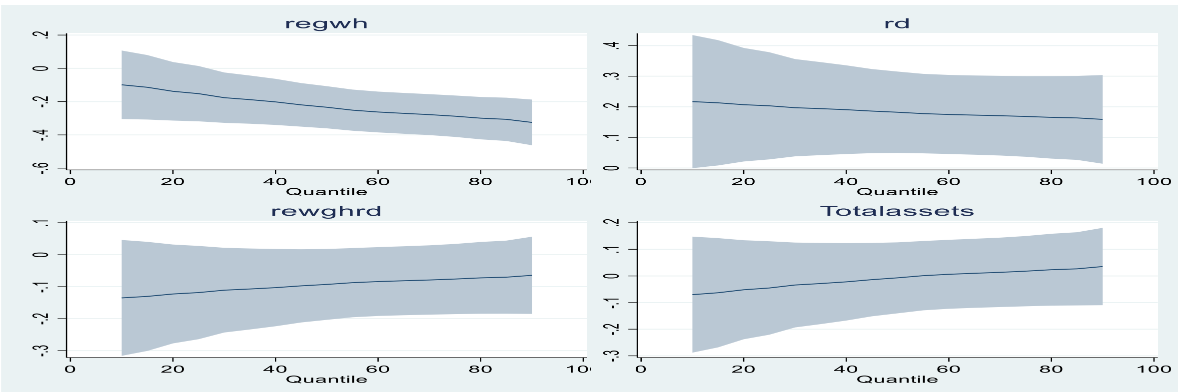

Fig. 18. Change in panel quantile regressions coefficients for the role R&D in the impact of REP on GHG emissions.

Table 24. The nonlinear relationship between REP, R&D and GHG emissions.

Quantile variable	Location	Scale	Quantiles								
			0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
REP	-.147*	-.087 **	.002	-.045	-.094	-.126	-.159**	-.191 ***	-.212 ***	-.235 ***	-.276 ***

REP²	-.160***	.023	-.200**	-.187**	-.174***	-.166***	-.157***	-.149***	-.143***	-.137**	-.126**
R&D	.160	.003	.153	.155*	.157**	.159**	.160*	.161*	.162**	.163**	.165**
R&D²	-.007	-.007	.005	.001	-.002	-.005	-.008	-.011	-.013	-.015	-.019
TA	-.025	.036	-.087	-.067	-.047	-.034	-.020	-.007	.001	.011	.028

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 24 contains the result related to the nonlinear impact of REP, R&D on GHG emissions by employing the MMQR. The outcomes show that the impact of REP on GHG emissions is positive in quantile 0.10 and it turns to become negative since the 2th quantile till 0.95th quantile. But this impact becomes significant only at the middle of the whole quantiles. In contrast, the REP^2 is significantly and negatively impacts GHG emissions across each of the quantiles (0.10th to .90th). Thus, the testing model outcomes provides empirical results that validate the inverted U-shape in the said sample. Clearly, the finding of MMQR regression confirm the results of the GMM tests model in table 8. The findings in table 24 shows that the coefficient of R&D on GHG emissions is positive and significant at the level of 5 % from the 3th to 9th quantile. However, this impact turns negative and insignificant across each of the quantiles (0.10th to .90th). This findings reenforce the results of GMM in table 8.

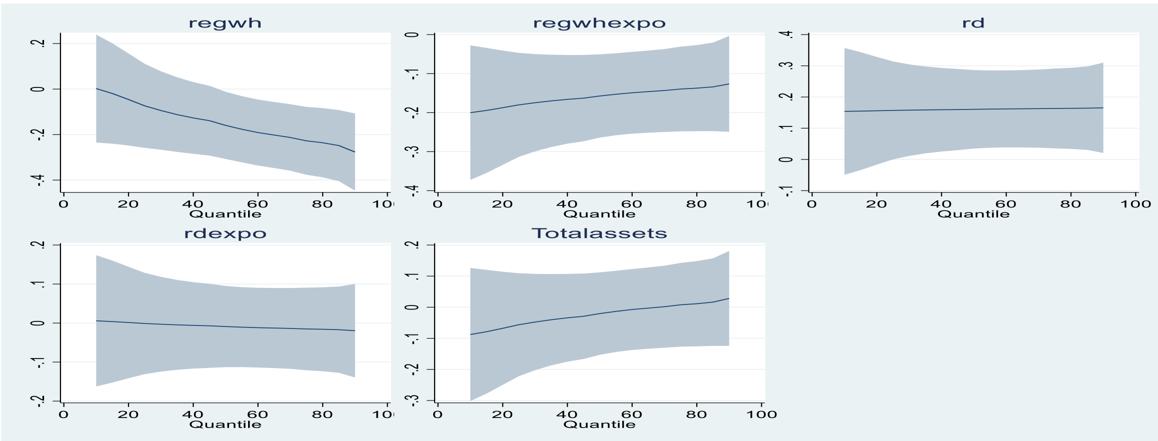

Fig. 19. Change in panel quantile regressions coefficients for the nonlinear relationship between REP, R&D and GHG emissions.

Table 25. The moderating Role of R&D in the nonlinear relationship between REP and GHG Emissions.

Quantile variable	Location	Scale	Quantiles								
			0.10	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
REP	-.178**	-.085*	-.036	-.077	-.125	-.158*	-.192**	-.223***	-.244 ***	-.264***	-.302***
REP²	-.136***	.017	-.166**	-.157**	-.148**	-.141**	-.134***	-.127***	-.123**	-.119**	-.111*
REP²×R&D	.068	.002	.064	.065	.067	.067	.068	.069	.070	.070	.071
REP×R&D	-.121	.002	-.125	-.124	-.122	-.121	-.120	-.119	-.119	-.118	-.117
R&D	.106	-.006	.117	.114	.110	.107	.105	.102	.100	.099	.096
TA	-.013	.045	-.090	-.067	-.042	-.024	-.006	.010	.021	.031	.052

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 25 shows the results of incorporating the interaction term between REP and R&D (REP×R&D) and REP squared and R&D (REP^2× R&D). results show that the coefficients associated with the interaction variable (REP×R&D) are positive, while the interaction between REP^2× R&D is negative, but both interaction terms are statistically insignificant. These empirical results indicate that the inverted U-shaped relationship between both REP^2 and R&D play a vital role in moderating the effect of R&D in the REP and GHG emissions nexus. Clearly, when the interaction terms (REP × R&D) and (REP^2 × R&D) have positive and negative signs respectively, the effect of REP on GHG emissions increases with R&D, and further REP has a vanishing effect on GHG emission reductions. This finding supports the GMM results in table 10.

To conclude, using MMQR regression provides strong evidence that REP impact positively GHG emission reduction in the long run and this impact has an inverted U-shape supporting the GMM method results. The finding confirms also the result of GMM related to the R&D in both, it is an inverted U-shape trend toward GHG emissions and its moderating role in the relationship between REP and GHG emission.

6.2.2 Robustness methodology check for the second empirical objective.

In order to corroborate the reliability of the empirical results concerning the impact of REP, R&D on financial performance proxied by accounting base metrics, the static panel data technic is used, namely: POL, fixed and random effects. The result of the robustness analysis of static panel technics are provided in tables 27 and 28. Accordingly, these tables will be compared with the original results of QML method in tables from 13 to 15.

For the static random effect estimation, all variables were required to be stationary. Thus, I begin with stationarity test by using the Levin, Lin, and Chu unit-root test. The results reported in table 26 confirms all variables are stationary with the exemptions of R&D and TA. However, when the trend term was included in the Im–Pesaran–Shin tests, both of these became stationary and subsequently for the final estimations both R&D and TA were de-trended.

Table 26. Panel Unit root results

Variables	**Levin, Lin, and Chu (LLC)**	
	Without trend	**with trend**
GHG	-9.4113*** (0.0000)	-15.3806 *** (0.0000)
REP	-8.5232*** (0.0001)	-41.3959 *** (0.0000)
R&D	-5.5740 0.4802	-17.7856 *** (0.0000)
TA	-1.8579 0.9259	-9.5914 *** (0.0000)

Note: ** represents 1% level of significance.

Subsequently, the impact of REP, R&D and control variables on accounting-based metrics is analysed.

Based on the results of the Hausman specification test in terms of choosing the best model between pooled, fixed and random, the latter is found to be the most appropriate. The result of random effect models is presented in the following tables.

Table 27. The impact of REP, R&D on accounting-based metrics (Static Random Effect-Robust Model)

Variables	**Model 1 (ROA) Random effects (Robust)**	**Model 2 (ROE) Random effects (Robust)**
REP	**.214*** **	**.213*** **
	3.10	3.04
R&D	-.029	-.040
	-0.36	-0.52
TA	.371 ***	.371 ***
	5.17	4.80
Dummy	-.405 ***	-.354 **
	-2.42	-2.07
_cons	.224 ***	.195 **
	2.41	2.07
Wald chi2 test	35.40	33.38
Prob	0.0000	0.0000
N of groups	27	27
Observations	243	243

Note: *** p<0.01, ** p<0.05, * p<0.1

As the results illustrated in table 27, REP and the rest of dependent variables still behaved similarly to the results of the original models in table 13. Importantly, the positive relationship between REP and all accounting base metrics could still be noticed. And the value of R&D's coefficient remain very week, negative and insignificant in both models. In contrast, TA, the control variable, has by far the largest impact on accounting base metrics in both models. These results is in line with (Dopierała et al., 2022) who used both, random and fixed effects models with panel dataset of 328 energy producers and found REP impacts positively ROA and ROE since the signing of the Paris Agreement. However, this results contradicts with (Ruggiero & Lehkonen, 2017) who utilized random and fixed effects models and found that the volume on renewable energy impacts negatively ROA and ROE on a sample of electric utilities switching to renewable power production.

Next, I analyse the impact of REP, R&D and control variable on market-based metrics. As can be seen from table 28, the result of Random effects model indicated that the coefficient and sing of the REP remained positive but insignificant in consist with the original results in table 15. This result is partially in line with (Ruggiero & Lehkonen, 2017) who used random and fixed effects and found a negative and significant relationship between REP and Tobin's Q. Also this result also contradicts partially with the findings reported by (Ruggiero & Lehkonen, 2017) who used random effect model and found negative and significant relationship between renewable energy volume and Tobin's Q in the short and long term. R&D does not have an impact on the market base metrics and these results come similar to the original estimation. In the meantime, TA has again the most profound positive impact on market price. Finally, all the coefficients of the dummies remain considerably high and negative.

Table 28. The impact of REP, R&D on market-based metrics (Static Random Effect-Robust Model).

