

**IBN HALDUN UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF ECONOMICS**

PH.D. THESIS

**ESSAYS ON RENEWABLE ENERGY CONSUMPTION
AND ITS TRANSITION TOWARDS
A SUSTAINABLE FUTURE**

IFTIKHAR MUHAMMAD

**THESIS SUPERVISOR
PROF. HASAN VERGİL**

ISTANBUL, 2023

**IBN HALDUN UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF ECONOMICS**

PH.D. THESIS

**ESSAYS ON RENEWABLE ENERGY CONSUMPTION
AND ITS TRANSITION TOWARDS
A SUSTAINABLE FUTURE**

by

IFTIKHAR MUHAMMAD

**A thesis submitted to the School of Graduate Studies in partial
fulfillment of the requirements for the degree of Doctor of
Philosophy in Economics**

**THESIS SUPERVISOR
PROF. HASAN VERGİL**

ISTANBUL, 2023

APPROVAL PAGE

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy in Economics

Thesis Jury Members

Title - Name Surname

Opinion

Signature

This is to confirm that this thesis complies with all the standards set by the School of Graduate Studies of Ibn Haldun University.

Date of Submission

Seal/Signature

ACADEMIC HONESTY ATTESTATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Surname:

Signature:



ÖZ

YENİLENEBİLİR ENERJİ TÜKETİMİ VE SÜRDÜRÜLEBİLİR
BİR GELECEĞE GEÇİŞ ÜZERİNE DENEMELER

İftikhar Muhammad

İktisat Doktora Programı

Öğrenci Numarası: 187051005

Open Researcher and Contributor ID (ORC-ID): 0000-0003-4747-9680

Ulusal Tez Merkezi Referans Numarası: 10565956

Tez Danışmanı: Prof. Dr. Hasan Vergil

Eylül 2023, 192 Sayfa

Bu doktora araştırma tezi, yenilenebilir enerji tüketimi ve sürdürülebilir bir geleceğe geçişi etkileyen faktörlerin ampirik bir analizini amaçlamaktadır. Yenilenebilir enerjiye duyulan ihtiyaç, yenilenemez kaynakların tükenmesi, iklim değişikliği hususundaki endişeler ve artan küresel enerji talebinden kaynaklanmaktadır. Bu Araştırma, ticaret serbestleşme politikaları, karbon emisyonları, teknolojik yenilik, gelir eşitsizliği, ekonomik büyüme, sermaye oluşumu ve petrol fiyatları gibi çeşitli boyutları inceleyerek, OECD ve BRICS ekonomilerine odaklanmaktadır. Artırılmış ortalama grup (Augmented Mean Group) tahmincisi ve birleştirilmiş ortalama grup (Pooled Mean Group) tahmincisi ile elde edilen bulgular, OECD ülkelerinde gelir eşitsizliği, GSYH büyümesi, ticaret açıklığı ve petrol fiyatlarının yenilenebilir enerji tüketimini olumlu yönde etkilediğini, karbon emisyonlarının ise olumsuz etkilediğini göstermektedir. BRICS ekonomilerinde ise gelir eşitsizliğindeki artış, sermaye oluşumu, CO2 emisyonları ve teknolojik gelişmelerin yenilenebilir enerjinin benimsenmesini engellediği ekonomik büyümenin ise daha yüksek yenilenebilir enerji tüketimine yol açtığı görülmüştür. Ülke-özü AMG tahmincisi, çeşitli OECD ve BRICS ekonomilerinde CO2 emisyonları ile yenilenebilir enerji tüketimi (YET) arasında belirgin ters orantı olduğunu tespit etmektedir. Bu ülkeler, etkili politikalar uygulayarak önemli CO2 emisyonlarında kayda değer düşüşler sağlamıştır. Ayrıca, yenilenebilir enerji tüketimi ve ekonomik büyüme arasında pozitif ilişkinin belirgin olduğu Amerika Birleşik Devletleri ve Çin gibi ülkelerde bu ilişki, yenilenebilir enerji

kaynaklarının aktif olarak entegre edildiğini göstermektedir. Petrol fiyatları, Portekiz ve Türkiye'de, belirli ekonomik faktörlerden etkilenecek yenilenebilir enerji tüketimi ile negatif bir ilişkiye sahiptir. Çin ve Rusya'da gelir eşitsizliği, yenilenebilir enerji teknolojilerine eşit olmayan erişim nedeniyle yenilenebilir enerji tüketimini olumsuz etkilemektedir. Brezilya'nın ters YET-sermaye birikimi ilişkisi, hidroelektriğe olan tarihsel bağımlılığın kaynaklanırken, Meksika, İsveç, Almanya, Finlandiya ve Norveç, yenilenebilir enerji tüketimini artırmak için ticaret serbestleştirme politikalarından faydalanmışlardır. Bu bulgular, politika yapıcılar için büyük önem taşımakta, etkili stratejiler oluşturmak ve yenilenebilir enerjinin benimsenmesini hızlandırmak için vazgeçilmez bilgiler sağlamaktadır. Bu tezden elde edilen politika çıkarımları, gelecek nesiller için daha yeşil ve sürdürülebilir bir gelecek inşa etmek için temel bir kılavuz görevi görmektedir.

Anahtar Kelimeler: AMG Tahminci, BRICS Ekonomileri, Çevresel Sürdürülebilirlik, OECD Ekonomileri, PMG Tahminci, Yenilenebilir Enerji Tüketimi.

ABSTRACT

ESSAYS ON RENEWABLE ENERGY CONSUMPTION AND ITS TRANSITION TOWARDS A SUSTAINABLE FUTURE

Iftikhar Muhammad

PhD in Economics

Student ID: 187051005

Open Researcher and Contributor ID (ORC-ID): 0000-0003-4747-9680

National Thesis Center Reference Number: 10565956

Thesis Supervisor: Prof. Hasan Vergil

September 2023, 192 Pages

This doctoral research thesis aims to conduct an empirical analysis of the factors that influence renewable energy consumption (REC) and its transition towards a sustainable future. The pressing need for adopting renewable energy arises from the depletion of non-renewable resources, concerns about climate change, and the escalating global energy demand. The study focuses on OECD and BRICS economies, examining dimensions such as trade policies, CO₂ emissions, technological innovation, income inequality, economic growth, capital formation, and oil prices. The findings obtained through the Augmented Mean Group (AMG) and Pooled Mean Group (PMG) estimators indicate that income inequality, GDP growth, trade openness, and oil prices positively affect REC in OECD countries, while carbon emissions have a negative association. In BRICS economies, an increase in income inequality, capital formation, CO₂ emissions, and technological advancements hampers the adoption of renewable energy, while economic growth leads to higher REC. The country-specific AMG estimator identifies significant inverse relationship between CO₂ emissions and REC in various OECD and BRICS economies. These countries have implemented effective policies, resulting in notable CO₂ reductions. Additionally, a positive REC-economic growth link is evident in nations such as the United States, and China, indicating active integration of renewable energy sources. Oil prices have a negative association with REC in Portugal and Turkey, influenced by specific economic factors. In China and Russia, income inequality negatively impacts REC due to unequal access

to renewable energy technologies. Brazil's inverse REC-capital formation relationship is attributed to historical reliance on hydropower, while Mexico, Sweden, Germany, Finland, and Norway benefit from trade liberalization policies in boosting REC. These findings hold pivotal significance for policymakers, providing indispensable insights to formulate effective strategies and expedite the adoption of renewable energy. The policy implications serve as a foundational guide for constructing a greener and more sustainable future for generations to come.

Keywords: AMG Estimator, BRICS Economies, Environmental Sustainability, OECD Economies, PMG Estimator, Renewable Energy Consumption.



ACKNOWLEDGEMENTS

I would like to extend my profound appreciation to my esteemed supervisor, Prof. Dr. Hasan Vergil, for his unwavering support, invaluable guidance, and constant encouragement throughout my Ph.D. journey. His exceptional erudition, extensive expertise, and insightful feedback have played an instrumental role in shaping the trajectory of my research and academic career. I would also like to extend my sincere thanks to the members of my dissertation committee, Prof. Dr. Asad Ul Islam Khan and Prof. Dr. Muhittin Kaplan, for their valuable time, effort, and constructive feedback, which greatly contributed to the quality and rigor of this research. I am deeply grateful to Dr. Rasim Özcan, Dr. Carolos Samuel Ramos-Meza, Dr. Vipin Jain, Dr. Asma Salman, and Dr. Paritosh Sharma for their valuable collaboration and assistance in data collection, analysis, and interpretation. Furthermore, I would like to extend my sincere appreciation to my colleagues and friends who have provided their unwavering support, encouragement, and inspiration during my Ph.D. journey. Their kindness, understanding, and camaraderie have made this experience more enjoyable and memorable.

Moreover, I have had the privilege of engaging in enlightening discussions during departmental seminars at Ibn Haldun University and intellectually stimulating Ph.D. research lunches. The insights and contributions provided by these attendees have played an instrumental role in enhancing the rigor and scope of my research pursuits. I extend my utmost gratitude to all these individuals for their valuable input, which has significantly enriched the academic dimension of my work. In addition, I am grateful to Ibn Haldun University for awarding me a full scholarship that has financed my doctoral studies.

Last but not least, I would like to convey my utmost appreciation to my family for their unconditional love, encouragement, and sacrifices. I am fully aware that this achievement would not have been possible without their constant support, and I am deeply grateful for their contributions to my success.

Iftikhar Muhammad
ISTANBUL, 2023

TABLE OF CONTENTS

ÖZ	iv
ABSTRACT	vi
ACKNOWLEDGEMENTS	viii
TABLE OF CONTENTS	ix
LIST OF TABLES	xii
LIST OF FIGURES	xiv
LIST OF SYMBOLS AND ABBREVIATIONS	xv
CHAPTER I INTRODUCTION	1
CHAPTER II AN OVERVIEW OF RENEWABLE ENERGY SOURCES	15
2.1. The Role of Renewable Energy in Diverse Sectors	17
2.1.1. Renewable Energy in the Electricity Sector.....	17
2.1.2. Renewable Energy in Buildings	18
2.1.3. Renewable Energy in Industrial and Agricultural Sectors	20
2.1.4. Renewable Energy in Transportation.....	22
2.2. Renewable Energy Policy Landscape	24
2.2.1. Climate Change Policies	25
2.2.2. Economic Development and Renewable Energy Targets	27
2.2.3. Policies for Cooling and Heating in Buildings	28
2.2.4. Policies for the Transportation Sector	29
2.2.5. Policies for Industrial and Agricultural Sectors	30
2.3. Renewable Energy Market Trends.....	31
2.3.1. Bioenergy	31
2.3.2. Geothermal	32
2.3.3. Heat Pumps	33
2.3.4. Hydropower.....	33
2.3.5. Ocean Power	34

2.3.6. Solar Photovoltaic	34
2.3.7. Concentrating Solar Thermal Power	35
2.3.8. Solar Thermal Cooling and Heating	36
2.3.9. Wind Power.....	36
2.4. Increasing Energy Access with Distributed Renewables.....	37
2.5. Renewable Energy Investment Trends.....	38
2.6. Renewable-Based Energy Systems	39
CHAPTER III DOES ENVIRONMENTAL SUSTAINABILITY AFFECT THE RENEWABLE ENERGY CONSUMPTION? NEXUS AMONG TRADE OPENNESS, CO2 EMISSIONS, INCOME INEQUALITY, RENEWABLE ENERGY, AND ECONOMIC GROWTH IN OECD COUNTRIES	42
3.1. Introduction	42
3.2. Literature Review	46
3.2.1. CO2 Emissions and REC Relationship.....	47
3.2.2. Trade Openness and REC Nexus	48
3.2.3. Oil Prices and REC Relationship	49
3.2.4. Economic Growth and REC Nexus.....	49
3.3. Data and Model Specification	50
3.4. Empirical Methodology	54
3.4.1. Cross-Sectional Dependence and Slope Homogeneity Tests.....	54
3.4.2. Unit Root Tests	54
3.4.3. Cointegration Test.....	55
3.4.4. Long-Run Estimation	56
3.5. Empirical Results and Discussion.....	56
3.6. Dumitrescu and Hurlin Panel Causality Test	67
3.7. Conclusion and Policy Implications.....	71
CHAPTER IV DO DRIVERS OF RENEWABLE ENERGY CONSUMPTION MATTER FOR BRICS ECONOMIES? NEXUS AMONG TECHNOLOGICAL	

INNOVATION, ENVIRONMENTAL DEGRADATION, ECONOMIC GROWTH, AND INCOME INEQUALITY	74
4.1. Introduction	74
4.2. Literature Review	78
4.3. Data and Methodology	81
4.4. Empirical Results and Discussion	85
4.5. Panel Causality Test	96
4.6. Conclusion and Policy Implications.....	98
CHAPTER V DO TRADE LIBERALIZATION POLICIES AFFECT THE GREEN ENERGY TRANSITION? NEXUS AMONG ENVIRONMENTAL DEGRADATION, GREEN ENERGY, AND OIL PRICES IN OECD COUNTRIES	102
5.1. Introduction	102
5.2. Literature Review	105
5.3. Data and Methodology	109
5.4. Findings and Discussion	114
5.5. Panel Causality Test	125
5.6. Conclusion and Policy Suggestions	127
CHAPTER VI CONCLUSION.....	130
REFERENCES	140
APPENDICES	182
APPENDIX A	182
APPENDIX B	183
APPENDIX C	184
CURRICULUM VITAE.....	192

LIST OF TABLES

Table 3.1. Descriptive Statistics.....	52
Table 3.2. Correlation Coefficient Matrix.....	53
Table 3.3. Results of Cross-Sectional Dependence (CSD) Tests.....	57
Table 3.4. Slope Homogeneity Tests Results.....	57
Table 3.5. Results of Unit Root Tests	58
Table 3.6. Results of Westerlund Durbin-Hausman Test	59
Table 3.7. Results of AMG Estimator.....	61
Table 3.8. Country-Specific Results of AMG Estimator	67
Table 3.9. Results of DH Panel Causality Test.....	70
Table 4.1. Descriptive Statistics.....	85
Table 4.2. Matrix of Correlation Coefficient (After Logarithm)	86
Table 4.3. Findings of Cross-Sectional Dependence (CSD) Tests	87
Table 4.4. Findings of Slope Homogeneity Test	87
Table 4.5. Findings of First Generation Unit Root Tests.....	87
Table 4.6. Findings of Second Generation Unit Root Test – CIPS.....	88
Table 4.7. Panel Cointegration Tests	89
Table 4.8. Results of the AMG and PMG Estimators.....	90
Table 4.9. Country-Wise Results of AMG Estimator	96
Table 4.10. Findings of DH Causality Test.....	97
Table 5.1. Descriptive Statistics.....	115
Table 5.2. Correlation Matrix.....	115
Table 5.3. CD, SH, and WDH Test Results.....	116
Table 5.4. First and Second Generation Unit Root Tests.....	116
Table 5.5. Outcomes of Long-Run Estimates (PMG and AMG).....	120
Table 5.6. Country-Specific Results of AMG Estimator	124
Table 5.7. Outcomes of DH Panel Causality Test	126

Table A.1. List of 23 OECD Countries.....	182
Table B.1. Variance Inflation Factors (VIF).....	183
Table C.1. Studies on the Factors Influencing Renewable Energy Consumption ...	184



LIST OF FIGURES

Figure 2.1. Renewable Energy Classification	15
Figure 2.2. Share of Modern RES from 2009 to 2020	17
Figure 2.3. Share of Green Electricity in Global Power Generation	18
Figure 2.4. Share of Renewable Energy in Buildings	20
Figure 2.5. Share of Green Energy in Industrial and Agricultural Sectors	22
Figure 2.6. Proportion of Green Energy in the Transportation Sector.....	24
Figure 2.7. Global Green Energy Policy Landscape in 2021.....	25
Figure 2.8. Countries' Net Zero Policies and Progress in 2021	27
Figure 2.9. Global Investment in Renewable Energy, 2011-2021	39
Figure 2.10. Top Countries in 2021 for Variable Renewable Electricity Penetration	40

LIST OF SYMBOLS AND ABBREVIATIONS

AMG	Augmented Mean Group
BP	British Petroleum
BRICS	Brazil, Russia, India, China, South Africa
CO ₂	Carbon dioxide
CPI	Consumer Price Index
CSD	Cross-sectional Dependence
CSP	Concentrating Solar Power
DH	Dumitrescu and Hurlin
DREA	Distributed Renewable Energy Access
EJ	Exajoules
ETS	Emission Trading System
EU	European Union
EVs	Electric Vehicles
FITs	Feed-in Tariffs
GDP	Gross Domestic Product
GE	Green Energy
GEC	Green Energy Consumption
GES	Green Energy Sources
GET	Green Energy Transition
GHGs	Greenhouse Gases
GW	Gigawatts
GWh	Gigawatt hours
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
MW	Megawatts
OECD	Organization for Economic Cooperation and Development
PMG	Pooled Mean Group
RE	Renewable Energy
REC	Renewable Energy Consumption
REN21	Renewable Energy Policy Network for the 21 st Century

RES	Renewable Energy Sources
SDGs	Sustainable Development Goals
SH	Slope Heterogeneity
SHP	Solar Heat Pumps
TFEC	Total Final Energy Consumption
TLPs	Trade Liberalization Policies
TWh	Terawatt hours
UAE	United Arab Emirates
UN	United Nations
VIF	Variance Inflation Factors
WDI	World Development Indicators
WWF	World Wildlife Fund
i	Cross-sections
t	Time Period
ε	Standard Error Term

CHAPTER I

INTRODUCTION

Climate change constitutes a paramount global challenge of our time, denoting persistent changes in the Earth's climate, encompassing shifts in average temperatures, weather dynamics, and precipitation patterns. This phenomenon is mainly attributed to anthropogenic activities, notably the combustion of non-renewables and deforestation, which engender substantial emissions of greenhouse gases (GHGs) such as methane, carbon dioxide, and nitrous oxide into the atmosphere. The GHGs ensnare solar heat, resulting in the escalation of global temperatures and precipitating a plethora of adverse consequences, such as rising sea levels, exacerbated frequency and intensity of heat waves, hurricanes, droughts, and an increased risk of extinction for many species of plants and animals (Kemp et al., 2022; Olabi and Abdelkareem, 2022). Additionally, climate change also has significant economic consequences, as it affects food and water security, human health, and infrastructure (Abeysekara et al., 2023).

Non-renewable sources of energy remain the predominant source of energy across the world, accounting for a substantial 85% of global primary energy consumption in 2021 (IEA, 2022; Perera and Nadeau, 2022). Among the various fossil fuels, oil is the most commonly utilized, followed by coal and natural gas. The widespread use of non-renewables is having a profound influence on the earth's climate system. In particular, the Arctic region is warming at an alarming rate—three times faster than the global average—and is expected to be nearly ice-free in the summer months within the next three decades. This has major ramifications for the regulation of the planet's temperature, as the Arctic acts as a crucial reflector of sunlight into space (Heino et al., 2020; Grunst et al., 2023). The United Nations (UN) has reported that human activities, including deforestation, habitat destruction, and overfishing, have placed over a million species of plants and animals at risk of extinction¹. The World Wildlife

¹ <https://unstats.un.org/sdgs/report/2020/>

Fund (WWF) further highlights that human activities have resulted in a 68% decline in global wildlife populations over the past 50 years². In addition, the Intergovernmental Panel on Climate Change (IPCC) has documented that GHG emissions resulting from human activities have exhibited a 70% increase between 1970 and 2017 (IPCC, 2019). This trend is further evidenced by a recent study by Karakurt and Aydin (2023), which found that global carbon dioxide emissions increased by 4% in 2020, despite the economic deceleration resulting from the COVID-19 pandemic. The United States, China, and India are among the leading emitters of CO₂ globally, collectively contributing over half of all emissions. Other major emitters include Russia, Japan, and several countries within the European Union (Zhang et al., 2022). In 2015, the Paris Agreement was formed with the aim of mitigating the global impact of CO₂ emissions. The agreement sets out to limit the increase in global temperatures to below 2°C above pre-industrial levels and strives to make an effort to limit this increase to 1.5°C. To obtain this goal, participating countries have pledged to reduce their emissions and to increase the use of renewable energy sources (UNFCCC, 2015; UNFCCC, 2022).

Renewable energy pertains to the energy procured from naturally replenishing sources, including solar, wind, hydropower, biomass, geothermal, and ocean energy. In contrast to finite fossil fuels that emit greenhouse gases, renewable energy sources (RES) are environmentally friendly, sustainable, and have a minimal impact on the environment (Calvo and Valero, 2022). Renewable energy (RE) technologies, such as wind turbines, solar panels, and hydropower facilities, allow for the harnessing of these natural sources to generate electricity without emitting harmful pollutants, as seen with fossil fuels. The growing demand for energy, combined with the limitations of traditional fossil fuels and the harm they inflict on the environment, has made renewable energy an increasingly attractive solution to meet energy security and environmental concerns (Elahi et al., 2022). RE constituted roughly 26% of the world's total final energy consumption in 2021 (IEA, 2022). Additionally, RES represented almost 60% of newly installed power capacity globally in the same year (REN21, 2022). According to Li et al. (2023), by 2030, the incorporation of wind power into the global energy mix has the potential to furnish more than 20% of the world's

² <https://www.worldwildlife.org/pages/2020-annual-report>

electricity. A recent study by Zheng et al. (2023) states that by 2050, RES have the potential to meet more than 80% of the world's electricity demand. This transition to RES would bring about substantial reductions in GHG emissions and thereby help alleviate the devastating effects of climate change. Moreover, by promoting the wider use of RE, we can protect the environment for generations to come, ensuring a sustainable future (Nazir et al., 2020). The adoption of RES is not only environmentally beneficial but also economically advantageous (Gielen et al., 2019). The RE sector is growing at an unprecedented rate, with 11 million jobs globally (Xu et al., 2019). This growth in the sector is stimulating economic development and driving global economic growth. In addition, RES are less susceptible to price fluctuations and supply disruptions compared to traditional fossil fuels, which provides stability in energy prices, benefiting businesses and consumers alike (Mukhtarov et al., 2020). The utilization of RE promotes energy independence and reduces dependence on foreign oil, thereby enhancing national security (Ivanovski and Marinucci, 2021).

The principle of environmental sustainability is a major impetus force behind the growth of RE (Güney, 2019). The term "sustainability" refers to the ability of an ecosystem to support life and maintain its diversity and productivity for future generations. The deterioration of the environment and the depletion of natural resources can lead to serious consequences for both human health and the natural world, as well as impact the economy negatively (Perin and Jones, 2019). RES play a crucial role in preserving the environment by reducing pollution and waste from energy systems and promoting the conservation of natural resources (Abbasi et al., 2022). Additionally, relying on RES helps to reduce dependence on non-RES, thereby ensuring their availability for future generations (Kirikkaleli and Adebayo, 2021). Economic growth and environmental sustainability are often perceived as conflicting objectives (Saint Akadiri et al., 2019). On the one hand, economic growth is vital for supporting the growing global population and improving living standards, while on the other hand, environmental sustainability is essential for ensuring access to clean air, water, and a healthy planet for future generations (Hysa et al., 2020). However, it is possible to strike a balance between the two by adopting sustainable business practices and investing in clean technologies (Sandberg et al., 2019). The transition to renewable energy offers a valuable opportunity for economic growth by creating new job opportunities, fostering innovation, and attracting investment (Haseeb et al., 2019;

Majid, 2020). Moreover, sustainable practices and investments in renewable energy can improve the competitiveness of businesses and increase the overall productivity of the economy (Wang et al., 2022). However, it is crucial to approach the transition to RE and sustainability with caution to avoid disrupting the economy. For instance, phasing out fossil fuels too quickly could affect energy supplies and have an adverse influence on the economy (He et al., 2022). On the other hand, investments in renewable energy and sustainable practices can lead to long-term economic benefits, such as reducing dependence on fossil fuels, improving energy security, and promoting a more sustainable future (Amjith and Bavanish, 2022). In conclusion, the interconnection between economic growth and environmental degradation presents significant global challenges. Addressing these challenges requires a collaborative effort from governments, businesses, and individuals, including lowering GHG emissions, investing in renewable energy, and taking steps to reduce environmental degradation. Effective policies and technologies to support this transition will be crucial in ensuring a sustainable future for both the planet and its inhabitants.

Further, the adoption and utilization of RES are subject to diverse influences, encompassing political, social, economic, and technological factors. These multifaceted elements assume a crucial role in determining the pace and extent of renewable energy consumption across various regions and countries. A thorough comprehension of the impact of these factors is essential for the formulation of effective policies and strategies aimed at fostering the adoption and utilization of RES. Consequently, the present thesis delves into the intricate dynamics that influence the adoption and utilization of renewable energy sources in the OECD (Organization for Economic Co-operation and Development) and BRICS (Brazil, Russia, India, China, and South Africa) countries

The OECD is an intergovernmental economic organization, established in 1961, comprising 38 member countries, primarily high-income economies with advanced technological capabilities. Within the framework of the OECD, renewable energy has gained considerable momentum among its member nations. Many OECD countries have set ambitious renewable energy targets, and some, such as Denmark and Iceland, have already achieved a majority of their energy needs through renewables (Cergibozan, 2022). These countries have adopted cutting-edge technologies like solar

photovoltaics (PV), wind turbines, and advanced biomass and geothermal facilities, leading to enhanced efficiency, reduced costs, and improved energy storage capacities, thereby bolstering the competitiveness of renewable energy compared to conventional sources. The governments of OECD countries have played a pivotal role in promoting renewable energy adoption through supportive policies and incentives, such as feed-in tariffs, renewable portfolio standards, tax credits, grants, and subsidies, which stimulate investments in renewable energy projects and advance their development (Croutzet and Dabbous, 2021).

Moreover, these countries have demonstrated their commitment to global environmental goals by aligning their energy transition targets with international agreements like the Paris Agreement, thus reinforcing their determination to combat climate change and reduce greenhouse gas emissions (Melnyk et al., 2020). OECD nations are also at the forefront of research and innovation in the renewable energy sector, hosting pioneering research institutions and innovative companies that strive to enhance efficiency, develop novel materials, and explore emerging technologies like wave and tidal energy. Recognizing the significance of public awareness and acceptance of the successful adoption of renewable energy, OECD countries have launched comprehensive public engagement campaigns to educate the populace about the benefits of renewable energy and address concerns associated with its deployment (Dogru et al., 2020).

International cooperation and knowledge-sharing initiatives have become integral to the renewable energy landscape among OECD countries, fostering collaborative efforts to promote renewable energy development globally. Through research collaborations, the exchange of best practices, and providing technical assistance to developing nations, OECD countries endeavor to create a sustainable energy future on a global scale (Mujtaba et al., 2022). Given their status as major economies, the collective endeavors of OECD countries profoundly impact global energy consumption and climate change. Successfully transitioning to renewable energy, these nations serve as exemplars for other countries, inspiring them to follow suit and embrace cleaner energy solutions (Gozgor et al., 2020). Addressing the imperative of climate change necessitates a reduction in greenhouse gas emissions, and

understanding the factors influencing renewable energy consumption becomes indispensable in crafting effective strategies to steer away from fossil fuels.

Furthermore, the integration of renewable energy technologies can offer considerable economic advantages, including job creation and investments in innovative industries, thereby fostering economic growth and bolstering competitiveness among OECD countries. As vanguards of technology and innovation, OECD countries stand poised to drive further advancements in renewable energy technologies. In-depth studies of the factors influencing their consumption can pinpoint areas for research and development, thereby propelling technological innovations in the renewable energy sector.

The insights and knowledge gleaned from studying renewable energy consumption in OECD countries are invaluable, extending far beyond national boundaries. This wealth of information informs policymakers worldwide, nurturing international cooperation and collaborative efforts to address pressing global energy and environmental challenges. Ultimately, the transition to renewable energy in OECD countries bears considerable significance in combating climate change and achieving sustainable development. By exploring the factors affecting renewable energy consumption, the path towards a cleaner and more sustainable future is paved, advancing the collective goals of sustainable development, energy security, and environmental preservation on a global scale.

The BRICS economies have also made significant strides in embracing renewable energy, indicating the growing importance of this transition (Usman and Makhdum, 2021). The BRICS countries, comprising major emerging economies with substantial energy demands and significant roles in global energy consumption, are endowed with abundant renewable energy resources. The diverse geographical and climatic conditions within the BRICS nations provide them with the opportunity to harness a wide array of renewable sources (Chen et al., 2023).

During the past few years, the BRICS economies have experienced rapid growth in renewable energy capacity, primarily driven by proactive governmental promotion and investment in renewable energy projects (Adebayo et al., 2023). These initiatives aim

to diversify their energy mix and reduce their reliance on fossil fuels. Notably, solar energy has witnessed remarkable growth among the BRICS nations, with China and India leading as global pioneers in solar energy capacity. Both countries have undertaken large-scale solar projects and have ambitious plans for further expansion (Mahalik et al., 2021). Additionally, wind power has gained momentum in BRICS economies, with China and India taking the lead in wind energy capacity installation, capitalizing on favorable wind conditions in various regions. Furthermore, hydropower remains a well-established renewable energy source in several BRICS countries, particularly in Brazil, a major hydroelectric power producer that harnesses its abundant water resources for electricity generation (Nathaniel et al., 2021). Moreover, certain BRICS nations have acknowledged the value of biomass and bioenergy as renewable energy sources, with ongoing exploration into the use of agricultural residues, organic waste, and other biomass materials for power generation and biofuel production (Akram et al., 2021).

To promote the adoption of renewable energy, BRICS governments have implemented diverse policy measures and incentives. These include feed-in tariffs, renewable energy targets, tax incentives, and research grants, all aimed at stimulating private investments in the renewable energy sector (Shah et al., 2022). Additionally, the BRICS countries have shown a keen interest in collaborating on renewable energy initiatives, engaging in joint research projects, technology transfer, and knowledge-sharing to advance renewable energy development. Many BRICS nations have set ambitious energy transition targets and commitments to increase the share of renewable energy in their energy mix, aligning their efforts with broader sustainability and climate change objectives (Wahab et al., 2022).

The considerable strides taken by BRICS economies in embracing renewable energy and transitioning towards cleaner alternatives underscore their firm commitment to sustainable development and the mitigation of global energy and environmental challenges. Considering the collective impact of these nations in terms of global population, land area, and GDP, conducting a comprehensive study on the factors influencing renewable energy consumption within the BRICS framework assumes paramount importance. Insights into these factors can have broader implications for the global energy transition and sustainable development. As economic growth

accelerates and energy demands surge within these economies, renewable energy assumes a pivotal role in meeting these needs while simultaneously mitigating environmental impact and reducing reliance on finite fossil fuel reserves. Analyzing the determinants impacting renewable energy consumption can facilitate the formulation of strategies to address energy requirements in a sustainable manner. Furthermore, given the vast and diverse renewable energy resources available in BRICS nations, a profound comprehension of the factors that facilitate or hinder their effective utilization becomes indispensable in optimizing the deployment of renewable energy.

In summary, a comprehensive examination of the factors influencing renewable energy consumption and the transition towards cleaner energy sources within the BRICS economies holds paramount importance. Given their growing global significance, rapid economic expansion, abundant renewable resources, commitments to climate change mitigation, energy security concerns, technological capabilities, and alignment with sustainable development goals, such analysis provides invaluable insights. These insights can guide policymakers in making judicious decisions, facilitating sustainable energy planning, and fostering international cooperation towards realizing a cleaner, more sustainable, and ecologically responsible energy future. The success of such endeavors not only benefits the BRICS nations but also significantly contributes to global efforts to address the pressing challenges of energy and environmental sustainability.

In the realm of literature on renewable energy and environmental sustainability, certain research gaps have been identified, which are elucidated as follows:

- The existing body of research on REC and its transition towards a sustainable future lacks comprehensive studies that encompass the interplay of multiple factors influencing this transition. Previous research often focuses on specific aspects, leading to a research gap in exploring the holistic interactions and complexities of drivers and barriers impacting the adoption and sustainability of renewable energy. Additionally, the scarcity of studies investigating these factors within both OECD and BRICS economies limits our understanding of potential regional variations in the adoption of green energy technologies.

- The impact of income inequality on green energy consumption and its transition has been largely overlooked in the context of both the OECD and BRICS economies. Income inequality significantly impacts the adoption of renewable energy technologies. Higher-income households have the financial means to invest in technologies like solar panels and energy-efficient appliances, whereas lower-income households often face financial barriers, hindering their ability to access these technologies despite their long-term benefits. Consequently, this results in an unequal distribution of clean energy solutions, perpetuating environmental and economic disparities. Furthermore, income disparities influence political influence, with wealthier individuals and corporations having greater lobbying power, potentially leading to policies that do not align with broader environmental goals. Tax policies and regulations related to renewable energy can also favor higher-income groups. Moreover, wealthier communities are better equipped to invest in infrastructure supporting renewable energy, leading to disparities in the availability and reliability of clean energy sources. Community-based renewable energy projects, which offer benefits like local job creation and reduced energy costs, may face feasibility challenges in lower-income communities due to limited resources. Additionally, the significance of studying income inequality lies in its connection to several outcomes that can influence the adoption of renewable energy sources. For instance, income inequality has been linked to health and well-being (Zhang and Awaworyi Churchill, 2020; Gugushvili et al., 2020), environmental factors (Sager, 2019), and economic growth (Aiyar and Ebeke, 2020). Considering that addressing income inequality may lead to social advantages and positive externalities that accelerate the adoption of renewable energy, it is imperative to empirically examine the relationship between renewable energy consumption and income inequality to inform policymaking.

- The influence of trade liberalization policies (TLPs) on the green energy transition in OECD countries remains underexplored within the literature on green energy and environmental sustainability. TLPs can have a profound impact on renewable energy consumption by fostering an environment conducive to the growth of clean energy industries. When trade barriers are reduced or eliminated, it becomes easier for countries to import and export renewable energy technologies, components, and expertise. This leads to increased market competition and economies of scale, driving down the costs of renewable energy infrastructure. As a result, solar panels, wind

turbines, and other green technologies become more affordable and accessible to a wider range of consumers and businesses. Additionally, trade liberalization can facilitate the exchange of knowledge and best practices in renewable energy development, allowing countries to learn from each other's successes and innovations. This cross-pollination of ideas and technologies can accelerate the transition towards sustainable energy systems on a global scale. Furthermore, access to international markets can incentivize domestic industries to invest in research and development, spurring technological advancements in renewable energy. Despite the significant role of international trade in shaping energy markets and environmental policies, limited research focuses on how trade openness affects the adoption and advancement of renewable energy technologies. This research gap hampers a comprehensive understanding of the relationship between trade liberalization and the promotion of sustainable energy practices.

- Prior research on the determinants of REC has predominantly focused on analyzing groups of countries collectively, neglecting to investigate the impact of these determinants within each individual country. This study endeavors to address this research gap by examining the influence of various social, economic, technical, and environmental factors on REC and its transition within two distinct groups of countries: the OECD countries and the BRICS countries. Moreover, this research surpasses conventional group-level analysis and conducts a separate investigation for each country within these designated groups.

The current thesis endeavors to make a substantial contribution to the existing body of knowledge by conducting an in-depth investigation and analysis of the intricate interplay of environmental, social, economic, and technological factors that exert influence on renewable energy consumption and its journey towards a sustainable future in both OECD and BRICS economies. To achieve this goal, the research adopts a comprehensive approach by analyzing multiple dimensions, including trade liberalization policies, CO₂ emissions, technological innovation, income inequality, economic growth, capital formation, and oil prices. By examining these facets, the study presents a holistic perspective on the drivers of green energy adoption in both the OECD and BRICS regions.

Further, Prior research on the determinants of REC has predominantly focused on analyzing groups of countries collectively, neglecting to investigate the impact of these determinants within each individual country. This study endeavors to address this research gap by examining the influence of various social, economic, technical, and environmental factors on REC and its transition within two distinct groups of countries: the OECD countries and the BRICS countries. Moreover, this research surpasses conventional group-level analysis and conducts a separate investigation for each country within these designated groups. This comprehensive approach enables us to uncover more intricate and policy-oriented insights concerning both the groups as a whole and the unique characteristics of each individual country. By discerning the specific factors influencing REC at the country level, our study contributes valuable information that can inform tailored policies and strategies, fostering the accelerated adoption of renewable energy sources. Ultimately, the research aims to facilitate a more sustainable and efficient energy transition within the OECD and BRICS countries, taking into account their distinctive attributes and challenges in embracing renewable energy technologies.

Furthermore, the thesis addresses the research gap related to income inequality and its impact on renewable energy consumption patterns and sustainability. By investigating the interplay between income inequality, economic growth, and the adoption of green energy, the research sheds light on the socio-economic dimensions of the transition to sustainable energy sources. Another noteworthy contribution of the thesis lies in its examination of the influence of trade liberalization policies on the green energy transition within OECD countries. Through an investigation of the interconnected relationships among environmental degradation, green energy consumption, and oil prices in the context of trade openness, the research provides valuable insights into how international trade policies can shape the progress of sustainable energy initiatives.

Moreover, numerous scholars in the realm of panel data analysis have investigated the impacts of diverse economic, social, and political factors on REC across various regions and countries. However, these studies utilized statistical techniques that did not consider the existence of slope heterogeneity (SH) and cross-sectional dependence (CSD), thereby increasing the likelihood of generating erroneous conclusions and

compromising the accuracy of the results. Consequently, researchers must account for these issues while analyzing data that encompasses multiple observations of diverse entities such as countries, individuals, or firms. One of the panel data models that can be used to address these issues is the AMG estimator. The AMG estimator is a statistical technique that is commonly employed to estimate the parameters of dynamic panel data models characterized by heterogeneous slope coefficients (Kong et al., 2020). Dynamic panel data models are widely used in the social sciences and economics to study data that involves multiple observations over time and across entities. The AMG estimator is an extension of the mean group (MG) estimator and pooled mean group (PMG) estimator, which assume constant slope coefficients across entities and constant slope coefficients over time, respectively. The AMG estimator combines the strengths of the MG and PMG estimators by allowing for both time-varying coefficients and heterogeneous slope coefficients (Badmus et al., 2022). To implement the method, the model parameters are first estimated using the PMG estimator and then adjusted to account for heterogeneity in the slope coefficients through a transformation of the residuals. The AMG estimator is an essential tool as it produces more accurate and dependable estimates of the model characterized by heterogeneous slope coefficients (Paramati and Roca, 2019). By accounting for CSD and SH, the AMG estimator can enhance the efficiency of estimates and improve the statistical inference of the analysis (Xia et al., 2022). This is particularly relevant in fields such as economics, where precise parameter estimation is critical for policymaking and gaining insights into the underlying relationships between variables.