Variables	**Model 1 (**Tobin's Q**)** Random effects (Robust)	**Model 2 (**Market price**)** Random effects (Robust)
REP	**.073**	**.103**
	0.98	1.12
R&D	.062	.054
	0.88	0.74
TA	.068	.385***
	0.71	4.32
Dummy	-.979***	-.760***
	-6.27	-4.01
_cons	.808**	.583***
	2.61	3.08
Wald chi2 test	41.16	38.94
Prob	0.0000	0.00000
N of groups	27	27
Observations	243	243

Note: *** p<0.01, ** p<0.05, * p<0.1

Overall, the results of robustness check using a random effects model substantiates the earlier findings of QML method via the fixed effects test in tables 13 and 15.

6.3 Robustness check for replacing the dependent and control variables.

To ensure the reliability of previous findings, I further performed several robustness tests substituting key dependent and control variables. More specifically, for the models in the first empirical chapter which examines the impact of REP, R&D and TA on environmental performance, I conduct the following change (i) GHG emission, the dependent Variable, is replaced with scope 1 emissions. The latter is a direct GHG emissions that are directly attributed to a company's operations such as flaring, fugitive, leakage and the combustion needed for drilling. As mentioned earlier, scope 1 GHG emissions accounts for more than 90% in the said sample. thus, providing a focused and critical measure of environmental performance. (ii) TA, the control variable, was replaced with two alternative proxies of firm size and operational scale, that is, the number of employees and daily barrels of oil and gas production. These alternatives address potential concerns regarding the sole reliance on asset-based measures and provide different perspectives on company scale. For the models in the second empirical chapter, which assess the impact of REP, R&D, and TA on financial performance, the following changes are conducted (i) ROCE is included as an alternative accounting-based metric, and market capitalization served as an alternative market-based metric. (ii) TA, the control Variable, is replaced again with both, the number of employees and oil and gas production in all models to consistently test the robustness of the control for firm size and activity. As it can be seen from table 29 to 35, the regression results of all models consistently mirrored those of our original models, regardless of the minor with regard to the coefficient of REP and R&D in terms of the signs, statistical significance and magnitude. Also, the results of the replaced control variable varied only slightly. This high degree of consistency across alternative specifications affirms the reliability and robustness of the primary regression results.

To conclude, this chapter validated the main findings by utilizing subsamples of EU and non-EU companies, alternative econometric specifications, and different measurement proxies. As shown across all tables in this chapter, the regression results consistently confirm the baseline estimates, demonstrating the reliability of the original analysis.

Table 29. The linear impact of REP, R&D and control variable on GHG emissions.

Scope 1 emissions (dependent variable)			Employees (independent variable)			Oil and gas production (independent variable)		
Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)
Scope 1	**.481***	**.481**	**GHG-1**	**.575***	**.575***	**GHG-1**	.511***	.511***
	(3.47)	(2.15)		(6.98)	(3.06)		(21.71)	(5.29)
REP	**-.671***	**-.671**	**REP**	**-.381***	**-.381***	**REP**	**-.268***	**-.268**
	(-3.96)	(-2.45)		(-9.18)	(-2.96)		(-7.94)	-2.70)
R&D	**-.534**	**-.534***	**R&D**	**-.191***	**-.191**	**R&D**	**-.002**	**-.002**
	(-2.61)	(-1.69)		(-4.02)	(-1.28)		(-0.04)	(-2.43)
TA	**.655***	**.655**	**Employees**	**.259***	**.259**	**Oil and gas production**	**.264***	**.264**
	(3.47)	(2.51)		(5.28)	(2.43)		(6.21)	(2.69)
Constant	-.053	-.053	Constant	.028***	.028**	Constant	-.041**	-.041
	(-1.08)	-0.62		1.24	0.46		-2.47	-0.89
Sargan test	0.262	0.262	Sargan test	0.221	0.221	Sargan test	0.385	0.86
Hansen test	0.447	0.36	Hansen test	0.149	0.149	Hansen test	0.344	0.36
AR (1)	0.004	0.019	AR (1)	0.005	0.018	AR (1)	0.004	0.11
AR (2)	0.492	0.529	AR (2)	0.510	0.579	AR (2)	0.518	0.30
Number of groups	27	27	Number of groups	27	27	Number of groups	27	27
Number of instruments	18	18	Number of instruments	23	23	Number of instruments	24	24
Observations	189	189	Observations	189	189	Observations	189	189

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 30. The linear Moderating role of R&D in the relationship between REP and GHG emissions.

Scope 1 emissions (dependent variable)			Employees (independent variable)			Oil and gas production (independent variable)		
Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)
Scope 1	**.513***	**.513***	GHG-1	.504 ***	.504***	GHG-1	.511***	.525***
	(9.63)	**(5.06)**		(20.67)	(4.51)		(21.71)	(6.01)
REP	-.545***	-.545***	REP	-.347 ***	-.347***	REP	-.268***	-.178**
	(-7.03)	(-3.32)		(-12.80)	(-2.96)		(-7.94)	(-0.96)
R&D	.032**	.032	R&D	.084 ***	.084	R&D	-.002	.037
	(0.54)	(0.23)		(2.41)	(0.54)		(-0.04)	(0.33)
REP×R&D	-.064	-.064	REP×R&D	-.059	-.059	REP×R&D	-.096***	-.096*
	(-2.63)	(-0.91)		(-2.27)	(-0.78)			(-1.93)
TA	.275***	.275*	**Employees**	.019	.019	**Oil and gas production**	.264***	.579**
	(3.03)	(1.68)		(0.28)	(0.07)		(6.21)	(2.39)
Constant	-.006	-.006	Constant	-.003***	-.003**	Constant	-.041**	-.072
	(-0.29)	-0.13		-0.30	0.46		-2.47	-1.73
Sargan test	0.244	0.244	Sargan test	0.176	0.176	Sargan test	0.385	0.469
Hansen test	0.418	0.418	Hansen test	0.189	0.189	Hansen test	0.344	0.715
AR (1)	0.003	0.006	AR (1)	0.004	0.009	AR (1)	0.004	0.006
AR (2)	0.442	0.465	AR (2)	0.790	0.814	AR (2)	0.518	0.60427
Number of groups	27	27	Number of groups	27	27	Number of groups	27	24
Number of instruments	24	24	Number of instruments	24	24	Number of instruments	24	189
Observations	216	216	Observations	216	216	Observations	189	

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 31. The nonlinear impact of REP and R&D on GHG Emissions

Scope 1 emissions (dependent variable)			Employees (independent variable)			Oil and gas production (independent variable)		
Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)
Scope 1	.496***	.496***	GHG-1	.554 ***	.554***	GHG-1	.549***	.559***
	(8.50)	**(4.30)**		(3.96)	(3.55)		(3.74)	(3.39)
REP	.446***	.446**	**REP**	.538**	.538*	**REP**	.631***	.631**
	(4.13)	(2.51)		(2.72)	(2.06)		(3.95)	(2.72)
REP^2	-.541	-.541***	REP^2	-.624***	-.624**	REP^2	-.674***	-.674 ***
	(-6.31)	(-3.73)		(-2.97)	(-2.55)		(-3.69)	(-2.91)
R&D	.300	.300	R&D	.193	.193	R&D	.190	.190
	(3.48)	1.74		(1.41)	(0.80)		(1.35)	(0.77)
$R\&D^2$	-.354***	-.354	$R\&D^2$	-.324**	-.324**	$R\&D^2$	-.266*	-.266
	(-5.90)	(-2.68)		(-2.68)	(-2.44)		(-1.85)	(-1.57)
TA	.198	.198	**Employees**	.145**	.145**	**Oil and gas production**	.169 **	1.11
	(-2.41)	(1.61)		(.070)	(1.37)		(1.75)	(.070)
Constant	.473***	.473	Constant	.489***	.489	Constant	.434 ***	.434
	(8.81)	(4.23)		(3.91)	(2.82)		(3.62)	(2.36)
Sargan test	0.727	0.727	Sargan test	0.784	0.784	Sargan test	0.695	0.695
Hansen test	0.877	0.877	Hansen test	0.802	0.802	Hansen test	0.725	.725
AR (1)	0.002	0.005	AR (1)	0.006	0.007	AR (1)	0.003	0.004
AR (2)	0.274	0.373	AR (2)	0.739	0.763	AR (2)	0.828	0.844
Number of groups	27	27	Number of groups	27	27	Number of groups	27	27
Number of instruments	25	25	Number of instruments	18	18	Number of instruments	18	18
Observations	162	162	Observations	162	162	Observations	162	162

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 32. Long-run effect of REP and R&D on GHG emissions:

Scope 1 emissions (dependent variable)		Employees (independent variable)	Oil and gas production (independent variable)
Variables	Two-step system-GMM (Robust)	Two-step system-GMM (Robust)	Two-step system-GMM (Robust)
REP	-1.29**	-.898***	-.550***
	-2.01	-2.72	-2.71
R&D	-1.02	-.451	-.004
	-1.44	-0.91	-0.02

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 33. The moderating role of R&D in the nonlinear relationship between REP and GHG Emissions.

Scope 1 emissions (dependent variable)			**Employees (independent variable)**			**Oil and gas production (independent variable)**		
Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)	Variables	Two-step system-GMM	Two-step system-GMM (Robust)
Scope 1	.537***	.537**	**GHG-1**	.691***	.691**	**GHG-1**	.722***	.722***
	(5.16)	**(2.69)**		(7.13)	(2.65)		(7.76)	(4.34)
REP	.106***	.106	**REP**	.216**	**.216**	**REP**	.173	.173
	(1.21)	(0.53)		(2.27)	(1.36)		(1.53)	(0.51)
REP^2	-.547	-.547	**REP^2**	-.729***	-.729***	REP^2	-.533***	-.533
	(-3.86)	(-1.59)		(-2.97)	(-3.80)		(-3.01)	(-0.89)
REP×R&D	-.045	-.045	**REP×R&D**	.574**	**.574**	REP×R&D	.401*	.401
	(-0.15)	(-0.07)		(2.67)	(1.57)		(1.79)	(0.78)
REP^2×R&D	-.034	-.034	**REP^2×R&D**	-.402**	**-.402**	REP^2×R&D	-.279	-.279
	(-0.13)	(-0.06)		(-2.61)	(-1.54)		(-1.41)	(-0.52)
R&D	.341	.341	R&D	.514**	.514	R&D	.158	.158
	(1.2)	(0.61)		(2.12)	(1.51)		(0.50)	(.17)
TA	.077	.077	**Employees**	**.087**	**.087**	**Oil and gas production**	.137*	**.137**
	0.98	(0.44)		1.66	(1.16)		0.50	0.64
Constant	.425***	.425*	Constant	.517***	.517**	Constant	.360*	.360
	(4.56)	(1.76)		(4.80)	(2.62)		(2.51)	(0.76)
Sargan test	0.523	0.523	Sargan test	0.824	0.824	Sargan test	0.873	0.873
Hansen test	0.354	0.354	Hansen test	0.507	0.507	Hansen test	0.210	0.210
AR (1)	0.014	0.042	AR (1)	0.015	0.057	AR (1)	0.005	0.010
AR (2)	0.982	0.986	AR (2)	0.452	0.531	AR (2)	0.269	0.321
Number of groups	27	27	Number of groups	27	27	Number of groups	27	27
Number of instruments	20	20	Number of instruments	20	20	Number of instruments	20	18
Observations	216	216	Observations	216	216	Observations	216	162

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 34. The impact of REP, R&D and control variables on accounting-based metrics (QML Model).

	ROCE (dependent variable)			Employees (independent variable)						Oil and gas production (independent variable)				
Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Random effect (Robust)	QML Random effect (Robust)
$\boldsymbol{ROCE}_{\boldsymbol{it-1}}$	.169***	.073	ROA	.201***	.035	ROE	.179***	.079	ROA	.272***	-.207**	ROE	.255**	-.182
	2.87	1.36		(3.72)	(0.50)		(3.22)	(1.33)		(4.03)	(-1.11)		(2.66)	(-0.15)
REP	.212***	.189***	REP	.276***	.254***	REP	.274***	.266***	REP	.260***	.264**	REP	.253***	.289**
	2.81	2.73		(3.52)	(3.13)		(3.38)	(3.02)		(3.40)	(2.15)		(2.87)	(3.23)
R&D	-.066	-.057	R&D	.059***	.029	R&D	.049***	.023***	R&D	.031***	.040	R&D	.025	.032
	-1.02	-0.85		(0.80)	(0.36)		(0.66)	(0.30)		(0.40)	(0.44)		(0.32)	(0.28)
TA	.415***	.383***	**employees**	-.033	.041***	**employees**	-.038	.004	**Oil and gas production**	.053	.107	**Oil and gas production**	.035	.070
	4.76	5.81		(-0.44)	(0.53)		(-0.50)	(-0.50)		(-0.58)	(1.11)		(0.45)	(0.72)
Dummy	-.513***	-.411***	Dummy	-.276	-.224	Dummy	-.201	-.155	Dummy	-.290	-.130	Dummy	-.217	-.090
	-3.47	-2.73		(-2.16)	(-1.61)		(-1.60)	(-1.16)		(-2.44)	(-0.60)		(-1.38)	(-0.20)
Constant	.324***	.262***	Constant	.217	.183	Constant	.166	.134	Constant	.228	.104	Constant	.180	.075
	3.94	3.14		(2.93)	(2.39)		(2.30)	(1.85)		(3.14)	(1.06)		(1.90)	(0.31)
Number of groups	27	27	Number of groups	27	27	Number of groups	27	27	Number of groups	27	27	Number of groups	27	27
Observations	216	243	Observations	216	243	Observations	216	243	Observations	216	243	Observations	216	243
Husman test	19.23			17.18			5.55			5.43			239.56	
P value	0.000			0.0042			0.3526			0.3656			0.0000	

Table 35. The impact of REP, R&D and control variables on Market-based metrics (QML Model).

	ROCE (dependent variable)			Employees (independent variable)						Oil and gas production (independent variable)				
Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Fixed effect (Robust)	QML Random effect (Robust)	Variables	QML Random effect (Robust)	QML Random effect (Robust)
$\boldsymbol{marketcap}_{\boldsymbol{it-1}}$	**.428 *****	**.274**	Tobin's Q	.379***	.492	Market price	.378***	.387	Tobin's Q	.356***	.369**	Market price	.376**	.337***
	5.94	5.31		(6.34)	(3.05)		(7.02)	(4.20)		(6.13)	(2.25)		(6.12)	(5.71)
REP	.047	.052	REP	.092	.110	REP	.169*	.164***	REP	.092	.104	REP	.178*	.172*
	0.59	0.68		(1.24)	(1.47)		(1.84)	(1.80)		(1.22)	(1.3)		(1.07)	(1.81)
R&D	.016	.042	R&D	.076	.057	R&D	.089	.084	R&D	.093	.077	R&D	.084	.080
	0.22	0.73		(1.24)	(0.91)		(1.27)	(1.18)		(1.35)	(1.12)		(0.32)	(1.03)
TA	.436 ***	.367 ***	**employees**	.034	.022	**employees**	.052***	.043	**Oil and gas production**	-.019	-.020	**Oil and gas production**	.073	.081
	5.76	5.12		(0.55)	(0.38)		(0.71)	(0.56)		(-0.27)	(-0.27)		(0.84)	(0.94)
Dummy	-.840 ***	-.795***	Dummy	-.860***	-.796	Dummy	-.568***	-.558***	Dummy	-.868***	-.868***	Dummy	-.556***	-.559***
	-7.56	-6.26		(-7.06)	(-5.25)		(-3.69)	(-3.59)		(-7.35)	(-6.24)		(-3.64)	(-3.56)
Constant	.549 ***	.522***	Constant	.693***	.625	Constant	.526	.514***	Constant	.705***	.673***	Constant	.512***	.517***
	8.82	7.89		(3.41)	(3.10)		(4.32)	(4.69)		(3.47)	(3.36)		(4.16)	(4.17)
Number of groups	27	27	Number of groups	27	27	Number of groups	27	27	Number of groups	27	27	Number of groups	27	27
Observations	216	243	Observations	216	243	Observations	216	243	Observations	216	243	Observations	216	243
Husman test	11.69			41.21			2.63			4.66			1.81	
P value	0.0392			0.0000			0.7567			0.4594			0.8752	

Note: *** p<0.01, ** p<0.05, * p<0.1

7. Conclusion

The escalating levels of GHG emissions primarily driven by oil and gas extraction and production of international petroleum companies poses one of the most serious threats to the environment globally. The landmark PA signed in 2015 had established a critical global imperative of net zero emission by 2050. This mandate necessitates a profound shift from fossil fuels to renewable energy, which is well known as the energy transition. IPCs are uniquely positioned to play a pivotal role in this transition, given their historical and ongoing status as the backbone of the global energy sector. The rapid advancement and growth of renewable energy provides international petroleum companies a cross cutting solution to mitigate GHG emissions and contribute significantly towards achieving the ambitious of net zero emission goal by the mid of this century. Indeed, with only 25 years remaining to meet this global target, the composition of fossil fuel is still dominate electricity generation needed for the expansion of human activities. This raises the importance of renewable energy which has a great potential in reshaping the energy sector, thereby addressing the critical challenges posed by climate change. Moreover, the deployment of renewable energy at a micro level has a positive impact on GHG emission reduction and financial performance as the results of clean operation process (Porter & Linde, 1995). However, comprehensive studies specifically measuring the impact of REP on environmental and financial performance within petroleum industry, remain conspicuously overlooked in the previous literature. Therefore, in this thesis, it has been argued that REP by IPCs can enhance both their environmental and financial performance, aligning with PH and NRBV. In doing so, it has been utilized second econometric generation to measure the linear and nonlinear relationship from the side of REP on environmental and financial performance in a panel of 27 selected IPCs covering the period from 2015 to 2023. The general results of this thesis support both PH and NRBV. i.e., the increase in REP impacts positively GHG reduction, and in return enhance the financial performance. More specifically, the empirical results reveal that REP positively affects GHG emissions reduction in the short and long run, and this effect has an inverted U-shaped trend. As for financial performance, results revealed that the impact of REP exerts a significantly positive impact on financial performance measured by accounting-based (ROA and ROE), however, findings revealed that the impact of REP on market-based proxied by Tobin's Q and market price is neutral. As for R&D, results demonstrate the dual function of R&D; it serves as a direct mechanism for short-term GHG emission reductions and simultaneously enhances the capacity of REP on GHG emission reductions. Finally, to address potential heterogeneity, I segmented IPCs into two groups of EU and non-EU, the result underscores the significance of regional characteristics in the relationship between REP and GHG emissions and between REP and accounting base metrics. Specifically, the effect of REP on GHG emissions and accounting base metrics is found to be more pronounced in EU IPCs relatively to non-EU IPCs. Based on the above, adopting net zero emission goal and increasing the investment in renewables in the chosen sample, result in enhancing the environmental and financial performance.

7.1 Policy implication and Limitations.

The results of this thesis have an important implication for policymakers in petroleum companies and governments. For the formers, thesis findings demonstrated that increasing REP, as a tool to meet the net zero emissions, represents a strategic approach that contribute to lower GHG emissions and, at the same time, to enhance financial performance. Therefore, reallocating the resources optimally in petroleum companies by increasing the investment in renewables and decrease fossil fuel investments will result in the improvement of both, environmental and financial performance. Importantly, the ability of petroleum companies in reducing GHG emission depends remarkably on the scale of REP. In other words, the impact of REP in reducing GHG emissions is not immediate; in the initial stage, the impact of REP on GHG emissions reduction may be negligible. But above a critical threshold, REP will affect positively GHG emission. As for R&D, it is also a vital variable not only in decreasing GHG emissions directly but also in enhancing the impact of REP on GHG emissions reduction. Therefore, we recommend the policymakers at IPCs to dedicate and increase the budget of R&D in two area. Namely: (i) Next-generation renewable like green hydrogen and (ii) low carbon technologies such as CCUS and the direct air capture to curtail GHG emissions from the operational process of petroleum industry. This dual R&D strategy will result in simultaneous increase of REP and the reduction of GHG emissions.

For the policymaking, facilitating the investment in renewable projects by offering financial incentives, green grants, or low-interest loans is crucial so as to encourage petroleum companies to transition toward energy companies with net zero emission by 2050. Also, policy- makers should strengthen the regulations and impose higher environmental standards on petroleum industry such as cap and trade systems and carbon taxes. For academics, this thesis offers a comprehensive exploration of the energy transition and the pursuit of net-zero emissions in the petroleum industry. In the future researchers might study the impacts of each type of REP source, such as solar, wind and biogas, on GHG emissions and financial metrics. In addition, including other important variables, such as oil price and governance in the model is recommended. Last, our sample consists only of large petroleum companies, future research should cover small and medium petroleum companies, thus enabling us to compare the impact of REP of petroleum companies of different sizes. This thesis also suggests that the implementation of GHG emissions reduction by adopting net zero emission and increasing renewables could be applied in other polluting sectors such as coal and agriculture.