In light of the aforementioned discussion, this thesis utilizes robust panel data techniques, such as the AMG estimator, to explore the impact of various factors, including technological innovations, economic growth, oil prices, capital formation, income disparity, and environmental degradation, on renewable energy consumption and its transition towards a sustainable future. By examining the role of these factors, the research contributes to the development of informed policies and strategies for promoting renewable energy adoption and achieving sustainable energy goals. Specifically, technological innovations play a crucial role in making renewable energy technologies more competitive and accessible, while economic growth and capital formation can shape energy consumption patterns and create opportunities for sustainable energy solutions. Moreover, understanding the impact of oil prices and

trade liberalization policies is essential for mitigating energy security risks and promoting international cooperation in the transition to green energy sources. Finally, addressing income inequality ensures equitable access to renewable energy resources, contributing to the overall sustainability and inclusiveness of the energy transition.

The current thesis seeks to address the following research questions:

- What are the factors that influence renewable energy consumption in OECD economies?
- How do trade openness, income inequality, GDP growth, environmental degradation, renewable energy, and oil prices interact with each other in OECD countries?
- What are the main drivers of renewable energy consumption in the BRICS economies?
- Can REC be influenced by the dynamics of income inequality in the BRICS economies?
- What are the potential trade-offs and synergies between GDP growth, income disparity, capital formation, innovation, and REC in the BRICS economies?
- How does the relationship between trade liberalization policies and the green energy transition vary across different OECD countries?

The current thesis delves into issues pertaining to economic sustainability, environmental sustainability, and energy policies, thereby contributing to the academic and research communities. The study offers valuable insights into the design and implementation of future energy and economic policies and provides policy implications for promoting green energy globally, with specific emphasis on OECD and BRICS nations. The practical significance of the empirical outcomes of the study lies in their usefulness for policymakers, providing guidance for decisions on REC, sustainable growth, and the reduction of carbon emissions in OECD and BRICS economies.

The thesis follows a structured organization as outlined below:

Chapter I offers an introduction and overview of the thesis, presenting its objectives, research gaps, research questions, and contributions. **Chapter II** presents an extensive overview of renewable energy sources, encompassing a comprehensive examination of various aspects, including the renewable energy policy landscape, renewable energy market trends, renewable energy investment trends, and renewable-based energy systems. The chapter aims to provide a thorough understanding of the diverse components that constitute renewable energy sources and the dynamic trends and developments shaping the renewable energy sector. **Chapter III** scrutinizes the effects of trade openness, income disparity, economic development, environmental degradation, and oil prices on renewable energy consumption in OECD countries. **Chapter IV** investigates the influence of innovations, income disparity dynamics, and GDP growth on the adoption of renewable energy and its role in supporting environmental sustainability in BRICS economies. **Chapter V** aims to determine whether trade liberalization policies can advance the transition to renewable energy by promoting trade openness. Additionally, this chapter analyzes the influence of GDP growth, environmental degradation, and oil prices on renewable energy consumption, as well as the interrelationships among these variables in the context of OECD economies. Lastly, **Chapter VI** succinctly summarizes the thesis's findings and provides policy implications derived from these findings. Additionally, it offers directions for future research and addresses the limitations encountered during the study.

CHAPTER II

AN OVERVIEW OF RENEWABLE ENERGY SOURCES

Renewable energy sources (RES), also known as green or sustainable energy sources, are natural resources that can be replenished continuously or at a rate equal to or greater than their rate of consumption. Unlike non-renewable sources like fossil fuels (coal, oil, and natural gas), renewable energy sources are considered environmentally friendly and have a minimal impact on climate change and air pollution. These energy sources can be categorized into different types, as demonstrated in Figure 2.1 (Kebede et al., 2022).

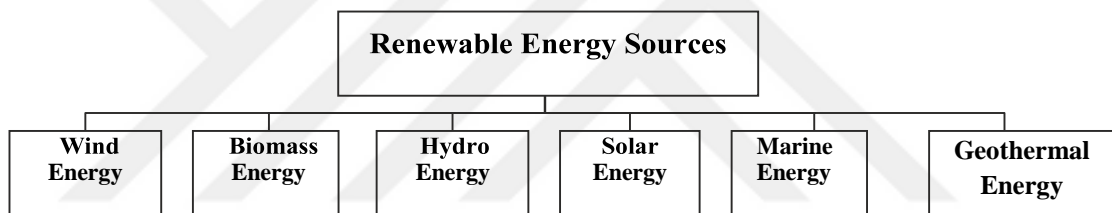


Figure 2.1. Renewable Energy Classification (Kebede et al., 2022)

The deployment of RE technologies has experienced significant growth in recent years, making renewable energy an increasingly important source of power in many economies across the world. In 2021, the growth of RES was affected by the COVID-19 pandemic and the increased global commodity costs that disrupted supply chains and delayed projects. However, despite these setbacks, RES still achieved a record growth in power capacity (IEA, 2022). Figure 2.2 provides an overview of the portion of modern RES in overall energy generation from 2009 to 2020. In 2009, 8.7% of global energy generation came from modern RES such as hydro power, renewable heat, biofuel, and other renewable sources (excluding traditional uses of biomass). This figure increased to 11.7 percent in 2019. In 2020, modern renewables' share increased further to 12.6%, with hydropower, renewable heat, biofuel, and other renewables accounting for 3.9%, 4.8%, 1%, and 2.8%, respectively. Despite a decrease in energy

demand due to the COVID-19 pandemic, the share of non-renewables (at 79.6% in 2019 and 78.5% in 2020) changed little between the two years. Additionally, the investment in RES amounted to an impressive USD 366 billion, leading to a remarkable surge in global power production. This investment has enabled solar and wind power to contribute over 10% of the world's power in 2021 (Abba et al., 2022). Political commitments to renewable electricity use in heat pumps and electric vehicles have also strengthened. However, the shift to renewable-based energy systems still faces significant obstacles. These include the increase in global demand for electricity, which rose by 4% in 2021 and was primarily met with natural gas and coal, resulting in record CO₂ emissions (Yang et al., 2022). Further, a large amount of money was put into and supported non-renewables, with USD 5.9 trillion spent in 2020 equal to approximately 7% of the world's GDP (Liu et al., 2022). In 2019, renewables only accounted for 28% of electricity sector usage, while electrical end-uses only accounted for 17% of overall energy consumption. The lowest percentage of renewables was in the transportation sector (3.7%), and the remaining thermal energy uses accounted for more than half (51%) of overall energy consumption, with renewables contributing just 11.2% (IEA, 2022). Despite the progress made in RE, the slow growth in energy efficiency, energy conservation, and renewable energy adoption hinders the necessary shift away from non-renewables to meet the world's energy needs and lower GHG emissions. In order to achieve a more secure, affordable, resilient, and sustainable energy future, it is imperative that the energy system undergo a structural change that is based on renewable energy and energy efficiency.

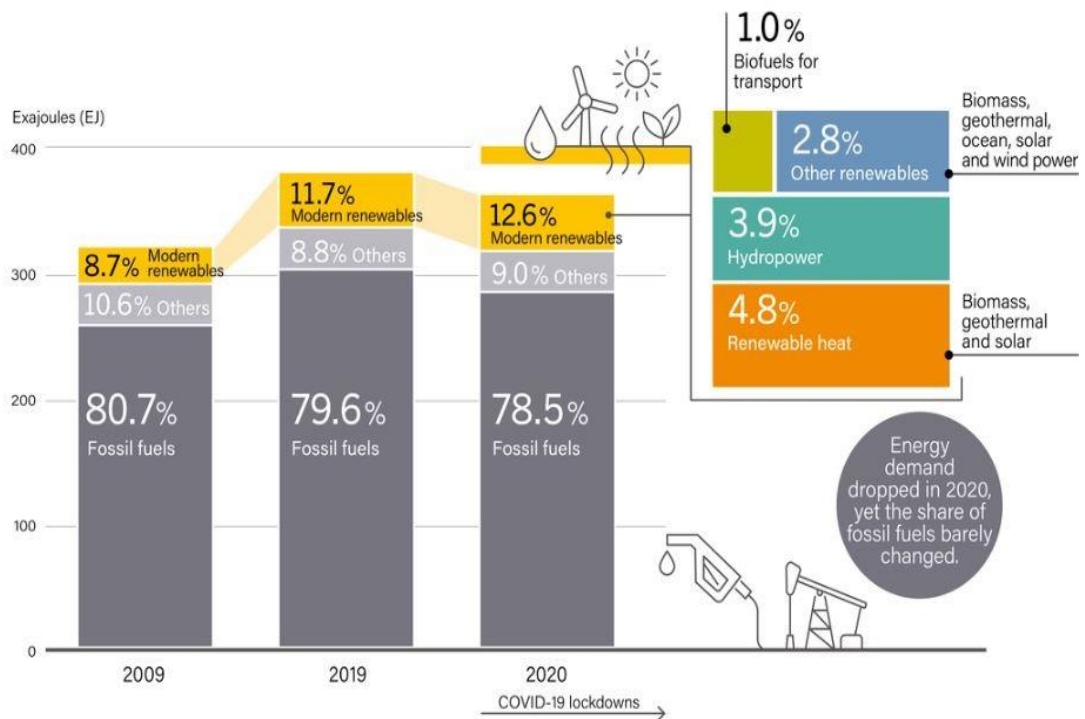


Figure 2.2. Share of Modern RES from 2009 to 2020 (IEA, 2022)

2.1. The Role of Renewable Energy in Diverse Sectors

Renewable energy assumes a pivotal role across diverse sectors, making a substantial contribution to sustainable development and ameliorating the detrimental impacts of climate change. The pervasive integration of renewable energy sources is catalyzing transformative changes in crucial sectors, encompassing the electricity sector, buildings, transportation, industrial, and agricultural domains. The subsequent overview outlines the multifaceted applications of renewable energy in each of these sectors:

2.1.1. Renewable Energy in the Electricity Sector

The renewable energy sector has made substantial strides in recent years, driven by the significant growth of wind power and solar photovoltaic (PV) technologies. Despite encountering various challenges such as disruptions in supply chains, shipping delays, and soaring prices of solar and wind energy components, the capacity additions of green power rose by 17% in 2021, achieving an unprecedented milestone of over 314

gigawatts (GW) of added capacity (IEA, 2022). Moreover, the total installed capacity of green power also increased by 11% to approximately 3146 GW. However, this growth falls short of meeting the global net-zero emissions target by 2050 (Su et al., 2022). In 2021, wind and solar power collectively accounted for more than 10% of global power generation (Akadiri et al., 2022). Notably, China emerged as the first country to surpass 1 terawatt of installed capacity of RE in 2021, adding 136 GW of RE capacity, which constituted around 43% of the global increase, excluding concentrating solar power (CSP) (Song et al., 2022). At the end of 2021, the number of countries with non-hydropower renewable capacity exceeding 10 GW increased to 22, compared to only nine countries in 2011. RES continued to account for an increasing proportion of net power additions, reaching an all-time high of 84% of newly built capacity. In 2021, RES generated 28.3% of the world's electricity, up from 20.4% in 2011 and on par with 2020 levels (28.5%) (see figure 2.3).

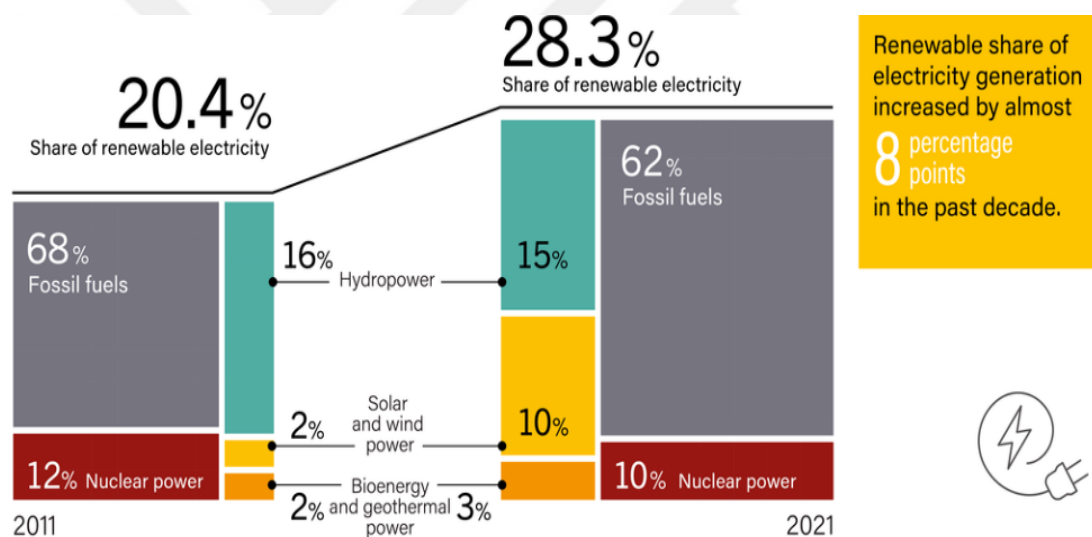


Figure 2.3. Share of Green Electricity in Global Power Generation (IEA, 2022)

2.1.2. Renewable Energy in Buildings

RES play a pivotal and indispensable role in mitigating the carbon emissions associated with buildings and enhancing their energy efficiency. The construction and operation of buildings significantly contribute to GHG emissions, primarily through energy consumption for lighting, heating, cooling, and other functions (Langevin et al., 2019). In recent years, there has been a remarkable increase in the utilization of

RE in buildings, as depicted in Figure 2.4, which presents the proportion of RE in the building sector. The share of RE in final building energy consumption has risen from 10.7% in 2009 to 14.7% in 2019. Green electricity and modern bio-heat have emerged as the predominant sources of RE in buildings. However, despite this commendable progress, the overall energy demand of buildings continues to escalate, encompassing both the energy consumed during the construction phase and the operational phase. Notably, two-thirds of renewable heat in buildings is derived from direct utilization of modern RE, while the remaining portion is sourced from indirect means such as district heating and electricity. Furthermore, the adoption of green electricity for heat generation in buildings has been growing at an annual rate of 5.3%, with the share of electricity in building heating increasing from 2.0% to 3.3% between the period of 2009 to 2019 (IEA, 2022). In developing economies, traditional biomass still fulfills a significant portion of the global heating requirements for buildings. Nevertheless, the share of traditional biomass in building heating has declined from 30% in 2009 to an estimated 26% in 2020 (Jiang et al., 2022). In the year 2021, government policies have played a pivotal and instrumental role in promoting the adoption of RE in buildings through mechanisms such as pricing, regulatory measures, and financial support (Rabbat et al., 2022). However, it is noteworthy that despite these commendable efforts, incentives for non-renewable-based appliances persist, potentially undermining the efficacy of RE policies. Moreover, the growth of RE use in buildings has been limited due to several factors, including the rebound in worldwide energy demand and a lack of adequate financial incentives. Additionally, the sluggish progress in energy efficiency and conservation poses a formidable challenge to the transition towards green energy-based systems in buildings. To realize a sustainable energy future, it is imperative to proactively address these challenges through the implementation of robust policies and the provision of compelling incentives to foster the widespread adoption of renewable energy in buildings.

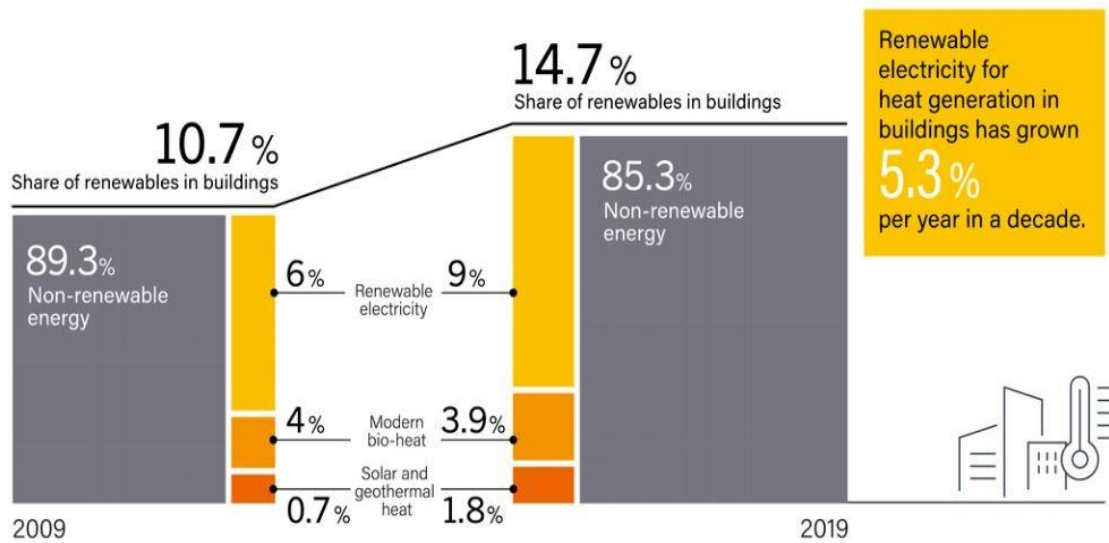


Figure 2.4. Share of Renewable Energy in Buildings (IEA, 2022)

2.1.3. Renewable Energy in Industrial and Agricultural Sectors

The adoption of RES in the industrial and agricultural sectors offers several benefits, including the mitigation of GHG emissions, decreased energy costs, enhanced energy efficiency, and increased energy security (Golmohamadi, 2022; Raihan and Tuspekova, 2022). In the industrial sector, RES can be used to power industrial processes and diminish the dependence on traditional non-renewables. Similarly, the use of biomass to generate heat for industrial processes can reduce the reliance on non-renewables and improve the sustainability of the manufacturing sector. RES can also be used to improve the energy efficiency of industrial processes. For example, the implementation of energy-efficient pumps, motors, and energy management systems, can help reduce the energy consumption of industrial processes (Philibert, 2017). Additionally, the use of RES can help reduce the energy costs associated with industrial processes, which can be a significant cost for many industries (Chang and Lee, 2016). In the agricultural sector, RES can be used to power irrigation systems, reduce the energy costs of crop drying, and power other agricultural operations. For example, the use of solar power to power irrigation pumps can reduce the energy costs associated with irrigation, which can be a significant cost for many farmers (Rahman et al., 2022). Similarly, the use of biomass to power crop drying systems can reduce the energy costs associated with this process. RES can also be used to improve the

sustainability of agricultural operations. For example, the use of biogas from livestock manure for heat and power generation on farms would diminish dependence on non-renewables and improve the sustainability of agricultural operations (Paris et al., 2022).

Further, renewable sources of energy hold considerable promise in mitigating the carbon footprint of the industrial and agricultural sectors (Tutak and Brodny, 2022). These sectors are substantial contributors to global GHG emissions, primarily through the use of energy for industrial processes and agricultural operations. In the industrial sector, the burning of fossil fuels for energy production constitutes a key contributor to carbon emissions. The production of cement, steel, and other materials also releases significant amounts of CO₂ (Bogdanov et al., 2021). The industrial sector accounts for approximately 37% of global CO₂ emissions. The largest emitters in the industrial sector are the manufacturing, construction, and power generation industries. The manufacturing sector alone accounts for approximately 21% of global CO₂ emissions (IEA, 2022). The agricultural sector also contributes to CO₂ emissions through the utilization of non-renewables in agricultural operations, such as tractors, irrigation systems, and crop drying. In the agricultural sector, emissions from the usage of non-renewables and the release of methane and nitrous oxide from livestock, rice cultivation, and fertilizer use contribute to greenhouse gas emissions (Usman and Makhdum, 2021). The agricultural sector accounts for approximately 10–12% of global greenhouse gas emissions (IEA, 2022).

Over the past decade, there has been an increase of four percentage points in the proportion of RE in the agriculture and industry sectors, driven primarily by the electrification of industrial processes (Thrän et al., 2020). However, the share of green energy in the overall final energy demand in the end-use sectors remained low. Figure 2.5 presents the proportion of RE in the industrial and agricultural sectors from 2009 to 2019. During this period, the renewable energy share in the industry and agriculture sectors' TFEC has increased from 12.5% to 16.1%. Approximately half of this RE is utilized for heat production, primarily obtained from modern bioenergy, with minor contributions from solar thermal and geothermal sources. The remaining half is generated from green electricity. The use of green electricity for industrial heating has experienced an 80% increase from 2009 to 2019, which is attributed to the growing

trend of electrifying industrial processes (IEA, 2021). Furthermore, there have been multiple pilot projects implemented in challenging-to-decarbonize sectors, such as steel production, to demonstrate the viability of utilizing renewable hydrogen for industrial applications. Despite limited direct RE policies in the industry sector in 2021, governments have expressed their commitment to supporting decarbonization efforts in steel and concrete production and have developed industry-specific decarbonization roadmaps that incorporate the utilization of RE and renewable hydrogen (IEA, 2022).

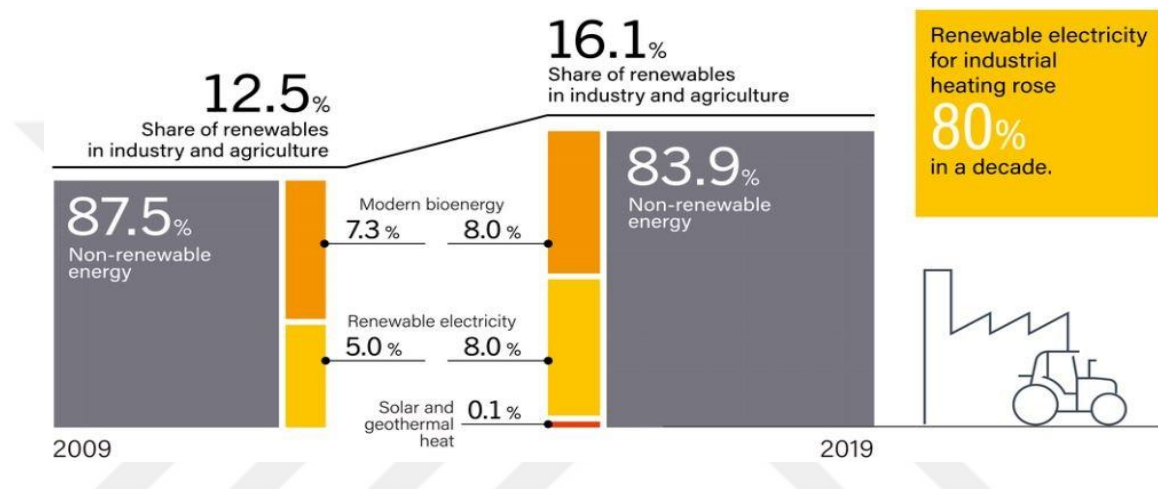


Figure 2.5. Share of Green Energy in Industrial and Agricultural Sectors
(IEA, 2021)

2.1.4. Renewable Energy in Transportation

The transportation sector stands as a prominent contributor to global GHG emissions, serving as a primary catalyst for climate change (Bai et al., 2020). Thus, the incorporation of RES in transportation bears paramount importance in curbing these emissions and mitigating the adverse effects of climate change. The utilization of RE in the transportation domain offers a plethora of advantages, including the reduction of GHG emissions, abatement of air pollution, and enhancement of energy security (Amin et al., 2020). RES such as biofuels, electric power, hydrogen fuel cells, and solar power can be used to power vehicles in the transportation sector. Biofuels are fuels derived from organic matter, such as corn, sugarcane, or vegetable oil. They can be blended with traditional fossil fuels or used on their own in specially designed-

engines (Sarkar et al., 2021). Electric vehicles (EVs) operate by utilizing electricity to power their motors, which can be generated from RES such as hydropower, solar power, or wind power (Li et al., 2019). Hydrogen can be produced from renewable sources and used in fuel cells to power vehicles, producing only water as a byproduct (Shirwani et al., 2020). Moreover, solar energy can be harnessed to produce electricity for EVs or to power charging stations (Kou et al., 2022).

Over the past decade (2009–2019), the proportion of RE in the transportation sector has substantially increased (IEA, 2022). As depicted in Figure 2.6, the proportion of renewable electricity and biofuel has risen from 0.2% and 0.4%, respectively, in 2009 to 2.2% and 3.3%, respectively, in 2019. Furthermore, the overall proportion of RE has surged from 2.4% to 3.7% during this period. In addition, biofuel production has surpassed pre-pandemic levels for both biodiesel and ethanol in 2021 (IEA, 2022). Although hydrogen and synthetic fuels have gained traction in some regions as transport fuels, there has been limited investment in renewable hydrogen. However, across nearly all modes of transportation, electrification has witnessed a notable increase in 2021. This growth can be attributed to targets and policy support for EVs, along with technological progress, advancing economic competitiveness, and the increased availability of such vehicles. In fact, global sales of electric cars, as well as other electric vehicles like two- and three-wheelers and buses, have experienced a substantial upswing in 2021, with electric car sales alone reaching a remarkable 6.6 million, more than double the number sold in 2020 (Yuan et al., 2021). Nevertheless, despite the presence of renewable energy targets in the transport sector, many countries have fallen short of meeting these targets. This can be primarily attributed to the lack of supportive policy frameworks that promote an effective transition towards sustainable energy and transportation or to the inadequacy or lack of enforcement of existing frameworks (Nadolny et al., 2022).

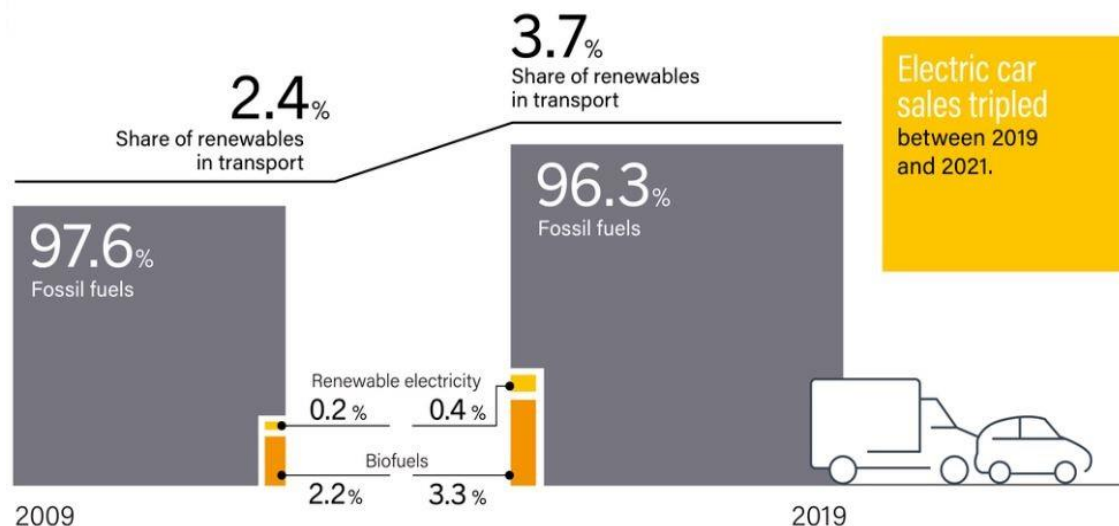


Figure 2.6. Proportion of Green Energy in the Transportation Sector (IEA, 2022)

2.2. Renewable Energy Policy Landscape

The unwavering dedication to supporting RES through policy measures, particularly in the power sector, has remained steadfast as the global transition towards a low-carbon and sustainable economy gains traction (Bashir et al., 2022). According to Figure 2.7, a substantial number of countries, totaling 156, have implemented regulatory policies for RE in the power sector in 2021. These policies include mechanisms such as tendering, feed-in tariffs (FITs), net metering, feed-in premiums, and renewable portfolio standards. Additionally, 70 countries have implemented transport policies, including mandates for ethanol, biodiesel, and non-blend fuels, while 26 countries have instituted cooling and heating policies, such as renewable heat FITs and solar heat obligations.

It is noteworthy that nearly all nations across the globe have adopted strategies to incentivize the widespread adoption of RE technologies (IEA, 2022). However, the majority of these policies have primarily targeted the power sector, with relatively fewer efforts focused on promoting RE usage in other sectors, such as buildings, transport, and industry. Nevertheless, there has been a growing emphasis on

electrifying end-use sectors, such as heating and road transport, which has increasingly become a priority for policymakers.

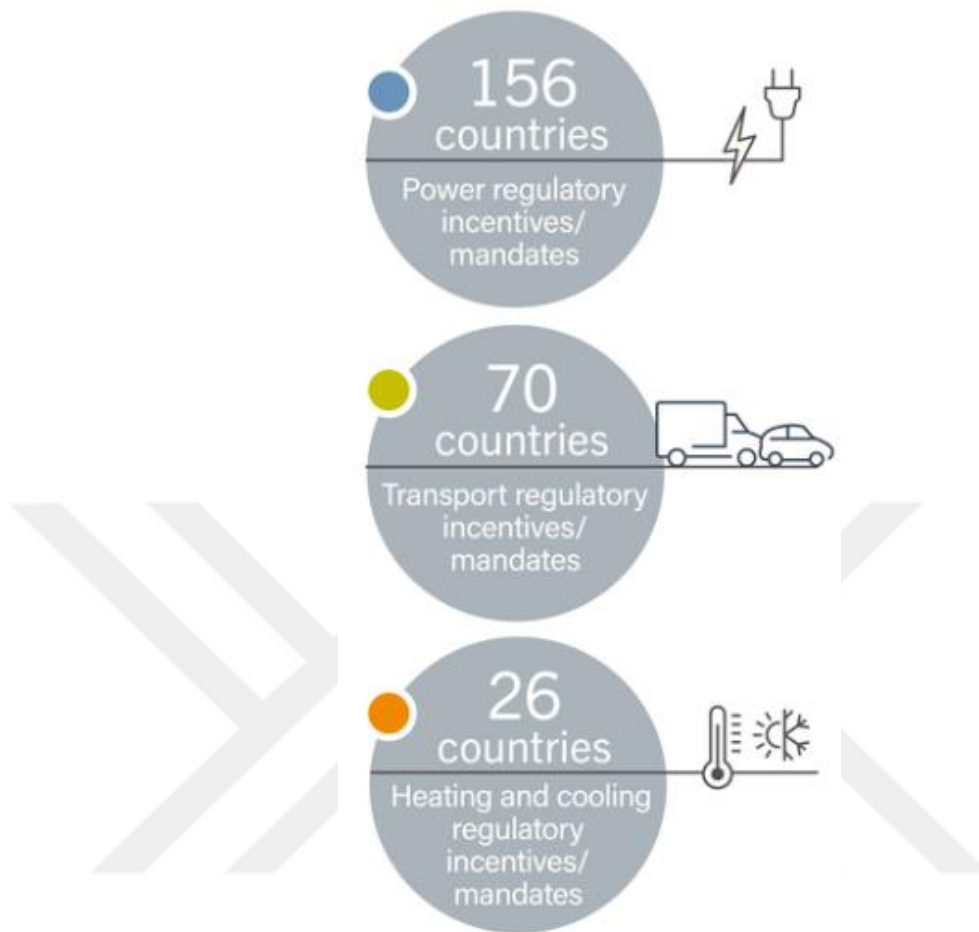


Figure 2.7. Global Green Energy Policy Landscape in 2021 (IEA, 2022)

2.2.1. Climate Change Policies

In recent years, there has been a noteworthy acceleration in the adoption of climate change policies, especially as nations have made commitments and announced targets to achieve net-zero emissions leading up to the UN climate talks in Scotland. The implementation status of these policies is presented in Figure 2.8, which outlines the net-zero policies of various countries in 2021 (REN21, 2022). Approximately 88% of global emissions are accounted for by 135 countries and the European Union (EU), which have established some form of net-zero targets (REN21, 2022). The EU has implemented several policies, such as the Emissions Trading System (ETS) and the Renewable Energy Directive, and has committed to achieving net-zero emissions by

2050 (Dechezleprêtre et al., 2023). Similarly, China has pledged to attain carbon neutrality by the year 2060 and is investing significantly in renewable energy and policies to reduce emissions from industrial production. India has also committed to reducing its emissions intensity by 33–35% from 2005 levels by the year 2030, to generate 40% of its electricity from RES, and has launched various initiatives to promote renewable energy and energy efficiency (Wesseh et al., 2022). Furthermore, some countries, including Brazil and Japan, have set net-zero targets for 2050 and implemented policies to scale up renewable energy and promote energy efficiency (REN21, 2022). The implementation of net-zero targets varies significantly among countries, as many targets are not supported by specific legislation.

In the year 2021, a mere one-fifth of countries globally had officially enshrined net-zero targets into their legal frameworks, while approximately half of the countries had incorporated such targets into some form of policy. The remaining one-third of countries were still in the preliminary stage of making declarations regarding net-zero goals. It should be noted that some developing countries, including Bhutan, Guinea-Bissau, Cambodia, Benin, Gabon, Guyana, Liberia, Suriname, and Madagascar, have already attained net-zero emissions. However, these countries take into account the significant role of forests as natural carbon sinks. Furthermore, out of the 135 nations that have set net-zero targets, only 84 have established comprehensive RE targets that encompass their entire economies. Even more concerning is that only 36 of these countries have set targets for achieving 100% RE, indicating a significant disparity between the commitments made towards net-zero goals and actual plans for scaling up RES. In recent times, policymakers have increasingly focused on decarbonizing the transportation sector, with some governments announcing bans on the utilization of non-renewables in road transport as a means of enhancing policy support for net-zero initiatives (REN21, 2022).



Figure 2.8. Countries' Net Zero Policies and Progress in 2021 (REN21, 2022)

2.2.2. Economic Development and Renewable Energy Targets

RES have emerged as a central pillar of national economic development strategies, as concerns surrounding energy security and escalating energy costs have propelled the integration of renewables into these plans. In the aftermath of the global COVID-19 pandemic, many countries have set ambitious renewable energy targets as part of their post-recovery plans. These targets aim to support the green energy transition and accelerate the shift towards a low-carbon economy (Chong et al., 2022). As of the conclusion of 2021, a total of 169 countries have implemented a diverse array of targets, at either the national or subnational level, with the aim of bolstering the adoption of RES across various sectors of their economies (IEA, 2022). For instance, the United States has established a goal of achieving 100% clean energy in the power sector by 2035, accompanied by interim objectives to reduce GHG emissions by 50% by 2030 and achieve net-zero emissions by the year 2050. The U.S. has also announced intentions to invest a staggering \$2 trillion in RE and infrastructure over the next four years (Chen et al., 2022). China has set a target to derive 35% of its electricity generation from RES by 2030, with the ultimate aim of achieving carbon neutrality by 2060 (Yao et al., 2022). The EU has established a target of achieving a minimum of 32% of its overall energy demand from RES by 2030, with individual member states setting their own national targets. Furthermore, the EU seeks to increase the proportion of RE in the transport sector to 14% and the proportion of RE in the cooling and heating

sectors to 40% (Stec and Grzebyk, 2022). India has set a target of obtaining a colossal 450 GW of RE capacity by 2030. Of this, 280 GW is expected to come from solar power, 140 GW from wind power, and the remaining from other renewable sources such as biomass, small hydro, and waste-to-energy (Kumar et al., 2022). The UAE has set an ambitious target of increasing the proportion of RE in its energy mix to 50% by 2050 as part of its overarching objective to reduce its carbon footprint by 70% and augment the contribution of RE to its overall energy mix. Japan has established a target to increase its RE share to 22-24% of overall electricity generation by 2030, with a goal to increase its total renewable energy capacity to 24-27% of its total energy mix by 2030 (Al-Sarihi and Mansouri, 2022). However, it is important to note that the targets mentioned earlier, which were specific to individual countries or groups of countries, were largely concentrated in the power sector, consistent with the trends observed in previous years. In contrast, a substantial number of targets related to the areas of transport, cooling, and heating had lapsed in 2020, with only a limited number of economies introducing new targets in 2021 to supplant them (REN21, 2022).

Further, in line with previous years, competitive pricing strategies such as auctions and tenders continued to be preferred over pricing policies set administratively, such as FITs. Although there are no existing nationwide mandates for rooftop solar PV installations on buildings, certain states or provinces have implemented such policies, particularly for new constructions or significant house renovations, with the aim of promoting small-scale RE generation (Tanaka et al., 2022). Overall, the adoption of RES is recognized as a crucial element in addressing climate change and promoting economic growth. The setting of ambitious renewable energy targets by countries around the world is a positive step towards achieving these goals.

2.2.3. Policies for Cooling and Heating in Buildings

In spite of the considerable potential of renewable cooling and heating technologies in the context of buildings, policy advancements in this domain have been limited. Globally, buildings still heavily rely on fossil fuels for their heating needs. In 2021, 29 countries had committed to targets aimed at increasing the adoption of renewable cooling and heating in buildings. Although this represents an increase from the 19 goals set in 2020, it remains a modest increase, with many expired targets not being

replaced (IEA, 2022). Financial incentives have emerged as the most prevalent form of policy support employed to scale up the adoption of renewable heating (Meles and Ryan, 2022). In Europe, the EU's Energy Efficiency Directive mandates that all member states attain a minimum of 32% improvement in energy efficiency by 2030, with a specific focus on buildings (Hainsch et al., 2022). In the United Kingdom, a 2019 amendment to the Climate Change Act set a goal to attain net-zero emissions by 2050, including emissions from buildings. Furthermore, the UK government has established a goal to phase out the installation of non-renewable-based heating systems in new houses by 2025 (Akomea-Frimpong et al., 2022). In the USA, several states have set targets for the adoption of renewable cooling and heating technologies in buildings, with California, New York, and Massachusetts being among the leaders in this area (Li et al., 2022).

2.2.4. Policies for the Transportation Sector

In recent times, significant attention has been directed towards renewable energy policies as a means of fostering sustainable development in the transportation sector. Notably, the focus has been primarily on road transportation, while other modes such as rail, aviation, and shipping have received comparatively less emphasis (Yu et al., 2023). Although biofuel support policies have been prevalent in the transport sector, there has been no increase in the number of countries implementing biofuel mandates. Instead, policy attention has shifted towards the electrification of transportation, with road transportation being a key focal point (Dai et al., 2023). For instance, the EU has set a goal of having at least 14 million EVs on the road by 2030 and is providing financial incentives to support the purchase of electric vehicles (Cerruti et al., 2023). Similarly, the Chinese government has set a target of having 20% of all new car sales be electric vehicles by 2025 (Zahoor et al., 2023). In the United States, several states have set renewable energy targets for the transportation sector. For example, California aims to have 5 million EVs on the roads by 2030, while New York aims to have 850,000 EVs on the roads by 2025. These goals are supported by financial incentives, such as rebates and investments in electric vehicle charging infrastructure (Fayziyev et al., 2022). However, there is a need for continued efforts to encourage the adoption of RES in the transport sector, with a focus on developing comprehensive policies that support the adoption of clean energy sources across all modes of transportation.