The primary limitation of this thesis is the paucity of numeric data, particularly regarding the REP variable. This scarcity stems from two main factors. First, the majority of IPCs only began significant renewable investments following the 2015 net-zero declarations. Second, inconsistencies in corporate reporting persist; for instance, while major entities such as Chevron and ExxonMobil have adopted net-zero goals and active renewable portfolios, they do not disclose specific REP data in GWh.

Consequently, the final sample is restricted to 27 large-scale upstream IPCs. A second limitation is that sample focuses exclusive on IPCs. While these companies are early adopters of net-zero strategies, their high capital intensity means the findings may not be directly applicable to national oil companies or smaller enterprises. Furthermore, the post-2015 observation period reflects a specific regulatory climate following the PA, which may differ from prior or future market conditions. A third limitation pertains to potential endogeneity resulting from self-selection bias. While the petroleum industry is undergoing a strategic pivot toward a greener energy mix, the continued global dominance of hydrocarbons ensures that traditional companies remain active participants. However, the decision to diversify into renewables is non-random; companies transitioning earlier may possess superior baseline financial resources or organizational capabilities. Consequently, the observed performance outcomes may be partially attributed to these pre-existing characteristics rather than the transition itself. In light of the foregoing, caution should be exercised when extrapolating these results to national oil companies or other carbon-intensive industries. Recognizing these sectoral differences is essential to avoid misguiding policymakers regarding the broader implications of this research. Future studies could refine these findings by employing a Heckman two-step procedure. By incorporating an Inverse Mills Ratio derived from a selection equation, researchers can formally decouple the impact of business model innovation from latent company-specific traits, providing a more robust estimate of the causal link between green diversification and financial performance.

References:

Aalto, P., Haukkala, T., Kilpeläinen, S., & Kojo, M. (2021). Introduction: Electrification and the energy transition. *Electrification: Accelerating the Energy Transition*, 3–24. https://doi.org/10.1016/B978-0-12-822143-3.00006-8

Abraham-Dukuma, M. C. (2021). Dirty to clean energy: Exploring 'oil and gas majors transitioning''.' *Extractive Industries and Society*, *8*(3), 100936. https://doi.org/10.1016/j.exis.2021.100936

Abraham-Dukuma, M. C., Dioha, M. O., Aholu, O. C., Emodi, N. V., Ogbumgbada, C., & Isah, A. (2021). A marriage of convenience or necessity? Research and policy implications for electrifying upstream petroleum production systems with renewables. *Energy Research and Social Science*, *80*(April), 102226. https://doi.org/10.1016/j.erss.2021.102226

Abudu, H., Cai, X., & Lin, B. (2022). How upstream petroleum industry affects economic growth and development in petroleum producing-countries: Evidence from Ghana. *Energy*, *260*(May 2021), 125139. https://doi.org/10.1016/j.energy.2022.125139

Ahmad, M., & Zheng, J. (2021). Do innovation in environmental-related technologies cyclically and asymmetrically affect environmental sustainability in BRICS nations? *Technology in Society*, *67*(September), 101746. https://doi.org/10.1016/j.techsoc.2021.101746

Ajide, F. M., Dada, J. T., & Oladipupo, S. A. (2025). Mobile Money Adoption and Democratic Institutions: The Implications for Shadow Economy in Africa. *International Journal of Public Administration*, *00*(00), 1–15. https://doi.org/10.1080/01900692.2025.2525147

Akram, R., Chen, F., Khalid, F., Ye, Z., & Majeed, M. T. (2020). Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries. *Journal of Cleaner Production*, *247*, 119122. https://doi.org/10.1016/j.jclepro.2019.119122

Al-Ghussain, L. (2019). Global warming: review on driving forces and mitigation. *Environmental Progress and Sustainable Energy*, *38*(1), 13–21. https://doi.org/10.1002/ep.13041

Alam, M. S., Atif, M., Chien-Chi, C., & Soytaş, U. (2019). Does corporate R&D investment affect firm environmental performance? Evidence from G-6 countries. *Energy Economics*, *78*, 401–411. https://doi.org/10.1016/j.eneco.2018.11.031

Alfalih, A. A. (2025). Assessing the impact of green technological innovation and human capabilities on renewable energy supply: Evidence from the top-greenest countries. *Sustainable Energy Technologies and Assessments*, *73*(December 2023). https://doi.org/10.1016/j.seta.2024.104152

Alharthi, M., Dogan, E., & Taskin, D. (2021). Analysis of CO_2 emissions and energy consumption by sources in MENA countries: evidence from quantile regressions. *Environmental Science and Pollution Research*, *28*(29), 38901–38908. https://doi.org/10.1007/s11356-021-13356-0

Ali, N. Bin, & Usman, M. (2018). Reliability of search in systematic reviews: Towards a quality assessment framework for the automated-search strategy. *Information and Software Technology*, *99*(May 2017), 133–147. https://doi.org/10.1016/j.infsof.2018.02.002

Ambec, S., & Lanoie, P. (2008). Does it pay to be green? A systematic overview. *Academy of Management Perspectives*, *22*(4), 45–62. https://doi.org/10.5465/amp.2008.35590353

Anwar, A., Siddique, M., Eyup Dogan, & Sharif, A. (2021). The moderating role of renewable and non-renewable energy in environment-income nexus for ASEAN countries: Evidence from Method of Moments Quantile Regression. *Renewable Energy*, *164*, 956–967. https://doi.org/10.1016/j.renene.2020.09.128

Aragón-Correa, J. A., & A. Rubio-López, E. (2007). Proactive Corporate Environmental Strategies: Myths and Misunderstandings. *Long Range Planning*, *40*(3), 357–381. https://doi.org/10.1016/j.lrp.2007.02.008

Arellano, M., & Bond, S. (1991). Some Test of Spesification for Data Panel: Monte Carlo Evidence and an Aplication of Employment Equations. *Source: The Review of Economic Studies*, *58*(2), 277–297. doi:10.2307/2297968

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, *68*(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-D

Armeanu, D. S., Joldes, C. C., Gherghina, S. C., & Andrei, J. V. (2021). Understanding the multidimensional linkages among renewable energy, pollution, economic growth and urbanization in contemporary economies: Quantitative assessments across different income countries' groups. *Renewable and Sustainable Energy Reviews*, *142*(February). https://doi.org/10.1016/j.rser.2021.110818

Azam, M., Khan, A. Q., Bakhtyar, B., & Emirullah, C. (2015). The causal relationship between energy consumption and economic growth in the ASEAN-5 countries. *Renewable and Sustainable Energy Reviews*, *47*, 732–745. https://doi.org/10.1016/j.rser.2015.03.023

Bai, C., Feng, C., Yan, H., Yi, X., Chen, Z., & Wei, W. (2020). Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions? *Journal of Environmental Management*, *264*(December 2019), 110482. https://doi.org/10.1016/j.jenvman.2020.110482

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO_2 emissions? *Energy Policy*, *113*(November 2017), 356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Baltagi, B. H. (2021). Econometric Analysis of Panel Data (Springer Texts in Business and Economics) - Sixth Edition. In *Springer*.

Barney, J. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management*, *17*(1), 99–120. https://doi.org/10.1177/014920639101700108

Baskaya, M. M., Samour, A., & Tursoy, T. (2022). the Financial Inclusion, Renewable Energy and CO_2 Emissions Nexus in the Brics Nations: New Evidence Based on the Method of Moments Quantile Regression. *Applied Ecology and Environmental Research*, *20*(3), 2577–2595. https://doi.org/10.15666/aeer/2003_25772595

Berchicci, L., & King, A. (2007). Postcards from the edge. *Artnews*, *116*(2), 74–79.

Berger-Schmitz, Z., George, D., Hindal, C., Perkins, R., & Travaille, M. (2023). What explains firms' net zero adoption, strategy and response? *Business Strategy and the Environment*, *32*(8), 5583–5601. https://doi.org/10.1002/bse.3437

Biksey, T., & Cowan-Ellsberry, C. (2002). The dirty dozen. *Water Environment and Technology*, *14*(11), 30–33.

Boon, M. (2019). A climate of change? The oil industry and decarbonization in historical perspective. *Business History Review*, *93*(1), 101–125. https://doi.org/10.1017/S0007680519000321

Breausch T. S, & Pagan A.R. (1979). A Simple Test for Heteroscedasticity and Random Coeficient Variation. *Econometrica*, *Vol. 47*(1), 1287–1294.

Calculli, C., D'Uggento, A. M., Labarile, A., & Ribecco, N. (2021). Evaluating people's awareness about climate changes and environmental issues: A case study. *Journal of Cleaner Production*, *324*(September). https://doi.org/10.1016/j.jclepro.2021.129244

Canal Vieira, L., Longo, M., & Mura, M. (2022). Will the regime ever break? Assessing socio-political and economic pressures to climate action and European oil majors' response (2005-2019). *Climate Policy*, *22*(4), 488–501. https://doi.org/10.1080/14693062.2022.2044283

Chen, F., Wang, L., Gu, Q., Wang, M., & Ding, X. (2022). Nexus between natural resources, financial development, green innovation and environmental sustainability in China: Fresh insight from novel quantile ARDL. *Resources Policy*, *79*(August), 102955. https://doi.org/10.1016/j.resourpol.2022.102955

Cheng, C., Ren, X., Dong, K., Dong, X., & Wang, Z. (2021). How does technological innovation mitigate CO_2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *Journal of Environmental Management*, *280*(June 2020), 111818. https://doi.org/10.1016/j.jenvman.2020.111818

Cheng, C., Ren, X., & Wang, Z. (2019). The impact of renewable energy and innovation on carbon emission: An empirical analysis for OECD countries. *Energy Procedia*, *158*, 3506–3512. https://doi.org/10.1016/j.egypro.2019.01.919

Cheng, C., Ren, X., Wang, Z., & Cheng, Y. (2019). Heterogeneous impacts of renewable energy and environmental patents on CO 2 emission - Evidence from the BRIICS. *Science of the Total Environment*, *668*, 1328–1338. https://doi.org/10.1016/j.scitotenv.2019.02.063

Christiansen, K. L., Hajdu, F., Planting Mollaoglu, E., Andrews, A., Carton, W., & Fischer, K. (2023). "Our burgers eat carbon": Investigating the discourses of corporate net-zero commitments. *Environmental Science and Policy*, *142*(January), 79–88. https://doi.org/10.1016/j.envsci.2023.01.015

Clarkson, P. M., Li, Y., Richardson, G. D., & Vasvari, F. P. (2011). Does it really pay to be green? Determinants and consequences of proactive environmental strategies. *Journal of Accounting and Public Policy*, *30*(2), 122–144. https://doi.org/10.1016/j.jaccpubpol.2010.09.013