2.2.5. Policies for Industrial and Agricultural Sectors

Numerous countries worldwide have put in place renewable energy policies and targets for their industrial and agricultural sectors to mitigate their carbon footprints and transition toward sustainable development (IEA, 2022). For instance, Germany has established the Renewable Energy Sources Act, which seeks to increase the proportion of RE in the country's energy mix. This policy comprises measures to encourage the utilization of RE in the industrial and agricultural sectors, such as providing financial incentives and grants to improve energy efficiency and installing RE systems (Krug et al., 2022). Similarly, China has implemented several renewable energy policies, including the Top-Runner Program, which stimulates the adoption of energy-efficient technologies and renewable energy systems in industries (Qi et al., 2023). The United States has implemented various renewable energy policies, such as the Advanced Manufacturing Partnership, which promotes the integration of renewable energy technologies in manufacturing processes. Moreover, several states in the U.S. have set renewable energy targets for the agricultural sector, such as California's objective to generate 50% of its agricultural energy from RES by 2030 (Bashir et al., 2022). India has put in place several policies, such as "the Kisan Urja Suraksha Evam Utthan Mahabhiyan scheme," which seeks to install solar pumps for agricultural purposes (Akadiri and Adebayo, 2022). Brazil has implemented several policies, including the RenovaBio program, which aims to boost the use of biofuels in the transportation and industrial sectors. This program incorporates measures like tax incentives and the establishment of a certification system for biofuels (Grangeia et al., 2022). However, renewable hydrogen has emerged as a promising technology to facilitate industrial decarbonization. While numerous nations have announced support plans for hydrogen in 2021, the majority of hydrogen production still relies on fossil fuels. Nevertheless, in 2021, 38 countries and the EU established a hydrogen roadmap to promote the development of this technology (IEA, 2022). In addition, there has been a growing interest in the use of renewables in agriculture, with a particular focus on agri-voltaics. This promising technology has the potential to facilitate sustainable agricultural practices by simultaneously generating clean energy and agricultural products from the same land (Jain et al., 2021).

2.3. Renewable Energy Market Trends

The renewable energy market has experienced rapid expansion in recent times, with solar and wind power emerging as key players in the shift towards a more sustainable energy system. The IEA predicts that RES will constitute almost 90% of the world's newly added power capacity by 2025 (IEA, 2022). This growth has been fueled by a combination of government policies, falling technology costs, and increased public awareness of the need for sustainable energy sources. In addition, there has been a notable surge in investments in RE, both from the private sector and from public institutions, leading to further advancements in technology and increased affordability. In this context, an in-depth analysis of the market trends pertaining to various RES is elucidated below. This comprehensive overview provides insights into the current state of the RE market, encompassing recent developments, emerging trends, and future prospects for each energy source.

2.3.1. Bioenergy

In 2020, bioenergy contributed 5.3% to the world's overall energy demand, constituting almost half of the total RE in overall energy consumption. Specifically, bioenergy contributed 14.7 exajoules (EJ) of energy for heating, which corresponds to 7.6% of the world's energy demand. The agricultural and industrial sectors accounted for two-thirds of this energy consumption, while the remaining one-third was utilized in buildings (IEA, 2022). The usage of bioenergy in industries is mostly concentrated in economies with substantial bio-based industries like China, Brazil, India, and the US. Conversely, North America and Europe are the primary users of bioenergy for buildings (REN21, 2022). The utilization of bioenergy in district heating systems has witnessed a significant increase in recent years (Jeswani et al., 2020). Biofuels, mainly biodiesel and ethanol, contributed about 3.5% of the total energy utilized in the transport sector in the year 2020. Despite experiencing a temporary dip in production levels in 2020 due to the impact of the pandemic, biofuel production rebounded to 2019 levels in 2021. However, high feedstock costs have posed constraints on production in 2021 (IEA, 2022). Ethanol, which is the most widely used biofuel, experienced a 26% increase in production from 2011 to 2021, while biodiesel production doubled in the same period due to increased production and use in Asia

(Chen et al., 2023). Hydrotreated vegetable oil (HVO) experienced a 36% production increase in 2021. In the power sector, the contribution of bioenergy increases by 10% in 2021, and it has witnessed an overall increase of 88% since 2011 (Julio et al., 2023). Notably, China continued to be the world's top producer of bioelectricity, with a 4.5-fold increase in production since 2011 (Wang et al., 2022). The US, Brazil, and Germany are the next-largest bioelectricity producers, but their production has not greatly expanded in recent times, in contrast to other European and Asian countries (Dovich Filho et al., 2023).

2.3.2. Geothermal

In 2020, geothermal electricity generation was approximately 97 terawatt-hours (TWh), whereas the direct utilization of geothermal heat amounted to around 128 TWh (IEA, 2021). Moving forward to 2021, the global geothermal power generating capacity was estimated to be around 14.5 GW. Although the generation of RE increased by over 5% in 2021, the production of geothermal electricity was influenced by extreme weather events (IEA, 2022). Notably, Turkey and Indonesia were the geothermal electricity markets that were most active, while traditionally large markets like the Philippines have seen little to no capacity increases lately. In terms of reported capacity additions, the top 10 markets during 2016–2021 were Turkey (with 0.9 GW added), Indonesia (with 0.7 GW), Kenya (with 0.2 GW), and the US (with 0.2 GW), with additions of less than 0.1 GW in Chile, Japan, Iceland, New Zealand, Mexico, and Costa Rica (REN21, 2022). The largest market, Turkey, has, however, seen a significant slowdown recently that may be partially linked to diminished government support, such as decreased FITs (Davraz et al., 2022). In 2021, a total of 35 gigawatt-hours (GWh) was estimated to be the global capacity for geothermal direct usage, which involves the direct extraction of geothermal power for thermal applications. The total amount of energy utilized for thermal practices reached around 141 TWh in the same year, a notable increase from the expected 12.8 TWh (IEA, 2022). The largest market for geothermal direct usage has now been identified as China (Hu et al., 2022). Moreover, China, Japan, Turkey, and Iceland continue to be the leading nations in terms of geothermal direct use (IEA, 2022).

2.3.3. Heat Pumps

The adoption of heat pumps as a sustainable alternative for residential heating remains limited, with a mere 7% of worldwide heating requirements in residential buildings being met by heat pumps in 2020, while water heaters and non-renewable-powered heaters continue to comprise approximately half of the heating equipment traded (IEA, 2021). Nevertheless, heat pumps are becoming increasingly common in new buildings, suggesting a shift toward their greater integration into heating systems. Air-source heat pumps remained the dominant technology in the global market in 2021, with China, Japan, Europe, and North America leading sales (REN21, 2022). Although in 2017 air-source heat pump sales in China reached their peak, these units have been prevalent in Japan for over two decades, with sales remaining relatively stable (Zhou et al., 2022). Sales of heat pumps in the US have grown more rapidly than other heating alternatives, whereas Europe experienced double-digit growth in 2021, with France, Italy, and Germany being the top markets, with the latter showing a remarkable 28% growth (REN21, 2022). The technological maturity of heat pumps, their ability to provide flexibility in electricity networks and heating systems, as well as their contribution to decarbonizing building heating, have prompted governments to include them in their climate-related policies. Measures such as updating regulations and building codes and providing purchase subsidies in the form of grants, tax credits, or loans can help offset the costs associated with heat pumps, especially during building renovations (Jiang et al., 2022). Heat pumps can be a cost-effective solution in new buildings. Notably, Ireland and Germany have introduced carbon pricing mechanisms and funding programs to promote the utilization of heat pumps in 2021 (Meles and Ryan, 2022; Marijanovic et al., 2022).

2.3.4. Hydropower

The global hydropower market continued to demonstrate enduring patterns, as evidenced by the addition of new capacity totaling at least 26 GW in 2021, resulting in a cumulative global installed hydropower capacity of approximately 1,197 GW (REN21, 2022). China maintained its position as the foremost leader in capacity additions, with India, Canada, Nepal, Turkey, Indonesia, Zambia, Norway, and Kazakhstan following suit. Nevertheless, despite these ongoing additions, worldwide

hydropower production decreased by 3.5% in 2021 due to changes in hydrological conditions, such as sustained droughts in the major producing regions of the Americas and Asia (IEA, 2022). These changes in operating conditions are likely to be the result of climate-induced impacts, such as the melting of Himalayan glacier icecaps, resulting in long-term changes in outcome. The largest reduction in production in 2021 was observed in Brazil, Turkey, and the US. Other significant markets that experienced more moderate annual reductions, including Canada, India, and China, experienced larger multi-year declines. On the other hand, worldwide pumped storage capacity increased by approximately 1.9% in 2021, with the majority of new installations taking place in China (IEA, 2021). Governments and industry players are considering a range of solutions in response to the effects of climate change on hydropower output, such as adapting operations to changing hydrological conditions and investing in storage technologies, among others.

2.3.5. Ocean Power

Ocean Energy represents vast, untapped potential in the RE market. Despite representing the smallest portion of renewable energy, the industry rebounded in 2021 after significant delays in planned deployments caused by disruptions from the COVID-19 pandemic (Quaranta and Davies, 2022). During 2021, approximately 4.6 megawatts (MW) of capacity were successfully added, bringing the overall installed capacity to a formidable 524 MW. While the industry is still focusing on pilot projects and small-scale demonstrations with capacities below 1 MW, it is making strides toward semi-permanent installations. This progression is particularly prominent in Europe, with Scotland serving as a focal point of development activity. However, China, Canada, and the US are also showing notable developments and policy support (IEA, 2022). The commercialization of ocean power technologies relies on critical financial and other forms of encouragement from governments to leverage private finance.

2.3.6. Solar Photovoltaic

Solar photovoltaic (PV) energy continued to grow rapidly, as evident by the newly added capacity of 175 GW in 2021. The global cumulative installed capacity for solar

PV has now reached around 942 GW, representing a significant increase in the industry (REN21, 2022). The increased economic competitiveness of solar power, along with the utilization of power purchase agreements, has contributed to the addition of 100 GW of new installations in centralized utility-scale solar PV. This trend has been particularly prominent in Spain, India, France, and the US (REN21, 2022). Additionally, distributed solar PV installations also experienced growth, with a 25% increase in 2021, adding 75 GW (IEA, 2022). The driving force behind this growth has been the escalating electricity prices, which have prompted various entities to adopt self-consumption measures and reduce their reliance on the distribution grid whenever feasible. Self-consumption has proven to be particularly advantageous in countries such as China, Australia, Germany, and Brazil, where distributed systems have gained considerable traction (Allouhi et al., 2022). However, after several years of declining costs, the cost of PV modules increased by an estimated 57% in 2021. This increase can be attributed to a shortage of polysilicon and a rise in shipping container costs from China. Consequently, the significance of domestic production of PV modules has been underscored, as evidenced by India's imposition of exceptionally high solar import duties and the US' extension of import tariffs (Zazoum, 2022).

2.3.7. Concentrating Solar Thermal Power

Renewable energy sources represented the majority of newly installed capacities, accounting for 84% of the global energy mix in 2021 (IEA, 2022). Despite reductions in technology costs, the concentrated solar power (CSP) market experienced a decline in growth, with an aggregate installed capacity of 6 GW during the same year. This contraction was largely due to the deactivation of around 300 MW of outdated CSP power plants in the USA, which offset the launch of the 110 MW Cerro Dominador plant in Chile (REN21, 2022). Over the past decade, the CSP industry has faced stiff competition from solar PV, changes in policies, and failed projects in previously powerful markets like the US and Spain. Nevertheless, there are ongoing construction projects for CSP plants with a combined capacity of over 1 GW in China, the UAE, South Africa, and Chile, with most projects utilizing parabolic trough technology and incorporating thermal energy storage (TES) into their design (Mills et al., 2022). As of year-end 2021, five continents had a total of 23 GWh of TES and CSP power plants

in operation, accounting for a substantial 40% of the world's total energy storage capacity, excluding hydropower. (IEA, 2022).

2.3.8. Solar Thermal Cooling and Heating

The worldwide solar thermal market experienced 3% growth, reaching a total capacity of 524 GWh, of which 25.6 GWh were newly installed in 2021 (IEA, 2022). Among the countries that contributed to this growth, China, India, Brazil, Turkey, and the USA emerged as the leading nations for new solar thermal installations. The annual sales of solar thermal units increased in various countries, such as Italy, Brazil, India, France, Poland, Greece, Portugal, Morocco, and the US (REN21, 2022). This heightened demand for solar thermal solutions can be attributed to several factors, such as supportive programs implemented as part of economic recovery plans, increased activities in the construction sector, and the surge in global non-renewables and electricity prices. Besides, the market consolidation trend continued in 2021, with a notable 15% increase in production observed among the top twenty flat plate collector producers (Fouladvand et al., 2022). Additionally, Chinese manufacturers have expanded their range of sustainable heating options by providing stand-alone solar heat pump (SHP) solutions (Xia et al., 2022). Furthermore, in 2021, a total of 71 SHP solutions, amounting to 36 MWh, commenced operations worldwide, reflecting an 8% increase and bringing the total number of SHP plants to approximately 975. Notably, the largest SHP system in Europe, with a capacity of 15 MWh, has been commissioned to supply heat for a French whey powder company. Moreover, there has been a growing interest in electrifying heating, leading to an increased demand for PV-thermal (PV-T) solutions. According to IEA (2022), 30 manufacturers sold about 88 MWh of PV-T capacity in 2021, representing a significant 45% increase compared to the 61 MWh sold in 2020. France, the Netherlands, Germany, Israel, and Spain were identified as the top markets for new PV-T capacity expansions.

2.3.9. Wind Power

The global wind power sector witnessed the installation of approximately 102 GW, with a record-breaking 18.7 GW of offshore capacity in 2021 (IEA, 2022). China emerged as the market leader, followed by the US, Vietnam, Brazil, and the UK.

Despite a decline in onshore installations in China and the US, nearly all regions across the world witnessed remarkable market growth, with worldwide installations (excluding China) increasing by over 14%. The primary drivers of new capacity were the economics of wind energy, energy security, and climate change mitigation (Liu et al., 2022). However, a number of problems, such as inadequate grid infrastructure and permit restrictions, plagued the wind power industry in 2021. In addition, the COVID-19 pandemic, supply chain issues, shipping delays, escalating costs of raw materials, and labor shortages led to increased costs, with average prices outside of China rising to levels not seen since 2015. This resulted in some manufacturers reporting losses (Luo et al., 2022). In response to these challenges, the industry is actively prioritizing technological advancements to attain the lowest possible levelized cost of energy, as well as addressing logistical issues and enhancing the environmental and social sustainability of wind energy. Although offshore wind power capacity constitutes a relatively small portion of the global total, it is gaining substantial attention, with more governments, developers, and energy providers turning to floating offshore turbines. Furthermore, the industry is advocating for a broader recognition of wind power's contribution to the system as a whole, beyond just its decreasing costs and prices (Zhang et al., 2022).

2.4. Increasing Energy Access with Distributed Renewables

Despite reaching a global electricity access rate of 90% among the population, approximately one-third of the global populace, equivalent to around 2.6 billion individuals, still lacks access to clean cooking facilities, relying mainly on conventional biomass usage (IEA, 2022). In order to enhance the resilience of these vulnerable populations against various shocks, including climate change, pandemics, conflicts, and economic fluctuations, the adoption of distributed renewable energy access (DREA) can be advantageous (Wang et al., 2022). In 2021, off-grid solar device demand continued to encounter challenges such as shortages, supply disruptions, and price hikes. Approximately 7.43 million off-grid solar devices were sold in the same year, with one-third of those sales being accounted for by the pay-as-you-go (PAYGO) model and the remaining two-thirds by cash transactions. However, these technologies provide relatively low levels of electricity access, with portable lanterns and small devices accounting for 83% of sales, and solar home systems accounting for a mere

17% (IEA, 2022). Affordability continues to be a major obstacle, despite efforts to target the market's weakest segments, particularly in isolated rural areas with greater levels of poverty (Shahzad et al., 2022). Among mini-grid technologies, solar PV has experienced the most rapid expansion, with a capacity of approximately 365 MW as of 2019 and integration into 55% of mini-grids (REN21, 2022). Private developers have entered the market even though national utilities now own a number of mini-grids; nonetheless, they are having trouble increasing their financial and operational capability and raising equity. Large-scale investment strategies that can leverage global risk-mitigation infrastructure and mobilize private equity are becoming more prevalent in this context. However, despite these efforts, it is projected that by 2030, clean cooking solutions may not be accessible to everyone, falling 30% short of the target. In the productive appliance sector, poorly made and inefficient items, largely traded in sub-Saharan Africa, present a significant pricing challenge (Monyei et al., 2022). Only a handful of developing nations have established minimum energy performance guidelines for household appliances. The sales of clean cooking solutions have faced hindrances due to supply chain breakdowns and reduced demand as a consequence of the COVID-19 pandemic (IEA, 2022). In the year 2020, non-biomass cookstoves constituted 42% of the total sales of clean cookstoves (IEA, 2021). The viability of various business models in the clean cooking sector has been facilitated by the utilization of smart devices, particularly with the emergence of "Pay-as-You-Go" (PAYGo) models, and the potential for wider adoption of carbon finance to fund stove programs (Montoya-Duque et al., 2022). The financing landscape for clean cooking solutions is undergoing a gradual transformation, with a discernible shift from relying on grants to leveraging corporate stocks as a primary means of raising capital. Remarkably, the lion's share of these funds has been concentrated in a select group of seven companies. Notably, the majority of these investments have been directed towards liquefied petroleum gas (LPG) stoves, accounting for 26% of the total, followed by biomass at 25%, and biogas systems at 19% (Zhang et al., 2022).

2.5. Renewable Energy Investment Trends

Despite the profound effects of the COVID-19 pandemic, new investments in green energy and fuels hit a historic high in 2021, with an estimated USD 366 billion invested globally (IEA, 2022). New investments were still dominated by solar PV and wind

power, with solar PV making up 56% of the total and wind power making up 40% (see Figure 2.9). With a share of 37%, China emerged as the greatest source of global investment, followed by Europe, Asia (other than China and India), and the USA. Notably, despite the pandemic's adverse effects, investment in new RE projects demonstrated resilience, surpassing investments in non-renewables or nuclear power plants. Additionally, sustainable finance taxonomies have become increasingly relevant for renewable energy, with stakeholders eligible for technological screening and pre-screening for interested investors. The Paris Agreement underscores the imperative to align financial flows with the objective of keeping the increase in global temperature to 1.5 degrees Celsius, which calls for far more investment in green energy than was done in the preceding decade (Schleussner et al., 2022). Furthermore, divestment trends continued in 2021, with many institutions and investors committing to divest from fossil fuels, potentially signaling a shift in broader financing frameworks toward renewable energy (REN21, 2022).

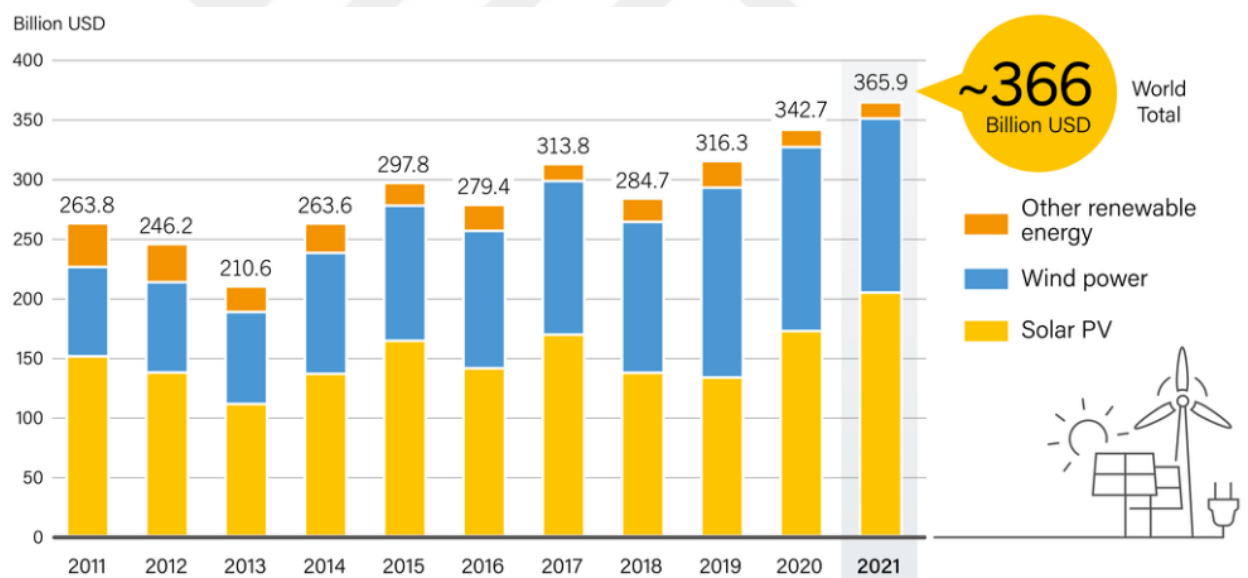


Figure 2.9. Global Investment in Renewable Energy, 2011-2021 (IEA, 2022)

2.6. Renewable-Based Energy Systems

Throughout a significant portion of human history, renewable energies derived from the sun, water, and wind served as the main source of energy for communities worldwide. However, during the 19th and 20th centuries, the dominance of oil, coal,

and natural gas displaced RES (Mehrenjani et al., 2022). In recent years, renewables have resurged as a leading source of energy in certain areas, particularly for electricity, due to the declining costs of solar and wind and power (Fatima et al., 2022). Figure 2.10 shows the share of variable green electricity production and maximum daily penetration of leading countries in 2021. The term "maximum penetration" refers to the highest daily share of generation from variable green electricity divided by the daily electrical load. The share of variable RES, namely wind and solar power, exceeded 10% of the global electricity mix in 2021. Notably, Denmark witnessed a share of over 50% in solar and wind power, whereas Spain, Ireland, and Uruguay achieved over 30% (IEA, 2022).

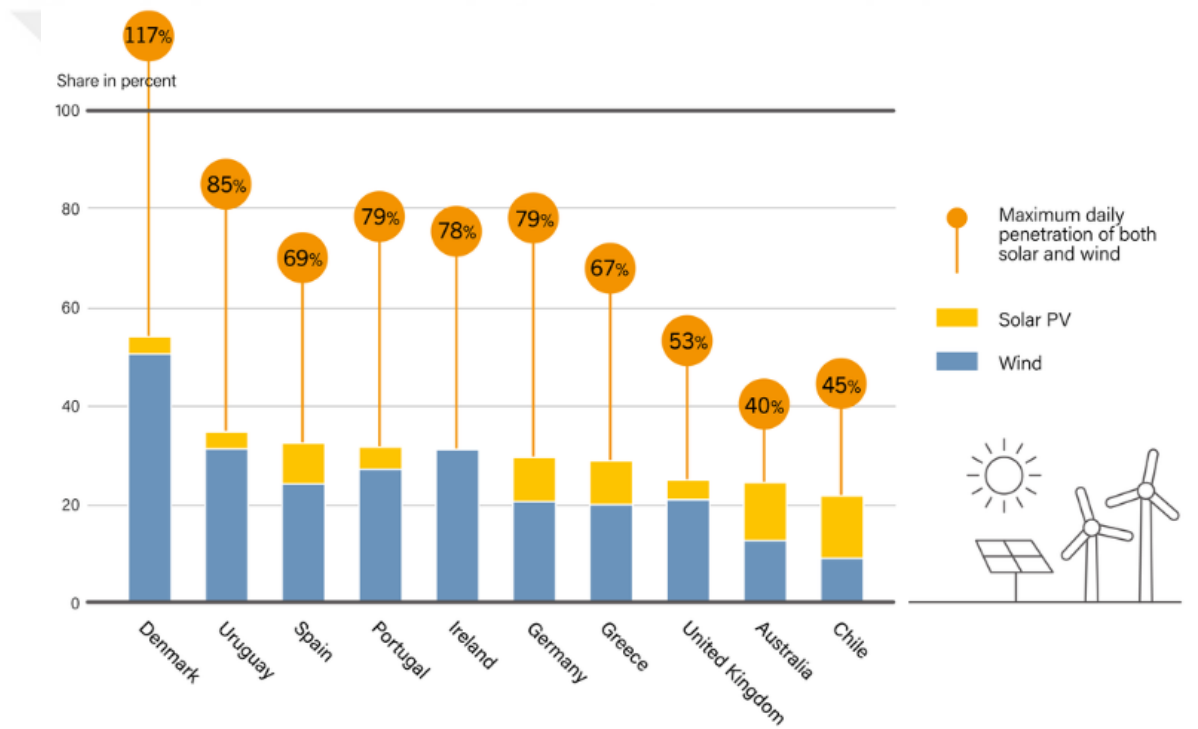


Figure 2.10. Top Countries in 2021 for Variable Renewable Electricity Penetration (IEA, 2022)

To date, no comprehensive examples of renewable power-based systems that encompass the power, cooling, heating, and transport sectors exist. Nonetheless, the infrastructural, technological, and operational prerequisites of such systems are presently being established. Increasingly affordable energy storage, demand-side flexibility, and expanding transmission infrastructure allow regions with diverse

resource endowments to shift towards entirely green power-based systems. Moreover, an increasing number of authorities are employing their green power sources to encourage the spread of renewables into other energy sectors (Falama et al., 2023). Higher proportions of RE are made possible by correspondence-enabled cooling and heating technology such as thermal storage technologies, air conditioners, and heat pumps (Zhang and Wang, 2023). Renewable-powered transport is made possible through the emergence of EVs, which can be charged utilizing just green electricity (Vishnuram and Nastasi, 2023).



CHAPTER III

DOES ENVIRONMENTAL SUSTAINABILITY AFFECT THE RENEWABLE ENERGY CONSUMPTION? NEXUS AMONG TRADE OPENNESS, CO₂ EMISSIONS, INCOME INEQUALITY, RENEWABLE ENERGY, AND ECONOMIC GROWTH IN OECD COUNTRIES

3.1. Introduction

Technological advancements, rapid population growth, urbanization, industrial development, and the expansion of business practices all contribute to increased energy demand around the world. However, the rapidly rising energy demand has raised significant environmental challenges, especially global warming triggered by the concentration of CO₂ emissions, which are primarily generated by the combustion of oil, natural gas, and coal (Jardon et al., 2017; Shayanmehr et al., 2020; Altarhouni et al., 2021).

Despite the increasing concerns regarding the rise in carbon emissions and climate change, non-renewables are still the key drivers of GDP growth (Ivanovski et al., 2021). Countries are, in fact, unable to cut environmental emissions while also increasing their incomes. To put it another way, continued economic growth necessitates increased energy consumption, which results in increased carbon emissions. Many agree that renewable/green energy sources will help to rebalance environmental quality and economic development (Azam et al., 2021). Therefore, the green energy sector is now attracting more and more attention from governments, businesses, and academics in different countries and regions, which can be due to several factors (IPCC, 2018). Lately, oil prices have been fluctuating, and energy security has been called into question (Al Rousan et al., 2018). At the same time, other challenges such as health risks, climate change, economic losses, environmental

concerns, and fossil fuel consumption, all contribute to the current focus on green energy sources (Muhammad et al., 2021).

In OECD countries, renewable/green energy consumption (REC) continues to be the key source of economic growth. According to the IEA (2020), between 1990 and 2000, the annual growth rate of green energy was 1.7%, which then increased to 3.2% over the period 2000-2018. Moreover, the OECD countries had the highest green energy share of overall energy supply in 2018, at 13.5%, compared to any other region. Furthermore, for the past three decades, renewable energy has been used in the transportation sector in OECD countries to maintain environmental sustainability. Because of concerns regarding climate change, and carbon emissions, OECD nations have put a greater emphasis on diversifying energy sources and ensuring energy supply.

Given the importance of renewable energy, a number of studies have investigated the determinants that influence its adoption (Qamruzzaman and Jianguo, 2020; Chen et al., 2021). Recently, a subset of these studies looked into the relationship between REC and trade openness (Alam and Murad, 2020; Zeren and Akkus, 2020). Trade openness has an impact on domestic energy use through a variety of pathways, including technology diffusion, economies of scale, and factors of production that are affected by composite effects (Wan et al., 2015). The importance of trade in the promotion of environmentally sustainable technologies cannot be overlooked (Khan et al., 2017). Since it has the potential to transfer clean energy technologies, trade is crucial for 'greening' the energy market. Trade openness is advantageous due to the efficient utilization of resources and the benefits of economies of scale (Semancikova, 2016). Furthermore, both export and import can offer better inputs for green energy consumption. In a nutshell, trade liberalization will further foster renewable energy sources. Hence, green energy sources, have the potential to be a major factor of long-term economic growth and climate change (Alam and Murad, 2020). There have been few empirical studies on the connection between renewable energy consumption and foreign trade (Adewuyi and Awodumi, 2017; Amri, 2019; Zafar et al., 2019), and their results are often inconclusive, indicating disagreement among economists and researchers. In short, the magnitude and direction of the impact of trade openness on

REC are critical because it may have consequences for OECD countries' foreign trade and climate policies.

Further, when income increases, so does energy consumption, indicating a positive association between REC and economic growth. Since non-renewables could be used as a substitute for clean energy, oil prices can also have an impact on REC. Moreover, income inequality may have an impact on REC through an economic and political channel (Uzar, 2020). In terms of the economic channel, inequality will influence green energy consumption by influencing societal patterns like individualism, short-termism, and commercialism. Income Inequality erodes social cohesion and trust, limiting collaborative action and encouraging individualism (Berthe and Elie, 2015; Uzar, 2020). There is a lack of environmental sensitivity, rent-seeking behavior, and high usage of non-renewable resources to satisfy one's demands in cultures characterized by a lack of social cohesion and collective action as a result of inequality (Laurent, 2015). People in such communities place a high emphasis on short-term advantages and are unconcerned with the long-term consequences of their current consuming habits, which may have an impact on renewable energy adoption, with serious environmental consequences (Uzar, 2020). Also, people consume to maintain and improve their social position in such societies, which is characterized by ostentatious consumerism and status competitiveness (Berthe and Elie, 2015). Simultaneously, lower-income social groups imitate the dominant social groups' consumption habits (Uzar, 2020). The rise of consumerism, which is based on social status and influence rather than environmental quality, is a major factor in the adoption of renewable energy. Consumption patterns that do not support clean energy use tend to place an additional burden on the environment (Berthe and Elie, 2015). Secondly, in terms of political stream, by altering the quality of institutions and power interactions between different social groups, income inequality can have an impact on REC. Income distribution, energy use, and environmental policy are all influenced by institutions (Sequeira and Santos, 2018). Inequality in income might be a sign of poor institutions (Uzar, 2020), which discourage efficient investment (Mehrara et al., 2015) and impede the efficiency of environmental regulations (Fredriksson and Svensson, 2003). In such deplorable institutional settings, elite groups engage in environmentally harmful actions (Uzar, 2020). The general lack of investment translates to a low rate of investment in renewable energy, which influences clean energy adoption. Income

disparity, in turn, promotes power disparities, which play a crucial role in the formulation of environmental policies (Boyce, 1994). By giving the power to define environmental policies to the elite groups who profit from traditional energy sources, power disparities impact the usage of renewable energy and how institutions work (Uzar, 2020). Poorer groups find it difficult to benefit from renewable energy consumption due to profit-seeking behavior (Strunz et al., 2016). Consequently, the power dynamics among these groups will affect renewable energy deployment. Moreover, the demand for renewable energy can be hampered by CO₂ emissions. Clean energy is provided by renewable energy sources, which can help to minimize carbon emissions. Therefore, CO₂ emissions could be a key factor in green energy consumption (Samour et al., 2022; Dogan and Muhammad, 2019; Omri and Nguyen, 2014).

This chapter aims to look at the influence of trade openness, income inequality, economic growth, CO₂ emissions, and real oil prices on the consumption of renewable energy in 23 OECD countries over the period from 1991-2020 and adds to the current literature in the following novel manners: (1) We believe the results of this chapter are more reliable and comprehensive than those of any other earlier studies on the factors influencing REC since this study performed country-specific and panel analyses using a sizable data set and numerous analytical approaches. (2) We included income inequality as a possible variable in the association between carbon emissions, green energy, and trade openness because it had previously been overlooked in the literature and thus adds to the existing literature for OECD countries. The emphasis on income inequality is critical since it has been connected to a number of outcomes that can affect REC. For example, income inequality has been linked to health and well-being (Zhang and Awaworyi Churchill, 2020; Gugushvili et al., 2020), the environment (Sager, 2019), and economic growth (Aiyar and Ebeke, 2020). Because the social advantages and positive externalities of addressing income inequality may help accelerate the adoption of REC, it is critical to empirically verify the relationship between REC and income inequality in order to guide policy. (3) The bulk of the existing literature makes the presumption of cross-sectional independence using unit root and cointegration tests when examining the relationship between REC, trade openness, and carbon emissions. However, macro-level data often deviates from this assumption, leading to low power and scale distortions in cross-sectional testing

(Pesaran, 2015). To fix this discrepancy in the literature, we adopted newly developed panel data techniques based on second-generation estimators that take into account slope homogeneity and cross-sectional dependence.

3.2. Literature Review

Renewable energy has emerged as a crucial component of environmental sustainability in recent times. As the world grapples with the looming threat of climate change and the detrimental effects of traditional fossil fuels on the environment, the imperative for a sustainable and clean source of energy has become more pressing than ever before. RES are not only abundant and infinite but also emit minimal GHGs that contribute to the perilous phenomenon of global warming. Therefore, renewable energy holds the potential to reduce CO₂ emissions, mitigate the impacts of climate change, and provide a more sustainable energy source for future generations. The adoption and utilization of RES are affected by various factors, including political, social, economic, and technological factors. These multifarious factors play a pivotal role in determining the rate and level of renewable energy consumption in various regions and countries. Understanding the impact of these factors is essential in designing effective policies and strategies that promote the adoption and utilization of RES.

Table C.1 in Appendix C provides evidence of the contributions made by several researchers to the field of panel data analysis, which involves examining the effects of various economic, social, and political factors on REC in diverse regions and countries. However, these studies utilized statistical techniques that did not consider the existence of slope heterogeneity and cross-sectional dependence, thereby increasing the likelihood of generating erroneous conclusions and compromising the accuracy of the results. Consequently, researchers must account for these issues while analyzing data that encompasses multiple observations of diverse entities such as countries, individuals, or firms. In response to these concerns, the AMG estimator has been adopted as one of the panel data models to tackle such challenges. Furthermore, it is important to note that no existing study has yet undertaken an analysis of the impact of income inequality on REC in OECD countries. As a result, the present chapter fills this research gap by employing the AMG estimator to assess the long-run relationship between income inequality and renewable energy consumption, while also

considering other factors that influence renewable energy consumption. Studying the relationship between income inequality and REC in OECD countries offers insights into sustainable energy adoption among different income groups. It addresses social equity concerns by identifying barriers and opportunities for equitable energy transitions. Evidence-based research on this subject has the potential to significantly assist policymakers in developing inclusive energy policies that address disparities and promote fair distribution of clean energy resources, impacting socioeconomic development and quality of life. Understanding income inequality's impact on renewable energy adoption facilitates the formulation of strategies to overcome obstacles in the global transition to sustainable energy. Moreover, such analysis fosters international cooperation and the exchange of best practices among OECD countries in promoting sustainable energy solutions, ultimately contributing to a clean and inclusive energy future.

The OECD countries were among the first to introduce and examine environmental sustainability plans to the UN (OECD, 2017). These countries should have been the forerunners in terms of sustainable development because they account for a significant portion of the global economy and have the financial resources to invest in green energy to spur economic development. However, according to the latest CO2 emissions report, OECD countries are still experiencing increasing levels of carbon emissions (OECD, 2019). Furthermore, the literature indicates that to tackle global warming, policymakers in OECD nations should design green energy and ecologically sound policies. Taking cues from this discussion, the literature on the association between REC, CO2 emissions, trade openness, oil prices, and economic growth will be reviewed in this section.

3.2.1. CO2 Emissions and REC Relationship

Numerous studies have linked the increased fossil fuel consumption to higher carbon emissions in both developed and developing countries around the world over the last two decades. Different policymakers and governments have acknowledged green energy's role in lowering carbon emissions and meeting energy demand. Therefore, in order to examine the dynamics of carbon emissions and REC, a variety of studies have been undertaken. For example, For the US, Jaforullah and King (2015) investigate that

REC is negatively associated with carbon emissions from 1960 to 2007. The negative relationship between the two variables is also found by other researchers, including Al-Mulali et al. (2016), Samour et al. (2022), Godil et al. (2021), Sharif et al. (2020), Akram et al. (2020), Suki et al. (2020), Yu et al. (2020), Destek and Aslan (2020), Sharif et al. (2019), Khan et al. (2019), Sharif et al. (2017), and Bhattacharya et al. (2016). Furthermore, Rafiq and Salim (2014) find a one-way causality running from REC to CO₂ emissions. Also, for China and India, a two-way causality between the two variables is discovered by Rafiq and Salim (2014). Omri and Nguyen (2014) investigate the factors that influence REC in sixty-four economies and their findings show that CO₂ emissions affect REC positively. Aguirre and Ibikunle (2014) demonstrate that excessive power consumption trends in the manufacturing industries, GDP per capita, Kyoto Protocol ratification, and CO₂ discharges are all key factors of REC in thirty-eight countries. Similarly, Chen (2020) demonstrates imports per capita, urbanization, exports per capita, and carbon emissions are all considered key factors influencing REC in various regions of China.

3.2.2. Trade Openness and REC Nexus

The majority of past studies have examined the link between energy usage and trade openness. They disagree, nevertheless, on the magnitude and the direction of the relationship. According to Shahbaz et al. (2014), trade liberalization reduces power demand by allowing technology transfer while also improving environmental efficiency. Moreover, Copeland (2005) suggests that energy consumption per capita and trade are positively associated. However, few empirical studies have been performed to analyze the association between trade openness and REC. For example, Sebri and Salha (2014) explore the association between REC and trade openness in BRICS countries by employing the VECM and ARDL bound test, for the years 1971 to 2010 (1992 to 2010 for Russia). The findings reveal that trade openness and REC are bidirectionally related in Brazil and India. Similarly, a causal association between REC and trade openness was investigated by Yazdi and Mastorakis (2014) in Iran. The ARDL bound test and the VECM approaches were employed in this study. Their findings indicate a short-term causality between the two variables. Moreover, in a study of 24 nations, the REC and trade openness nexus is also explored by Tiba et al. (2016). The study covers the years 1990 to 2011, and the research is carried out using

the GMM estimator. The results indicate a bidirectional causal relationship between trade openness and REC in China, the United Kingdom, and Sweden.

3.2.3. Oil Prices and REC Relationship

Oil prices are used to assess the effects of various energy consumption patterns (Gourevitch, 1978; Geller et al., 2006). As oil prices rise, demand for renewable energy rises as a result of technological advancements and lower carbon emissions costs. Sadorsky (2009a), Reboredo, (2015), Shah et al. (2018), and Kyritsis and Serletis, (2019), Shahzad (2020), Samour and Pata (2022) are among the recent studies looking at the association between real oil prices and green energy consumption. According to Cheon and Urpelainen (2012), oil prices increase renewable energy consumption via technological advancements. According to Brini et al. (2017), a surge in oil prices have a significant impact on REC in Tunisia. Karacan et al. (2021) and Guo et al. (2021) both discovered that oil prices have a negative impact on REC in Russia and the G7 countries, respectively. Murshed and Tanha (2021) used a panel data model to show that oil prices in India and Pakistan have a negative impact on REC. Moreover, in South America, a long-term association between the two variables (real oil prices and REC) is found by Apergis and Payne (2015). Similarly, Nilsson (2019) and Hsiao et al. (2019) demonstrate that oil prices might be regarded as a crucial influence on green energy consumption. Also, they find that clean energy consumption and oil prices are positively related to technological innovation.

3.2.4. Economic Growth and REC Nexus

Economic growth has been identified as a key factor of REC in numerous studies. Yao et al. (2019) investigate the factors affecting REC in OECD countries, while Przychodzen and Przychodzen (2020) investigate the factors affecting REC in several transition economies. According to their results, economic growth is a crucial determinant of REC, and both variables are positively related. Several other scholars have also discovered a positive association between the two variables (Belaid and Zrelli, 2019; Ghazouani et al., 2021; Mukhtarov et al., 2020; Fan and Hao, 2020; Samour et al., 2022). In the same vein, Salim and Rafiq (2012) examine the factors that influence REC in five economies: Turkey, Philippines, Brazil, Indonesia, and

China. Their findings show that in Indonesia, India, China, and Brazil, income and carbon emissions are significant factors influencing REC, while in Turkey and the Philippines, REC is primarily driven by per capita income. Moreover, in 24 OECD countries, an inverse U-shaped relationship between the two variables is discovered by Destek and Sinha (2020). Further, for 25 OECD countries, Alam and Murad (2020) discovered that while long-run economic development encourages REC, short-run economic development has a detrimental impact on REC.

Although there is much discussion in the literature about the association between REC, carbon emissions, trade openness, income inequality, energy prices, and economic growth, the findings are still inconclusive. Since the estimation methods used are not based on an adequate quantitative system, most studies are criticized for the validity of the measured coefficients and elasticities. Previous studies used estimation techniques such as FMOLS, 2SLS, and GMM, which neglect cross-sectional dependence and slope heterogeneity, which is essential for unbiased and robust results. Hence, this chapter contributes to the current literature by using the latest panel data technique (AMG estimator) that allows CSD and slope heterogeneity to evaluate the heterogeneous effects of selected independent variables on REC across 23 OECD economies.

3.3. Data and Model Specification

This chapter utilizes a balanced panel of 23 OECD countries, over the period from 1991 to 2020. The selection of these specific 23 OECD countries is based on data availability. The current chapter seeks to analyze the influence of real oil prices, trade openness, economic growth, and carbon emissions on REC. For the list of countries, see Appendix A. We chose the OECD countries as a sample of our study because firstly they account for a significant segment of global net worth. Secondly, the OECD countries are recognized as the world's largest energy users and forerunners in green energy production. Thirdly, OECD economies are the main CO₂ emitters. As of 2019, OECD countries account for 35% of global emissions (OECD, 2019). Since OECD countries are the world's largest energy users and pioneers in renewable energy, as well as having better income standards and contributing a substantial portion of global

carbon discharges, it is critical to investigate the variables that influence REC in these countries.

In this chapter, REC is used as a dependent variable. Explanatory variables include income inequality, trade openness, GDP per capita (a proxy for economic growth), CO₂ emissions, and real oil prices. The rationale behind selecting these explanatory variables lies in their potential relevance and significance in comprehending the factors influencing REC within the study's scope. Each variable represents a distinct aspect that may contribute to shaping REC patterns. For instance, income inequality serves as a pivotal socio-economic indicator, reflecting wealth and resource distribution among different societal segments. Its impact on energy consumption patterns can influence the accessibility and adoption of renewable energy sources across diverse income groups. Additionally, trade openness, which signifies a country's engagement in international trade, may enhance access to global renewable energy technologies and resources, thus affecting REC levels.

Moreover, GDP per capita, acting as a proxy for economic growth, reflects a nation's overall economic development and prosperity. By examining its relationship with REC, the study seeks to elucidate how economic prosperity influences renewable energy adoption. Furthermore, the consideration of CO₂ emissions, a critical environmental factor intrinsically linked to energy consumption, enables an understanding of how countries with higher CO₂ emissions may be inclined towards shifting to renewable energy sources as part of climate change mitigation and carbon footprint reduction efforts. Another influential variable, oil prices, significantly impact energy markets, influencing the attractiveness of renewable energy alternatives. Variations in oil prices can prompt shifts in energy consumption patterns, thereby impacting the adoption of renewable energy technologies.

Through the incorporation of these explanatory variables into the analysis, the study aims to offer a comprehensive comprehension of how various economic, social, and environmental factors interact and exert influence over REC within the selected OECD countries. By identifying key drivers and barriers to renewable energy adoption, this research assists policymakers in devising effective strategies to promote sustainable energy development.

The data on REC (share in total final energy consumption), per capita CO2 emissions (metric tons), trade openness (% of Gross Domestic Product), and GDP per capita (constant 2010 US\$) is sourced from World Development Indicators (WDI, 2020). The Gini index (a proxy for income inequality) data is taken from the Standardized World Income Inequality Database of Solt (SWIID, 2019). Furthermore, the data on oil prices (West Texas Intermediate \$/bbl) comes from the British Petroleum statistics (2020). The consumer price index (CPI) of selected countries, derived from WDI, is used to transform crude oil prices into real oil prices. The estimated slope coefficients can be explained as elasticity since all the selected variables are transformed using natural logarithms.

Table 3.1 provides descriptive statistics for all selected variables for 23 OECD countries. It shows that the mean of REC in our sample countries is 2.50, with -0.49 and 4.11 as the lowest and highest values, respectively. The average value of CO2 emissions is 1.95, and the estimated standard deviation is 0.53, indicating that there is little variability. Moreover, we found that the average per capita GDP, which accounts for economic growth, is 10.27, and the average trade openness is 4.12. Furthermore, during the sample period, the mean of real oil price and income inequality is -0.68 and 3.43, respectively.

Table 3.1. Descriptive Statistics

Statistical Description	lnREC	lnCO2	lnGDP	lnTO	lnROP	lnGN
Mean	2.50	1.95	10.27	4.12	-0.68	3.43
Maximum	4.11	3.00	11.42	5.12	5.19	3.94
Minimum	-0.49	0.26	8.40	2.77	-1.97	3.04
Std. Dev.	1.01	0.53	0.71	0.46	0.71	0.21
Observations	575	575	575	575	575	575

Table 3.2 shows the correlations for the selected variables after logarithm. Real oil prices and CO2 emissions have the highest associations with the REC, which is followed by income inequality, trade openness, and economic growth. These findings contribute to the hypothesis that economic growth, carbon emissions, trade

liberalization, income inequality, and real oil prices are all important determinants of renewable energy consumption. Also, a variance inflation factors (VIF) test is used to search for possible multicollinearity, with the findings indicating no multicollinearity issue in the model variables since the mean VIF (2.45) is less than the threshold value of 4. Multicollinearity findings are presented in Appendix B.

Table 3.2. Correlation Coefficient Matrix

Variable	lnREC	lnCO2	lnGDP	lnTO	lnROP	lnGN
LnREC	1.0000					
lnCO2	-0.3714	1.0000				
LnGDP	-0.0674	0.7351	1.0000			
LnTO	0.0574	0.0637	0.2592	1.0000		
LnROP	0.1900	-0.3070	-0.2602	0.0374	1.0000	
LnGN	0.0983	-0.6006	-0.7789	-0.4946	0.2903	1.0000

Our empirical model is as follows:

$$\text{REC} = f(\text{CO2}, \text{GDP}, \text{TO}, \text{ROP}, \text{GN})$$

(3.1)

Whereas, CO2, GDP, TO, ROP, GN stand for carbon emissions, economic growth, trade openness, real oil prices, and income inequality, respectively. Renewable energy consumption is represented by REC. Moreover, we used the logarithmic specification of all variables in order to obtain more relevant and intuitive results; hence, Eq. (3.1) can be rewritten as follows:

$$\ln \text{REC}_{it} = \alpha_0 + \alpha_1 \ln \text{CO2}_{it} + \alpha_2 \ln \text{GDP}_{it} + \alpha_3 \ln \text{TO}_{it} + \alpha_4 \ln \text{ROP}_{it} + \alpha_5 \ln \text{GN}_{it} + \varepsilon_{it}$$

(3.2)

In equation (3.2) “i” stands for cross-sections, “t” represents time dimension, ε stands for error term, and α_j ($j=1, 2, \dots, 5$) stands for the coefficients to be estimated for the long-run effects of proposed explanatory variables on REC.

3.4. Empirical Methodology

3.4.1. Cross-Sectional Dependence and Slope Homogeneity Tests

The appearance of cross-sectional dependence (CSD) in panel data is a serious problem that must be checked before proceeding with empirical estimation. CSD is triggered by growing association across social and economic channels, as well as previously unnoticed common shocks, rendering traditional panel estimators inconclusive. Disregarding CSD can have severe implications and using methods that presume cross-sectional (CS) independence may lead to incorrect findings. (Sarafidis and Wansbeek, 2012). Therefore, in this chapter, in order to see whether there is CSD in our panel data, we utilized three different CSD tests, including the Pesaran CD test, the Breusch-Pagan LM test, and the Pesaran LM test. Furthermore, in panel data, slope heterogeneity (SH) is a potential issue that could affect the accuracy of panel estimators. Therefore, before moving towards empirical analysis, it's critical to look for slope heterogeneity in a model. Based on these facts, the \hat{S} test of Swamy (1970), as well as $\tilde{\Delta}_{SHT}$, and $\tilde{\Delta}_{ASHT}$ test of Pesaran and Yamagata (2008) are used to investigate slope homogeneity. The following are the equations for slope homogeneity tests:

$$\mathbf{S} = \sum_{i=1}^N (\hat{\beta}_i - \hat{\beta}_{WFE})' \frac{X'MX}{\sigma_i^2} (\hat{\beta}_i - \hat{\beta}_{WFE}) \quad (3.3)$$

$$\Delta_{SHT} = (N)^{\frac{1}{2}} (2k)^{\frac{-1}{2}} \left(\frac{1}{N} \hat{\mathbf{S}} - \mathbf{k} \right) \quad (3.4)$$

$$\Delta_{ASHT} = (N)^{\frac{1}{2}} \left(\frac{2k(T-k-1)}{T+1} \right)^{\frac{-1}{2}} \left(\frac{1}{N} \hat{\mathbf{S}} - 2\mathbf{k} \right) \quad (3.5)$$

3.4.2. Unit Root Tests

In this chapter, we utilized both first-generation tests (IPS and ADF tests) and the second-generation test (CIPS test), to examine the integration order of selected variables. The CIPS test, introduced by Pesaran (2007), is more critical than other unit root tests because it assumes CSD. Conventional unit root tests lead to incorrect

findings in the existence of CSD. Despite this, this chapter utilizes the entire unit root tests listed above to ensure that the findings are free of bias. The following is the CIPS test equation:

$$\Delta I_{i,t} = a_i + b_i I_{i,t-1} + c_i \bar{I}_{t-1} + \sum_{l=0}^p d_{il} \Delta \bar{I}_{t-l} + \sum_{l=0}^p e_{il} \Delta I_{t-l} + e_{it} \quad (3.6)$$

In the equation above, Cross-Sectional (CS) means of lagged levels and first differences are presented by \bar{I}_{t-1} and $\Delta \bar{I}_{t-1}$, respectively. The Cross-Section Augmented Dickey–Fuller (CADF) statistics can be measured by using Eq. (3.6), while the Cross-Sectionally Augmented IPS (CIPS) test statistic can be attained using the following equation:

$$\widehat{CIPS} = \frac{1}{N} \sum_{i=0}^n CADF_i \quad (3.7)$$

3.4.3. Cointegration Test

The Westerlund (2008) panel cointegration technique is employed in this chapter to investigate the factors affecting REC in OECD countries. Because of the strong presumption of CSD and SH, this test has more strength than conventional cointegration approaches. Conventional cointegration techniques, according to Phillips and Sul (2003), produce misleading and contradictory results in the existence of CSD and SH. Therefore, to determine if the model has cointegration, this study utilizes Westerlund's (2008) cointegration technique, which measures two statistics: DHg (Durbin Hausman group) and DHp (Durbin Hausman panel). The DHg and DHp statistics can be obtained using the following equations:

$$DH_g = \sum_{i=1}^n \hat{X}_i (\tilde{S}_i - \hat{S}_i)^2 \sum_{t=2}^T \hat{e}_{it-1}^2 \quad (3.8)$$

$$DH_p = \hat{X}_i (\tilde{S}_i - \hat{S}_i)^2 \sum_{i=1}^n \sum_{t=2}^T \hat{e}_{it-1}^2 \quad (3.9)$$

3.4.4. Long-Run Estimation

To investigate the long-run association between the variables, this chapter adopts the AMG estimator proposed by Eberhardt and Bond (2009) and Bond and Eberhardt (2013). In the existence of CSD and SH, the AMG estimator has the potential to generate effective estimates (Sadorsky, 2012). This estimator is made up of a common dynamic mechanism that reveals the main model's unobservable common factors. The AMG estimation process consists of two steps:

$$\text{Step-1: } \Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + c_i f_t + \sum_{t=2}^T d_i \Delta D_t + e_{it} \quad (3.10)$$

$$\text{Step-2: } \hat{\beta}_{AMG} = N^{-1} \sum_{i=1}^N \hat{\beta}_i \quad (3.11)$$

In the above equations, ΔY_{it} represents the dependent variable; ΔX_{it} denotes the explanatory variable; f_t represents the heterogeneous element; β_i represents country-specific estimation coefficients; $\hat{\beta}_{AMG}$ represents the mean group estimator; the coefficient of time dummies is indicated by d_i and the intercept and error component are denoted by α_i and e_{it} , respectively.

3.5. Empirical Results and Discussion

CSD is the primary concern in the economic-energy literature when it comes to the estimation of panel data (Dong et al., 2018; Ahmad and Zhao, 2018). The findings are unreliable when CSD is overlooked (Pesaran, 2004). Therefore, in this chapter, we adopt the Pesaran CD test, Breusch-Pagan LM test, and Pesaran scaled LM test to measure the CSD among the countries, and the findings are shown in Table 3.3, providing empirical evidence that any shock if happens in one economy may affect other economies as well. Furthermore, the slope homogeneity tests are presented in Table 3.4, indicating that slope parameters are heterogeneous.

Further, the order of integration of selected variables is investigated using a variety of unit root tests (IPS, ADF, CIPS). Table 3.5 shows that the order of integration of

selected variables is mixed; some are stationary at level, while others are stationary at the first difference. Although all unit root tests yield similar findings, the CIPS test's findings are more relevant because it assumes CSD.

Table 3.3. Results of Cross-Sectional Dependence (CSD) Tests

Variable	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD
LnREC	3249.031***	133.190***	20.461***
lnCO2	2254.359***	88.971***	19.812***
LnGDP	5333.072***	225.837***	72.630***
LnTO	3229.772***	132.334***	50.639***
LnROP	4708.194***	198.058***	59.675***
LnGN	2258.341***	89.148***	3.4073***
CSD for Model	2272.434***	89.775***	4.847***
Note: *** indicates significance at the 1% level			

Table 3.4. Slope Homogeneity Tests Results

	Statistic	P-value
Swamy \hat{S}	123.513***	0.0075
$\tilde{\Delta}_{SHT}$	1666.673***	0.0000
$\tilde{\Delta}_{ASHT}$	2003.091***	0.0000
Note: *** indicates significance at 1% level		

Table 3.5. Results of Unit Root Tests

Variables	At Level		At 1 st difference		The order of integration
	Intercept	Intercept and trend	Intercept	Intercept and trend	
IPS unit root test					
LnREC	4.8830	0.3086	- 17.1055***	- 17.4357***	I(1)
lnCO2	3.0037	2.5257	- 16.2887***	- 16.9227***	I(1)
LnGDP	0.4642	2.5038	- 10.4838***	- 9.37209***	I(1)
LnTO	-0.8938	-3.4452***	-	-	I(0)
LnROP	0.2155	1.2190	- 12.2507***	- 8.42120***	I(1)
lnGN	-0.7432	-1.3149*	-	-	I(0)
ADF unit root test					
lnREC	28.0872	45.6762	329.790***	309.311***	I(1)
lnCO2	31.2520	35.5893	320.227***	295.850***	I(1)
lnGDP	47.2139	35.8735	192.959***	165.340***	I(1)
lnTO	60.1106**	79.3968***	-	-	I(0)
lnROP	37.1723	24.8437	212.522***	142.680***	I(1)
lnGN	74.5313***	60.8161**	-	-	I(0)
Pesaran CIPS unit root test					
lnREC	-1.4526	-2.8895***	-	-	I(0)
lnCO2	-1.4734	-2.6715**	-	-	I(0)
lnGDP	-2.0089	-2.3729	-2.5468***	-2.7466**	I(1)
lnTO	-2.0634	-2.1144	-2.7206***	-2.7099**	I(1)
lnROP	-2.7748***	-1.8803	-	-	I(0)
lnGN	-2.7045***	-2.5393	-	-	I(0)
Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The CIPS test critical values were tabulated by Pesaran (2007)					

After examining the stochastic behavior of variables, the cointegration test of Westerlund (2008) is adopted. The findings are shown in Table 3.6, rejecting the null hypothesis of the Westerlund (2008) statistics of DHg and DHp, suggesting the presence of a long-run association between the variables. Hence, the estimation of long-run parameters is possible while contemplating CSD.

Table 3.6. Results of Westerlund Durbin-Hausman Test

	Statistic	P-value
DHg	157.300***	0.0000
DHp	11.147***	0.0000
Note: The *** indicates significance at the 1% level		

After using Westerlund's (2008) cointegration test, the chapter adopts the AMG estimator to gauge the long-run association between the selected variables. In the existence of SH and CSD, the AMG estimator provides more reliable findings. Table 3.7 shows the findings of the panel AMG estimator. Except for CO₂, all of the variables have a positive impact on REC. The positive effects of economic growth (GDP), trade openness (TO), real oil prices (ROP), and income inequality (GN) on REC suggest that increasing these variables boosts REC in OECD economies. Furthermore, a statistically significant negative relationship is found between CO₂ and REC.

According to the findings, REC and economic growth are positively associated. Economic growth causes a 0.4892% rise in REC on average. The positive association between the two variables is also found by other researchers, including Sadosky (2009b), Popp et al. (2011), Salim and Rafiq (2012), Omri and Nguyen (2014), Lucas et al. (2016), and Nyiwul (2017). The positive association between economic growth and REC demonstrates that OECD countries with higher economic output can invest more in green energy consumption/generation in economic activities. Therefore, green energy's share will increase in overall energy consumption, while fossil fuel consumption will decrease in OECD economies.

The findings show an inverse relationship between REC and CO₂ emissions, indicating that REC results in a 0.7846% decrease in carbon emissions. This finding is backed by Wang and Dong (2019), Panwar et al., (2011), and Balsalobre-Lorente et al. (2019). Renewable energy is environmentally friendly and mitigates CO₂ emissions. Also, as sustainable energy sources, they have the potential to meet current and future generations' energy needs. Furthermore, the findings indicate that trade openness is critical in promoting REC in OECD countries. Trade openness causes a 0.1489% rise in REC on average. These results are supported by other researchers, including Sbia et al. (2014), Mbarek et al. (2018), and Cheng et al. (2019).

The findings demonstrate that REC and oil prices have a positive association. Real oil prices, on average, trigger a 0.0525% rise in REC. By analyzing the positive influence of oil prices on REC in OECD economies, it is possible to conclude that these economies are both developed and concerned about environmental implications for humans and other species. Considering that if they continue to consume more fossil fuels (coal, oil, and natural gas), they will either import more from other nations or pollute the ecological landscape by extracting more fossil fuels for economic purposes. As the fossil fuel supply is inadequate, it is self-evident that their excessive use in economic activities would result in its unavailability or, at some point, its exhaustion. Given the increase in oil prices, OECD countries would have been able to boost the availability of green energy, which is easily accessible, affordable, and considered to be less polluting. Our results are in line with the findings of other researchers, including Sadorsky (2009b), Chang et al. (2009), Brunnschweiler (2010), and Lu (2017). Furthermore, in OECD economies, income inequality is found to be a significant factor of REC. Income inequality causes a 0.6115% rise in renewable energy demand on average. These findings are consistent with the findings of McGee and Greiner (2019) and Asongu and Odhiambo (2019). Despite the potential benefits that can be stimulated by investments from the highest income group, income inequality could potentially seriously slow down the adoption of renewable energy sources (Uzar, 2020). Higher inequality characterized by top income shares, however, can promote investment in renewable energy and, as a result, its adoption rates when the economic and institutional framework permits it (Barro, 1999). Our findings show that while creating policies for the adoption and promotion of renewable energy,

policymakers must strike a balance while paying special attention to the influence of income inequality.

Table 3.7. Results of AMG Estimator

Variables	Coefficient	Standard error	Z-stat.	Prob. Value
lnCO2	-0.7846***	0.1459	-5.38	0.000
lnGDP	0.4892**	0.2073	2.36	0.018
lnTO	0.1489***	0.0316	4.71	0.000
lnROP	0.0525**	0.0248	2.12	0.034
lnGN	0.6115**	0.2647	2.31	0.021
Wald-test	66.47***			0.000
RMSE	0.0413			

Note: ***, and ** indicate 1% and 5% significant level, respectively.

Table 3.8 presents the AMG estimator’s country-specific findings. According to the findings, CO2 emissions and REC have a significant negative association in 16 out of 23 countries, including the Netherlands, the United States, Finland, Greece, Portugal, Austria, Germany, Spain, the United Kingdom, Denmark, New Zealand, Sweden, Chile, Colombia, Mexico, and Turkey. Many of these countries have implemented robust policies and incentives with the aim of fostering the widespread adoption of renewable energy sources. These policies encompass a range of measures, including feed-in tariffs, tax credits, subsidies, and the establishment of renewable energy targets (Gozgor et al., 2020). Such initiatives effectively stimulate both businesses and individuals to invest in and utilize renewable energy. Consequently, the escalating utilization of renewable energy contributes to the displacement of fossil fuel-based energy generation, thereby leading to a notable reduction in CO2 emissions (Nicolli and Vona, 2019). In addition, the advancement and adoption of renewable energy technologies have constituted significant progress in these countries. Technological innovations have resulted in heightened efficiency and diminished costs associated with renewable energy production. As these renewable technologies become increasingly competitive, they naturally emerge as an appealing option for meeting energy demands while simultaneously diminishing reliance on carbon-intensive

energy sources (Zhao et al., 2023). Further, environmental concerns and a heightened awareness of climate change have become prevalent in these countries. Consequently, augmented societal and political pressure has emerged, compelling a transition towards cleaner and more sustainable energy alternatives. As a direct consequence of this shift in perspective, the demand for renewable energy sources has surged, accompanied by a willingness to invest in cleaner technologies, resulting in a tangible reduction in CO₂ emissions (Stevens et al., 2023). Moreover, a significant number of these countries are signatories to international agreements, as exemplified by the Paris Agreement, which seeks to curtail global warming and mitigate greenhouse gas emissions. In compliance with these commitments, these nations have been prompted to intensify their adoption of renewable energy as a means to curb CO₂ emissions and address the challenges posed by climate change. Furthermore, these nations recognize the strategic benefits of diversifying their energy sources by increasing the proportion of renewables in their energy mix. Such a course of action strengthens their energy security by reducing their dependence on fossil fuels and minimizing the importation of energy-intensive fuels (Karlilar et al., 2023). As a result, these countries are less susceptible to fluctuations in international energy markets and geopolitical uncertainties, thus bolstering their stability and resilience.

Moreover, a significant positive association between REC and economic growth is found in 7 out of 23 economies, including the Netherlands, the United States, Finland, Austria, Canada, Mexico, and Turkey. Conversely, the findings in some countries, namely Norway and Hungary, show a significant negative association between economic growth and REC. Countries exhibiting positive relationships with renewable energy have likely made substantial investments in renewable energy infrastructure, resulting in increased accessibility and cost-effectiveness of renewable energy sources. This proactive approach encourages businesses to adopt renewable energy solutions, leading to notable reductions in energy costs and a strengthened competitive position, consequently exerting a positive influence on economic growth (Abbas et al., 2023). Moreover, the development and expansion of the renewable energy sector facilitate the creation of job opportunities and foster economic activity. This, in turn, contributes to elevated employment rates and higher income levels, leading to augmented consumer spending and overall economic growth (Hou et al., 2023). Further, by elevating the share of renewable energy in their energy mix, these countries diminish

their dependence on fluctuating fossil fuel markets, bolstering energy security and stability, thereby ensuring a more dependable energy supply for industries and businesses and further supporting economic growth. Furthermore, nations that actively promote renewable energy consumption tend to have robust environmental and climate policies. These forward-looking policies not only attract sustainable investments but also foster the adoption and advancement of green technologies, which, in turn, stimulate economic growth while mitigating adverse environmental impacts (Su et al., 2023).

Conversely, the observed negative association between economic growth and REC in countries like Norway and Hungary can be attributed to several factors. Some countries heavily rely on non-renewable resources as a significant source of revenue and economic growth, leading to resistance from industries vested in traditional energy sectors when transitioning to renewable energy (Kilinc-Ata and Dolmatov, 2023). Moreover, certain countries might face policy barriers, including inadequate incentives or regulatory frameworks that hinder the widespread adoption of renewable energy. A lack of sufficient support for renewable energy initiatives can limit their growth potential and, consequently, their impact on economic growth (Liao et al., 2023). The economic structure of some countries may also pose challenges to the adoption of renewable energy. For instance, high levels of industrialization or dependence on specific sectors can hinder the seamless integration of renewable energy sources into existing infrastructure. Additionally, countries heavily reliant on hydroelectric power or other intermittent renewable sources (as in the case of Norway) may encounter difficulties related to energy storage and grid stability, potentially impeding economic growth. The intermittency of such renewable sources can pose operational challenges that require innovative solutions for efficient energy utilization (Zhang et al., 2023). In conclusion, the positive relationship between countries and renewable energy adoption fosters economic growth by reducing energy costs, enhancing competitiveness, and creating job opportunities. However, the negative association observed in certain countries can be attributed to factors such as resistance from traditional energy sectors, policy barriers, incompatible economic structures, and challenges related to intermittent renewable sources (Aydin and Bozatli, 2023). Addressing these challenges can unlock the full potential of renewable energy to drive sustainable economic growth while also promoting environmental stewardship.

The findings reveal a positive association between real oil prices and REC in 9 out of the 23 economies under study. These economies include the Netherlands, the United States, Belgium, Greece, Austria, Sweden, the United Kingdom, Chile, Colombia, and Hungary. Several factors contribute to this observed phenomenon. Firstly, higher oil prices have the effect of motivating both consumers and industries to explore alternative, cost-effective energy sources. As renewable energy becomes increasingly competitive in terms of its price and accessibility, it emerges as a viable option to consider when oil prices experience an upturn (Chu, 2023). Secondly, certain countries among the aforementioned group have implemented supportive policies and financial incentives aimed at stimulating the adoption of renewable energy (Jin et al., 2023). Consequently, these policies lead to an increase in renewable energy consumption, irrespective of fluctuations in oil prices. Furthermore, countries heavily reliant on oil imports to meet their energy demands perceive renewable energy as a strategic approach to enhance energy security and mitigate dependence on foreign oil (Wu, 2023). This perspective fosters a positive association between oil prices and renewable energy consumption.

Conversely, a notable and statistically significant negative association is observed between real oil prices and REC, specifically in Portugal and Turkey. This can be attributed to several reasons. To begin with, both Portugal and Turkey may have limited investments in renewable energy infrastructure or may possess policies that impede the growth of the renewable energy sector, even in the presence of increasing oil prices. Additionally, these countries may continue to heavily rely on fossil fuels to meet their energy needs, resulting in a heightened preference for cheaper fossil fuel alternatives over renewable energy sources when oil prices rise (Katircioglu and Katircioglu, 2023). Furthermore, the unique economic and market factors pertaining to Portugal and Turkey may influence the dynamics of renewable energy demand and supply in such a way that it negatively correlates with fluctuations in oil prices (Aydin and Bozatli, 2023).

In Norway, Germany, the United Kingdom, and Mexico, there exists a positive relationship between trade openness and REC. The policy of trade openness in these countries facilitates their access to advanced renewable energy technologies and resources available on international markets. This engagement in global trade allows

for the importation of renewable energy equipment, components, and expertise, thereby expediting the adoption and deployment of renewable energy systems (Pata and Samour, 2023). Furthermore, participation in international trade enables these nations to diversify their energy sources, reducing their dependence on a singular energy supplier or type. This diversification enhances their energy security and resilience, minimizing their vulnerability to supply disruptions or price fluctuations in specific energy resources (Cergiboza, 2022). Another important outcome of trade openness is the fostering of competition within the domestic energy market. The heightened competition in this sector encourages investments in renewable energy and spurs innovation as countries strive to gain a competitive advantage on the global energy stage (Dagar et al., 2022). Moreover, the inclusion of these countries in global trade networks and international agreements concerning climate change and renewable energy targets serves as motivation for them to increase their renewable energy consumption levels. Fulfilling their environmental obligations, they embrace renewable energy as a pivotal component of their energy mix (Saleem et al., 2022). Lastly, trade-driven access to a diverse array of renewable energy products and technologies contributes to raising public awareness and acceptance of renewable energy solutions. As a result, this stimulates consumer demand for sustainable energy alternatives (Nan et al., 2022).

The findings further indicate that income inequality and REC are interconnected in specific countries. Specifically, in the Netherlands, Denmark, and Germany, there is a positive linkage between income inequality and REC. Conversely, in the United States, a negative association exists between these two factors. In countries demonstrating a positive relationship, such as the Netherlands, Denmark, and Germany, the presence of robust government policies and incentives encourages the adoption of renewable energy sources. These measures often include subsidies, feed-in tariffs, tax credits, and regulations to promote REC (Cao et al., 2022). However, it is important to note that these policies may not be equally accessible to all income groups, leading to a higher uptake of renewable energy among wealthier households that can afford the initial costs or benefit more from the incentives. Furthermore, these countries have made significant advancements in the development and adoption of renewable energy technologies. As these technologies become more advanced and cost-effective, the initial investment required for transitioning to renewable energy sources becomes

more manageable for higher-income households, resulting in increased REC within this demographic (Khan et al., 2022). Additionally, societal awareness and concern for environmental issues and climate change are generally higher in countries like the Netherlands, Denmark, and Germany. This heightened environmental consciousness fosters a greater willingness among higher-income individuals to invest in and support renewable energy solutions, contributing to the positive correlation between income inequality and REC (Radulescu et al., 2022).

Conversely, the United States experiences higher levels of income inequality compared to the aforementioned European countries. This disparity can hinder lower-income households in the U.S. from investing in renewable energy technologies, despite the presence of government incentives or policies (Yasmeen et al., 2022). Consequently, REC may be higher among wealthier households, leading to the observed negative relationship between income inequality and REC. Additionally, unlike the consistent and comprehensive renewable energy policies seen in certain European countries, the United States follows a more fragmented approach to renewable energy regulations and incentives. Variability in policies across states can create disparities in renewable energy adoption based on geographical location and financial resources of households (Niaz et al., 2022). Moreover, historically, the U.S. has provided substantial subsidies to the fossil fuel industry, making conventional energy sources relatively cheaper for consumers. This economic incentive reduces the motivation for both individuals and businesses to transition to renewable energy sources, particularly for lower-income households (Nakhli et al., 2022).

Table 3.8. Country-Specific Results of AMG Estimator

Country	lnCO2	LnGDP	lnTO	lnROP	lnGN
Netherlands	-1.3845***	2.0012***	-0.2378	0.1818***	2.5377***
Norway	-0.0036	-0.4009*	0.2401*	-0.0352	-0.2395
France	-0.1751	-1.3020	0.2496	0.0372	0.9355
United States	-1.7482*	2.3150**	0.2549	0.1171**	-3.9020**
Belgium	-0.4009	1.0146	0.4229	0.2559***	-1.5425
Finland	-0.3521***	0.1327*	0.2029	-0.0301	0.6085
Greece	-0.9233**	-0.4711	-0.0176	0.0776**	0.7115
Japan	-0.5401	1.3571	0.1077	-0.0678	-1.2461
Portugal	-1.6112***	0.7612	0.1945	-0.1603**	1.6086
Austria	-1.0498***	0.9303***	0.1674	0.0658***	0.2237
Canada	-0.1651	0.4430*	-0.0253	0.0058	0.1064
Denmark	-0.4955***	-0.8278	0.1975	0.0443	1.5006**
Germany	-1.5013***	-0.6358	0.8906***	0.0074	3.5805***
New Zealand	-0.8145***	0.48628	0.0681	-0.0456	0.5967
Spain	-1.7921***	1.4098	0.1051	0.0565	-0.0097
Sweden	-0.4384***	0.1816	0.2338	0.0818***	0.4789
Switzerland	-0.2206	0.4695	-0.0311	-0.0108	-0.1640
United Kingdom	-2.8834***	0.9017	1.2854*	0.2994***	4.2436
Chile	-0.5338***	0.5353	-0.1415	0.1198*	1.1677
Colombia	-0.6162**	-0.0972	0.2349	0.1322***	0.7226
Hungary	0.0885	-2.9761***	0.1724	0.2686***	1.0982
Mexico	-1.0439***	0.8275***	0.1438**	0.0191	0.8321
Turkey	-1.2118***	0.7698***	0.1107	-0.0745***	-3.1292

Note: The *, **, and *** indicate significance at 10%, 5%, and 1% level, respectively.

3.6. Dumitrescu and Hurlin Panel Causality Test

In the preceding section of this chapter, we applied the AMG estimator to evaluate the long-term relationships between variables, accommodating both heterogeneous and homogeneous relationships across different countries or entities within the panel. It is important to note, however, that the AMG estimator primarily focuses on estimating long-run associations and may not explicitly elucidate the short-term causal dynamics

among the variables. To address this limitation, in this chapter, we have incorporated the Dumitrescu and Hurlin (DH) panel causality test, which is purposefully designed for identifying short-run causal relationships within a panel data context. This test serves to complement the AMG estimator by exploring not only the enduring relationships but also the more immediate cause-and-effect interactions between the factors influencing renewable energy consumption. This dual analytical approach allows for a comprehensive examination of the interplay between these factors over both short- and long-term horizons, thereby enhancing the depth and rigor of our analysis.

The DH panel causality test, proposed by Dumitrescu and Hurlin (2012), is relevant and applicable when there is CSD in the error terms. In balanced and heterogeneous panel models, the test can also be used when the time period (T) is greater than the number of cross-sections (N), i.e., $T > N$. The DH panel causality test hypothesis can be evaluated using an average Wald statistic, which is as follows:

$$WD_{N,T}^{HNC} = N^{-1} \sum_{i=1}^N WD_{i,t}$$

(3.12)

Whereas, $WD_{i,t}$ represents the Wald statistics and averaging each Wald statistic for cross-sections yields the $WD_{N,T}^{HNC}$ statistic.

The DH panel causality test is selected for this study for several reasons. First, it is designed explicitly for panel data analysis, which is highly suitable for the study as it involves multiple countries observed over time (Ahmed et al., 2022). Secondly, the DH test takes into consideration cross-sectional dependence, which is essential when dealing with data from diverse countries or regions that may exhibit interdependence or similar behaviors (Magoti et al., 2020). Thirdly, this test accounts for potential heterogeneity across countries in the panel, contributing to more robust causal inference (Abdullah and Tursoy, 2021).

Moreover, being an extension of the Granger causality test for panel data, the DH test is well-suited for studying causal relationships in this specific context. By employing the DH panel causality approach, the chapter aims to discern potential causal links

between the selected explanatory variables and REC. This endeavor offers valuable insights into the underlying dynamics and policy implications, furthering the promotion of sustainable energy development.

Table 3.9 presents the results of the DH causality test, revealing significant causal relationships among the variables under investigation. Specifically, REC, trade openness, income inequality, and real oil prices all demonstrate a one-way causal relationship with CO₂ emissions. Notably, income inequality and REC exhibit a bidirectional causal relationship, indicating that changes in income inequality can influence REC, and vice versa. This suggests that the adoption and accessibility of renewable energy technologies may have varying effects on different income groups, and concurrently, income disparities can impact the feasibility and affordability of renewable energy solutions. Furthermore, the findings demonstrate unidirectional causality from oil prices and income inequality to GDP, suggesting that alterations in oil prices and income inequality can impact the level of GDP within the studied context. Elevated oil prices may lead to increased production costs and energy expenditures, influencing economic growth. Similarly, greater income inequality can influence resource distribution and wealth allocation, with potential implications for overall economic performance.

Additionally, Table 3.9 highlights unidirectional causality running from GDP to REC, indicating that within OECD economies, REC will rise in tandem with economic growth. This implies that changes in GDP can influence REC levels. As GDP represents a country's economic output, higher GDP can potentially facilitate greater resources and capacity for investment in renewable energy infrastructure and technologies. At both micro and macro levels, citizens and governments within the OECD have recognized that unsustainable fossil fuel usage is a primary driver of environmental degradation. Consequently, there is a prevailing inclination to prioritize green energy over fossil fuels in various consumption and production activities. These causality findings provide valuable insights into the intricate interactions and feedback loops between CO₂ emissions, renewable energy consumption, trade openness, income inequality, real oil prices, and GDP. Policymakers and researchers can utilize these insights to enhance their comprehension of these dynamics and develop more effective strategies to address environmental and economic challenges.