Climate Disclosure Project. (2017). CDP Carbon Majors Report 2017. *The Carbon Majors Database*, *July*, 1–15.

https://cdn.cdp.net/cdp-production/cms/reports/documents/000/002/327/original/Carbon-Majors-Report-2017.pdf

Dai, J., Cantor, D. E., & Montabon, F. L. (2017). Examining corporate environmental proactivity and operational performance: A strategy-structure-capabilities-performance perspective within a green context. *International Journal of Production Economics*, *193*(July), 272–280. https://doi.org/10.1016/j.ijpe.2017.07.023

Danish, & Ulucak, R. (2021). Renewable energy, technological innovation and the environment: A novel dynamic auto-regressive distributive lag simulation. *Renewable and Sustainable Energy Reviews*, *150*(January), 111433. https://doi.org/10.1016/j.rser.2021.111433

Dauda, L., Long, X., Mensah, C. N., Salman, M., Boamah, K. B., Ampon-Wireko, S., & Kofi Dogbe, C. S. (2021). Innovation, trade openness and CO_2 emissions in selected countries in Africa. *Journal of Cleaner Production*, *281*. https://doi.org/10.1016/j.jclepro.2020.125143

de Freitas Netto, S. V., Sobral, M. F. F., Ribeiro, A. R. B., & Soares, G. R. da L. (2020). Concepts and forms of greenwashing: a systematic review. *Environmental Sciences Europe*, *32*(1). https://doi.org/10.1186/s12302-020-0300-3

Delmas, Nairn-Birch, M. A., & S, N. (2011). UCLA Recent Work Title IS THE TAIL WAGGING THE DOG? AN EMPIRICAL ANALYSIS OF CORPORATE CARBON FOOTPRINTS AND FINANCIAL PERFORMANCE Permalink Publication Date. *Working Paper No. 6. UCLA Institute of the Environment and Sustainability*. https://escholarship.org/uc/item/3k89n5b7

Deng, W., Meng, T., Kharuddin, S., Ashhari, Z. M., & Zhou, J. (2024). The impact of renewable energy consumption, green technology innovation, and FDI on carbon emission intensity: Evidence from developed and developing countries. *Journal of Cleaner Production*, *483*(August), 1–10. https://doi.org/10.1016/j.jclepro.2024.144310

Dincer, I. (2000). Renewable energy and sustainable development: A crucial review. *Renewable & Sustainable Energy Reviews*, *4*(2), 157–175. https://doi.org/10.1016/S1364-0321(99)00011-8

Dkhili, H., & Dhiab, L. Ben. (2020). The impact of renewable energy consumption on carbon dioxide emissions and economic growth in the Kingdom of Saudi Arabia. *International Journal of Advanced and Applied Sciences*, *7*(12), 127–132. https://doi.org/10.21833/ijaas.2020.12.014

Dong, F., Li, Y., Gao, Y., Zhu, J., Qin, C., & Zhang, X. (2022). Energy transition and carbon neutrality: Exploring the non-linear impact of renewable energy development on carbon emission efficiency in developed countries. *Resources, Conservation and Recycling*, *177*(June 2021), 106002. https://doi.org/10.1016/j.resconrec.2021.106002

Dong, K., Sun, R., & Hochman, G. (2017). Do natural gas and renewable energy consumption lead to less CO_2 emission? Empirical evidence from a panel of BRICS countries. *Energy*, *141*(2017), 1466–1478. https://doi.org/10.1016/j.energy.2017.11.092

Dopierała, Ł., Mosionek-Schweda, M., Laskowicz, T., & Ilczuk, D. (2022). Financial performance of renewable energy producers: A panel data analysis from the Baltic Sea Region. *Energy Reports*, *8*, 11492–11503. https://doi.org/10.1016/j.egyr.2022.09.009

Dorigoni, S., & Anzalone, G. A. (2024). *Production of energy from renewable sources and financial performance of European utilities : A panel-data analysis*. *194*(June).

Du, L., Jiang, H., Adebayo, T. S., Awosusi, A. A., & Razzaq, A. (2022). Asymmetric effects of high-tech industry and renewable energy on consumption-based carbon emissions in MINT countries. *Renewable Energy*, *196*(December 2021), 1269–1280. https://doi.org/10.1016/j.renene.2022.07.028

Duch-Brown, N., & Costa-Campi, M. T. (2015). The diffusion of patented oil and gas technology with environmental uses: A forward patent citation analysis. *Energy Policy*, *83*, 267–276. https://doi.org/10.1016/j.enpol.2015.03.001

Elheddad, M., Benjasak, C., Deljavan, R., Alharthi, M., & Almabrok, J. M. (2021). The effect of the Fourth Industrial Revolution on the environment: The relationship between electronic finance and pollution in OECD countries. *Technological Forecasting and Social Change*, *163*(December 2020), 120485. https://doi.org/10.1016/j.techfore.2020.120485

Elsayed, K., & Paton, D. (2005). The impact of environmental performance on firm performance: Static and dynamic panel data evidence. *Structural Change and Economic Dynamics*, *16*(3 SPEC. ISS.), 395–412. https://doi.org/10.1016/j.strueco.2004.04.004

Fang, W., Liu, Z., & Surya Putra, A. R. (2022). Role of research and development in green economic growth through renewable energy development: Empirical evidence from South Asia. *Renewable Energy*, *194*, 1142–1152. https://doi.org/10.1016/j.renene.2022.04.125

Feng, H. (2022). The Impact of Renewable Energy on Carbon Neutrality for the Sustainable Environment: Role of Green Finance and Technology Innovations. *Frontiers in Environmental Science*, *10*(July), 1–16. https://doi.org/10.3389/fenvs.2022.924857

Fethi, S., & Rahuma, A. (2020). The impact of eco-innovation on CO_2 emission reductions: Evidence from selected petroleum companies. *Structural Change and Economic Dynamics*, *53*, 108–115. https://doi.org/10.1016/j.strueco.2020.01.008

Frumhoff, P. C., Heede, R., & Oreskes, N. (2015). The climate responsibilities of industrial carbon producers. *Climatic Change*, *132*(2), 157–171. https://doi.org/10.1007/s10584-015-1472-5

Fujii, H., Iwata, K., Kaneko, S., & Managi, S. (2013). Corporate Environmental and Economic Performance of Japanese Manufacturing Firms: Empirical Study for Sustainable Development. *Business Strategy and the Environment*, *22*(3), 187–201. https://doi.org/10.1002/bse.1747

Gallego-Álvarez, I., Segura, L., & Martínez-Ferrero, J. (2015). Carbon emission reduction: The impact on the financial and operational performance of international companies. *Journal of Cleaner Production*, *103*, 149–159. https://doi.org/10.1016/j.jclepro.2014.08.047

Gallo, A. B., Simões-Moreira, J. R., Costa, H. K. M., Santos, M. M., & Moutinho dos Santos, E. (2016). Energy storage in the energy transition context: A technology review. *Renewable and Sustainable Energy Reviews*, *65*, 800–822. https://doi.org/10.1016/j.rser.2016.07.028

Gao, X., Zhang, F., & Jiang, S. (2025). Adapting to policy changes: How firms' R&D responses affect their performance. *Research Policy*, *54*(1). https://doi.org/10.1016/j.respol.2024.105143

Ge, F., & Mehmood, U. (2024). How natural resource, renewable energy, and energy productivity integrate with environmental quality under the load capacity curve in OECD nations. *Journal of Cleaner Production*, *459*(February), 142564. https://doi.org/10.1016/j.jclepro.2024.142564

Ghisetti, C., & Rennings, K. (2014). Environmental innovations and profitability: How does it pay to be green? An empirical analysis on the German innovation survey. *Journal of Cleaner Production*, *75*, 106–117. https://doi.org/10.1016/j.jclepro.2014.03.097

Gozgor, G., Ho, T., Li, J., & Mousavi, M. M. (2024). The impact of energy diversification on firm performance: The moderating role of corporate social responsibility. *International Review of Financial Analysis*, *96*(October). https://doi.org/10.1016/j.irfa.2024.103704

Graham, N. (2019). Canadian Fossil Capitalism, Corporate Strategy, and Post-Carbon Futures. *Canadian Review of Sociology*, *56*(2), 224–250. https://doi.org/10.1111/cars.12244

Gujarati, D. N., & Porter, D. C. (2009). Single-equation regression models. In *Basic Econometrics* (Fifth Edit). McGraw-HillCompanies.

Gyamfi, B. A., Agozie, D. Q., & Bekun, F. V. (2022). Can technological innovation, foreign direct investment and natural resources ease some burden for the BRICS economies within current industrial era? *Technology in Society*, *70*(June), 102037. https://doi.org/10.1016/j.techsoc.2022.102037

Hailemariam, A., Ivanovski, K., & Dzhumashev, R. (2022). Does R&D investment in renewable energy technologies reduce greenhouse gas emissions? *Applied Energy*, *327*(July), 120056. https://doi.org/10.1016/j.apenergy.2022.120056

Han, J.-J., Kim, H. J., & Yu, J. (2016). Empirical study on relationship between corporate social responsibility and financial performance in Korea. *Asian Journal of Sustainability and Social Responsibility*, *1*(1), 61–76. https://doi.org/10.1186/s41180-016-0002-3

Hansen, G. H., & Steen, M. (2015). Offshore oil and gas firms' involvement in offshore wind: Technological frames and undercurrents. *Environmental Innovation and Societal Transitions*, *17*, 1–14. https://doi.org/10.1016/j.eist.2015.05.001

Hao, Y. (2022). The relationship between renewable energy consumption, carbon emissions, output, and export in industrial and agricultural sectors: evidence from China. *Environmental Science and Pollution Research*, *29*(42), 63081–63098. https://doi.org/10.1007/s11356-022-20141-0

Hao, Y., Li, X., & Murshed, M. (2023). Role of environmental regulation and renewable energy technology innovation in carbon neutrality: A sustainable investigation from China. *Energy Strategy Reviews*, *48*(March). https://doi.org/10.1016/j.esr.2023.101114

Hart, S. L. (1995). A Natural-Resource-Based View of the Firm Published by : Academy of Management Linked references are available on JSTOR for this article : You may need to log in to JSTOR to access the linked references . A NATURAL-RESOURCE-BASED VIEW OF THE FIRM. *Academy of Management Review*, *20*(4), 986–1014.

Hart, S. L., & Ahuja, G. (1996). Orsato-2006-Competitive Environmental Strategi. *Business Strategy and the Environment*, *5*(1), 30–37.