Table 3.9. Results of DH Panel Causality Test

Null hypothesis	W-statistic	\bar{Z}-statistic	P-value
lnREC \neq lnCO2	6.0448***	17.1078	0.0000
lnREC \neq lnGDP	1.6512	2.2083	0.5250
lnREC \neq lnTO	2.0906	3.6985	0.4125
lnREC \neq lnROP	1.5803	1.9679	0.5275
lnREC \neq lnGN	5.3674**	8.0748	0.0275
lnCO2 \neq lnREC	2.2029	4.0792	0.2225
lnCO2 \neq lnGDP	1.7946	2.6946	0.3700
lnCO2 \neq lnTO	1.1456	0.4937	0.8625
lnCO2 \neq lnROP	1.9376	3.1797	0.4025
lnCO2 \neq lnGN	2.8120	1.9471	0.6900
lnGDP \neq lnREC	3.3720*	8.0439	0.0775
lnGDP \neq lnCO2	3.5807	8.7517	0.1100
lnGDP \neq lnTO	3.1915	7.4318	0.2075
lnGDP \neq lnROP	3.6971	9.1463	0.2425
lnGDP \neq lnGN	4.4506	5.8764	0.2575
lnTO \neq lnREC	1.4103	1.3914	0.7650
lnTO \neq lnCO2	3.8623**	9.7064	0.0250
lnTO \neq lnGDP	2.4152	4.7993	0.1900
lnTO \neq lnROP	1.3154	1.0697	0.6800
lnTO \neq lnGN	3.9089	4.5773	0.1525
lnROP \neq lnREC	3.8885**	9.7954	0.0200
lnROP \neq lnCO2	6.5285***	18.7479	0.0050
lnROP \neq lnGDP	5.0465**	13.7223	0.0225
lnROP \neq lnTO	1.6077	2.0609	0.5550
lnROP \neq lnGN	4.2451	5.3835	0.2000
lnGN \neq lnREC	3.8685***	9.7276	0.0025
lnGN \neq lnCO2	3.1633*	7.3362	0.0600
lnGN \neq lnGDP	4.9793***	13.4945	0.0025
lnGN \neq lnTO	2.4194	4.8134	0.2225
lnGN \neq lnROP	1.9023	3.0599	0.5175

Note: The *, **, and *** indicate significance at 10%, 5%, and 1% level, respectively. The symbol \neq represents “does not cause”.

3.7. Conclusion and Policy Implications

The detrimental impacts of non-renewable energy sources have received a lot of attention and are recognized as a concern in global public policy. Thus, promoting the use of renewable energy has been the aim of global climate policy. Renewable energy adoption rates are still far behind established targets, despite the fact that country-specific initiatives have increased them over time. The literature has examined a number of aspects that affect the adoption of renewable energy sources in order to inform policy.

Using the AMG estimator, which allows for CSD and SH, this chapter looks at the association between REC, economic growth, CO₂ emissions, income inequality, oil prices, and trade openness in 23 OECD economies from 1991 to 2020. The empirical findings obtained through the AMG estimator reveal that REC and the independent variables have a long-run linkage. All explanatory variables are positively associated with REC, with the exception of CO₂ emissions, which is negatively associated with REC. These findings are consistent with the conclusions drawn by prior researchers, including Akar (2016), Murshed (2019), Uzar (2020), Alam and Murad (2020), and Yang and Song (2023). Moreover, long-run elasticities for carbon emissions, GDP, trade openness, energy (oil) prices, and income inequality are -0.7846%, 0.4892%, 0.1489%, 0.0525%, and 0.6115%, respectively.

The country-specific AMG estimator reveals statistically significant negative associations between CO₂ emissions and REC in 16 out of 23 countries. These countries, including the Netherlands, the United States, Finland, Greece, Portugal, Austria, Germany, Spain, the United Kingdom, Denmark, New Zealand, Sweden, Chile, Colombia, Mexico, and Turkey, have implemented policies and incentives aimed at fostering the adoption of renewable energy, resulting in notable reductions in CO₂ emissions. Additionally, a positive correlation between REC and economic growth is observed in seven countries, namely the Netherlands, the United States, Finland, Austria, Canada, Mexico, and Turkey. Conversely, Norway and Hungary exhibit a negative association, potentially attributable to resistance from traditional energy sectors and policy barriers. Furthermore, real oil prices exhibit a positive association with REC in nine countries, including the Netherlands, the United States,

Belgium, Greece, Austria, Sweden, the United Kingdom, Chile, Colombia, and Hungary. Conversely, Portugal and Turkey show a negative relationship, which may be influenced by specific economic and market factors. Moreover, trade openness demonstrates a positive correlation with REC in Norway, Germany, the United Kingdom, and Mexico, facilitating access to advanced renewable energy technologies and promoting competition in the renewable energy sector. Also, Income inequality and REC are positively linked in the Netherlands, Denmark, and Germany, indicating that wealthier households may have higher levels of renewable energy consumption. In contrast, the United States shows a negative association, potentially due to income disparities affecting renewable energy adoption. This negative relationship may be influenced by government policies and the affordability of renewable energy solutions.

The findings from the DH causality test indicate that there are one-way causal relationships between CO₂ emissions and REC, trade openness, income inequality, and real oil prices. However, there is bidirectional causality observed between income inequality and REC, suggesting mutual influence between these two factors. Furthermore, there is a unidirectional impact from both oil prices and income inequality on GDP, while GDP influences REC in a unidirectional manner.

The following policy implications could be implemented based on the findings of this chapter to further enhance the quality of the environment in OECD economies. As economic growth positively influences REC, policymakers should prioritize the fostering of sustainable economic development while promoting the adoption of renewable energy sources. Implementing policies that incentivize investments in renewable energy infrastructure and technologies can foster economic prosperity while advancing environmental sustainability. Additionally, the positive correlation between income inequality and REC underscores the importance of addressing income disparities to ensure widespread access to and adoption of renewable energy across diverse income groups. Tailored policies that provide incentives for renewable energy usage and ensure affordability for lower-income populations can promote a more equitable energy transition. Further, the observed positive relationship between trade openness and REC highlights the potential benefits of increased international trade in facilitating access to global renewable energy technologies and resources. Policymakers should focus on promoting trade openness and forging international

collaborations to expedite the integration and dissemination of renewable energy solutions. Furthermore, the negative association between CO₂ emissions and REC signifies the efficacy of renewable energy adoption in reducing carbon emissions. Policymakers must prioritize policies that encourage the transition from fossil fuel-based energy sources to renewable alternatives, thus contributing to effective climate change mitigation. Moreover, to address the influence of real oil prices on REC, policymakers should strategize to stabilize energy prices and manage oil price fluctuations. Investing in renewable energy technologies can reduce dependency on fossil fuels, thereby mitigating the impact of oil price volatility on energy markets. Lastly, the identification of a long-run linkage between REC and the independent variables underscores the significance of adopting comprehensive and integrated energy strategies for sustainable energy development. Policymakers should formulate strategies that holistically consider economic, environmental, and social factors, ensuring a seamless and sustainable energy transition. By adhering to these policy implications, policymakers can lay the groundwork for a greener and more sustainable future for OECD economies, harmonizing economic growth with environmental stewardship.

CHAPTER IV

DO DRIVERS OF RENEWABLE ENERGY CONSUMPTION MATTER FOR BRICS ECONOMIES? NEXUS AMONG TECHNOLOGICAL INNOVATION, ENVIRONMENTAL DEGRADATION, ECONOMIC GROWTH, AND INCOME INEQUALITY

4.1. Introduction

By 2030, the 7.9 billion people who currently inhabit the planet are projected to reach 8.5 billion (UN, 2021). Sustainable development is hampered by continued rapid population growth. Fulfilling the requirements of the present generation without depleting the resources available to following generations is what sustainable development entails. To put it another way, sustainable development aims to conserve the environment for present-day needs as well as those of future generations (Wang et al., 2022; Usman and Radulescu, 2022). To solve environmental challenges, such as global warming, it is essential to adhere to the 17 Sustainable Development Goals (SDGs) (IPCC, 2014). Global warming is largely caused by the enormous amount of carbon that human activity adds to the atmosphere. It develops as a consequence of the industrialization, population pressures, and urbanization that occur in economies all over the world as a result of the high reliance on fossil fuels.

In the absence of global agreement on mitigation and adaptation measures taken by developing and developed countries to normalize greenhouse gas (GHG) concentrations caused by CO₂ emissions and regulate climate change and environmental deterioration within a global context, policymakers of individual nations are making progress, and exerting efforts in their own capacities to stabilize and mitigate the effects of global warming. In order to attain these objectives, governments are more intentionally implementing new environmental policies and establishing regulatory standards aimed at modifying their energy usage patterns.

Various recommended approaches include developing new, efficient, and environmentally friendly technology, increasing the effectiveness of existing technologies, and/or making a partial or complete switch to renewable energy sources (RES). The latter, i.e., dependence on RES, is the approach that offers the best chance of rapidly replacing non-renewables (Olabi et al., 2021; Mahalik et al., 2021; Sayed et al., 2021).

Renewable energy must be incorporated into economical and technically practical GHGs reduction strategies (Gyamfi et al., 2018; Wang et al., 2022). By lowering reliance on fossil fuels, renewable energy can help in reducing emissions and ensure energy security (Saboori et al., 2022). RES can enhance air quality and human health, reduce energy costs, lessen negative effects on the environment, and create jobs (REN21, 2020). Furthermore, energy import prices can be decreased by utilizing indigenous RES including wind, biomass, solar, hydropower, and geothermal (Duan et al., 2022). In light of all these environmental considerations, nations are switching to renewable energy. In 2015, RES provided about 19% of the energy consumed worldwide (REN21, 2017). By 2025, it is anticipated that renewable energy will outpace coal in the production of electricity, and by 2050, RES will produce half of the world's electricity (EIA, 2019).

Recent studies have explored the variables that affect the uptake of renewable energy in light of its importance (Zhao et al., 2022; Chen et al., 2021). Some of these researches looked at how REC and technical innovation are related (Khan et al., 2022; Alam and Murad, 2020). The rapid deployment of RES to satisfy energy needs and alter the pattern of energy use could result from technological innovation. Cost reductions and technical breakthroughs have reportedly increased investment in renewable energy by 17%, according to the IEA (2019), which is a sign of both technological progress and environmental sustainability. Moreover, energy consumption rises along with income, suggesting a strong connection between economic development and REC. Additionally, income inequality may affect renewable energy consumption. For instance, income disparity can influence societal trends like individualism, short-termism, and commercialism, which in turn might affect the deployment of renewable/green energy (Uzar, 2020). It may also have an impact on REC by altering institutional quality and the distribution of power among

various social groups. Power disparities have an impact on REC and how institutions operate by giving the elite groups who profit from traditional energy sources the power to define environmental regulations. Due to profit-seeking conduct, it is difficult for less fortunate populations to benefit from the usage of renewables (Castrejon-Campos et al., 2022). Consequently, the distribution of green energy will be influenced by the power dynamics between these groups. Furthermore, renewable energy sources are used to produce clean energy, which can lessen carbon emissions. Hence, a significant factor of renewable energy could be CO₂ emissions (Samour et al., 2022; Dogan and Muhammad, 2019; Omri and Nguyen, 2014).

The BRICS economies—Brazil, Russia, India, China, and South Africa—are the subject of a case study. The BRICS economies have significantly influenced global energy consumption and production because of their rapid economic expansion and large population levels. Due to their size and rapid economic expansion, the BRICS economies have a huge impact on the advancement of the global economy. Between 1985 and 2016, the BRICS countries' GDP expanded rapidly, from US \$2187 billion to US \$16,266 billion, with a 6.5% annual growth rate on average (World Bank, 2017). By 2030, the BRICS nations' share of global GDP will have risen to 37.7%, significantly ahead of Europe (15.3%), and the United States (15%). The fact that the BRICS represent more than 50% of world economic growth, 40% of the global population, and nearly 20% of world trade can be used to assess the economic progress of BRICS (NDB, 2018). By 2050, the BRICS economies are expected to outperform even the world's most developed economies (G7) (Pao and Tsai, 2010). The BRICS economies' massive energy consumption is causing global CO₂ emissions (Khobai et al., 2021). About 38% of global CO₂ emissions are attributable to these economies (Khobai et al., 2021).

Due to their rapid economic growth and high energy consumption, the BRICS nations now place a high priority on energy security. In this case, using renewable energy might be a good way to achieve sustainable energy usage. Using the bootstrap panel cointegration technique (2007), AMG estimator, PMG estimator, and Dumitrescu and Hurlin (DH) causality test, this chapter attempts to analyze the factors influencing REC in BRICS economies over the period 1992-2019.

This chapter contributes to the present body of knowledge in the following ways: (I) The study addresses a crucial aspect that has been overlooked in the investigation of factors influencing REC, especially in BRICS economies. It explores the impact of income inequality on REC, revealing profound socioeconomic implications and sustainability challenges. The research highlights how income inequality significantly hinders the accessibility and affordability of renewable energy technologies, creating barriers for adoption among lower-income individuals and communities. By recognizing this issue, policymakers can develop targeted policies to ensure equitable access to renewable energy resources. Furthermore, it underscores the urgency for inclusive and sustainable energy policies that align with the UN Sustainable Development Goals, particularly Goal 10 (reducing inequality) and Goal 7 (promoting affordable and clean energy), which are crucial for achieving sustainable development. The study also emphasizes income inequality's role in influencing renewable energy and its implications for climate change mitigation and social and political stability. Policymakers are urged to investigate this connection thoroughly to effectively address the social challenges related to renewable energy adoption, thereby fostering a more just and environmentally sustainable energy landscape. (II) The study provides policymakers and decision-makers with a comprehensive understanding of the interconnections between economic growth, technological innovation, capital formation, and environmental degradation with regards to REC. This understanding is crucial for designing effective strategies to maximize the efficient use of RES. (III) On the empirical side, the study addresses renowned issues in panel econometrics, namely slope homogeneity (SH) and cross-sectional dependence (CSD). Unlike previous research that neglected to test for CSD and SH, this chapter employs up-to-date panel estimation techniques to overcome these challenges. By utilizing this robust econometric modeling approach, the study produces reliable results that are instrumental in decision-making processes within BRICS economies. (IV) The study employs the AMG estimator to account for the unique features of each nation in the panel. This ensures that reliable and unbiased coefficient estimates are generated for each economy, making the obtained results more policy-oriented and applicable in practical decision-making scenarios.

4.2. Literature Review

In the literature for studies on renewable energy, there has been a clear progression in recent years. This is due to the fact that using RES is acknowledged as one of the key ways to lower the quantity of CO₂ emissions in the energy system and combat climate change (Zhao et al., 2022; Muhammad et al., 2022). Several studies have been conducted on the variables affecting the utilization of renewable/green energy. For instance, over the past decade, several researchers have researched the association between REC and GDP growth. Some of them have discovered a positive association (Namahoro et al., 2021; Ullah et al., 2021; Ahmad et al., 2022; Ehigiamusoe, K. U., & Dogan; Wang et al., 2022; Aslan et al., 2022; Chen et al., 2022), while others have discovered a negative association (Ocal and Aslan, 2013; Bhattacharya et al., 2016). The negative association between GDP growth and REC points to the likelihood that the economy is being overburdened by the high costs of renewable energy deployment, which in turn causes economic activity to slow down as a result of rising expenses. For example, Bhattacharya et al. (2016) found that the increased usage of green energy resulted in a slowdown in economic growth in Israel, the US, India, and Ukraine, indicating that these nations may continue to use fossil fuels for future growth.

Further, a number of studies are dedicated to examining one or more of four widely accepted hypotheses regarding the association between GDP growth and REC. The first hypothesis, also referred to as the growth hypothesis, states that there is a one-way causality linking REC and GDP growth. According to this argument, changes in REC and associated regulations will have a huge influence on economic expansion because energy is such a critical component of production. The growth hypothesis is supported empirically by studies such as Adams et al. (2018), and Bilgili and Ozturk (2015). The conservation hypothesis, which proposes a unilateral causal association between REC and GDP growth, is likewise validated by a number of studies (Dong et al., 2018; Tiwari, 2011). Other studies that emphasize the bidirectional causal link between economic expansion and green energy support the feedback hypothesis (Amri, 2017; Kahia et al., 2017; Eren et al., 2019). Finally, a number of studies supported the neutrality hypothesis, which claims no direct or indirect causal link between economic expansion and green energy usage (Menegaki, 2011; Bowden and Payne, 2010).

Moreover, countries are encouraged to employ more renewable energy sources and promote environmental protection as the need to reduce CO₂ emissions to prevent global climate change. Therefore, CO₂ emissions were included as one of the explanatory variables in earlier research that looked at the variables affecting REC. For instance, Sadorsky (2009) revealed that REC in G7 nations is significantly influenced by increases in CO₂ emissions. A study by Salim and Rafiq (2012) demonstrated that REC in India, China, Brazil, and Indonesia was significantly influenced by carbon emissions. Regardless of how they classified their sample, Omri and Nguyen (2014) discovered that rising CO₂ emissions were the primary factor driving the REC. However, when Apergis and Payne (2014) looked at the link for the Central American countries, they also discovered a strong link between REC and carbon emissions. Mac Domhnaill and Ryan (2020) showed that over the period from 2000 to 2015, greater levels of carbon emissions encouraged the adoption of renewable energy in the production of electricity in EU. Moreover, Nguyen and Kakinaka (2019) discovered that the REC and CO₂ emissions had different relationships. Their research suggests that in low-income countries, REC is positively correlated with carbon emissions, but in high-income ones, it is negatively correlated.

According to Jamil et al. (2022), renewable energy considerably lowers CO₂ emissions and accelerates GDP growth. According to Khezri et al. (2022), who give evidence from diverse economies that REC reduces the risk of environmental deterioration. According to Jebli and Youssef (2017), using RES can assist increase agricultural production and fight global warming. In a same vein, Wang et al. (2021) show that REC is adversely connected with carbon emissions and recommend creating strategies for easy access to renewable energy to combat climate change. The same conclusion, which shows that renewable energy is favorable to CO₂ mitigation, is reported by Sinha and Shahbaz (2018), Balsalobre-Lorente and Leito (2020), and Bilgili et al. (2021). However, economic growth may increase environmental degradation. Moreover, Belad and Zrelli (2019) discovered short-term two-way causal association between carbon emissions and REC using a panel of nine Mediterranean nations. Lin and Zhu (2019) examined variables affecting the growth of green energy technology in China. The results demonstrate that innovation is positively affected by investments in R&D and that high CO₂ emissions speed up the development of green energy technology.

Also, the crucial importance of research and development in fostering green technological innovation has been confirmed by numerous studies (Bointner, 2014; Lin and Zhu, 2019; Su et al., 2022), and it has also been demonstrated that technological innovation has a favorable influence on REC (Khan et al., 2021). Cheon and Urpelainen (2012) specifically looked into the association between technological innovation in energy sector and discovered that innovation in energy sector is a successful strategy for coping with the sharp fluctuations in oil prices. They also discovered that government and corporate investments in new energy technology have been profitable due to the political and economic strength of the innovation system brought about by high oil prices. Their study's theoretical justification for the profitability of investments in green energy is essential given the existing dominance of traditional energy. According to Irandoust (2018), technological innovations in Denmark and Norway encourage REC, however in Sweden and Finland, the opposite is true due to the countries' differing energy systems and other factors. He et al. (2018) analyzed the effects of technical innovation on RE in China. The findings show that technological research and development is one of the key variables impacting REC. The question of whether or not the introduction of new technology broadens renewable energy is examined by Xie et al. (2020). The findings show that the advancement of new technologies has a significant influence on REC. However, renewable energy cannot be significantly influenced by the available technology. According to Salvarli and Salvarli (2020), renewable energy will drive future energy needs, hence its production must be efficient. The findings investigate how technical innovation is a crucial component of renewable development that may help resolve environmental degradation. According to Li and Shao (2021), the production of green energy has a negative effect on innovation. Besides, Irandoust (2016) found the unidirectional causal relationship that the utilization of renewable energy follows technological advancement. Additionally, Tang and Tan (2013) discovered that technological innovation has a substantial role in reducing the use of non-renewable energy sources.

Furthermore, current research has examined the linkage between income disparity and REC (McGee and Greiner, 2019; Uzar 2020; Muhammad et al., 2022; Shahbaz et al., 2022; Sharma and Rajpurohit, 2022). Using parametric approach, Uzar (2020) analyzes the influence of income disparity on REC from 2000 to 2015. In 175 countries between 1990 and 2014, McGee and Greiner (2019) investigate how economic

disparity modifies the relationship between REC and carbon emissions. In order to effectively replace fossil fuels, they argue that measures intended to increase the REC should be geared toward lowering income inequality. Besides, Bai et al. (2020) are concerned about the possibility that income disparity may reduce the impact of green energy technological innovation on the deterioration of the environment in terms of carbon emissions. According to their definition of a considerable threshold impact in regard to income inequality, policies aimed at decreasing income disparity may also help lower CO₂ emissions. Given that income inequality has been associated with a number of outcomes that may have an impact on green energy, the emphasis on income disparity is crucial. For instance, inequality has been linked to many variables, including GDP growth, health and wellbeing, and the environment (Sager 2019; Gugushvili et al., 2020; Asongu and Odhiambo, 2021). The societal benefits and favorable externalities from tackling economic disparity can assist expedite the deployment of green energy. Therefore, in order to steer policy, it is crucial to demonstrate empirically the link between green energy and inequality

Having said that, this chapter uses the AMG estimator to look into the effects of GDP growth, income inequality, CO₂ emissions, gross fixed capital formation, and technological innovation on REC in BRICS countries. Slope heterogeneity and cross-sectional dependence are both taken into consideration by the AMG estimation technique to prevent the overgeneralization that impaired earlier research. The AMG provides results for the panel and for each of the BRICS economies. Consequently, more policy-oriented findings can be obtained. The empirical findings may assist policymakers in taking measures to increase REC and develop an energy system that is both economically and environmentally sustainable.

4.3. Data and Methodology

Using annual data from 1992 to 2019, this chapter examines the impact of CO₂ emissions, capital formation, technological innovation, GDP growth, and income disparity on REC in BRICS economies. The fact that these nations account for 37% of world energy usage, 20% of the world GDP, and 40% of world CO₂ emissions allows us to assess the sample's relevance (Banday and Aneja, 2019; Liu et al., 2022). Significant clean energy development is necessary to prevent these economies from

being compelled into costly, carbon-concentrated, and unstable energy systems, that will harm their ability to expand economically. To solve this, the BRICS economies have significantly boosted their spending on sustainable energy projects as the role of green energy in the global energy supply is rapidly becoming more established. As a result, investment in green energy is rising in developing and growing countries, notably in the BRICS nations. These nations account for 36% of the world's green energy capacity and 27% of the world's non-hydro energy capacity. As green energy is the most efficient approach to protect the environment, it is crucial to look at the factors affecting REC in these countries.

This chapter takes into account six variables: economic growth or per capita GDP (constant 2020 US\$), REC (share of overall energy consumption), gross fixed capital formation (% of GDP), CO₂ emissions per capita (metric tons), technological innovation (patent applications, residents), and income inequality (Gini index). The data on income inequality is sourced from Solt (2021), while the data on the other variables is gathered from World Development Indicators (WDI, 2021). All of the chosen variables are transformed using a natural logarithm, allowing elasticity to be utilized to explain the derived slope coefficients.

Our empirical model is as follows:

$$\ln \text{REC}_{it} = \beta_0 + \beta_1 \ln \text{GDP}_{it} + \beta_2 \ln \text{CO2}_{it} + \beta_3 \ln \text{INN}_{it} + \beta_4 \ln \text{GN}_{it} + \beta_5 \ln \text{GFCF}_{it} + \varepsilon_{it} \quad (4.1)$$

where REC stands for consumption of renewable energy. GDP, CO₂, INN, GN, and GFCF stand for economic growth, carbon emissions, technological innovation, income inequality, and gross fixed capital formation, respectively. Finally, “t”, “i”, and “ε” stand for time dimension, cross-sections of countries, and the error term, respectively.

Economic growth, as a fundamental indicator of a country's overall economic performance and prosperity, is included in the model. It is anticipated that countries experiencing higher economic growth will exhibit greater energy demand, including increased consumption of renewable energy. This connection is attributed to the fact

that economic development often stimulates amplified industrial and commercial activities, consequently driving energy needs.

Gross fixed capital formation, representing the total value of investments in physical assets like buildings, machinery, and infrastructure, is also considered in the model. Higher levels of capital formation can indicate an increased capacity for energy production and utilization, thereby potentially contributing to elevated REC.

CO₂ emissions, being closely tied to energy consumption and production, are incorporated as an explanatory variable. By doing so, the study endeavors to explore how a country's carbon footprint influences its renewable energy consumption. Nations with higher CO₂ emissions might exhibit stronger incentives to shift towards renewable energy sources to mitigate their environmental impact.

The role of technological innovation in shaping the energy landscape is recognized, and advancements in renewable energy technologies are acknowledged as potential drivers for increased adoption and utilization of cleaner energy sources. Including technological innovation as an explanatory variable enables researchers to assess its impact on renewable energy consumption.

Income inequality, a crucial social factor, is taken into account due to its potential influence on resource accessibility, including renewable energy. Higher-income inequality may lead to disparities in renewable energy adoption, with lower-income individuals and communities facing barriers in terms of access and affordability. Analyzing the impact of income inequality sheds light on equity concerns in renewable energy consumption.

By incorporating the aforementioned explanatory variables, the empirical model aims to provide a comprehensive analysis of the factors contributing to variations in renewable energy consumption across different countries or regions. Understanding the relationships between these variables can greatly assist policymakers in designing effective strategies to promote and manage renewable energy adoption while also considering broader economic, environmental, and social implications.

The Chapter adopts the AMG estimator presented by Bond and Eberhardt (2013) to examine the long-term relationship between the variables. In the presence of slope heterogeneity, and cross-sectional dependence, the AMG estimator has the potential to generate effective estimates (Sadorsky, 2012). This estimator is made up of a common dynamic mechanism that reveals the main model's unobservable common factors. The AMG estimation process consists of two steps:

$$\text{Step-1: } \Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + c_i f_t + \sum_{t=2}^T d_i \Delta D_t + e_{it} \quad (4.2)$$

$$\text{Step-2: } \hat{\beta}_{AMG} = N^{-1} \sum_{i=1}^N \hat{\beta}_i \quad (4.3)$$

In the above equations, ΔY_{it} represents the dependent variable; ΔX_{it} denotes the explanatory variable; f_t represents the heterogeneous element; β_i represents country-specific estimation coefficients; $\hat{\beta}_{AMG}$ represents the mean group estimator; the coefficient of time dummies is indicated by d_i and the intercept and error component are denoted by α_i and e_{it} , respectively.

The panel AMG estimate approach offers a long-run parameter but is unable to indicate whether factors are causally related, even though causality is crucial for formulating policy recommendations. Therefore, our study adopts the Dumitrescu and Hurlin (DH) (2012) test to explore the causal association between the selected variables as well as their directions. In balanced and heterogeneous panel models, the test can also be used when the time period (T) exceeds the cross-sections (N), i.e., $T > N$. The DH test hypothesis can be evaluated using the mean of Wald statistic, which is as follows:

$$WD_{N,T}^{HNC} = N^{-1} \sum_{i=1}^N WD_{i,t} \quad (4.4)$$

Whereas, $WD_{i,t}$ represents the Wald statistics, and averaging each Wald statistic for cross-sections yields the $WD_{N,T}^{HNC}$ statistic.

4.4. Empirical Results and Discussion

An overview of descriptive statistics is provided in Table 4.1. According to the results, the greatest and smallest lnREC average values are 3.8527 and 1.2754 for India and Russia, respectively. India has the lowest average GDP value (6.8931), while Brazil has the highest average GDP value (9.1716). In terms of carbon emissions, Russia has the greatest mean lnCO₂ value (2.4383), whereas India has the lowest (0.1017). Among BRICS countries, the highest and lowest lnINN mean values are 11.1418 and 6.5709 for China and South Africa, respectively. Moreover, according to the mean lnGN values, the highest income disparity is seen in South Africa, whereas Russia has the lowest. Further, the countries with the highest and lowest mean values of lnGFCF are China (3.6191) and South Africa (2.8894). For the BRICS panel, the average mean is highest for technological innovation (8.84), followed by economic growth (8.33), income inequality (3.82), gross fixed capital formation (3.15), REC (2.96), and carbon emissions (1.35), respectively. Further, the findings of correlation analysis, presented in Table 4.2, reveal that there is a significant correlation among selected variables, indicating that economic growth, CO₂ emissions, income inequality, technological innovation, and gross fixed capital formation are all significant drivers of REC.

Table 4.1. Descriptive Statistics

Countries	Statistics	lnREC	lnGDP	lnCO ₂	lnINN	lnGN	lnGFCF
Brazil	Mean	3.811	9.171	0.645	8.161	3.925	2.936
	Std. dev.	0.049	0.138	0.160	0.267	0.051	0.078
	Minimum	3.725	8.960	0.358	7.649	3.833	2.809
	Maximum	3.894	9.392	0.967	8.509	3.990	3.126
Russia	Mean	1.275	9.017	2.438	10.095	3.572	2.981
	Std. dev.	0.063	0.272	0.078	0.216	0.050	0.120
	Minimum	1.171	8.613	2.315	9.622	3.391	2.666
	Maximum	1.395	9.370	2.638	10.583	3.616	3.175
India	Mean	3.852	6.893	0.101	8.254	3.826	3.371
	Std. dev.	0.151	0.331	0.259	0.773	0.067	0.135
	Minimum	3.584	6.388	-0.262	7.097	3.718	3.151
	Maximum	4.047	7.468	0.579	9.439	3.906	3.578
South Africa	Mean	2.847	8.777	2.169	6.570	4.131	2.889

Table 4.1. (cont.)

	Std. dev.	0.058	0.122	0.067	0.503	0.016	0.119
	Minimum	2.745	8.615	2.044	4.927	4.104	2.718
	Maximum	2.950	8.933	2.300	6.910	4.151	3.157
China	Mean	3.017	7.814	1.400	11.141	3.679	3.619
	Std. dev.	0.401	0.618	0.436	1.590	0.079	0.130
	Minimum	2.459	6.787	0.835	9.211	3.517	3.412
	Maximum	3.494	8.779	2.022	13.783	3.761	3.795
Panel	Mean	2.960	8.334	1.351	8.844	3.826	3.159
	Std. dev.	0.959	0.929	0.919	1.806	0.203	0.310
	Minimum	1.171	6.388	-0.262	4.927	3.391	2.666
	Maximum	4.047	9.392	2.638	13.783	4.151	3.795
	Observations	120	120	120	120	120	120

Table 4.2. Matrix of Correlation Coefficient (After Logarithm)

Variables	lnREC	lnGDP	lnCO2	lnINN	lnGN	lnGFCF
lnREC	1.0000					
lnGDP	-0.4743	1.0000				
lnCO2	-0.8798	0.6269	1.0000			
lnINN	-0.4122	0.0228	0.2087	1.0000		
lnGN	0.4496	0.1847	-0.0788	-0.7053	1.0000	
lnGFCF	0.1966	-0.5856	-0.2907	0.6312	-0.3633	1.0000

We use the Pesaran scaled and Breusch-Pagan LM tests to examine whether the variables have CSD. At the 1% level of significance, the CSD test statistics indicate that the chosen variables are cross-sectionally dependent, rejecting the null hypothesis of cross-sectional independence (see Table 4.3). Furthermore, Table 4.4 demonstrates that the null hypothesis of the SH test is rejected, demonstrating the heterogeneity of the slope parameters.

Table 4.3. Findings of Cross-Sectional Dependence (CSD) Tests

Variable	Breusch-Pagan LM	Pesaran scaled LM
lnREC	73.8690***	14.2816***
lnGDP	217.1780***	46.3264***
lnCO2	79.5485***	15.5515***
lnINN	88.4409***	17.5399***
lnGN	129.3572***	26.6891***
lnGFCF	56.2924***	10.3513***
CSD for Model	107.0501***	21.7011***
Note: *** denotes a 1% level of significance		

Table 4.4. Findings of Slope Homogeneity Test

	Statistic	P-value
$\tilde{\Delta}$	1690.5247***	0.0000
$\tilde{\Delta}_{adj}$	2050.0623***	0.0000
Note: *** denotes a 1% level of significance		

To test for data stationarity, we employed first- and second-generation unit root tests, including IPS, ADF, LLC, and CIPS, and the findings are shown in Tables 4.5 and 4.6. Although the findings of all unit root tests are similar (mixed order of integration), the findings of the CIPS test are more significant since the CIPS test not only addresses the CSD problem but is also robust to the heterogeneity problem.

Table 4.5. Findings of First Generation Unit Root Tests

Variables	Level		1 st difference		Integration order
	Intercept	Intercept & trend	Intercept	Intercept & trend	
Im, Pesaran and Shin					
lnREC	0.5845	-0.5594	-6.0556***	-4.6138***	I(1)
lnGDP	3.3585	-0.7211	-3.7947***	-2.1381***	I(1)

Table 4.5. (cont.)

lnCO2	0.8271	-0.6278	-5.9592***	-4.6884***	I(1)
lnINN	1.2578	-1.7680**	-	-	I(0)
lnGN	-2.0599**	-1.2366	-	-	I(0)
lnGFCF	-0.4351	-0.1631	-7.3791***	-6.3573***	I(1)
ADF – Fisher					
lnREC	11.4198	13.4609	52.2532***	38.5385***	I(1)
lnGDP	1.47236	14.6388	32.3198***	20.3830**	I(1)
lnCO2	10.5745	13.3170	50.7522***	37.7255***	I(1)
lnINN	9.85442	18.6642**	-	-	I(0)
lnGN	24.3277***	26.1349***	-	-	I(0)
lnGFCF	9.06748	12.3440	63.8306***	50.7727***	I(1)
Levin, Lin, and Chu					
lnREC	0.7362	-0.4101	-5.3122***	-4.0985***	I(1)
lnGDP	0.4246	-0.8506	-3.6202***	-3.5199***	I(1)
lnCO2	0.4349	-1.5510*	-	-	I(0)
lnINN	1.2999	-1.7566**	-	-	I(0)
lnGN	-2.6644***	-2.5758***	-	-	I(0)
lnGFCF	-0.9125	0.0921	-7.5619***	-6.5681***	I(1)
Note: The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively.					

Table 4.6. Findings of Second Generation Unit Root Test – CIPS

Variables	Level		1 st difference		Integration order
	Intercept	Intercept & trend	Intercept	Intercept & trend	
lnREC	-2.4690**	-2.1081	-	-	I(0)
lnGDP	-1.9059	-2.7819*	-	-	I(0)
lnCO2	-2.0227	-3.2672***	-	-	I(0)
lnINN	-3.5374***	-1.5859	-	-	I(0)
lnGN	-1.6055	-2.3463	-2.4321**	-2.5578	I(1)
lnGFCF	-1.8639	-2.1865	-2.4406**	-2.4109	I(1)
Note: The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively. The critical values for the CIPS test were tabulated by Pesaran (2007)					

After examining the stochastic nature of the variables, several panel cointegration tests, including Pedroni, Fisher, Kao, and Westerlund (2007), are employed. The rejection of the null hypothesis in each cointegration test provided in Table 4.7 indicates that there is evidence of a long-term association between the variables. The long-run associations between the variables are evident in all cointegration tests, but the Westerlund (2007) test is more noteworthy because it incorporates the CSD issue using the bootstrap approach.

Table 4.7. Panel Cointegration Tests

Pedroni (Within-Dimension)		
	Statistic	Weighted Statistic
Panel v-Statistic	1.3961	0.2900
Panel rho-Statistic	0.0402	0.6503
Panel PP-Statistic	-3.3306***	-2.2614***
Panel ADF-Statistic	-3.3349***	-1.9030***
Pedroni (Between-Dimension)		
	Statistic	P-value
Group rho-Statistic	1.4123	0.9211
Group PP-Statistic	-2.7676***	0.0028
Group ADF-Statistic	-2.2241***	0.0131
Fisher		
No of CE(s)	Trace test	Max-Eigen test
None	218.0***	118.3***
At most 1	123.1***	75.58***
At most 2	60.95***	35.17***
At most 3	33.78***	19.16**
At most 4	24.18***	18.11**
At most 5	21.87**	21.87**
	Statistic	P-value
Kao		
ADF	-2.5643***	0.0052
Westerlund (2007)		
Statistic	Value	Robust P-value
Gt	-3.595**	0.028
Ga	-3.293	0.495
Pt	-6.960**	0.015
Pa	-1.562	0.753
Note: All cointegration tests are run with intercept only. The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively.		

Table 4.8. Results of the AMG and PMG Estimators

Variables	AMG		PMG	
	Coefficient	P-value	Coefficient	P-value
lnGDP	0.0229	0.938	0.2230***	0.012
lnCO2	-0.5004***	0.000	-0.7438***	0.000
lnINN	-0.1204**	0.035	-0.0678**	0.020
lnGN	-0.8908***	0.008	-1.4027***	0.000
lnGFCF	-0.0679*	0.085	-0.1843***	0.011

Note: The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively.

After establishing the long-run linkage between the variables, the AMG and PMG estimators are employed to determine the direction of the relationship between the variables and the size of the long-term coefficients and the series. The findings of the AMG and PMG techniques are shown in Table 4.8. The direction of the predicted coefficient remains the same when using different estimators, but the size and levels of significance have changed.

The findings from the AMG estimator indicate that GDP growth has a positive but insignificant impact on REC. The remaining variables, including carbon emissions (CO₂), technological innovation (INN), income inequality (GN), and capital formation (GFCF), have a negative and statistically significant effect on REC, suggesting that increasing these variables reduces REC in BRICS countries. The findings indicate that REC causes a 0.5004% drop in carbon emissions, demonstrating an adverse relationship between carbon emissions and REC. Destek and Aslan (2020), Abbasi et al. (2021), Namahoro et al. (2021), Radmehr et al. (2021), Jamil et al. (2022), Khezri et al. (2022), Samour et al. (2022), and Muhammad et al. (2022) all back up this finding. High carbon emissions are typically associated with increased reliance on fossil fuels and traditional energy sources. In BRICS countries, industries and sectors heavily dependent on fossil fuels may resist transitioning to renewable energy due to existing infrastructure and economic considerations (Adebayo et al., 2023). Moreover, renewable energy technologies may still be in the early stages of adoption and might not yet fully replace carbon-intensive energy sources in these countries.

Using the AMG estimator, it is discovered that the coefficient for technological innovation is negative and statistically significant. A 0.1204% decrease in REC results from a 1% rise in technical innovation. This finding is consistent with what Suki et al. (2022) discovered. Surprisingly, technological innovation can have a negative impact on REC in BRICS countries. One possible reason is that rapid advancements in technology might lead to more efficient fossil fuel extraction and usage, making them relatively cheaper and further delaying the adoption of renewable energy. Additionally, limited access to the latest renewable energy technologies or inadequate investment in research and development might hinder their widespread implementation (Wahab et al., 2022).

Also, the coefficient of capital formation is discovered to be negative and statistically significant, indicating that a 1% rise in GFCF reduces REC by 0.0679%. This result is consistent with the findings of Lin and Omoju (2017), and Yasmeen et al. (2021). GFCF refers to investments in physical assets, such as machinery and infrastructure, which are essential for economic development. In some cases, heavy investment in traditional energy infrastructure may be prioritized over renewable energy projects due to the immediate returns and established industries associated with fossil fuels. As a result, renewable energy projects might receive relatively less investment, leading to a slower growth rate in their adoption.

Further, it is discovered that income inequality has a negative and significant long-term effect on REC, suggesting that a fairer income distribution will lead to higher usage of renewable energy. This result is backed by Uzar and Eyuboglu (2019), Topcu and Tugcu (2020), Uzar (2020), Tan and Uprasen, and Shahbaz et al. (2022). The favorable effect of fairer income distribution on REC can be explained in several ways. First off, by easing people's financial worries, the lowering of income disparity can raise ecological consciousness. Environmental demands may rise as a result of ecological issues. Reduced individuality and higher communal consciousness may significantly contribute to the promotion of RES due to fairer income distribution. Governments can encourage green energy projects using incentive mechanisms like tax concessions and financing facilities in the context of people's need for a high-quality environment.

For robustness, the PMG estimator is used since it is both stable and effective at handling heterogeneity. The findings of the PMG estimator, which are presented in Table 4.8, concur with the results of the AMG estimator. According to the findings of the PMG estimator, a 1% increase in CO₂, INN, GN, and GFCF depletes REC by 0.7438%, 0.0678%, 1.402%, and 0.1843%, respectively. On the other hand, REC rises by 0.2230% for every 1% growth in GDP. These coefficients' magnitude and direction are approximately identical to those of the AMG estimator. Additionally, Table 4.9 presents the nation-specific findings of the AMG estimator. The results show that GDP and REC are significantly positively associated in China and Brazil. Both of these countries have undergone substantial economic growth in recent decades, resulting in heightened levels of industrialization, urbanization, and the emergence of a burgeoning middle class. This surge in economic activity has translated into escalated energy demands to support industrial production, transportation, and the needs of a larger populace. As a response to this mounting energy requirement, both nations have actively harnessed renewable energy sources (Joof et al., 2023). To facilitate the adoption of renewable energy, both China and Brazil have implemented favorable policies and incentives. These measures encompass feed-in tariffs, subsidies, tax credits, and investments in renewable energy infrastructure. Such conducive regulatory frameworks and financial support have stimulated investments by both businesses and individuals in renewable energy sources, consequently leading to an upswing in renewable energy consumption (Banu et al., 2022). Furthermore, substantial investments in renewable energy projects and technologies have been made by both countries. For instance, China has positioned itself as a global leader in solar panel manufacturing and installation, while Brazil has significantly augmented its electricity generation from renewable sources, primarily hydropower. These investments have bolstered the capacity and accessibility of renewable energy, further propelling its utilization (Sachan et al., 2023). In addition to their domestic efforts, both China and Brazil possess the advantage of diverse renewable energy resources due to their geographical diversity. Brazil enjoys abundant hydropower potential, whereas China is endowed with favorable conditions for solar and wind energy. This availability of diverse renewable resources has contributed to a more balanced and reliable energy mix, thereby attracting greater investment and utilization (Voumik and Sultana, 2022). Moreover, both nations have faced environmental challenges, including air pollution and deforestation. In recognition of these issues and the global

concerns surrounding climate change, there has been a growing awareness and commitment to promoting renewable energy as a cleaner and more sustainable alternative. As parties to international agreements related to climate change and sustainable development, such as the Paris Agreement, both these countries have been spurred to intensify their efforts to transition to renewable energy sources as part of their strategies to combat climate change and mitigate carbon emissions (Qing et al., 2023).

Moreover, findings reveal that technological progress reduces renewable energy use in Brazil, China, and Russia. Despite notable strides in renewable energy, Brazil, China, and Russia continue to heavily rely on fossil fuels to meet their energy demands. The advancement of technology in fossil fuel extraction, production, and consumption efficiency has the potential to yield cheaper and more accessible fossil fuel energy (Zeraibi et al., 2023). Consequently, established infrastructure and lower costs associated with fossil fuels may lead industries and consumers to favor them over renewable energy sources. Furthermore, these nations harbor energy-intensive industries, including manufacturing, mining, and heavy industries, which might find conventional energy sources, such as fossil fuels, economically more viable than transitioning to renewables. This preference could be reinforced if technological advancements further enhance the efficiency of energy-intensive processes (Hailiang et al., 2023). Additionally, substantial subsidies or incentives offered by these countries to support their fossil fuel industries may artificially reduce the cost of fossil fuels, thereby diminishing the competitiveness of renewable energy technologies in the energy market, even as these technologies improve. Moreover, despite experiencing economic growth, Brazil, China, and Russia may not have made sufficient investments in renewable energy infrastructure and research and development. Consequently, the pace of technological progress in the renewable energy sector may struggle to outpace advancements in conventional energy technologies (Tan and Uprasen, 2022). Regulatory or policy barriers may also hinder the adoption and integration of renewable energy into these countries' energy mix. Complex permitting processes, inadequate grid infrastructure, and inconsistent renewable energy policies are among the obstacles faced. Also, energy security concerns might play a role in maintaining a reliance on fossil fuels, particularly for countries like Russia with abundant fossil fuel reserves. The availability of domestic

fossil fuel resources may reduce the motivation to transition to renewable energy, despite technological advancements in the renewable energy sector (Deng et al., 2022). In conclusion, the interplay between technological progress and renewable energy use in Brazil, China, and Russia is influenced by various factors, including the prevalence of fossil fuels, energy-intensive industries, subsidies favoring fossil fuels, limited investment in renewables, policy barriers, energy security considerations, and historical inertia in the energy sector. To promote a shift toward more sustainable energy systems in these nations, it is essential to address these challenges and accelerate technological progress in renewable energy.

In India, Brazil, and China, an inverse association between CO₂ emissions and REC has been identified. This detrimental correlation is attributable to their ongoing dependence on fossil fuels, escalating energy demands, established infrastructure and investments, policy complexities, challenges related to grid integration, technological impediments, cultural influences, and economic factors (Sarwat et al., 2022). In order to effectuate a more substantial reduction in CO₂ emissions, these countries must diligently confront these challenges and accord paramount importance to the systematic transition towards renewable energy sources. Making renewable energy a central element of their energy policies and strategic frameworks is imperative to achieve this objective.

In Brazil, a substantial inverse relationship exists between REC and GFCF. This inverse correlation can be attributed to various economic and policy factors. Historically, Brazil's heavy reliance on hydropower for electricity generation, driven by abundant water resources, has resulted in a relatively lower emphasis on investing in alternative renewable energy sources. Consequently, GFCF tends to focus on conventional infrastructure for hydropower projects rather than diversifying into other renewable energy technologies (Ghosh, 2022). Furthermore, Brazil's prioritization of other pressing economic needs, such as industrial development, urbanization, and transportation infrastructure, leads to allocating more capital to these sectors deemed crucial for economic growth and job creation, possibly reducing investments in renewable energy. The policy landscape in Brazil might not fully support renewable energy investments, as stronger incentives could be provided for traditional energy sources, leading investors to hesitate in allocating capital to renewable projects

(Awosusi et al., 2022). Also, the significant upfront capital costs associated with investing in renewable energy projects, particularly large-scale installations like solar and wind farms, coupled with limited or expensive financing options, may impede their development despite their potential long-term benefits. Additionally, the relative immaturity of the renewable energy market in Brazil compared to conventional energy markets might be perceived as riskier or less stable, influencing investment decisions (Caglar, 2022). Moreover, the availability and efficiency of renewable energy technologies could also play a role; if certain technologies are not yet as cost-effective or reliable as conventional energy sources, investors may be hesitant to heavily invest in them.

The findings derived from the country-specific AMG estimator provide evidence of a negative association between income inequality and REC in both China and Russia. Income inequality gives rise to disparities in accessing essential resources and services, including energy. In the context of China and Russia, privileged individuals and communities typically enjoy superior access to renewable energy technologies, such as solar panels and wind turbines, which often involve substantial installation and maintenance costs. In contrast, lower-income households face challenges in affording these technologies and thus tend to rely more on conventional and less expensive energy sources like coal or natural gas (Barak, 2022). Further, the energy landscape is notably influenced by governmental policies and subsidies. In certain instances, financial incentives or subsidies for renewable energy projects may be selectively directed toward specific regions or wealthier segments of the population. Consequently, the adoption of renewable energy sources becomes more prevalent among affluent individuals or businesses, leading to an observable negative correlation between income inequality and renewable energy consumption (Rout et al., 2022). Furthermore, both China and Russia have prominent energy-intensive industries heavily dependent on conventional energy sources. These sectors are often dominated by large corporations or wealthy investors, resulting in concentrated energy consumption within them (Zooka et al., 2022). This concentration of conventional energy usage could be contributing to the identified negative relationship with renewable energy consumption, which may not be as prominent in these sectors. Moreover, income inequality can significantly influence the levels of education and awareness regarding renewable energy technologies. Individuals with higher incomes

tend to possess greater knowledge about the benefits of renewable energy and its long-term environmental advantages. Additionally, they may have the financial resources to invest in renewable energy education and initiatives (Kaur et al., 2023). Conversely, individuals with lower incomes may encounter limited access to such information and might demonstrate reduced prioritization of renewable energy adoption.

Table 4.9. Country-Wise Results of AMG Estimator

Country	lnGDP	lnCO2	lnINN	lnGN	lnGFCF
Brazil	0.721***	-0.788***	-0.250***	-0.495	-0.156***
Russia	0.342	-0.322	-0.216**	-1.212***	-0.001
India	-0.045	-0.530***	-0.020	-0.190	0.012
China	-0.822***	-0.603***	-0.124***	-0.865***	-0.053
South Africa	-0.142	-0.262	0.010	-1.790	-0.143
Note: The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively.					

4.5. Panel Causality Test

Upon establishing the long-term association between the variables employing the AMG and PMG estimators, we proceeded to employ the Dumitrescu and Hurlin (DH) panel causality test to discern short-term causal relationships between the variables. The findings of the DH test are presented in Table 4.10. According to these findings, there exists a bi-directional causality between GFCF and carbon emissions. An increase in GFCF leads to higher carbon emissions, which can be attributed to escalated industrial activity and energy consumption. Likewise, higher carbon emissions can act as a stimulus for increased investments in specific industries, potentially resulting in higher GFCF. Furthermore, a bi-directional causality is observed between GDP growth and gross fixed capital formation. Economic growth drives more investments in infrastructure, technologies, and industries. Conversely, higher investments in fixed capital can lead to increased economic activity and subsequent GDP growth. In addition, REC, CO2 emissions, capital formation, and technological innovation exhibit one-way causal links with economic growth. Moreover, unidirectional causal relationships are discovered: firstly, from REC,

income disparity, and technological innovation towards carbon emissions, indicating that higher REC, reduced income inequality, and innovation can result in decreased carbon emissions. Secondly, from REC and technological innovation towards GFCF, imply that greater emphasis on REC and technological advancement can drive increased investments in physical assets. Furthermore, a unidirectional causal relationship is found from income inequality to REC and technological innovation. This suggests that addressing income inequality can lead to increased technological innovation, reduced reliance on non-renewable energy imports, and a greater share of renewables in total energy consumption/production. In conclusion, these findings shed light on the complex interplay between various economic and environmental factors. The identified causal relationships underscore the importance of sustainable practices, technological advancements, and equitable income distribution to promote both economic growth and environmental well-being.

Table 4.10. Findings of DH Causality Test

Null hypothesis (H_0)	W-stat.	\bar{Z} -stat.	Prob.
$\ln\text{REC} \neq \ln\text{GDP}$	43.9531**	24.4986	0.0200
$\ln\text{REC} \neq \ln\text{CO}_2$	4.4173**	5.4032	0.0425
$\ln\text{REC} \neq \ln\text{INN}$	1.8339	1.3185	0.3300
$\ln\text{REC} \neq \ln\text{GN}$	16.7311	6.9269	0.2250
$\ln\text{REC} \neq \ln\text{GFCF}$	4.6716**	5.8054	0.0400
$\ln\text{GDP} \neq \ln\text{REC}$	6.5644	5.1032	0.1750
$\ln\text{GDP} \neq \ln\text{CO}_2$	26.4372	13.1921	0.1175
$\ln\text{GDP} \neq \ln\text{INN}$	3.3026	3.6407	0.3050
$\ln\text{GDP} \neq \ln\text{GN}$	2.1932	0.2161	0.9875
$\ln\text{GDP} \neq \ln\text{GFCF}$	28.0362*	14.2243	0.0775
$\ln\text{CO}_2 \neq \ln\text{REC}$	2.1770	0.1979	0.8850
$\ln\text{CO}_2 \neq \ln\text{GDP}$	7.2347***	9.8579	0.0025
$\ln\text{CO}_2 \neq \ln\text{INN}$	1.0321	0.0507	0.9750
$\ln\text{CO}_2 \neq \ln\text{GN}$	3.8864	2.1090	0.4150
$\ln\text{CO}_2 \neq \ln\text{GFCF}$	8.4294***	7.1883	0.0025
$\ln\text{INN} \neq \ln\text{REC}$	4.2694	2.5373	0.2975
$\ln\text{INN} \neq \ln\text{GDP}$	3.0339*	3.2158	0.0625
$\ln\text{INN} \neq \ln\text{CO}_2$	4.3933*	5.3653	0.0775
$\ln\text{INN} \neq \ln\text{GN}$	1.6785	-0.3594	0.8550

Table 4.10. (cont.)

$\ln\text{INN} \neq \ln\text{GFCF}$	3.6399*	4.1741	0.0975
$\ln\text{GN} \neq \ln\text{REC}$	5.2381**	6.7010	0.0150
$\ln\text{GN} \neq \ln\text{GDP}$	8.4857***	11.8359	0.0000
$\ln\text{GN} \neq \ln\text{CO2}$	3.8546*	4.5136	0.0750
$\ln\text{GN} \neq \ln\text{INN}$	4.4705**	5.4873	0.0475
$\ln\text{GN} \neq \ln\text{GFCF}$	1.9438	1.4924	0.5250
$\ln\text{GFCF} \neq \ln\text{REC}$	2.8164	2.8720	0.1225
$\ln\text{GFCF} \neq \ln\text{GDP}$	9.7033***	13.7611	0.0000
$\ln\text{GFCF} \neq \ln\text{CO2}$	2.7950*	2.8382	0.0700
$\ln\text{GFCF} \neq \ln\text{INN}$	1.1767	0.2794	0.8175
$\ln\text{GFCF} \neq \ln\text{GN}$	5.9968*	4.4686	0.0875
Note: The significant level of 1%, 5%, or 10% is indicated by the symbols ***, **, and *, respectively. The symbol \neq indicates “does not cause”.			

4.6. Conclusion and Policy Implications

Climate change continues to be a global issue, and energy needs will continue to rise as population growth accelerates. The problem with the climate is directly caused by the emission of greenhouse gases. Energy demand, in the meantime, supports economic expansion. As a result, the issues are now interrelated. All countries value economic development, yet the significant CO₂ emissions from current energy production directly contribute to environmental deterioration. Therefore, to maintain the economic significance of countries, green energy continues to be the most suitable replacement for the world's energy needs. Renewable energy is climate-friendly since it reduces or eliminates CO₂ emissions. Several nations have already begun their journey towards a low-carbon economy by concentrating on RES. Given this information, the goal of this chapter is to analyze the effects of economic growth, technological development, CO₂ emissions, gross fixed capital creation, and income disparity on REC.

In order to attain the study's objective, we adopt the PMG and AMG estimators for the BRICS economies over the period 1992 to 2019. The findings of the AMG estimator reveal that REC results in a 0.5004% decline in carbon emissions, signifying an adverse relationship between carbon emissions and REC. Furthermore,

technological innovation negatively and significantly affects REC, resulting in a 0.1204% decrease in REC for every 1% increase in technical innovation. Similarly, capital formation has a negative influence on REC, with a 1% rise in GFCF leading to a 0.0679% decrease in REC. Income inequality also exerts a negative and significant influence on REC in the long term, implying that a fairer income distribution promotes greater utilization of renewable energy. The PMG estimator corroborates the results obtained from the AMG estimator, demonstrating similar coefficients and directional relationships for the examined variables.

Country-specific findings indicate that GDP and REC are significantly and positively associated in China and Brazil, where renewable energy sources have been actively harnessed through favorable policies and investments. In Brazil, China, and Russia, technological progress leads to reduced renewable energy usage due to factors such as reliance on fossil fuels, energy-intensive industries, subsidies favoring fossil fuels, and limited investments in renewables. In India, Brazil, and China, an inverse association between CO₂ emissions and REC exists due to persisting fossil fuel dependence, complex policy frameworks, technological constraints, and economic factors. Transitioning to renewable energy is critical in these countries to mitigate CO₂ emissions effectively. Brazil exhibits a substantial inverse relationship between REC and GFCF, attributed to historical reliance on hydropower and limited investment in alternative renewable energy sources. In China and Russia, income inequality shows a negative association with REC, as privileged individuals have better access to renewable energy technologies, leading to disparities in renewable energy consumption. In conclusion, promoting renewable energy as a central element of energy policies and addressing economic, policy, and technological challenges are indispensable in achieving a sustainable energy transition. These findings underscore the significance of embracing renewable energy sources and implementing measures to reduce carbon emissions for a greener and more sustainable future in BRICS countries.

The study's findings suggest several policy implications that could be implemented to enhance the quality of the environment in BRICS economies. It is recommended that a stronger emphasis be placed on fostering research and development in renewable energy technologies. Policymakers should take measures to incentivize both private

and public investments in innovation, while also promoting collaboration between industries and research institutions. Support for startups and initiatives focused on renewable energy advancements should also be encouraged. This multifaceted approach is expected to result in the development of more efficient and cost-effective renewable energy technologies, thereby facilitating their widespread adoption.

Furthermore, efforts to reduce carbon emissions are predicted to positively impact renewable energy consumption. Policymakers are advised to prioritize the implementation of measures aimed at reducing carbon emissions, including the introduction of regulations, carbon pricing mechanisms, and support for cleaner energy alternatives. Such actions will create an enabling environment for the growth of renewable energy usage.

Investments in renewable energy infrastructure are seen as pivotal in increasing the adoption of renewable energy sources. Policymakers should actively promote public and private investments in renewable energy projects, as well as the upgrading of grid infrastructure to facilitate seamless integration of renewable energy. Additionally, offering financial incentives to businesses and households for investing in renewable energy systems can foster greater adoption.

Recognizing that income disparities may hinder the widespread adoption of renewable energy technologies, policymakers should implement targeted policies to address income inequality and ensure equitable access to renewable energy resources. This may involve providing financial assistance, subsidies, or supporting community-based renewable energy projects to bridge the accessibility gap among different socioeconomic groups.

Moreover, policies that foster economic development are considered vital in encouraging higher levels of renewable energy consumption. Policymakers should focus on creating an environment that promotes sustainable economic growth, enabling businesses to thrive and incorporating renewable energy as an integral part of sustainable business practices.

In summary, the policy implications derived from the study underscore the significance of promoting technical innovation, reducing CO2 emissions, investing in renewable energy infrastructure, addressing income inequality, and fostering economic growth to drive the higher adoption of renewable energy sources. By implementing these policies, governments can effectively advance their sustainable energy transition goals and contribute to a greener and more resilient future.



CHAPTER V

DO TRADE LIBERALIZATION POLICIES AFFECT THE GREEN ENERGY TRANSITION? NEXUS AMONG ENVIRONMENTAL DEGRADATION, GREEN ENERGY, AND OIL PRICES IN OECD COUNTRIES

5.1. Introduction

The industrial revolution has resulted in a significant increase in pollution levels, leading to climate change, which is a complex issue involving various economic, energy, and environmental factors (Huang et al., 2022). While energy production is essential for economic growth, it is also a significant source of greenhouse gas emissions (Acheampong et al., 2022). To mitigate the adverse effects of such emissions, environmentalists have emphasized the need for a green energy transition (GET) that involves replacing conventional fossil fuels with green energy sources (GES) (Zhang et al., 2021; Yahya et al., 2022; Rehman et al., 2023). This gradual transition to green energy (GE) policies can help in minimizing CO₂ emissions, reduce reliance on fossil fuels, diversify energy sources, and promote economic growth and jobs in services and manufacturing (Wang et al., 2023). It can also help in reducing negative shocks caused by fluctuations in imported oil prices, which can play a crucial role in stabilizing the economy (Kazemzadeh et al., 2023).

However, the transition to green energy necessitates considerable investments and policy reforms. Among the policies that can support this transition, trade liberalization policies (TLPs) are noteworthy, as they can promote free trade, encourage investment in green energy projects, and reduce the cost of green energy technologies by lowering tariffs and non-tariff trade barriers (Mohamed Yusoff et al., 2023). On the other hand, TLPs may also create competition between the green energy and fossil fuel industries, which could hinder the widespread adoption of green energy technologies (Lin et al.,

2023). Furthermore, TLPs may potentially affect the implementation and enforcement of environmental standards and regulations, resulting in less effective measures for encouraging the adoption of green energy technologies. Thus, examining the influence of TLPs on the GET is a matter of utmost significance in order to develop effective policies (Lee et al., 2022; Wei et al., 2023).

This chapter focuses on the OECD countries, which have some of the largest economies and consume a significant amount of energy. The transition towards green energy in these countries could potentially result in a substantial reduction in global carbon emissions and energy consumption. Despite representing only 18% of the world's population, the highly developed and industrialized OECD economies generated the majority of global economic growth (63%), development aid (95%), and trade (75%) (WDI, 2021; Ozcan and Bozoklu, 2021). As such, changes in their energy consumption patterns and trade policies could have far-reaching global economic consequences. The OECD countries are also leading investors in green energy technologies, and their policies promoting the transition towards green energy can provide valuable insights into similar efforts globally (Mujtaba et al., 2022). While these countries actively promote trade liberalization policies to boost international trade and GDP growth, the influence of such policies on the green energy transition remains unexamined. Thus, the present chapter intends to examine whether TLPs affect the GET in OECD countries by enhancing trade openness. Additionally, to develop effective policies for promoting sustainable energy practices, the chapter scrutinizes the impact of economic development, environmental degradation, and oil prices on GEC and the nexus among these variables for the period from 1991 to 2020 in a panel dataset of 23 OECD nations utilizing advanced panel data methods, including the augmented mean group (AMG) estimator, the pooled mean group (PMG) estimator, and the Dumitrescu and Hurlin (DH) panel causality test.

This chapter makes significant contributions to the existing literature in several key ways. Firstly, it emphasizes the critical importance of comprehending the influence of TLPs on the transition to green energy, as these policies can either facilitate or impede progress in this direction. Trade liberalization plays a significant role in facilitating access to green energy technologies by reducing import tariffs and trade restrictions on renewable energy products and equipment. This, in turn, enables countries to import

advanced green technologies, thereby promoting a cost-effective transition to renewable energy sources (Han et al., 2022). Furthermore, trade liberalization stimulates international trade and investment in the green energy sector, fostering larger and more dynamic markets, and attracting increased investments, research, and development, thus expediting the green energy transition. Additionally, trade liberalization allows nations to specialize in producing specific green energy components, enhancing efficiency, reducing costs, and increasing competitiveness compared to conventional fuels. However, it is essential to address challenges such as supply chain vulnerabilities, increased competition for domestic green industries, and the complexities of harmonizing policies. Striking a delicate balance between promoting trade, supporting domestic industries, and maintaining high environmental standards is crucial for achieving a sustainable shift towards renewable energy (Nwani et al., 2022).

Secondly, this study's focus on OECD countries, known for being among the largest energy consumers and greenhouse gas emitters worldwide, is of vital importance. Investigating the interrelation among environmental degradation, green energy, and oil prices within these nations is essential for formulating effective policies that facilitate the green energy transition. Moreover, despite the significance of transitioning to green energy to address climate change and reduce reliance on fossil fuels, the role of TLPs in influencing this transition has not received adequate attention in OECD countries. This research identifies this gap and highlights the need to explore the potential influence of TLPs on the adoption and development of green energy solutions within these nations. By doing so, valuable insights can be gained, which will contribute to the formulation of informed and impactful policies, thereby facilitating progress towards a greener energy landscape.

Thirdly, the study addresses shortcomings encountered in previous panel data research, specifically slope heterogeneity (SH) and cross-sectional dependence (CSD), which had affected the accuracy of their findings. To overcome these deficiencies, this study utilizes the AMG technique, which effectively accounts for both SH and CSD, resulting in reliable coefficient estimates for each country in the panel, thereby producing more policy-oriented results. Finally, the findings of this study hold immense value for policymakers, stakeholders, and scholars with an interest in the

green energy transition and international trade policies. The insights provided shed light on the primary barriers and opportunities for TLPs to facilitate the green energy transition in OECD countries, serving as a valuable resource for decision-makers seeking to shape effective policies in this critical domain.

5.2. Literature Review

Trade liberalization has been associated with several potential benefits for the green energy transition, such as increased investment and innovation in renewable energy technologies, better access to low-cost energy sources, and greater efficiency in the global distribution of renewable energy products (Zhou and Li, 2022; Lee et al., 2022). Kolcava et al. (2019) assert that trade liberalization can lower barriers to the adoption and diffusion of green energy technologies, such as tariffs, non-tariff barriers, and discriminatory regulations. By easing the flow of goods, services, and knowledge across borders, trade liberalization can expand access to innovative and cost-effective technologies, thereby accelerating the transition towards a low-carbon economy. According to Zheng et al. (2022), the impact of TLPs on the green energy transition depends on several factors, including the design of trade agreements, the level of environmental ambition, the availability of financial and technical support, and the coherence of energy and trade policies. The authors contend that trade agreements should be formulated to bolster rather than undermine the green energy transition by incorporating provisions that encourage the spread of clean technologies, support domestic green industries, and uphold environmental standards. The authors also underscore the importance of supplementing trade policies with other measures, such as investment, regulatory, and fiscal policies to guarantee a just and equitable shift towards a sustainable energy system. Akbar et al. (2020) employ a theoretical model to demonstrate that trade liberalization can facilitate the diffusion of green energy technologies by lowering the costs of importing and exporting goods and services related to renewable energy. The authors also provide empirical evidence from the wind energy sector to substantiate their findings. Tawiah et al. (2021) examine the influence of trade liberalization on green growth, including the green energy transition. The authors determine that trade liberalization can incentivize the uptake of green energy technologies by cutting costs, improving market access, and stimulating innovation. Similarly, Onifade et al. (2021) analyze the potential effect of trade

policies on the global green energy transition, including the role of trade liberalization. The authors conclude that trade liberalization can support the transition to renewable energy by intensifying competition, lowering costs, and promoting innovation.

Ghazouani et al. (2020) conducted a study to examine the effect of trade openness on the adoption of green technologies in the Asia-Pacific region from 1980 to 2017. The findings indicate that trade openness has a favorable influence on the adoption of green technologies. The authors attribute this to increased technology transfer and access to low-cost inputs for renewable energy production. In a similar manner, Ibrahim and Ajide (2021) investigate the impact of TLPs on energy consumption and air pollution within the context of the G-7 nations. The study concludes that trade liberalization facilitates the transfer of knowledge and technology between countries, which leads to a favorable impact on the adoption of clean technologies. In the same vein, Han et al. (2022) examine the impact of trade openness on GEC in China from 1990 to 2018. The results show that trade liberalization has a favorable influence on GEC by promoting investment in renewable energy technologies and enhancing access to financing for green energy projects.

Moreover, Rasoulinezhad and Saboori (2018) find that trade openness serves as the primary driver of green energy utilization across the twelve independent economies of the Commonwealth. The authors utilized the combined trade intensity index as an indicator of trade openness and applied the FMOLS technique to examine the linkage between trade liberalization and GE usage over the period of 1992–2015. Their findings reveal a modest increase in trade openness, corresponding to a 0.15% rise in the total consumption of renewables in these economies. However, the Granger and Dumitrescu-Hurlin causality tests failed to provide substantial evidence for a causal link between trade openness and the utilization of green energy. Along the same lines, Omri and Nguyen (2014) posit that TLPs contribute to the consumption of green energy across sixty-four nations with low, middle, and high-income levels. Employing the GMM approach, the study shows that a 1% increase in trade openness corresponds to a 0.19% and 0.25% increase in green energy usage in low- and middle-income. Further, in a comparative analysis of Nigeria, Saibu and Omuji (2016) acknowledge trade openness as a significant driver of green energy generation for electricity production in the country. However, they observe that economic growth acts as a

barrier to green energy adoption, with a minimal effect on the economy reducing green energy deployment by 2.76%. Furthermore, Sohag et al. (2015) highlight trade openness as a critical macroeconomic tool to foster innovation inflows necessary for enhancing the utilization of green energy sources (GES) in Asian countries. Besides, Coelho (2005) suggests that trade barriers are unsuitable for promoting the shift from non-renewables to biofuels in developing economies.

However, trade liberalization policies also have the potential to hinder the green energy transition, particularly in developing countries. Such policies can present challenges, as they may open up markets to cheaper fossil fuels and energy-intensive goods, thereby undermining the competitiveness of domestic green energy industries and discouraging investment in clean energy (Adedoyin et al., 2021). Additionally, trade agreements may contain provisions that restrict the ability of governments to regulate or incentivize green energy, or that permit foreign investors to challenge such measures through investor-state dispute settlement mechanisms (Pfeiffer & Mulder, 2013). In this context, Zheng et al. (2022) examine the association between TLPs and environmental degradation, including the adoption of renewable energy technologies, and discovered that trade liberalization could lead to increased carbon emissions and reduced deployment of renewable energy technologies. This is due to the creation of incentives for countries to rely on carbon-intensive industries and lower environmental standards to attract foreign investment. Similarly, Abaidoo and Agyapong (2022) conducted a study to examine the influence of trade liberalization on CO₂ emissions and the adoption of green technologies in 39 countries from 2001 to 2018. The authors find that trade liberalization has a negative effect on the adoption of renewable energy technologies, as it can lead to increased dependence on fossil fuels and reduced investment in clean energy technologies. In a similar manner, Duan et al. (2022) analyze the influence of trade openness on GEC and carbon emissions in China from 1997 to 2020 and discovered that trade openness has a negative influence on GEC, as it can lead to increased reliance on non-renewables and diminished investment in green technologies.

In addition to investigating the immediate association between trade openness and GET, numerous studies have employed an indirect methodology to examine this relationship (Barros and Martínez-Zarzoso, 2022; Bacchetta et al., 2022). These

investigations have emphasized the impact of trade liberalization arrangements on CO₂ emissions, with the anticipation of a decrease in carbon density as economies progress towards GET through trade liberalization. The underlying idea is that the introduction of green energy sources results in reduced levels of carbon emissions. In this context, Ho and Iyke (2019) provide empirical evidence supporting the notion that trade openness can control CO₂ emissions over the long term in selected Central and Eastern European countries, although short-term trade liberalization strategies did not appear to reduce carbon emissions.

Further, numerous studies have analyzed the association between GDP growth, environmental degradation, innovations, and the deployment of green energy sources. For instance, Blazejczak et al. (2014) employ a Sector-specific Energy Econometric Model (SEEM) to investigate the link between GDP growth and green energy deployment in Germany. Their outcomes reveal a positive net influence of GE deployment on GDP growth. Similarly, Sebri and Ben-Salha (2014) employ the ARDL bound testing technique to explore the causal nexus between GE, economic growth, and emissions for the BRICS economies over the period 1971-2010. Their outcomes reveal a bidirectional causal linkage between GDP growth and the growth of GE for all BRICS economies except India. In a similar manner, Shafiei and Salim (2014) analyze the association between green energy, non-renewables, and environmental deterioration in OECD nations for the period 1980-2011, employing the STIRPAT model. The research reveals a negative correlation between environmental degradation and GEC and a positive correlation between environmental degradation and fossil fuel usage. Their conclusion suggests that policymakers must develop and implement policies to encourage investments in the green energy sector.

Furthermore, Sinha et al. (2017) analyze the factors affecting environmental degradation between 1990 and 2014 for the N11 economies. Their results demonstrate that GEC and trade positively impact environmental sustainability, but urbanization, biomass, and fossil fuel usage have adverse effects. Furthermore, Padilla-Perez and Gaudin (2014) found a significant connection between innovations and economic growth in Central American economies. In a similar manner, Irandoust (2016) applied the Granger non-causality technique to check the impact or role of technological innovation on energy sources, specifically renewable ones. Their empirical results

suggest that technological innovation has a very important and effective duty in the nexus of green energy and growth. They employed real R&D spending as an indicator of technical advancement in the energy sector.

Having said that, this chapter uses the AMG, and the PMG techniques to look into the impact of trade liberalization policies on GET. Further, the chapter intends to analyze the nexus among economic development, environmental degradation, technological progress, trade liberalization policies, oil prices, and GEC in OECD countries. The outcomes of this chapter hold significant potential for guiding the development of effective policies and strategies to expedite the implementation and utilization of renewable energy technologies.

5.3. Data and Methodology

To conduct an empirical investigation into the impact of TLPs on GET and the nexus among economic development, technological advancements, environmental degradation, real oil prices, and GEC, we gathered yearly data from different sources between 1991 and 2020. Our sample comprised 23 OECD countries, which are listed in Appendix A. The selection of these countries is based on their recent urbanization, rapid industrialization, and high energy consumption, which underscores the significance of their transition to green energy sources in mitigating global carbon emissions. Besides, the linkage between trade liberalization policies, increased economic activity, and greenhouse gas emissions necessitates examining whether such policies facilitate or hinder the transition to green energy. Understanding the connection between TLPs and GET in OECD countries is vital to developing effective policies and strategies to accelerate the transition to sustainable energy sources. Additionally, OECD countries' experiences can offer valuable insights to developing nations seeking to adopt green energy and the global community to tackle climate change.

Our empirical model is as follows:

$$\text{GEC} = f(\text{ED}, \text{TLPs}, \text{EDT}, \text{TP}, \text{OP})$$

(5.1)

In the above equation, the variable GET (green energy transition) is scrutinized by its main indicator, green energy consumption (GEC). The variables ED, TLPs, EDT, TP, and OP stand for environmental degradation, trade liberalization policies, economic development, technological progress (patent applications, residents), and real oil prices (West Texas Intermediate \$/bbl), respectively. Trade openness (% of GDP) is used as a proxy for trade liberalization policies, whereas economic development is proxied by per capita GDP (constant 2010 US\$).

The use of GEC as a GET measure is supported by the targets of SDG7 to increase the clean energy share in overall energy usage at a global level. It provides an indication of the effectiveness of policies and initiatives aimed at promoting the use of green energy, as well as areas where further investment and policy intervention may be necessary to expedite the shift towards a sustainable energy system (Murshed, 2018).

The incorporation of environmental degradation as an explanatory variable is motivated by the imperative to comprehend the intrinsic connection between environmental challenges and renewable energy consumption. This inclusion holds paramount significance in devising effective policies aimed at mitigating these pressing environmental issues (Iqbal et al., 2023). Likewise, the consideration of TLPs as an explanatory variable is driven by their potential to exert substantial influence over a nation's accessibility to renewable energy technologies. Moreover, TLPs can significantly impact the competitiveness and expansion of domestic green energy industries (Apergis, 2010). Investigating the effects of trade policies on renewable energy consumption is thus instrumental in gaining insights into the role of international trade in either fostering or impeding the progress of the green energy transition.

The inclusion of economic development as an explanatory variable is undertaken to account for a country's overarching economic conditions and their potential sway on renewable energy consumption. Notably, higher levels of economic development often correspond with escalated energy demand (Hieu et al., 2023). Understanding this intricate relationship can effectively inform sustainable energy planning efforts. Furthermore, technological progress serves as a crucial explanatory variable, considering its pertinence to advancements in green energy technologies and their

consequential impact on renewable energy consumption. As technology continues to advance, the adoption and utilization of renewable energy sources become more feasible and cost-effective (Lohani et al., 2023). Lastly, the incorporation of oil prices as an explanatory variable is particularly relevant due to its potential to influence the competitiveness and attractiveness of renewable energy sources relative to conventional fossil fuels. Given the fluctuating nature of oil prices, they hold the power to significantly influence energy investment decisions and consequently bear implications for the overall transition to renewable energy (Sadorsky, 2009). Together, the incorporation of these explanatory variables seeks to enrich our comprehension of the multifaceted determinants influencing renewable energy consumption, thereby providing a robust foundation for the formulation of effective policies aimed at fostering sustainable energy practices and mitigating environmental challenges.

The data for the analysis has been collected from World Development Indicators (2021) and BP Statistics (2021). Moreover, to convert crude oil prices into real oil prices, the consumer price index (CPI) of chosen nations is utilized, and the data for which is also taken from World Development Indicators (2021).

Using a natural log, the model can be defined as follows:

$$\ln GEC_{it} = \delta_0 + \delta_1 \ln ED_{it} + \delta_2 \ln TLP_{sit} + \delta_3 \ln EDT_{it} + \delta_4 \ln TP_{it} + \delta_5 \ln OP_{it} + \mu_{it} \quad (5.2)$$

In equation (5.2), i denotes cross-sections, t represents the time period, and μ is the error term. Whereas δ_0 is the intercept, δ_1 , δ_2 , δ_3 , δ_4 , and δ_5 , are the parameters to be evaluated for the long-run effects of selected independent variables on GEC.