Hausman, J. A. (1978). Specification Tests in Econometrics EC ON ME R C A VOLUME 46 NOVEMBER, 1978 NUMBER 6 SPECIFICATION TESTS IN ECONOMETRICS. *Econometrica*, *46*(6), 1251–1271. http://www.jstor.org/stable/1913827%5Cnhttp://www.jstor.org/%5Cnhttp://www.jstor.org/action/showPublisher?publisherCode=econosoc.%5Cnhttp://www.jstor.org

Herzog, H. (2017). Financing CCS Demonstration Projects: Lessons Learned from Two Decades of Experience. *Energy Procedia*, *114*(November 2016), 5691–5700. https://doi.org/10.1016/j.egypro.2017.03.1708

Holtz-Eakin D, Newey, W., & Rosen, H. S. (1988). Estimating Vector Autoregressions with Panel Data Author (s): Douglas Holtz-Eakin , Whitney Newey , Harvey S . Rosen Published by : The Econometric Society Stable URL : http://www.jstor.org/stable/1913103 . *Journal of the Econometric Society*, *56*(6), 1371–1395.

Hsiao, C., Pesaran, M. H., & Kamil Tahmiscioglu, A. (2002). Maximum likelihood estimation of fixed effects dynamic panel data models covering short time periods. *Journal of Econometrics*, *109*(1), 107–150. https://doi.org/10.1016/S0304-4076(01)00143-9

Hulshof, D., & Mulder, M. (2020). The impact of renewable energy use on firm profit. *Energy Economics*, *92*. https://doi.org/10.1016/j.eneco.2020.104957

IEA. (2016). *Medium-Term Market Report 2016 Market Analysis and Forecasts to 2021*. 278. https://www.iea.org/publications/freepublications/publication/MTRMR2016.pdf

IEA. (2020a). Renewable 2020 - Analysis and forecast to 2025. *International Energy Agency (IEA)*, *1*, 1–172. https://www.iea.org/reports/renewables-2020

IEA. (2020b). The Oil and Gas Industry in Energy Transitions. *The Oil and Gas Industry in Energy Transitions*, 165.

IEA. (2020c). The Oil and Gas Industry in Energy Transitions. *The Oil and Gas Industry in Energy Transitions*. https://doi.org/10.1787/aef89fbd-en

IEA. (2022). International Energy Agency (IEA) World Energy Outlook 2022. *IEA*, 524. https://www.iea.org/reports/world-energy-outlook-2022

IEA. (2023a). *IEA (2024), Renewables 2023, IEA, Paris*. 141. www.iea.org

IEA. (2023b). *Net Zero Roadmap 2023 Update-Executive summary A Global Pathway to Keep the 1.5 °C Goal in Reach*. www.iea.org/t&c/

IEA. (2023c). *Renewable Energy Market Update: Outlook for 2023 and 2024 - International Energy Agency*. 87. https://iea.blob.core.windows.net/assets/63c14514-6833-4cd8-ac53-f9918c2e4cd9/RenewableEnergyMarketUpdate_June2023.pdf

IEA. (2023d). *World Energy Investment 2023,https://www.iea.org/reports/world-energy-investment-2023*.

IEA. (2023e). *World Energy Outlook.*

IEA. (2024). *World Energy Outlook.* 23–28.

Inoue, Y., & Lee, S. (2011). Effects of different dimensions of corporate social responsibility on corporate financial performance in tourism-related industries. *Tourism Management*, *32*(4), 790–804. https://doi.org/10.1016/j.tourman.2010.06.019

IPCC. (2018). An IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Pover. *Global Warming of 1.5°C*, 1–24. https://www.cambridge.org/core/product/identifier/9781009157940%23prf2/type/book_part

IPCC. (2023). Summary for Policymakers: Synthesis Report. *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 1–34.

IRENA. (2023). Renwable Power Generation Costs in 2023. In *Irena* (Vol. 58, Issue 12).

Iwata, H., & Okada, K. (2011). How does environmental performance affect financial performance? Evidence from Japanese manufacturing firms. *Ecological Economics*, *70*(9), 1691–1700. https://doi.org/10.1016/j.ecolecon.2011.05.010

Jahangir, S. M. R., & Dural, B. Y. (2018). Crude oil, natural gas, and economic growth: impact and causality analysis in Caspian Sea region. *International Journal of Management and Economics*, *54*(3), 169–184. https://doi.org/10.2478/ijme-2018-0019

Jarboui, S. (2021). Renewable energies and operational and environmental efficiencies of the US oil and gas companies: A True Fixed Effect model. *Energy Reports*, *7*, 8667–8676. https://doi.org/10.1016/j.egyr.2021.04.032

Jiang, Y., Hossain, M. R., Khan, Z., Chen, J., & Badeeb, R. A. (2024). Revisiting Research and Development Expenditures and Trade Adjusted Emissions: Green Innovation and Renewable Energy R&D Role for Developed Countries. *Journal of the Knowledge Economy*, *15*(1), 2156–2191. https://doi.org/10.1007/s13132-023-01220-0

Justice, G., Nyantakyi, G., & Isaac, S. H. (2024). The effect of renewable energy on carbon emissions through globalization. *Heliyon*, *10*(5), e26894. https://doi.org/10.1016/j.heliyon.2024.e26894

Khan, I., Hou, F., Irfan, M., Zakari, A., & Le, H. P. (2021). Does energy trilemma a driver of economic growth? The roles of energy use, population growth, and financial development. *Renewable and Sustainable Energy*

Reviews, *146*(May), 111157. https://doi.org/10.1016/j.rser.2021.111157

Khan, S., Akbar, A., Nasim, I., Hedvičáková, M., & Bashir, F. (2022). Green finance development and environmental sustainability: A panel data analysis. *Frontiers in Environmental Science*, *10*(November), 1–11. https://doi.org/10.3389/fenvs.2022.1039705

Khanna, M., Quimio, W. R. H., & Bojilova, D. (1998). Toxics release information: A policy tool for environmental protection. *Journal of Environmental Economics and Management*, *36*(3), 243–266. https://doi.org/10.1006/jeem.1998.1048

King, A., & Lenox, M. (2002). Exploring the locus of profitable pollution reduction. *Management Science*, *48*(2), 289–299. https://doi.org/10.1287/mnsc.48.2.289.258

Koengkan, M., Fuinhas, J. A., & Silva, N. (2021). Exploring the capacity of renewable energy consumption to reduce outdoor air pollution death rate in Latin America and the Caribbean region. *Environmental Science and Pollution Research*, *28*(2), 1656–1674. https://doi.org/10.1007/s11356-020-10503-x

Konar, S., & Cohen, M. A. (2001). *konar2001 Does the market value environmental performance*. *83*(May), 281–289.

Kripfganz, S. (2016). Quasi–maximum likelihood estimation of linear dynamic short-T panel-data models. *Stata Journal*, *16*(4), 1013–1038. https://doi.org/10.1177/1536867x1601600411

Law, S. H., Kutan, A. M., & Naseem, N. A. M. (2018). The role of institutions in finance curse: Evidence from international data. *Journal of Comparative Economics*, *46*(1), 174–191. https://doi.org/10.1016/j.jce.2017.04.001

Le, H., & Nguyen-Phung, H. T. (2024). Assessing the impact of environmental performance on corporate financial performance: A firm-level study of GHG emissions in Africa. *Sustainable Production and Consumption*, *47*(February), 644–654. https://doi.org/10.1016/j.spc.2024.04.024

Le, T. H., & Nguyen, C. P. (2019). Is energy security a driver for economic growth? Evidence from a global sample. *Energy Policy*, *129*(August 2018), 436–451. https://doi.org/10.1016/j.enpol.2019.02.038

Lee, C. C., & Wang, T. (2024). The impact of renewable energy policies on the energy transition -– An empirical analysis of Chinese cities. *Energy Economics*, *138*(June). https://doi.org/10.1016/j.eneco.2024.107838

Lee, K. H., Cin, B. C., & Lee, E. Y. (2016). Environmental Responsibility and Firm Performance: The Application of an Environmental, Social and Governance Model. *Business Strategy and the Environment*, *25*(1), 40–53. https://doi.org/10.1002/bse.1855

Lee, K. H., & Min, B. (2015). Green R&D for eco-innovation and its impact on carbon emissions and firm performance. *Journal of Cleaner Production*, *108*, 534–542. https://doi.org/10.1016/j.jclepro.2015.05.114

Li, N., Dilanchiev, A., & Mustafa, G. (2023). From oil and mineral extraction to renewable energy: Analyzing the efficiency of green technology innovation in the transformation of the oil and gas sector in the extractive industry. *Resources Policy*, *86*(September). https://doi.org/10.1016/j.resourpol.2023.104080

Li, W., Elheddad, M., & Doytch, N. (2021). The impact of innovation on environmental quality: Evidence for the non-linear relationship of patents and CO_2 emissions in China. *Journal of Environmental Management, 292*(May), 112781. https://doi.org/10.1016/j.jenvman.2021.112781

Li, W., Fan, J., & Zhao, J. (2022). Has green finance facilitated China's low-carbon economic transition? *Environmental Science and Pollution Research*, *29*(38), 57502–57515. https://doi.org/10.1007/s11356-022-19891-8

Liguo, X., Ahmad, M., & Khattak, S. I. (2022). Impact of innovation in marine energy generation, distribution, or transmission-related technologies on carbon dioxide emissions in the United States. *Renewable and Sustainable Energy Reviews*, *159*(February), 112225. https://doi.org/10.1016/j.rser.2022.112225

Lin, B., & Zhu, J. (2019). The role of renewable energy technological innovation on climate change: Empirical evidence from China. *Science of the Total Environment, 659*, 1505–1512. https://doi.org/10.1016/j.scitotenv.2018.12.449

Lin, Y., Anser, M. K., Peng, M. Y. P., & Irfan, M. (2023). Assessment of renewable energy, financial growth and in accomplishing targets of China's cities carbon neutrality. *Renewable Energy*, *205*(November 2022), 1082–1091. https://doi.org/10.1016/j.renene.2022.11.026

Lin, Y., Mahmood, M. A., Meng, W., & Ali, Q. (2024). Green economy transition in Asia Pacific: A holistic assessment of renewable energy production. *Journal of Cleaner Production*, *437*(September 2023). https://doi.org/10.1016/j.jclepro.2024.140648

Lobov, D., & Rybin, M. (2022). Openness to External Innovation in Major Oil and Gas Companies. *International Journal of Systematic Innovation*, *7*(4), 39–50. https://doi.org/10.6977/IJoSI.202212_7(4).0003

Lu, H., Guo, L., & Zhang, Y. (2019). Oil and gas companies' low-carbon emission transition to integrated energy companies. *Science of the Total Environment*, *686*, 1202–1209. https://doi.org/10.1016/j.scitotenv.2019.06.014

Lucas, R. E. J. (1988). On The Mechanics of Economic Development. Journal of Monetary Economics. In *Journal of Monetary Economics* (Vol. 22, Issue 1, pp. 3–42).

Machado, J., & Silva, J. M. . (2019). Journal of Econometrics. *Journal of Econometrics*, *78*(1), 1–130. https://doi.org/10.1016/s0304-4076(97)80003-6

Maradana, R. P., Pradhan, R. P., Dash, S., Gaurav, K., Jayakumar, M., & Chatterjee, D. (2017). Does innovation promote economic growth ? Evidence from European countries. *Journal of Innovation and Entrepreneurship*, 1–23. https://doi.org/10.1186/s13731-016-0061-9

Martí-Ballester, C. P. (2017). Sustainable energy systems and company performance: Does the implementation of sustainable energy systems improve companies' financial performance? *Journal of Cleaner Production, 162*, S35–S50. https://doi.org/10.1016/j.jclepro.2016.12.015

Masoomi, B., Sahebi, I. G., Gholian-Jouybari, F., Mejia-Argueta, C., & Hajiaghaei-Keshteli, M. (2024). The role of internet of things adoption on the sustainability performance of the renewable energy supply chain: A conceptual framework. *Renewable and Sustainable Energy Reviews*, *202*(April 2023). https://doi.org/10.1016/j.rser.2024.114610

Maury, B. (2022). Strategic CSR and firm performance: The role of prospector and growth strategies. *Journal of Economics and Business*, *118*(September 2021). https://doi.org/10.1016/j.jeconbus.2021.106031

Mdaghri, A., & Raghibi, A. (2025). On the nonlinear relationship between bank liquidity creation and financial stability: the moderating role of institutional quality in African economies. In *Journal of Business Economics* (Issue 0123456789). Springer Berlin Heidelberg. https://doi.org/10.1007/s11573-025-01226-x

Meadow, D. H., Meadows, D. L., Randers, J., & III, william W. B. (1972). The Limits to Growth : A Report to The Club of Rome (1972) by Donella H . Meadows , Dennis l . Meadows , Jorgen Randers , William W . Behrens III Abstract established by Eduard Pestel " The Limits to Growth ." *The Club of Rome*, 1–9.

Meadows, D. H., Meadows, D. L., Randers, J., & III, william W. B. (2018). Limits to growth. In *Dictionary of Ecological Economics: Terms for the New Millennium*. https://doi.org/10.4337/9781788974912.L.27

Miklautsch, P., & Woschank, M. (2022). A framework of measures to mitigate greenhouse gas emissions in freight transport : Systematic literature review from a Manufacturer ' s perspective. *Journal of Cleaner Production*, *366*(October 2021), 132883. https://doi.org/10.1016/j.jclepro.2022.132883

Moral-Benito, E. (2012). *moral penito 2012.pdf*.

Morgunova, M., & Shaton, K. (2022). The role of incumbents in energy transitions: Investigating the perceptions and strategies of the oil and gas industry. *Energy Research and Social Science*, *89*(March 2021), 102573. https://doi.org/10.1016/j.erss.2022.102573

Morina, F., Ergün, U., & Hysa, E. (2021). Understanding drivers of renewable energy firm's performance. *Environmental Research, Engineering and Management*, *77*(3), 32–49. https://doi.org/10.5755/j01.erem.77.3.29230

Muhammad, S., & Hoffmann, C. (2024). From investment to impact: The role of green finance and technological innovation on German energy transition. *Renewable Energy*, *237*(October). https://doi.org/10.1016/j.renene.2024.121665

Muzayanah, I. F. U., Lean, H. H., Hartono, D., Indraswari, K. D., & Partama, R. (2022). Population density and energy consumption: A study in Indonesian provinces. *Heliyon*, *8*(9), e10634. https://doi.org/10.1016/j.heliyon.2022.e10634

Nelson, R. R. (1981). Linked references are available on JSTOR for this article : Research on Productivity Growth and Productivity Differences : Dead Ends and New Departures. *Journal of Economic Literature*, *19*(3), 1029–1064.

Nepal, R., & Paija, N. (2019). Energy security, electricity, population and economic growth: The case of a developing South Asian resource-rich economy. *Energy Policy*, *132*(June), 771–781. https://doi.org/10.1016/j.enpol.2019.05.054

Ng, A., & Zheng, D. (2018). Let's agree to disagree! On payoffs and green tastes in green energy investments. *Energy Economics*, *69*, 155–169. https://doi.org/10.1016/j.eneco.2017.10.023

Nickell, S. (1981). Biases in Dynamic Models with Fixed Effects Author (s): Stephen Nickell Published by : The Econometric Society Stable URL : http://www.jstor.org/stable/1911408 Accessed : 04-06-2016 16 : 07 UTC. *Journal of the Econometric Society*, *49*(6), 1417–1426.

Nilsen, T. (2017). Innovation from the inside out: Contrasting fossil and renewable energy pathways at Statoil. *Energy Research and Social Science*, *28*(October 2016), 50–57. https://doi.org/10.1016/j.erss.2017.03.015

ÓhAiseadha, C., Quinn, G., Connolly, R., & Connolly, M. (2020). Energy and Climate Policy — An Evaluation of Global. *Energies*, *13*(18), 4839. https://www.mdpi.com/1996-1073/13/18/4839

Olabi, A. G., Obaideen, K., Elsaid, K., Wilberforce, T., Sayed, E. T., Maghrabie, H. M., & Abdelkareem, M. A. (2022). Assessment of the pre-combustion carbon capture contribution into sustainable development goals SDGs using novel indicators. *Renewable and Sustainable Energy Reviews*, *153*(October 2021). https://doi.org/10.1016/j.rser.2021.111710

OPEC. (2022). World oil outlook 2045. In *World oil outlook report*. http://www.nber.org/papers/w16019

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Bmj*, *372*. https://doi.org/10.1136/bmj.n71

Palmer, K., Oates, W. E., & Portney, P. R. (1995). Tightening environmental standards: The Benefit-Cost or the No-Cost paradigm? *Economic Costs and Consequences of Environmental Regulation*, *9*(4), 435–448. https://doi.org/10.1257/jep.9.4.119

Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P. W., Fernandez-Manjarrés, J. F., Araújo, M. B., Balvanera, P., Biggs, R., Cheung, W. W. L., Chini, L., Cooper, H. D., Gilman, E. L., Guénette, S., Hurtt, G. C., Huntington, H. P., Mace, G. M., Oberdorff, T., Revenga, C., … Walpole, M. (2010). Scenarios for global biodiversity in the 21st century. *Science*, *330*(6010), 1496–1501. https://doi.org/10.1126/science.1196624

Petrović, P., & Lobanov, M. M. (2020). The impact of R&D expenditures on CO_2 emissions: Evidence from sixteen OECD countries. *Journal of Cleaner Production, 248*. https://doi.org/10.1016/j.jclepro.2019.119187

Porter, M. E. (1991). *T--*. *12*.

Porter, M. E., & Linde, C. Van Der. (1995). *Toward a New Conception of the Environment-Competitiveness Relationship*. *9*(4), 97–118.

Preston, L. E., & O'Bannon Douglas P. (1997). Preston1997. *Business & Society*, *36*(4), 419–429.

Quader, M. A., Ahmed, S., Ghazilla, R. A. R., Ahmed, S., & Dahari, M. (2015). A comprehensive review on energy efficient CO_2 breakthrough technologies for sustainable green iron and steel manufacturing. *Renewable and Sustainable Energy Reviews*, *50*, 594–614. https://doi.org/10.1016/j.rser.2015.05.026

Qudrat-Ullah, H., & Nevo, C. M. (2021). The impact of renewable energy consumption and environmental sustainability on economic growth in Africa. *Energy Reports*, *7*, 3877–3886. https://doi.org/10.1016/j.egyr.2021.05.083

Rahuma, A., & Fethi, S. (2022). *RESEARCH ARTICLE A new approach to evaluate environmental strategy : Empirical evidence from international petroleum companies using the balanced scorecard model*. *March*, 3152–3165. https://doi.org/10.1002/bse.3068

Raihan, A., Muhtasim, D. A., Khan, M. N. A., Pavel, M. I., & Faruk, O. (2022). Nexus between carbon emissions, economic growth, renewable energy use, and technological innovation towards achieving environmental sustainability in Bangladesh. *Cleaner Energy Systems*, *3*(August), 100032. https://doi.org/10.1016/j.cles.2022.100032

Romer, P. (1986). Inceasing returns and long term growth. *Journal of Political Economics*, *4*(5), 1002–1037. http://rcer.econ.rochester.edu/RCERPAPERS/rcer_27.pdf

Roodman, D. (2009). *How to do xtabond2 : An introduction to difference and system GMM in Stata*. *1*, 86–136.

Ruggiero, S., & Lehkonen, H. (2017). Renewable energy growth and the financial performance of electric utilities: A panel data study. *Journal of Cleaner Production*, *142*, 3676–3688. https://doi.org/10.1016/j.jclepro.2016.10.100

Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. *Environmental Research*, *186*(April), 109567. https://doi.org/10.1016/j.envres.2020.109567

Salygin, V. I., & Lobov, D. S. (2021). Defining major oil and gas companies’ development strategies in the era of energy transition. *Vestnik MGIMO-Universiteta*, *14*(5), 149–166. https://doi.org/10.24833/2071-8160-2021-5-80-149-166

Samour, A., Moyo, D., & Tursoy, T. (2022). Renewable energy, banking sector development, and carbon dioxide emissions nexus: A path toward sustainable development in South Africa. *Renewable Energy*, *193*, 1032–1040. https://doi.org/10.1016/j.renene.2022.05.013

Schabek, T. (2020). The financial performance of sustainable power producers in emerging markets. *Renewable Energy*, *160*, 1408–1419. https://doi.org/10.1016/j.renene.2020.06.067

Schumpeter, J. A. (2013). *Socialism*.