Following the specification of the model presented in equation 5.2, the current study employs several panel estimation techniques. However, in panel data, the existence of CSD poses a significant challenge that must be addressed prior to empirical estimation. CSD arises due to increasing correlations across economic and social channels and previously unobserved common shocks, which can render traditional panel estimators indeterminate. Failure to account for CSD can lead to significant implications, and utilizing techniques that assume cross-sectional independence may result in erroneous

conclusions (Sarafidis and Wansbeek, 2012). Accordingly, the current study utilizes several CSD tests to identify the existence of CSD in the panel data. Moreover, slope heterogeneity is a potential issue in panel data that may impact the accuracy of panel estimators. Therefore, it is crucial to examine slope heterogeneity in a model prior to proceeding with empirical analysis. To investigate slope homogeneity, the \hat{S} test of Swamy (1970), along with the $\tilde{\Delta}$ SHT and $\tilde{\Delta}$ ASHT tests of Pesaran and Yamagata (2008), are employed. The equations for the tests of SH are as follows:

$$\mathbf{S} = \sum_{i=1}^N (\hat{\beta}_i - \hat{\beta}_{WFE})' \frac{X'MX}{\hat{\sigma}_i^2} (\hat{\beta}_i - \hat{\beta}_{WFE}) \quad (5.3)$$

$$\Delta_{\text{SHT}} = (N)^{\frac{1}{2}} (2k)^{-\frac{1}{2}} \left(\frac{1}{N} \hat{\mathbf{S}} - \mathbf{k} \right) \quad (5.4)$$

$$\Delta_{\text{ASHT}} = (N)^{\frac{1}{2}} \left(\frac{2k(T-k-1)}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{N} \hat{\mathbf{S}} - 2\mathbf{k} \right) \quad (5.5)$$

Moreover, the study employs both first-generation unit root tests, specifically the IPS and ADF tests, as well as the second-generation unit root test, namely the CIPS test, to assess the integration order of the variables. The CIPS test, developed by Pesaran (2007), is particularly significant as it accounts for CSD, which is not considered in traditional unit root tests. The use of conventional unit root tests in the presence of CSD may yield misleading results. Nonetheless, to ensure the absence of bias in the findings, all the aforementioned unit root tests are employed in the current study. The equation for the CIPS test is presented below:

$$\Delta I_{i,t} = a_i + b_i I_{i,t-1} + c_i \bar{I}_{t-1} + \sum_{l=0}^p d_{il} \Delta \bar{I}_{t-l} + \sum_{l=0}^p e_{il} \Delta I_{t-l} + e_{it} \quad (5.6)$$

The above equation presents the cross-sectional means of lagged levels, represented by \bar{I}_{t-1} , and first differences, represented by $\Delta \bar{I}_{t-1}$. Equation (5.6) can be used to calculate the Cross-Section Augmented Dickey-Fuller (CADF) statistics, while the

Cross-Sectionally Augmented IPS (CIPS) test statistic can be obtained using the following equation:

$$\widehat{CIPS} = \frac{1}{N} \sum_{i=0}^n CADF_i \quad (5.7)$$

Further, the Westerlund (2008) panel cointegration method is employed to investigate the variables that influence GEC in OECD economies. This approach is particularly robust as it accounts for the strong presence of CSD and SH, which traditional cointegration methods fail to address and may lead to misleading and inconsistent results (Phillips and Sul, 2003). Therefore, to determine whether the model exhibits cointegration, the study utilizes Westerlund's (2008) cointegration method, which produces two statistics: DHg (Durbin-Hausman group) and DHp (Durbin-Hausman panel). The DHg and DHp statistics can be computed using the following equations:

$$DH_g = \sum_{i=1}^n \widehat{X}_i (\widetilde{S}_i - \widehat{S}_i)^2 \sum_{t=2}^T \widehat{e}_{it-1}^2 \quad (5.8)$$

$$DH_p = \widehat{X}_i (\widetilde{S}_i - \widehat{S}_i)^2 \sum_{i=1}^n \sum_{t=2}^T \widehat{e}_{it-1}^2 \quad (5.9)$$

The application of conventional methods in the presence of CSD and SH can result in imprecise and inconsistent estimation outcomes (Muhammad et al., 2022). As such, in this study, we adopted the Augmented Mean Group (AMG) technique proposed by Teal and Eberhardt (2010) to investigate the long-term impact of trade liberalization policies, environmental deterioration, economic development, technical progress, and oil prices on GEC. The AMG estimator is a commonly used approach for estimating dynamic panel data models, as it allows for individual-specific coefficients while still imposing the constraint of time homogeneity (Khan et al., 2020a). It involves first differencing the model and estimating individual-specific coefficients using ordinary least squares (OLS), while also accounting for unobserved common factors, incorporating year dummies, and viewing the process as a common dynamic one (Teal and Eberhardt, 2010). The AMG equation can be formulated as follows:

$$Y_{i,t} = \alpha'_{i,t} + \beta_{1i}X_{i,t} + c_i h(\bar{c} l_{i,t}) + e_{i,t} \quad (5.10)$$

Where $l_{i,t}$ is the unobservable common component that enables the diverse impact on the dependent variable.

Furthermore, to validate the results obtained from the AMG estimator, this study employs the Pooled Mean Group (PMG) estimator. The PMG estimator is a useful tool for assessing long-term relationships and their applicability in both small and large panels. It entails the estimation of a pooled time series model using standard OLS, which is efficient when the assumption of homogeneous coefficients over individuals and time is met. By pooling the data, the PMG estimator exploits the commonalities across individuals and time to estimate the coefficients more efficiently. Furthermore, this approach is appropriate for variables with a mixed order of integration, namely I(0) and I(1) (Khan et al., 2020b). We first evaluate the long-term coefficients using both AMG and PMG methods and subsequently explore the causal relationship between the selected variables utilizing the Durbin-Hausman (DH) panel causality test. When the time series and cross-sections are unbalanced ($T \neq N$), the DH technique provides accurate estimates. Moreover, the DH test accounts for panel data issues such as CSD and SH (Banday and Aneia, 2019).

5.4. Findings and Discussion

Table 5.1 presents the descriptive statistics of the analyzed variables for selected OECD nations. The results demonstrate that economic development has the highest mean value of 10.27, which ranges between 8.40 and 11.42. Technological progress exhibits a maximum of 12.85 and a minimum of 3.98, while TLPs have a maximum of 5.12 and a minimum of 2.77. In addition, GEC ranges from 0.49 to 4.11; environmental degradation ranges from 0.26 to 3.00; and oil prices range from 1.97 to 5.19. The analysis further indicates that TLPs have the least volatility, while technological progress shows high volatility. Moreover, the correlation matrix presented in Table 5.2 shows a significant correlation among the selected variables. The findings suggest that environmental degradation, TLPs, economic development, technological progress, and oil prices are significant factors contributing to GEC.

Table 5.1. Descriptive Statistics

Statistical Description	lnGEC	lnED	lnTLPs	lnEDT	lnTP	lnOP
Mean	2.5054	1.9501	4.1270	10.2726	7.7811	-0.6860
Maximum	4.1170	3.0046	5.1268	11.4248	12.8589	5.1987
Minimum	-0.4971	0.2691	2.7734	8.4047	3.9889	-1.9754
Std. Dev.	1.0191	0.5353	0.4654	0.7117	2.0118	0.7186
Observations	575	575	575	575	575	575

Table 5.2. Correlation Matrix

Variable	lnGEC	lnED	lnTLPs	lnEDT	lnTP	lnOP
lnGEC	1.0000					
lnED	-0.3714	1.0000				
lnTLPs	0.0574	0.0637	1.0000			
lnEDT	-0.0674	0.7351	0.2592	1.0000		
lnTP	-0.4267	0.5919	-0.3981	0.5139	1.0000	
lnOP	0.1900	-0.3070	0.0374	-0.2602	-0.1908	1.0000

For the empirical analysis, first, we applied CD tests, and the outcomes are displayed in Table 5.3. The null hypothesis of all three tests is rejected at 1%, indicating the cross-sectional reliance of every variable under consideration. This demonstrates that a shock that hits one nation in the panel could spread to others. The Pesaran & Yamagata (2008) SH test, provided in the same table, is likewise significant at 1%, indicating the heterogeneity of the slope parameters. Furthermore, Table 5.4 presents the outcomes of unit root tests, revealing a mixed order of integration. This allows employing the Westerlund Durbin-Hausman (WDH) cointegration test. The outcomes of the WDH test are provided in Table 5.3, demonstrating the existence of a long-run linkage between the variables.

Table 5.3. CD, SH, and WDH Test Results

	Statistic	P-value
Cross-sectional Dependence Test		
Pesaran scaled LM	110.8364***	0.0000
Pesaran CD	6.778545***	0.0000
Breusch-Pagan LM	2746.204***	0.0000
Slope Homogeneity Test		
Swamy \hat{S}	231.5431***	0.0000
$\tilde{\Delta}$	5509.5156***	0.0000
$\tilde{\Delta}_{adj}$	6621.6137***	0.0000
Westerlund Durbin-Hausman Test		
DHg	20.723***	0.0000
DHp	7.686***	0.0000
Note: ***p < 0.001		

Table 5.4. First and Second Generation Unit Root Tests

Variables	Level		1 st difference		Order of Integration
	Intercept	Intercept & trend	Intercept	Intercept & trend	
ADF – Fisher					
LnGEC	28.0872	45.6762	329.790***	309.311***	I(1)
LnED	31.2520	35.5893	320.227***	295.850***	I(1)
LnTLPs	60.1106*	79.3968***	-	-	I(0)
LnEDT	47.2139	35.8735	192.959***	165.340***	I(1)
LnTP	53.6078	39.2560	302.839***	234.916***	I(1)
lnOP	37.1723	24.8437	221.522***	142.680***	I(1)
Im, Pesaran and Shin					
LnGEC	4.88300	0.30861	-17.1055***	-17.4357***	I(1)
LnED	3.00374	2.52567	-16.2887***	-16.9227***	I(1)
LnTLPs	-0.89380	-3.44523***	-	-	I(0)
LnEDT	0.46420	2.50384	-10.4838***	-9.37209***	I(1)

Table 5.4. (cont.)

LnTP	1.06130	0.89904	-16.2582***	-13.3196***	I(1)
lnOP	0.21548	1.21897	-12.2507***	-8.42120***	I(1)
Pesaran CIPS					
LnGEC	-1.4526	-2.8895**	-	-	I(0)
LnED	-1.4734	-2.6715***	-	-	I(0)
LnTLPs	-2.0834	-2.1144*	-	-	I(0)
LnEDT	-2.0089	-2.3729**	-	-	I(0)
LnTP	-1.6821	-1.7874	-2.8726***	-3.2929***	I(1)
lnOP	-2.7748**	-1.8803	-	-	I(0)
Note: ***p < 0.01, **p < 0.05, *p < 0.1					

As previously mentioned, the existence of CD, SH, and long-term relationships among the variables of interest led to the adoption of the AMG estimation technique. The outcomes of the AMG technique are presented in Table 5.5, indicating that all explanatory variables, except for technological progress, have a statistically significant impact on GEC in OECD countries. Specifically, trade liberalization policies, real oil prices, and economic development have a favorable impact on GEC, while environmental degradation has an adverse impact.

Furthermore, a 1% increase in oil prices and economic development significantly increases GEC by 0.05% and 0.36%, respectively. These outcomes are in line with the findings of Armeanu et al. (2021). The positive influence of economic development on GEC can be explained by the fact that higher levels of income and investment can be directed toward promoting the transition to green energy. This can include financing the research and development of new green energy technologies, investing in infrastructure that supports green energy production and distribution, and providing incentives for businesses and consumers to adopt green energy practices. Economic development can also lead to increased public awareness and concern about environmental issues, which can increase demand for green energy and political support for its adoption. Additionally, economic development can provide governments with greater resources and political will to implement policies that promote a green energy transition, such as subsidies for green energy production, tax incentives, and regulations that require the adoption of green energy practices.

Conversely, the positive influence of higher oil prices on the green energy transition may seem counterintuitive, as they can be challenging for industries and consumers that rely on fossil fuels. However, high oil prices can incentivize innovation, reduce dependence on fossil fuels, and increase political support for sustainable energy policies. This can culminate in the acceptance of environmentally friendly energy practices and technologies, as well as increased investment in green energy infrastructure.

The promotion of GES in OECD nations is considered an effective strategy for achieving a more sustainable and low-carbon economy through the reduction of trade barriers. Empirical evidence suggests that a rise of 1% in trade openness levels among OECD countries leads to a statistically significant increase of 0.135% in GEC. These findings demonstrate a positive correlation between TLPs and GET. This is consistent with earlier research by Omri and Nguyen (2014), which identifies TLPs as a primary driver of GEC. Trade liberalization serves as a pivotal enabler for countries to access an expanded array of technologies, encompassing those related to green energy. By reducing or removing trade barriers, nations find it increasingly facile to import and assimilate state-of-the-art green energy solutions pioneered by other countries. This process fosters the seamless transfer of knowledge and expertise, thereby expediting the progress of the green energy transition (Huilan et al., 2022). Furthermore, the implementation of trade liberalization policies often engenders heightened competition within domestic markets, culminating in the realization of economies of scale and cost reductions. These favorable dynamics impart considerable benefits to the green energy sector, rendering renewable energy technologies more economically viable and competitive in comparison to conventional fossil fuel-based energy sources. Consequently, a pronounced impetus materializes, encouraging both businesses and consumers to embrace and transition towards green energy alternatives (Sadiqa et al., 2022).

Moreover, the appeal of trade liberalization extends to attracting foreign direct investment in domestic green energy endeavors. International investors perceive countries with open and liberalized trade policies as more enticing investment destinations due to the concomitant mitigation of trade-related uncertainties and risks (Ibrahim et al., 2022). As a consequence, augmented investment inflows infuse the

green energy sector with greater financial resources, elevating its capacity to support vital research, development, and deployment of renewable energy technologies.

Additionally, trade liberalization frequently operates in tandem with international agreements and cooperative initiatives addressing environmental concerns. Within the context of the OECD countries, numerous signatories to global accords pertaining to climate change and environmental sustainability emerge. Consequently, as countries undertake trade liberalization and open their markets, there is an augmented proclivity to align their national strategies with internationally recognized norms and commitments relevant to green energy transitions (Olanrewaju et al., 2022). Significantly, trade liberalization serves as a conduit for countries to encounter diverse regulatory frameworks and policy approaches pertaining to green energy. This exposure fosters an environment of mutual learning and information exchange, empowering nations to adopt optimal practices and refine their own policies in order to expedite the green energy transition (Pata et al., 2023). Overall, trade liberalization policies establish a conducive environment that nurtures innovation, investment, and cooperation within the realm of green energy. By facilitating the seamless exchange of technologies, resources, and ideas, these policies play a constructive role in driving the transition towards sustainable and ecologically sound energy systems across OECD countries.

Conversely, environmental degradation is negatively associated with GEC, with a 0.766% decline observed in OECD countries. This negative relationship highlights the importance of increasing GEC to mitigate the adverse effects of greenhouse gas (GHG) emissions. Green energy sources, including wind and solar energy, are crucial to achieving carbon neutrality by 2050. While the transition to renewable energy sources can pose challenges for manufacturing economies, the use of GES can ensure environmental sustainability, reduce carbon emissions, and increase energy efficiency. Prior studies by Samour et al. (2022), and Magazzino et al. (2021) have also reported similar findings, demonstrating the inverse association between environmental degradation and GEC. Overall, the findings of our study suggest that to attain energy sustainability through the green energy transition, it is advisable for nations associated with this goal to gradually expand their economic engagement in global trade while ensuring the protection of their domestic welfare. Additionally, our findings highlight

that measures that support economic growth and implement sustainable energy policies can significantly facilitate the transition toward a more sustainable and low-carbon economy.

Table 5.5. Outcomes of Long-Run Estimates (PMG and AMG)

Variables	PMG		AMG	
	Coefficient	P-value	Coefficient	P-value
LnED	-1.7219***	0.000	-0.7669***	0.000
LnTLPs	0.2748***	0.000	0.1359***	0.003
LnEDT	1.3559***	0.000	0.3605*	0.091
LnTP	-0.1576***	0.000	0.0026	0.927
lnOP	0.0368**	0.042	0.0567**	0.016

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

Table 5.6 provides the nation-wise outcomes of the AMG technique. The findings reveal that environmental degradation and GEC have a substantial inverse relationship in sixteen out of the twenty-three OECD nations, including Turkey, Mexico, Colombia, Chile, the UK, Sweden, Spain, New Zealand, Germany, Denmark, Austria, Portugal, Greece, Finland, Belgium, and the Netherlands. In these nations, a considerable portion of their energy composition continues to heavily rely on fossil fuels, thereby contributing to environmental deterioration through the release of greenhouse gases and other harmful pollutants. Consequently, their transition to renewable energy sources might encounter a relatively sluggish pace, leading to a diminished share of green energy within the overall energy mix (Ofori et al., 2023). Additionally, certain countries may encounter challenges in terms of infrastructure and technology when endeavoring to adopt and integrate green energy solutions. The implementation and enhancement of requisite infrastructure to support renewable energy generation and distribution can be financially demanding and time-consuming, thus affecting the rate of green energy adoption (Chhabra et al., 2023). Moreover, the efficacy of policies and regulatory frameworks in encouraging green energy consumption exhibits variations across countries. In some instances, the existing policies may prove insufficiently robust or incentivizing to drive widespread adoption

of renewable energy technologies. Economic considerations also come into play, as certain countries might prioritize economic growth and development, leading to escalated industrial activities and energy consumption, which may potentially result in heightened levels of environmental degradation (Udeagha and Muchapondwa, 2023).

A significant favorable link between TLPs and GEC has been discovered in Mexico, Sweden, Germany, Finland, and Norway. In these nations, the implementation of supportive policies and incentives designed to foster green energy consumption has been evident. Additionally, TLPs have proven instrumental in facilitating the international trade of renewable energy technologies and resources, thereby enhancing the accessibility and adoption of environmentally friendly solutions within their territories (Bashir et al., 2023). Furthermore, Mexico, Sweden, Germany, Finland, and Norway are known for their advancements in green energy technologies and research, boasting robust technological capabilities that effectively facilitate the assimilation and integration of green energy solutions into their overall energy matrix (Appiah et al., 2023). Moreover, a notable characteristic of these countries is the elevated levels of public awareness and demand for sustainable and environmentally friendly practices. The proactive embrace of green energy by their populations and the fervent pursuit of sustainable development goals significantly contribute to the advancement of green energy consumption in these regions (Guloglu et al., 2023). The positive correlation between trade liberalization policies and green energy consumption is further influenced by the economic feasibility of adopting such energy alternatives. As the cost of renewable technologies continues to diminish, increasingly rivaling conventional energy sources in competitiveness, the attractiveness of adopting green energy solutions becomes even more pronounced. In addition, the strategic alliances and collaborations these nations establish with other countries and international organizations provide them with further advantages. Such partnerships facilitate the exchange of knowledge, technology transfers, and financial support for green energy initiatives, thus fostering the growth and success of various green energy projects within their borders (Hayat et al., 2023).

The outcomes also show that economic development and GEC are significantly positively associated in Turkey, Mexico, Canada, Austria, the Netherlands, and the USA. Elevated levels of economic development typically correlate with augmented

financial resources and expanded investment capacity. In these countries, the bolstered economic position facilitates substantial allocations of funds towards green energy projects and infrastructure, thereby fostering heightened levels of green energy consumption (Hassan et al., 2023). Additionally, these nations often boast well-established policies and incentivization mechanisms geared towards promoting green energy adoption. These pro-sustainability policy frameworks attract investments from both private enterprises and the public sector, creating an environment conducive to the widespread embrace of green energy solutions (Khurshid et al., 2023). Furthermore, the advanced economic status of these countries affords them better access to state-of-the-art green energy technologies and innovations. This advantage streamlines the process of integrating renewable energy sources into their existing energy portfolio. Moreover, economic development is frequently accompanied by endeavors to enhance energy efficiency and curtail energy wastage. Such initiatives, in turn, contribute to an increased proportion of green energy consumption in the overall energy consumption landscape (Shayanmehr et al., 2023).

However, the two variables (economic development and GEC) are found to be negatively correlated in Hungary, Germany, Denmark, and Greece. In these countries, there exists a relatively well-established and matured energy infrastructure, which is heavily reliant on conventional fossil fuel-based sources. Consequently, transitioning away from these deeply ingrained energy systems to embrace green energy sources may prove to be a challenging and gradual process (Yi et al., 2023). Moreover, nations endowed with substantial reserves of fossil fuels might encounter economic pressures compelling them to maintain their dependence on these exports, resulting in a decelerated progression towards green energy consumption (Naqvi et al., 2023). Furthermore, the pace of green energy adoption can be influenced by the availability of financial resources and access to cutting-edge green energy technologies. Countries confronted with financial constraints or limited entry to state-of-the-art green energy technologies may encounter a more protracted transition period towards renewable energy solutions (Dzwigol et al., 2023).

Furthermore, an inverse relationship is found between TP and GEC in the UK, Germany, and Greece, while a favorable relationship between the two variables is investigated in Hungary. The observed positive relationship between TP and GEC in

Hungary can be ascribed to the country's notable preparedness to adopt and assimilate innovative green energy technologies. This readiness is facilitated by the presence of supportive policies, substantial investment in research and development, and a proactive approach to embracing novel technologies, collectively contributing to a smoother transition towards green energy solutions (Gu et al., 2023).

In contrast, the UK, Germany, and Greece exhibit an inverse relationship between technological progress and green energy consumption, primarily due to their more entrenched energy infrastructure, heavily dependent on conventional fossil fuel-based sources. The complexities involved in transitioning away from such well-established energy systems to adopt green energy alternatives result in a more gradual and time-consuming process, despite advancements in other technological sectors (Wei et al., 2023). Furthermore, disparities in the effectiveness and stringency of policies and regulatory frameworks also influence this relationship. Hungary's implementation of more robust policies incentivizing green energy adoption contrasts with the other countries facing challenges in regulatory aspects and lacking sufficient incentives to drive substantial green energy consumption (Abuzreda et al., 2023). Moreover, the existing energy mix and industrial structure of each country play a significant role in shaping the correlation between technological progress and green energy consumption. The presence of energy-intensive industries or a substantial reliance on specific energy sources can impact their capacity to effectively integrate and adopt green energy technologies. These contextual factors contribute to the divergent patterns of green energy consumption vis-à-vis technological advancements across the specified nations (Golpira et al., 2023).

Moreover, a significant positive link between OP and GEC has been investigated in 12 economies, including Hungary, Mexico, Chile, Sweden, Austria, Portugal, Greece, Finland, Belgium, France, the Netherlands, and the USA. The escalation of oil prices renders conventional fossil fuel-based energy sources costlier and less appealing to both consumers and businesses. Consequently, these economies are incentivized to shift towards alternative and renewable green energy sources, which emerge as comparatively more competitive and economically viable options (Mahlik et al., 2023). Moreover, the surge in oil prices augments the impetus for these countries to invest in the advancement and implementation of green energy technologies. The

heightened oil prices create an economic milieu wherein green energy projects become more financially attractive and alluring, stimulating increased investments in the green energy sector. Additionally, energy security concerns prompt these nations to contemplate reducing their reliance on oil imports. The pursuit of green energy adoption enhances energy independence and mitigates vulnerability to oil price fluctuations and supply disruptions (Chiu et al., 2023).

On the other hand, an inverse relationship between OP and GEC is examined in the case of Turkey. This can be attributed to several factors unique to the country's context. Notably, Turkey may provide subsidies for energy, including oil, which can diminish the price signal impact of rising oil prices. The presence of subsidies mitigates the impact of oil price increments on energy consumers, consequently reducing the incentive to transition towards green energy alternatives (Chu et al., 2023). Moreover, Turkey's energy mix heavily relies on conventional fossil fuel sources, rendering a swift transition to green energy more challenging. The existing energy infrastructure and prior investments may be predominantly geared towards conventional energy sources, impeding a rapid shift towards green energy. Furthermore, the effectiveness of policies and regulatory frameworks promoting green energy adoption in Turkey may not be as robust as in the 12 economies experiencing a positive link. A less conducive policy environment could hinder the widespread uptake of green energy, irrespective of oil price fluctuations (Senyapar, 2023). Additionally, economic factors and priorities wield influence over decision-making regarding energy investments. Turkey's specific economic situation and the perceived cost-effectiveness of green energy adoption may shape its approach towards green energy consumption in light of changing oil prices (Dincer et al., 2023).

Table 5.6. Country-Specific Results of AMG Estimator

Country	lnED	lnTLPs	lnEDT	lnTP	lnOP
Turkey	-1.1222***	0.0937	0.6733***	0.0514	-0.0661***
Mexico	-1.0835***	0.1319*	0.8561***	-0.0467	0.0143
Hungary	0.4917	0.0648	-3.9401***	0.2526*	0.1933***
Colombia	-0.7042**	0.2296	-0.0535	0.0077	0.1330***
Chile	-0.4739***	-0.1304	0.4440	-0.0142	0.0901*

Table 5.6. (cont.)

United Kingdom	-2.6596***	0.9521	1.5231	-1.0866**	0.1570
Switzerland	-0.1654	0.0494	0.5081	0.1564	-0.0415
Sweden	-0.4608***	0.2801*	0.1899	0.0151	0.0833***
Spain	-1.7865***	0.1119	1.3107	0.0549	0.0488
New Zealand	-0.7020***	0.0550	0.6494	-0.0128	-0.0523
Germany	-1.8741***	1.2516***	-1.2614**	-0.8363***	-0.0260
Denmark	-0.5533***	0.4266	-1.3351**	0.0679	0.0774
Canada	-0.1968	-0.0171	0.4341*	0.0232	0.0049
Austria	-1.0204***	0.1063	0.9916***	-0.0180	0.0736***
Portugal	-1.5753***	0.0839	0.7517	-0.0334	-0.1334**
Japan	-0.4461	0.3272	0.6464	0.3028	-0.0498
Greece	-0.5650*	-0.1685	-0.6559***	-0.2622***	0.1395***
Finland	-0.3440***	0.2225**	0.2228	0.03088	-0.0536*
Belgium	-0.8219*	0.6717	-0.7451	-0.3365	0.2652***
United States	-1.5104	0.0808	2.4888**	-0.0815	0.1587***
France	-0.1499	0.2899	-0.8088	-0.8640	0.1062***
Norway	0.00711	0.2869**	-0.2808	-0.0353	-0.0232
Netherlands	-1.2396**	-0.4123	1.2994**	-0.1658	0.2362***
Note: ***p < 0.01, **p < 0.05, *p < 0.1					

5.5. Panel Causality Test

Following the estimation of the long-term relationship between the variables through the application of AMG and PMG estimators, we proceeded to employ the Dumitrescu and Hurlin (DH) causality test to discern short-term dynamic causal relationships. The outcomes of the DH causality test are presented in Table 5.7. The findings of this test lend support for the notion of unidirectional causality, which flows from GEC towards environmental degradation, TLPs, and technological progress. Unidirectional causality is also discovered from trade TLPs to real oil prices and from economic development to technological progress. Moreover, environmental degradation, GEC, economic development, and technological progress all have a bidirectional causal relationship with real oil prices. Overall, these causality findings indicate complex interrelationships between the studied variables. GEC appears to play a pivotal role in influencing various aspects, such as environmental degradation, TLPs, and technological progress. Additionally, TLPs seem to have an impact on real oil prices,

while economic development drives technological progress. Moreover, there is an intricate feedback loop among environmental degradation, GEC, economic development, technological progress, and real oil prices, where changes in one variable can have cascading effects on the others, and vice versa. These findings highlight the interconnected nature of these variables in the context of energy, environment, and economic dynamics, emphasizing the importance of considering multiple factors when formulating policies and strategies related to sustainable development and energy transition.

Table 5.7. Outcomes of DH Panel Causality Test

Null hypothesis (H₀)	W-stat.	Z̄-stat.	Prob.
lnGEC ≠ lnED	17.544***	29.687	0.0000
lnGEC ≠ lnTLPs	8.3963**	11.015	0.0525
lnGEC ≠ lnEDT	0.2768	-2.5569	0.5750
lnGEC ≠ lnTP	9.5027***	18.757	0.0100
lnGEC ≠ lnOP	0.4583***	-1.9152	0.0000
lnED ≠ lnGEC	0.7037	-1.0477	0.8150
lnED ≠ lnTLPs	0.4711	-1.8698	0.6600
lnED ≠ lnEDT	0.0353	-3.4106	0.2725
lnED ≠ lnTP	0.7763	-0.7909	0.8750
lnED ≠ lnOP	17.087***	19.111	0.0000
lnTLPs ≠ lnGEC	0.8601	-2.8499	0.4875
lnTLPs ≠ lnED	0.4292	-2.0181	0.6200
lnTLPs ≠ lnEDT	0.2902	-2.5094	0.5500
lnTLPs ≠ lnTP	0.2690	-2.5843	0.4800
lnTLPs ≠ lnOP	34.606***	46.811	0.0000
lnEDT ≠ lnGEC	0.6494	-1.2394	0.8050
lnEDT ≠ lnED	2.7582	6.2161	0.1100
lnEDT ≠ lnTLPs	0.2826	-2.5364	0.5475
lnEDT ≠ lnTP	6.3042**	18.753	0.0300
lnEDT ≠ lnOP	3.1222***	7.5032	0.0000
lnTP ≠ lnGEC	0.5946	-1.4334	0.7875

Table 5.7. (cont.)

$\ln TP \neq \ln ED$	0.1794	-2.9013	0.4625
$\ln TP \neq \ln TLPs$	0.6181	-1.3501	0.7700
$\ln TP \neq \ln EDT$	1.7476	2.6430	0.5625
$\ln TP \neq \ln OP$	13.244***	13.035	0.0000
$\ln OP \neq \ln GEC$	3.8885**	9.7954	0.0200
$\ln OP \neq \ln ED$	6.5285***	18.747	0.0050
$\ln OP \neq \ln TLPs$	1.6077	2.0609	0.5550
$\ln OP \neq \ln EDT$	5.0465**	13.722	0.0225
$\ln OP \neq \ln TP$	3.5869**	8.7725	0.0375
Note: ***p < 0.01, **p < 0.05, *p < 0.1. The symbol \neq indicates “does not cause”.			

5.6. Conclusion and Policy Suggestions

Globalization is widely considered to be a global economic strategy that aims to achieve the world's growth targets through free trade and financial arrangements. However, to ensure sustainable development, efficient management of liberalization techniques is necessary, which requires breaking down the growth process into environmental and socioeconomic development within a sustainable framework. Trade liberalization policies, in particular, can improve environmental welfare only if the associated costs are integrated. In this context, increasing trade openness ideally leads to the promotion of GET, which not only reduces greenhouse gas emissions but also supplements fossil fuels to meet the persistent increase in the world's energy demand. Based on this premise, this chapter applies the AMG and DH techniques to examine the influence of trade liberalization policies on GET and the nexus among environmental degradation, economic development, technological progress, TLPs, oil prices, and GEC across 23 OECD countries from 1991–2020.

The results obtained from the AMG estimator indicate that trade liberalization policies, real oil prices, and economic development have a positive impact on GET, while environmental degradation has a negative impact. Economic development plays a crucial role in promoting green energy transition through increased income,

investment, research, and supportive policies. Similarly, trade liberalization policies facilitate technology transfer and investments in the green energy sector. Despite challenges, higher oil prices incentivize innovation and reduce reliance on fossil fuels, promoting environmentally friendly energy practices and infrastructure investment.

The country-specific AMG estimator reveals an inverse relationship between environmental degradation and GET in sixteen OECD nations, including Turkey, Mexico, Colombia, Chile, the UK, Sweden, Spain, New Zealand, Germany, Denmark, Austria, Portugal, Greece, Finland, Belgium, and the Netherlands. Infrastructure, technology limitations, policy effectiveness, and economic factors contribute to the negative correlation between economic development and GET in Hungary, Germany, Denmark, and Greece. Hungary exhibits a positive link between technological progress and GET due to the proactive adoption of green energy technologies, while the UK, Germany, and Greece show an inverse relationship due to established energy infrastructure. Additionally, in Mexico, Sweden, Germany, Finland, and Norway, a positive association between TLPs and GEC has been found. These countries have implemented supportive policies and incentives to promote green energy use. TLPs have been crucial in facilitating the international trade of renewable energy technologies, making eco-friendly solutions more accessible. These nations are advanced in green energy technologies and research, integrating sustainable options effectively. Their populations show high awareness and demand for environmentally friendly practices, contributing to the success of green energy consumption. The decreasing cost of renewable technologies also makes green energy solutions increasingly competitive. Strategic alliances with other countries and organizations further boost their green energy projects. Moreover, twelve economies, including Hungary, Mexico, Chile, Sweden, Austria, Portugal, Greece, Finland, Belgium, France, the Netherlands, and the USA, demonstrate a significant positive association between oil prices and GET. Conversely, Turkey's inverse relationship between oil prices and GET is influenced by subsidies, fossil fuel reliance, policy effectiveness, and economic factors.

The DH causality test supports unidirectional causality from GET to environmental degradation, TLPs, and technological progress. Unidirectional causality is also observed from TLPs to real oil prices and from economic development to

technological progress. Additionally, there is a bidirectional causal relationship between environmental degradation, GET, economic development, and technological progress with real oil prices. Moreover, the findings of the PMG estimator are consistent with those of the AMG estimator, confirming the robustness of the study's long-term outcomes.

Drawing on the empirical results, a range of policy recommendations can be proposed to accelerate the adoption and deployment of green technologies in OECD economies. For instance, policymakers in the OECD can reduce or eliminate tariffs on eco-friendly technologies such as solar panels, wind turbines, and batteries, which could stimulate their uptake by encouraging competition, innovation, and affordability. Also, harmonizing regulatory standards across OECD countries could reduce trade barriers and simplify the process of adopting and utilizing green energy technologies. In addition, governments can promote green energy investments by removing investment barriers and providing incentives for investors, including investment-friendly policies, regulatory frameworks, and access to financing and other resources. Governments can also promote cross-border energy trade by implementing policies and regulatory frameworks that facilitate the import and export of green energy, such as renewable energy certificates or green power trading programs. Further, the trade of green energy-related services, such as consulting, engineering, and project management services, could be encouraged by governments to facilitate the development and implementation of green energy projects. Furthermore, OECD policymakers could encourage innovation and technology transfer in the green energy sector by implementing policies and programs that support research and development and the sharing of knowledge and expertise. Moreover, the participation of OECD governments in international trade agreements could promote trade liberalization and remove barriers to the trade of green energy technologies and services. Finally, to discourage the use of high-emission imports and non-renewables and to promote the transition to low-carbon and sustainable energy sources, climate-conscious authorities should consider imposing taxes on these imports.

CHAPTER VI

CONCLUSION

The need for renewable energy has become increasingly urgent in today's world due to several factors, including the depletion of non-renewable resources, climate change, and the ever-rising demand for energy. RES, with their inherent sustainability and environmentally benign characteristics, provide a viable alternative to traditional non-renewables. Different countries have adopted various approaches to the transition to renewable energy. Some countries have set ambitious targets for RE adoption and have implemented policies to catalyze the growth of the RE sector. Others have invested heavily in R&D to enhance the efficiency of green technologies. The transition to RE is a collective global endeavor, necessitating concerted action among nations to decrease carbon footprints and build a sustainable future. In this context, the present thesis constitutes a noteworthy contribution to the ongoing endeavors directed at scrutinizing the determinants that impact the utilization of RES, alongside the facilitating factors that underpin the transition to renewable energy. To this end, the study adopts an applied macro-level panel data approach to achieve these objectives.

The present concluding chapter comprises an analysis of whether the research questions posed in Chapters II, III, and IV have been sufficiently addressed. Furthermore, policy recommendations informed by the thesis's findings and the limitations of the research conducted are presented.

Chapter II aims to address the following research questions: Does an increase in trade openness result in a surge in REC in OECD countries? How does environmental sustainability impact the consumption patterns of RES? What other factors influence renewable energy consumption, and how significant are they compared to environmental degradation and trade openness? How do trade openness, income disparity, GDP growth, environmental degradation, and oil prices interact with each other to influence the utilization of RES? What are the policy implications derived

from examining the relationship between income disparity, trade openness, GDP growth, environmental degradation, oil prices, and the utilization of RES? The findings obtained through the AMG estimator reveal that increasing trade openness leads to an increase in REC and that environmental sustainability has a positive impact on REC as well. Additionally, economic growth, income disparity, and fluctuations in oil prices all contribute to an increase in REC.

The country-specific AMG estimator reveals statistically significant negative associations between CO₂ emissions and REC in 16 out of 23 countries. These countries, including the Netherlands, the United States, Finland, Greece, Portugal, Austria, Germany, Spain, the United Kingdom, Denmark, New Zealand, Sweden, Chile, Colombia, Mexico, and Turkey, have implemented policies and incentives aimed at fostering the adoption of renewable energy, resulting in notable reductions in CO₂ emissions. Additionally, a positive correlation between REC and economic growth is observed in seven countries, namely the Netherlands, the United States, Finland, Austria, Canada, Mexico, and Turkey. Conversely, Norway and Hungary exhibit a negative association, potentially attributable to resistance from traditional energy sectors and policy barriers. Furthermore, real oil prices exhibit a positive association with REC in nine countries, including the Netherlands, the United States, Belgium, Greece, Austria, Sweden, the United Kingdom, Chile, Colombia, and Hungary. Conversely, Portugal and Turkey show a negative relationship, which may be influenced by specific economic and market factors. Moreover, trade openness demonstrates a positive correlation with REC in Norway, Germany, the United Kingdom, and Mexico, facilitating access to advanced renewable energy technologies and promoting competition in the renewable energy sector. Also, Income inequality and REC are positively linked in the Netherlands, Denmark, and Germany, indicating that wealthier households may have higher levels of renewable energy consumption. In contrast, the United States shows a negative association, potentially due to income disparities affecting renewable energy adoption. This negative relationship may be influenced by government policies and the affordability of renewable energy solutions.

Furthermore, Chapter II presents compelling evidence supporting a unidirectional causal linkage between REC, income disparity, trade openness, oil prices, and CO₂ emissions. Specifically, an increase in REC, income disparity, trade openness, and oil

prices lead to an increase in environmental degradation. However, there exists a two-way causal link between income inequality and REC. Chapter II also reveals that there is a unidirectional causality running from oil prices and income disparity to GDP, and from GDP to REC. Overall, these findings suggest that policies aimed at promoting trade openness, environmental sustainability, and income equality could lead to an increase in REC and a reduction in CO₂ emissions in OECD countries.

Chapter III aims to answer the following research questions: What are the main drivers of renewable energy consumption in the BRICS economies? Can REC be influenced by the dynamics of income inequality in the BRICS economies? What are the potential trade-offs and synergies between GDP growth, income disparity, capital formation, innovation, and REC in the BRICS economies? The findings elucidated in Chapter III substantiate that there exists a positive correlation between economic growth and REC. Conversely, an escalation in income inequality, technological innovations, carbon emissions, and capital formation displays a negative association with REC. The PMG estimator corroborates the results obtained from the AMG estimator, demonstrating similar coefficients and directional relationships for the examined variables.