Shahzad, U., Gupta, M., Sharma, G. D., Rao, A., & Chopra, R. (2022). Resolving energy poverty for social change: Research directions and agenda. *Technological Forecasting and Social Change*, *181*(November 2021), 121777. https://doi.org/10.1016/j.techfore.2022.121777

Shao, X., Zhong, Y., Liu, W., & Li, R. Y. M. (2021). Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. *Journal of Environmental Management*, *296*(March), 113189. https://doi.org/10.1016/j.jenvman.2021.113189

Shu, D. Y., Deutz, S., Winter, B. A., Baumgärtner, N., Leenders, L., & Bardow, A. (2023). The role of carbon capture and storage to achieve net-zero energy systems: Trade-offs between economics and the environment. *Renewable and Sustainable Energy Reviews*, *178*(March), 113246. https://doi.org/10.1016/j.rser.2023.113246

Solow, R. (1956). A Contribution to the Theory of Economic Growth Author (s): Robert M . Solow Source : The Quarterly Journal of Economics , Vol . 70 , No . 1 (Feb ., 1956), pp . 65-94 Published by : The MIT Press Stable URL : http://www.jstor.org/stable/1884513. *Growth (Lakeland)*, *70*(1), 65–94.

Song, Y., Li, L., Shahbaz, M., & Bukhari, A. A. A. (2024). Does an environmental stringent policy really matter to achieve environmental sustainability in BRICS-T region? Evidence from novel method of moments quantile regression approach. *Journal of Environmental Management*, *368*(June), 121898. https://doi.org/10.1016/j.jenvman.2024.121898

Soto, M. (2009). The last decade has been productive in the development of Generalised Methods of Moments (GMM) estimation. *Knowledge Creation Diffusion Utilization*, *July*.

Su, C. W., Pang, L. D., Tao, R., Shao, X., & Umar, M. (2022). Renewable energy and technological innovation: Which one is the winner in promoting net-zero emissions? *Technological Forecasting and Social Change*, *182*(May), 121798. https://doi.org/10.1016/j.techfore.2022.121798

Subhan, M., Irfan, M., Pan, X., Ahmad, G., Naeem, M. H., & Zamir, M. N. (2024). Unveiling the dynamic impact of energy generation on economic sustainability in Canada: A roadmap towards sustainable development. *Journal of Cleaner Production*, *434*(August 2023), 139783. https://doi.org/10.1016/j.jclepro.2023.139783

Sueyoshi, T., & Goto, M. (2009). Can environmental investment and expenditure enhance financial performance of US electric utility firms under the clean air act amendment of 1990? *Energy Policy*, *37*(11), 4819–4826. https://doi.org/10.1016/j.enpol.2009.06.038

Sun, D. Q., Yi, B. W., Xu, J. H., Zhao, W. Z., Zhang, G. S., & Lu, Y. F. (2018). Assessment of CO_2 emission reduction potentials in the Chinese oil and gas extraction industry: From a technical and cost-effective perspective. *Journal of Cleaner Production*, *201*, 1101–1110. https://doi.org/10.1016/j.jclepro.2018.08.044

Tatsuo, K. (2010). An analysis of the eco-efficiency and economic performance of Japanese companies. *Asian Business and Management*, *9*(2), 209–222. https://doi.org/10.1057/abm.2010.3

Töbelmann, D., & Wendler, T. (2020). The impact of environmental innovation on carbon dioxide emissions. *Journal of Cleaner Production*, *244*. https://doi.org/10.1016/j.jclepro.2019.118787

Toghyani, M., & Saadat, A. (2024). From challenge to opportunity: Enhancing oil refinery plants with sustainable hybrid renewable energy integration. *Energy Conversion and Management*, *305*(March), 118254. https://doi.org/10.1016/j.enconman.2024.118254

Tran, Q. H. (2022). The impact of green finance, economic growth and energy usage on CO_2 emission in Vietnam – a multivariate time series analysis. *China Finance Review International*, *12*(2), 280–296. https://doi.org/10.1108/CFRI-03-2021-0049

Trimech, A. (2024). Exploring the interplay of renewable energy and carbon dioxide emissions across US sectors through wavelet approach. *Environmental Progress and Sustainable Energy*, *January*. https://doi.org/10.1002/ep.14454

Trumpp, C., & Guenther, T. (2017). Too Little or too much? Exploring U-shaped Relationships between Corporate Environmental Performance and Corporate Financial Performance. *Business Strategy and the Environment*, *26*(1), 49–68. https://doi.org/10.1002/bse.1900

Usman, O., Alola, A. A., & Akadiri, S. Saint. (2022). Effects of domestic material consumption, renewable energy, and financial development on environmental sustainability in the EU-28: Evidence from a GMM panel-VAR. *Renewable Energy*, *184*, 239–251. https://doi.org/10.1016/j.renene.2021.11.086

Vestrelli, R., Fronzetti, A., & Laura, A. (2024a). When attention to climate change matters : The impact of climate risk disclosure on firm market value. *Energy Policy*, *185*(33), 113938. https://doi.org/10.1016/j.enpol.2023.113938

Vestrelli, R., Fronzetti, A., & Laura, A. (2024b). When attention to climate change matters : The impact of climate risk disclosure on firm market value When attention to climate change matters : The impact of climate risk disclosure on firm market value. *Energy Policy*, *185*(December 2023), 113938. https://doi.org/10.1016/j.enpol.2023.113938

Walley, N., & Whitehead, B. (1994). *s Not Easy Being Green*.

Wang, J. he, Mamkhezri, J., Khezri, M., Karimi, M. S., & Khan, Y. A. (2022). Insights from European nations on the spatial impacts of renewable energy sources on CO_2 emissions. *Energy Reports*, *8*, 5620–5630. https://doi.org/10.1016/j.egyr.2022.04.005

Wang, R., Mirza, N., Vasbieva, D. G., Abbas, Q., & Xiong, D. (2020). The nexus of carbon emissions, financial development, renewable energy consumption, and technological innovation: What should be the priorities in light of COP 21 Agreements? *Journal of Environmental Management*, *271*(July), 111027. https://doi.org/10.1016/j.jenvman.2020.111027

WCED. (1987). Report of the World Commission on Environment and Development : Our Common Future Acronyms and Note on Terminology Chairman ' s Foreword. *Report of the World Commission on Environment and Development: Our Common Future*.

Windmeijer, F. (2005). A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics*, *126*(1), 25–51. https://doi.org/10.1016/j.jeconom.2004.02.005

Wolde-Rufael, Y., & Mulat-Weldemeskel, E. (2022). The moderating role of environmental tax and renewable energy in CO_2 emissions in Latin America and Caribbean countries: Evidence from method of moments quantile regression. *Environmental Challenges*, *6*(November 2021).

https://doi.org/10.1016/j.envc.2021.100412

Wooldridge, J. M. (2016). Econometrics Introductory. In *Cengage Learning*.

World economic forum. (2025). *The Global Risks Report 2025 20th Edition*.

Wurlod, J. D., & Noailly, J. (2018). The impact of green innovation on energy intensity: An empirical analysis for 14 industrial sectors in OECD countries. *Energy Economics*, *71*, 47–61. https://doi.org/10.1016/j.eneco.2017.12.012

Xia, D., & Wang, X. Q. (2021). The synergetic impact of environmental and innovation information disclosure on corporate financial performance: An empirical study based on China coal listed companies. *Technovation*, *100*(February 2020), 102179. https://doi.org/10.1016/j.technovation.2020.102179

Xie, J., Nozawa, W., Yagi, M., Fujii, H., & Managi, S. (2019). Do environmental, social, and governance activities improve corporate financial performance? *Business Strategy and the Environment*, *28*(2), 286–300. https://doi.org/10.1002/bse.2224

Xin, D., Ahmad, M., Lei, H., & Khattak, S. I. (2021). Do innovation in environmental-related technologies asymmetrically affect carbon dioxide emissions in the United States? *Technology in Society*, *67*(July), 101761. https://doi.org/10.1016/j.techsoc.2021.101761

Xueming Luo ; C. B. Bhattacharya. (2006). Social Responsibility , Corporate Customer and Market Satisfaction , Value. *Journal of Marketing*, *70*(4), 1–18.

Yang, Y., Cai, W., & Wang, C. (2014). Industrial CO_2 intensity, indigenous innovation and R&D spillovers in China’s provinces. *Applied Energy*, *131*, 117–127. https://doi.org/10.1016/j.apenergy.2014.06.033

Yoro, K. O., & Daramola, M. O. (2020). CO_2 emission sources, greenhouse gases, and the global warming effect. In *Advances in Carbon Capture: Methods, Technologies and Applications*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-819657-1.00001-3

Zaidi, S., Danish, Hou, F., & Mirza, F. M. (2018). The role of renewable and non-renewable energy consumption in CO 2 emissions: a disaggregate analysis of Pakistan. *Environmental Science and Pollution Research*, *25*(31), 31616–31629. https://doi.org/10.1007/s11356-018-3059-y

Zeng, S. X., Meng, X. H., Yin, H. T., Tam, C. M., & Sun, L. (2010). Impact of cleaner production on business performance. *Journal of Cleaner Production*, *18*(10–11), 975–983. https://doi.org/10.1016/j.jclepro.2010.02.019

Zhang, B., Wang, Y., Liu, M., & Mehmood, U. (2024). How environmental patents, education, and energy transition impact greenhouse gases: evidence from E7 countries. *Frontiers in Environmental Science*, *12*(January), 1–15. https://doi.org/10.3389/fenvs.2024.1514728

Zhang, Y., & Chen, X. (2023). Spatial and nonlinear effects of new-type urbanization and technological innovation on industrial carbon dioxide emission in the Yangtze River Delta. *Environmental Science and Pollution Research*, *30*(11), 29243–29257. https://doi.org/10.1007/s11356-022-24113-2

Zhang, Y., Peng, Y., & Shen, B. (2017). *crossmark*. *100*(June 2015), 18–28.

Zhong, M., & Bazilian, M. D. (2018). Contours of the energy transition: Investment by international oil and gas companies in renewable energy. *Electricity Journal*, *31*(1), 82–91. https://doi.org/10.1016/j.tej.2018.01.001

Zhou, W., Jiang, D., Chen, D., Griffy-Brown, C., Jin, Y., & Zhu, B. (2016). Capturing CO_2 from cement plants: A priority for reducing CO_2 emissions in China. *Energy*, *106*, 464–474. https://doi.org/10.1016/j.energy.2016.03.090

Zoundi, Z. (2017). CO_2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, *72*(November 2016), 1067–1075. https://doi.org/10.1016/j.rser.2016.10.018

Our global in data, https://ourworldindata.org/emissions-by-fuel. (Accessed 23 January, 2025).

The gardian, 2019. https://www.theguardian.com/environment/2019/oct/09/revealed-20-firms-third-carbon-emissions. (Accessed 23 January, 2023).

Schumpeter, J. A. (1934). The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle.

Say, JB (2013). Treatise on political economy . Presses Électroniques de France.