The outcomes derived from the country-specific AMG estimator, as presented in Chapter III, indicate that GDP and REC are significantly and positively associated in China and Brazil, where renewable energy sources have been actively harnessed through favorable policies and investments. In Brazil, China, and Russia, technological progress leads to reduced renewable energy usage due to factors such as reliance on fossil fuels, energy-intensive industries, subsidies favoring fossil fuels, and limited investments in renewables. In India, Brazil, and China, an inverse association between CO₂ emissions and REC exists due to persisting fossil fuel dependence, complex policy frameworks, technological constraints, and economic factors. Transitioning to renewable energy is critical in these countries to mitigate CO₂ emissions effectively. Brazil exhibits a substantial inverse relationship between REC and GFCF, attributed to historical reliance on hydropower and limited investment in alternative renewable energy sources. In China and Russia, income inequality shows a negative association with REC, as privileged individuals have better access to renewable energy technologies, leading to disparities in renewable energy consumption. In conclusion, promoting renewable energy as a central element of

energy policies and addressing economic, policy, and technological challenges are indispensable in achieving a sustainable energy transition. These findings underscore the significance of embracing renewable energy sources and implementing measures to reduce carbon emissions for a greener and more sustainable future in BRICS countries.

The findings obtained from the panel causality test using the Dumitrescu-Hurlin method, as outlined in Chapter III, indicate that REC, CO₂ emissions, capital formation, and technological innovation are causally linked to economic growth in a one-way direction. Besides, the study reveals a one-way causality running from REC, income disparity, and technological innovation to carbon emissions, and from REC and technological innovation to gross fixed capital formation. Moreover, the chapter identifies a one-way causality running from income inequality to REC.

Chapter IV aims to answer the following questions: Do trade liberalization policies affect the green energy transition in OECD countries? What are the key drivers of the green energy transition in OECD countries, and how do trade liberalization policies interact with these drivers? How does the relationship between trade liberalization policies and the green energy transition vary across different OECD countries? The findings obtained through the AMG estimator indicate that the adoption of policies aimed at promoting trade liberalization plays a crucial role in expediting the transition toward green energy. Furthermore, an upsurge in green energy consumption is observed to be positively correlated with both economic development and escalating oil prices.

The findings derived from the country-specific AMG estimator, as presented in Chapter IV, unveil an inverse relationship between environmental degradation and GET in sixteen OECD nations, including Turkey, Mexico, Colombia, Chile, the UK, Sweden, Spain, New Zealand, Germany, Denmark, Austria, Portugal, Greece, Finland, Belgium, and the Netherlands. Infrastructure, technology limitations, policy effectiveness, and economic factors contribute to the negative correlation between economic development and GET in Hungary, Germany, Denmark, and Greece. Hungary exhibits a positive link between technological progress and GET due to the proactive adoption of green energy technologies, while the UK, Germany, and Greece

show an inverse relationship due to established energy infrastructure. Additionally, in Mexico, Sweden, Germany, Finland, and Norway, a positive association between TLPs and GEC has been found. These countries have implemented supportive policies and incentives to promote green energy use. TLPs have been crucial in facilitating the international trade of renewable energy technologies, making eco-friendly solutions more accessible. These nations are advanced in green energy technologies and research, integrating sustainable options effectively. Their populations show high awareness and demand for environmentally friendly practices, contributing to the success of green energy consumption. The decreasing cost of renewable technologies also makes green energy solutions increasingly competitive. Strategic alliances with other countries and organizations further boost their green energy projects. Moreover, twelve economies, including Hungary, Mexico, Chile, Sweden, Austria, Portugal, Greece, Finland, Belgium, France, the Netherlands, and the USA, demonstrate a significant positive association between oil prices and GET. Conversely, Turkey's inverse relationship between oil prices and GET is influenced by subsidies, fossil fuel reliance, policy effectiveness, and economic factors.

The panel causality test using the Dumitrescu-Hurlin method, conducted in Chapter IV, provides evidence supporting unidirectional causality from GET to environmental degradation, TLPs, and technological progress. Unidirectional causality is also observed from TLPs to real oil prices and from economic development to technological progress. Additionally, there is a bidirectional causal relationship between environmental degradation, GET, economic development, and technological progress with real oil prices. Moreover, the findings of the PMG estimator are consistent with those of the AMG estimator, confirming the robustness of the study's long-term outcomes.

With regard to the variables under investigation in Chapters II, III, and IV, there are certain similarities between Chapter II and Chapter IV. However, it should be noted that Chapter II examines the impact of income disparity on REC, while Chapter IV analyzes the influence of technological innovations on REC. Further, there are differences in the methodologies employed across these chapters. Chapter II exclusively utilizes the AMG estimator for long-run estimation, while Chapter III and Chapter IV employ both the AMG and PMG estimators to establish the long-run

association between the variables. Additionally, the number of observations varies across these chapters, with Chapter II and Chapter IV containing 575 observations for each variable, whereas Chapter III has 120 observations. Furthermore, these Chapters differ in their geographic and economic focus. Specifically, Chapter II and Chapter IV concentrate on 23 OECD countries, while Chapter III centers on the BRICS economies. Moreover, in all these chapters (II, III, and IV), we evaluate the findings for each country separately.

Although Chapters II, III, and IV present their own distinct findings, the collective outcomes of the thesis can be categorized into eight fundamental policy implications. These implications are derived from analyzing the positive and negative associations between various factors and the consumption of renewable energy.

- (i) Policymakers should prioritize investment in RE infrastructure and technology to encourage sustainable economic growth. Additionally, policies should be implemented to incentivize the adoption of RES, such as tax credits and subsidies for renewable energy production and use. Governments should also encourage private sector investment in renewable energy projects through regulatory frameworks and financial incentives. By prioritizing renewable energy consumption and production, policymakers can promote economic growth while mitigating the negative environmental impacts associated with traditional energy sources. This shift towards sustainable energy can also create new job opportunities and stimulate innovation, further contributing to economic growth.
- (ii) Policymakers should focus on creating policies that promote trade openness, which can enable the transfer of renewable energy technologies across countries. This can be achieved through trade agreements and investments in infrastructure to improve connectivity and access to markets. Furthermore, there is a need for international cooperation in addressing climate change, and policymakers should work together to develop a global framework for promoting renewable energy adoption and trade openness. By taking these steps, countries can work towards reducing their dependence on fossil fuels and transitioning to a more sustainable energy future.

- (iii) Policymakers should focus on implementing measures that promote the adoption of renewable energy sources, while simultaneously reducing carbon emissions from fossil fuels. This can be achieved through the implementation of renewable energy targets, carbon pricing, and subsidies for renewable energy production. In addition, regulations can be put in place to enforce stricter emissions standards for industries and promote energy-efficient practices in the transportation sector. It is also important to encourage public awareness and education campaigns on the benefits of renewable energy and the negative impacts of carbon emissions on the environment.
- (iv) Policymakers should focus on implementing policies that reduce the dependence on fossil fuels, such as renewable portfolio standards, feed-in tariffs, and carbon pricing. These policies can create market incentives for renewable energy investment and reduce the negative impacts of oil price volatility on the economy. Additionally, policymakers should also promote energy efficiency measures to reduce energy consumption and improve energy security. Furthermore, there is a need for international cooperation in addressing climate change, and policymakers should work together to develop a global framework for promoting renewable energy adoption and reducing oil dependency. By taking these steps, countries can reduce their vulnerability to oil price shocks, mitigate climate change, and achieve a sustainable energy future.
- (v) The negative association between technological progress and renewable energy consumption implies that policies should focus on incentivizing the development and deployment of more efficient and cost-effective renewable energy technologies. Governments and private industries should collaborate to provide financial support for the R&D of innovative RE technologies. Policies that promote the adoption of RE, such as tax credits and subsidies, should be implemented to encourage the utilization of these technologies. Furthermore, regulations should be enacted to ensure that traditional energy sources are held accountable for environmental externalities. It is also crucial to increase public awareness and education regarding the benefits of RE and the importance of its adoption for mitigating climate change. Addressing the negative association between technological progress and renewable energy consumption is crucial to

promoting sustainable development and achieving a cleaner, greener future for all.

- (vi) The negative association between gross fixed capital formation and renewable energy consumption implies that policymakers need to reevaluate their approach to promoting renewable energy. While the transition to renewable energy requires significant investments in infrastructure, it is crucial to ensure that these investments are not detrimental to overall economic growth. Policymakers must balance the need for economic development with the need to address climate change, and this requires a more nuanced approach to renewable energy policy. One potential solution is to incentivize private investment in renewable energy through tax credits and subsidies rather than relying solely on public sector investment. Additionally, policies that encourage the adoption of renewable energy in the private sector, such as feed-in tariffs and net metering, can help to drive demand for renewable energy and increase investment in the sector. Overall, policymakers must recognize that a comprehensive approach to promoting renewable energy is needed, one that balances the economic benefits of investment with the imperative of reducing greenhouse gas emissions.
- (vii) The positive association between REC and income inequality has important policy implications for OECD economies. Policymakers must recognize that renewable energy consumption may not necessarily reduce income inequality but instead may exacerbate it. Therefore, policies that aim to increase renewable energy consumption must also consider measures that address income disparity, such as social safety nets, progressive taxation, and investments in training and education. Additionally, policymakers should ensure that renewable energy policies do not disproportionately benefit the wealthy and instead prioritize policies that promote access to renewable energy for low-income households. Ultimately, a comprehensive approach that addresses both REC and income inequality is necessary for sustainable and equitable economic growth.
- (viii) The negative association between REC and income inequality implies that policies aimed at reducing income inequality could have positive effects on the adoption of RES. In BRICS economies, where income inequality is often high,

governments could implement policies that promote equal access to education and job opportunities, as well as fair taxation systems. This could lead to a more equitable distribution of income, which could in turn spur greater adoption of renewable energy sources. Additionally, policies that provide incentives for renewable energy investment, such as tax credits or subsidies, could be targeted toward low-income households to ensure their inclusion in the transition to renewable energy. Overall, policies aimed at reducing income disparity and promoting REC could have significant positive impacts on both the economy and the environment in BRICS economies.

However, it is crucial to note that the analysis of our results is confined to a specific dataset that covers only a limited number of countries and a defined time period. As a result, future scholars who employ different datasets may reach different conclusions than ours. Thus, it is crucial to consider this fact when evaluating the policy recommendations presented above. Further, this thesis has several limitations that require addressing in future research. Firstly, the study's limited scope to the OECD and BRICS economies may restrict the generalizability of the outcomes to other nations and groups of nations. To enhance the generalizability of the results, future research could explore the effects of factors influencing REC in emerging nations such as India and China, as well as in the European Union (EU), G20, or other groups of nations. Additionally, future research could consider quantile-level estimation and the spatial aspects of multilateral trade and RE production. To achieve stronger and more intriguing results, researchers could incorporate additional factors that influence renewable energy consumption and its transition, such as the cost of fossil fuels, government clean energy subsidies, institutional efficiency, stock market growth, and green technological innovations. While the current study focuses on the influence of income disparity on renewable energy consumption, forthcoming research endeavors could delve into the effects of income disparity on the trade-off between utilizing clean and polluting energy sources. Additionally, investigations could be conducted to ascertain how different indices of inequality, such as income disparity among the top 1%, wealth disparity, and wage inequality, may impact the utilization of renewable energy sources and environmental degradation. Furthermore, this study's scope could be extended to explore the influence of regional economic integration on the green energy transition, providing insight into whether international energy trading via

flexible trade agreements could increase green energy consumption and promote the green energy transition process.



REFERENCES

- Abaidoo, R., & Agyapong, E. K. (2022). Trade Liberalization and Environmental Sustainability Risk: Do Governance and Regulatory Structures Influence the Dynamics? *The International Trade Journal*, 36(5), 353-376.
- Abba, Z. Y. I., Balta-Ozkan, N., & Hart, P. (2022). A holistic risk management framework for renewable energy investments. *Renewable and Sustainable Energy Reviews*, 160, 112305.
- Abbas, S., Ahmed, Z., Sinha, A., Mariev, O., & Mahmood, F. (2023). Toward fostering environmental innovation in OECD countries: Do fiscal decentralization, carbon pricing, and renewable energy investments matter? *Gondwana Research*.
- Abbasi, K. R., Adedoyin, F. F., Abbas, J., & Hussain, K. (2021). The impact of energy depletion and renewable energy on CO₂ emissions in Thailand: fresh evidence from the novel dynamic ARDL simulation. *Renewable Energy*, 180, 1439-1450.
- Abbasi, K. R., Shahbaz, M., Zhang, J., Irfan, M., & Alvarado, R. (2022). Analyze the environmental sustainability factors of China: The role of fossil fuel energy and renewable energy. *Renewable Energy*, 187, 390-402.
- Abdullah, H., & Tursoy, T. (2021). Capital structure and firm performance: a panel causality test.
- Abeysekara, W. C. S. M., Siriwardana, M., & Meng, S. (2023). Economic consequences of climate change impacts on the agricultural sector of South Asia: A case study of Sri Lanka. *Economic Analysis and Policy*, 77, 435-450.
- Abuzreda, A., Hamad, T. A. M., Elayatt, A., & Ahmad, I. (2023). A Review of Different Renewable Energy Resources and Their Energy Efficiency Technologies. *Adn Envi Wa s Mana Rec*, 6(1), 384-389.
- Acheampong, A. O., Dzator, J., Dzator, M., & Salim, R. (2022). Unveiling the effect of transport infrastructure and technological innovation on economic growth, energy consumption and CO₂ emissions. *Technological Forecasting and Social Change*, 182, 121843.
- Ackah, I., & Kizys, R. (2015). Green growth in oil producing African countries: A panel data analysis of renewable energy demand. *Renewable and Sustainable Energy Reviews*, 50, 1157-1166.
- Adams, S., Klobodu, E. K. M., & Apio, A. (2018). Renewable and non-renewable energy, regime type and economic growth. *Renewable Energy*, 125, 755-767.

- Adebayo, T. S., Ullah, S., Kartal, M. T., Ali, K., Pata, U. K., & Ağa, M. (2023). Endorsing sustainable development in BRICS: The role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. *Science of the Total Environment*, 859, 160181.
- Adebayo, T. S., Ullah, S., Kartal, M. T., Ali, K., Pata, U. K., & Ağa, M. (2023). Endorsing sustainable development in BRICS: The role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. *Science of the Total Environment*, 859, 160181.
- Adedoyin, F. F., Alola, A. A., & Bekun, F. V. (2021). The alternative energy utilization and common regional trade outlook in EU-27: evidence from common correlated effects. *Renewable and Sustainable Energy Reviews*, 145, 111092.
- Adeyuyi, A. O., & Awodumi, O. B. (2017). Renewable and non-renewable energy-growth-emissions linkages: Review of emerging trends with policy implications. *Renewable and Sustainable Energy Reviews*, 69, 275-291.
- Aguirre, M., & Ibikunle, G. (2014). Determinants of renewable energy growth: A global sample analysis. *Energy Policy*, 69, 374-384.
- Ahmad, M., & Zhao, Z. Y. (2018). Empirics on linkages among industrialization, urbanization, energy consumption, CO2 emissions and economic growth: a heterogeneous panel study of China. *Environmental Science and Pollution Research*, 25(30), 30617-30632.
- Ahmad, U. S., Usman, M., Hussain, S., Jahanger, A., & Abrar, M. (2022). Determinants of renewable energy sources in Pakistan: An overview. *Environmental Science and Pollution Research*, 1-19.
- Ahmed, N., Sheikh, A. A., Hamid, Z., Senkus, P., Borda, R. C., Wysokińska-Senkus, A., & Glabiszewski, W. (2022). Exploring the causal relationship among green taxes, energy intensity, and energy consumption in nordic countries: Dumitrescu and Hurlin causality approach. *Energies*, 15(14), 5199.
- Akadiri, S. S., & Adebayo, T. S. (2022). Asymmetric nexus among financial globalization, non-renewable energy, renewable energy use, economic growth, and carbon emissions: impact on environmental sustainability targets in India. *Environmental Science and Pollution Research*, 29(11), 16311-16323.
- Akar, B. G. (2016). The determinants of renewable energy consumption: An empirical analysis for The Balkans. *European Scientific Journal*, 12(11).
- Akbar, A., Rehman, A., Ullah, I., Zeeshan, M., & Afridi, F. E. A. (2020). Unraveling the dynamic nexus between trade liberalization, energy consumption, CO2 emissions, and health expenditure in Southeast Asian countries. *Risk Management and Healthcare Policy*, 1915-1927.

- Akomea-Frimpong, I., Kukah, A. S., Jin, X., Osei-Kyei, R., & Pariafsai, F. (2022). Green finance for green buildings: A systematic review and conceptual foundation. *Journal of Cleaner Production*, 131869.
- Akram, R., Chen, F., Khalid, F., Huang, G., & Irfan, M. (2021). Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: a fixed effect panel quantile regression analysis. *Energy*, 215, 119019.
- 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.
- Al Rousan, S., Sbia, R., & Tas, B. K. O. (2018). A dynamic network analysis of the world oil market: Analysis of OPEC and non-OPEC members. *Energy Economics*, 75, 28-41.
- Alam, M. M., & Murad, M. W. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. *Renewable Energy*, 145, 382-390.
- Allouhi, A., Rehman, S., Buker, M. S., & Said, Z. (2022). Up-to-date literature review on Solar PV systems: Technology progress, market status and R&D. *Journal of Cleaner Production*, 132339.
- Al-Mulali, U., Ozturk, I., & Solarin, S. A. (2016). Investigating the environmental Kuznets curve hypothesis in seven regions: The role of renewable energy. *Ecological indicators*, 67, 267-282.
- Al-Mulali, U., Solarin, S. A., Sheau-Ting, L., & Ozturk, I. (2016). Does moving towards renewable energy cause water and land inefficiency? An empirical investigation. *Energy Policy*, 93, 303-314.
- Al-Sarihi, A., & Mansouri, N. (2022). Renewable energy development in the Gulf cooperation council countries: Status, barriers, and policy options. *Energies*, 15(5), 1923.
- Altarhouni, A., Danju, D., & Samour, A. (2021). Insurance Market Development, Energy Consumption, and Turkey's CO2 Emissions. New Perspectives from a Bootstrap ARDL Test. *Energies*, 14(23), 7830.
- Amin, A., Altinoz, B., & Dogan, E. (2020). Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. *Clean Technologies and Environmental Policy*, 22, 1725-1734.
- Amjith, L. R., & Bavanish, B. (2022). A review on biomass and wind as renewable energy for sustainable environment. *Chemosphere*, 293, 133579.

- Amri, F. (2017). Intercourse across economic growth, trade and renewable energy consumption in developing and developed countries. *Renewable and Sustainable Energy Reviews*, 69, 527-534.
- Amri, F. (2019). Renewable and non-renewable categories of energy consumption and trade: Do the development degree and the industrialization degree matter? *Energy*, 173, 374-383.
- Anton, S. G., & Nucu, A. E. A. (2020). The effect of financial development on renewable energy consumption. A panel data approach. *Renewable Energy*, 147, 330-338.
- Apergis, N. (2015). Does renewables production affect income inequality? Evidence from an international panel of countries. *Applied Economics Letters*, 22(11), 865-868.
- Apergis, N., & Eleftheriou, S. (2015). Renewable energy consumption, political and institutional factors: Evidence from a group of European, Asian and Latin American countries. *The Singapore Economic Review*, 60(01), 1550008.
- Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: evidence from a panel of OECD countries. *Energy policy*, 38(1), 656-660.
- Apergis, N., & Payne, J. E. (2014). The causal dynamics between renewable energy, real GDP, emissions and oil prices: evidence from OECD countries. *Applied Economics*, 46(36), 4519-4525.
- Apergis, N., & Payne, J. E. (2015). Renewable energy, output, carbon dioxide emissions, and oil prices: evidence from South America. *Energy Sources, Part B: Economics, Planning, and Policy*, 10(3), 281-287.
- Appiah, M., Li, M., Naeem, M. A., & Karim, S. (2023). Greening the globe: Uncovering the impact of environmental policy, renewable energy, and innovation on ecological footprint. *Technological Forecasting and Social Change*, 192, 122561.
- 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, 110818.
- Aslan, A., Ocal, O., Ozsolak, B., & Ozturk, I. (2022). Renewable energy and economic growth relationship under the oil reserve ownership: Evidence from panel VAR approach. *Renewable Energy*, 188, 402-410.
- Asongu, S. A., & Odhiambo, N. M. (2021). Inequality, finance and renewable energy consumption in Sub-Saharan Africa. *Renewable Energy*, 165, 678-688.

- Awosusi, A. A., Adebayo, T. S., Kirikkaleli, D., & Altuntaş, M. (2022). Role of technological innovation and globalization in BRICS economies: policy towards environmental sustainability. *International Journal of Sustainable Development & World Ecology*, 29(7), 593-610.
- Aydin, M., & Bozatli, O. (2023). The effects of green innovation, environmental taxes, and financial development on renewable energy consumption in OECD countries. *Energy*, 128105.
- Aydin, M., & Bozatli, O. (2023). The impacts of the refugee population, renewable energy consumption, carbon emissions, and economic growth on health expenditure in Turkey: new evidence from Fourier-based analyses. *Environmental Science and Pollution Research*, 30(14), 41286-41298.
- Azam, A., Rafiq, M., Shafique, M., Zhang, H., Ateeq, M., & Yuan, J. (2021). Analyzing the relationship between economic growth and electricity consumption from renewable and non-renewable sources: Fresh evidence from newly industrialized countries. *Sustainable Energy Technologies and Assessments*, 44, 100991.
- Bacchetta, M., Bekkers, E., Solleder, J., & Tresa, E. (2022). Environmental Goods Trade Liberalization: A Quantitative Modelling Study of Trade and Emission Effects.
- Badmus, J. O., Bisiriyu, S. O., & Alawode, O. S. (2022). Does COVID-19 shock endanger the flows of FDI in OECD? Empirical evidence based on AMG panel estimator. *Future Business Journal*, 8(1), 19.
- 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, 110482.
- Bai, C., Zhou, L., Xia, M., & Feng, C. (2020). Analysis of the spatial association network structure of China's transportation carbon emissions and its driving factors. *Journal of environmental management*, 253, 109765.
- Baldwin, E., Carley, S., Brass, J.N., MacLean, L.M., 2017. Global renewable electricity policy: a comparative policy analysis of countries by income status. *J. Comp. Policy Anal.: Res. Pract.* 19 (3), 277–298.
- Balsalobre-Lorente, D., & Leitão, N. C. (2020). The role of tourism, trade, renewable energy use and carbon dioxide emissions on economic growth: evidence of tourism-led growth hypothesis in EU-28. *Environmental Science and Pollution Research*, 27(36), 45883-45896.
- Balsalobre-Lorente, D., Gokmenoglu, K. K., Taspinar, N., & Cantos-Cantos, J. M. (2019). An approach to the pollution haven and pollution halo hypotheses in MINT countries. *Environmental Science and Pollution Research*, 26(22), 23010-23026.

- Banday, U. J., & Aneja, R. (2019). Renewable and non-renewable energy consumption, economic growth and carbon emission in BRICS: Evidence from bootstrap panel causality. *International Journal of Energy Sector Management*.
- Bano, S., Liu, L., & Khan, A. (2022). Dynamic influence of aging, industrial innovations, and ICT on tourism development and renewable energy consumption in BRICS economies. *Renewable energy*, 192, 431-442.
- Barak, D. (2022). The Impact of Income Inequality, Renewable Energy Consumption, Non-Renewable Energy Consumption and Per Capita Income on Poverty: Evidence from BRICS Economies. *Ekonomika*, 101(1), 62-83.
- Barro, R. J. (1999). Inequality, growth, and investment (No. w7038). *NBER Working Paper Series. Massachusetts*.
- Barros, L., & Martínez-Zarzoso, I. (2022). Systematic literature review on trade liberalization and sustainable development. *Sustainable Production and Consumption*.
- Bashir, M. A., Dengfeng, Z., Amin, F., Mentel, G., Raza, S. A., & Bashir, M. F. (2023). Transition to greener electricity and resource use impact on environmental quality: Policy based study from OECD countries. *Utilities Policy*, 81, 101518.
- Bashir, M. F., Sadiq, M., Talbi, B., Shahzad, L., & Adnan Bashir, M. (2022). An outlook on the development of renewable energy, policy measures to reshape the current energy mix, and how to achieve sustainable economic growth in the post COVID-19 era. *Environmental Science and Pollution Research*, 29(29), 43636-43647.
- Bayulgen, O., & Ladewig, J. W. (2017). Vetoing the future: political constraints and renewable energy. *Environmental politics*, 26(1), 49-70.
- Belaïd, F., & Zrelli, M. H. (2019). Renewable and non-renewable electricity consumption, environmental degradation and economic development: evidence from Mediterranean countries. *Energy Policy*, 133, 110929.
- Bengochea, A., & Faet, O. (2012). Renewable energies and CO2 emissions in the European Union. *Energy Sources, Part B: Economics, Planning, and Policy*, 7(2), 121-130.
- Berthe, A., & Elie, L. (2015). Mechanisms explaining the impact of economic inequality on environmental deterioration. *Ecological economics*, 116, 191-200.
- Best, R. (2017). Switching towards coal or renewable energy? The effects of financial capital on energy transitions. *Energy Economics*, 63, 75-83.
- Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, 162, 733-741.

- Bilgili, F., & Ozturk, I. (2015). Biomass energy and economic growth nexus in G7 countries: Evidence from dynamic panel data. *Renewable and Sustainable Energy Reviews*, 49, 132-138.
- Bilgili, F., Lorente, D. B., Kuşkaya, S., Ünlü, F., Gençoğlu, P., & Rosha, P. (2021). The role of hydropower energy in the level of CO2 emissions: An application of continuous wavelet transforms. *Renewable Energy*, 178, 283-294.
- Biresselioglu, M. E., & Karaibrahimoglu, Y. Z. (2012). The government orientation and use of renewable energy: Case of Europe. *Renewable energy*, 47, 29-37.
- Blazejczak, J., Braun, F. G., Edler, D., & Schill, W. P. (2014). Economic effects of renewable energy expansion: A model-based analysis for Germany. *Renewable and sustainable energy reviews*, 40, 1070-1080.
- Bogdanov, D., Gulagi, A., Fasihi, M., & Breyer, C. (2021). Full energy sector transition towards 100% renewable energy supply: Integrating power, heat, transport and industry sectors including desalination. *Applied Energy*, 283, 116273.
- Bointner, R. (2014). Innovation in the energy sector: Lessons learnt from R&D expenditures and patents in selected IEA countries. *Energy policy*, 73, 733-747.
- Bond, S., & Eberhardt, M. (2013). Accounting for unobserved heterogeneity in panel time series models. *University of Oxford*, 1-11.
- Bowden, N., & Payne, J. E. (2010). Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US. *Energy Sources, Part B: Economics, Planning, and Policy*, 5(4), 400-408.
- Boyce, J. K. (1994). Inequality as a cause of environmental degradation. *Ecological economics*, 11(3), 169-178.
- BP, British Petroleum, Statistical Review of World Energy (2021). British Petroleum, London. <https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf> (Accessed 3 July 2022).
- Brini, R., Amara, M., & Jemmali, H. (2017). Renewable energy consumption, international trade, oil price and economic growth inter-linkages: The case of Tunisia. *Renewable and Sustainable Energy Reviews*, 76, 620-627.
- British Petroleum (BP) (2020). Statistical Review of World Energy. British Petroleum, London. <https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf> (Accessed 10 July 2022).

- Brunnschweiler, C. N. (2010). Finance for renewable energy: an empirical analysis of developing and transition economies. *Environment and development economics*, 241-274.
- Bulut, U., Shahbaz, M., & Vo, X. V. (2022). Renewable energy-economic growth nexus revisited for the USA: do different approaches for modeling structural breaks lead to different findings?. *Environmental Science and Pollution Research*, 1-11.
- Cadoret, I., Padovano, F., 2016. The political drivers of renewable energies policies. *Energy Econ.* 56, 261–269.
- Caglar, A. E., Guloglu, B., & Gedikli, A. (2022). Moving towards sustainable environmental development for BRICS: investigating the asymmetric effect of natural resources on CO2. *Sustainable Development*, 30(5), 1313-1325.
- Calvo, G., & Valero, A. (2022). Strategic mineral resources: Availability and future estimations for the renewable energy sector. *Environmental Development*, 41, 100640.
- Cao, H., Khan, M. K., Rehman, A., Dagar, V., Oryani, B., & Tanveer, A. (2022). Impact of globalization, institutional quality, economic growth, electricity and renewable energy consumption on Carbon Dioxide Emission in OECD countries. *Environmental Science and Pollution Research*, 29(16), 24191-24202.
- Carley, S., Baldwin, E., MacLean, L. M., & Brass, J. N. (2017). Global expansion of renewable energy generation: An analysis of policy instruments. *Environmental and resource economics*, 68, 397-440.
- Carlsen, L., & Bruggemann, R. (2022). The 17 United Nations' sustainable development goals: a status by 2020. *International Journal of Sustainable Development & World Ecology*, 29(3), 219-229.
- Castrejon-Campos, O., Aye, L., Hui, F. K. P., & Vaz-Serra, P. (2022). Economic and environmental impacts of public investment in clean energy RD&D. *Energy Policy*, 168, 113134.
- Cergibozan, R. (2022). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. *Renewable Energy*, 183, 617-626.
- Cergibozan, R. (2022). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. *Renewable Energy*, 183, 617-626.
- Cerruti, G., Chiola, M., Bianco, V., & Scarpa, F. (2023). Impact of electric cars deployment on the Italian energy system. *Energy and Climate Change*, 100095.

- Chang, C. T., & Lee, H. C. (2016). Taiwan's renewable energy strategy and energy-intensive industrial policy. *Renewable and Sustainable Energy Reviews*, *64*, 456-465.
- Chen, C., Pinar, M., & Stengos, T. (2020). Renewable energy consumption and economic growth nexus: Evidence from a threshold model. *Energy Policy*, *139*, 111295.
- Chen, C., Pinar, M., & Stengos, T. (2021). Determinants of renewable energy consumption: Importance of democratic institutions. *Renewable Energy*, *179*, 75-83.
- Chen, H., Shi, Y., Xu, M., & Zhao, X. (2022). Investment in renewable energy resources, sustainable financial inclusion and energy efficiency: A case of US economy. *Resources Policy*, *77*, 102680.
- Chen, W. H., Biswas, P. P., Ong, H. C., Nguyen, T. B., & Dong, C. D. (2023). A critical and systematic review of sustainable hydrogen production from ethanol/bioethanol: Steam reforming, partial oxidation, and autothermal reforming. *Fuel*, *333*, 126526.
- Chen, Y., Mamon, R., Spagnolo, F., & Spagnolo, N. (2022). Renewable energy and economic growth: A Markov-switching approach. *Energy*, *244*, 123089.
- Chen, Z., Umar, M., Su, C. W., & Mirza, N. (2023). Renewable energy, credit portfolios and intermediation spread: Evidence from the banking sector in BRICS. *Renewable Energy*, *208*, 561-566.
- Cheng, C., Ren, X., Wang, Z., & Yan, C. (2019). Heterogeneous impacts of renewable energy and environmental patents on CO2 emission-Evidence from the BRIICS. *Science of the total environment*, *668*, 1328-1338.
- Cheon, A., & Urpelainen, J. (2012). Oil prices and energy technology innovation: An empirical analysis. *Global Environmental Change*, *22*(2), 407-417.
- Cheon, A., & Urpelainen, J. (2013). How do competing interest groups influence environmental policy? The case of renewable electricity in industrialized democracies, 1989–2007. *Political Studies*, *61*(4), 874-897.
- Chhabra, M., Giri, A. K., & Kumar, A. (2023). Do trade openness and institutional quality contribute to carbon emission reduction? Evidence from BRICS countries. *Environmental Science and Pollution Research*, *30*(17), 50986-51002.
- Chiu, Y. B., & Zhang, W. (2023). Moderating Effect of Financial Development on the Relationship between Renewable Energy and Carbon Emissions. *Energies*, *16*(3), 1467.
- Chong, C. T., Van Fan, Y., Lee, C. T., & Klemeš, J. J. (2022). Post COVID-19 ENERGY sustainability and carbon emissions neutrality. *Energy*, *241*, 122801.

- Chu, L. K. (2023). Environmentally related technologies and environmental regulations in promoting renewable energy: evidence from OECD countries. *Journal of Environmental Studies and Sciences*, 13(1), 177-197.
- Chu, L. K., Ghosh, S., Doğan, B., Nguyen, N. H., & Shahbaz, M. (2023). Energy security as new determinant of renewable energy: the role of economic complexity in top energy users. *Energy*, 263, 125799.
- Copeland, B. R. (2005). Policy endogeneity and the effects of trade on the environment. *Agricultural and Resource Economics Review*, 34(1203-2016-95320), 1-15.
- Croutzet, A., & Dabbous, A. (2021). Do FinTech trigger renewable energy use? Evidence from OECD countries. *Renewable Energy*, 179, 1608-1617.
- Dagar, V., Khan, M. K., Alvarado, R., Rehman, A., Irfan, M., Adekoya, O. B., & Fahad, S. (2022). Impact of renewable energy consumption, financial development and natural resources on environmental degradation in OECD countries with dynamic panel data. *Environmental Science and Pollution Research*, 29(12), 18202-18212.
- Dai, J., Alvarado, R., Ali, S., Ahmed, Z., & Meo, M. S. (2023). Transport infrastructure, economic growth, and transport CO2 emissions nexus: Does green energy consumption in the transport sector matter?. *Environmental Science and Pollution Research*, 1-13.
- Davraz, A., Nalbantçılar, M. T., & Önden, İ. (2022). Hydrogeochemical characteristics and trace element of geothermal systems in Central Anatolia, Turkey. *Journal of African Earth Sciences*, 195, 104666.
- Dechezleprêtre, A., Nachtigall, D., & Venmans, F. (2023). The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *Journal of Environmental Economics and Management*, 118, 102758.
- Deng, Z., Liu, J., & Sohail, S. (2022). Green economy design in BRICS: dynamic relationship between financial inflow, renewable energy consumption, and environmental quality. *Environmental Science and Pollution Research*, 1-10.
- Destek, M. A., & Aslan, A. (2020). Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries. *Renewable Energy*, 151, 1298-1306.
- Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries. *Journal of Cleaner Production*, 242, 118537.

- Dinçer, H., Yüksel, S., Çağlayan, Ç., Yavuz, D., & Kararoğlu, D. (2023). Can renewable energy investments be a solution to the energy-sourced high inflation problem?. In *Managing inflation and supply chain disruptions in the global economy* (pp. 220-238). IGI Global.
- Dogan, E., & Muhammad, I. (2019). Willingness to pay for renewable electricity: A contingent valuation study in Turkey. *The Electricity Journal*, 32(10), 106677.
- Dogru, T., Bulut, U., Kocak, E., Isik, C., Suess, C., & Sirakaya-Turk, E. (2020). The nexus between tourism, economic growth, renewable energy consumption, and carbon dioxide emissions: contemporary evidence from OECD countries. *Environmental Science and Pollution Research*, 27, 40930-40948.
- Dong, K., Hochman, G., Zhang, Y., Sun, R., Li, H., & Liao, H. (2018). CO2 emissions, economic and population growth, and renewable energy: Empirical evidence across regions. *Energy Economics*, 75, 180-192.
- Dong, K., Sun, R., & Dong, X. (2018). CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China. *Science of the Total Environment*, 640, 293-302.
- Dovichil Filho, F. B., Lora, E. E. S., Palacio, J. C. E., Venturini, O. J., & Jaén, R. L. (2023). An approach to technology selection in bioelectricity technical potential assessment: A Brazilian case study. *Energy*, 272, 126995.
- Duan, H., Liu, Y., & Wang, G. (2022). A novel dynamic time-delay grey model of energy prices and its application in crude oil price forecasting. *Energy*, 251, 123968.
- Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic modelling*, 29(4), 1450-1460.
- Dzwigol, H., Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2023). Renewable Energy, Knowledge Spillover and Innovation: Capacity of Environmental Regulation. *Energies*, 16(3), 1117.
- Eberhardt, M., & Bond, S. (2009). Cross-section dependence in nonstationary panel models: a novel estimator.
- Ehigiamusoe, K. U., & Dogan, E. (2022). The role of interaction effect between renewable energy consumption and real income in carbon emissions: Evidence from low-income countries. *Renewable and Sustainable Energy Reviews*, 154, 111883.
- EIA, International energy outlook 2019 with projections to 2050. US energy information administration. <https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf> (Accessed 10 July 2022).

- Elahi, E., Khalid, Z., & Zhang, Z. (2022). Understanding farmers' intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture. *Applied Energy*, 309, 118459.
- Eren, B. M., Taspınar, N., & Gokmenoglu, K. K. (2019). The impact of financial development and economic growth on renewable energy consumption: Empirical analysis of India. *Science of the Total Environment*, 663, 189-197.
- Falama, R. Z., Saidi, A. S., Soulouknga, M. H., & Salah, C. B. (2023). A techno-economic comparative study of renewable energy systems based different storage devices. *Energy*, 266, 126411.
- Fan, W., & Hao, Y. (2020). An empirical research on the relationship amongst renewable energy consumption, economic growth and foreign direct investment in China. *Renewable Energy*, 146, 598-609.
- Fatima, K., Minai, A. F., & Malik, H. (2022). Intelligent approach-based maximum power point tracking for renewable energy system: a review. *Intelligent Data Analytics for Power and Energy Systems*, 373-405.
- Fayziyev, P. R., Ikromov, I. A., Abduraximov, A. A., & Dehqonov, Q. M. (2022). Timeline: History of the Electric Car, Trends and the Future Developments. *Eurasian Research Bulletin*, 6, 89-94.
- Fouladvand, J., Ghorbani, A., Mouter, N., & Herder, P. (2022). Analysing community-based initiatives for heating and cooling: A systematic and critical review. *Energy Research & Social Science*, 88, 102507.
- Fredriksson, P. G., & Svensson, J. (2003). Political instability, corruption and policy formation: the case of environmental policy. *Journal of public economics*, 87(7-8), 1383-1405.
- Gan, J., & Smith, C. T. (2011). Drivers for renewable energy: A comparison among OECD countries. *Biomass and Bioenergy*, 35(11), 4497-4503.
- Geller, H., Harrington, P., Rosenfeld, A. H., Tanishima, S., & Unander, F. (2006). Policies for increasing energy efficiency: Thirty years of experience in OECD countries. *Energy policy*, 34(5), 556-573.
- Geng, J. B., & Ji, Q. (2016). Technological innovation and renewable energy development: evidence based on patent counts. *International Journal of Global Environmental Issues*, 15(3), 217-234.
- Ghazouani, A., Jebli, M. B., & Shahzad, U. (2021). Impacts of environmental taxes and technologies on greenhouse gas emissions: contextual evidence from leading emitter European countries. *Environmental Science and Pollution Research*, 28(18), 22758-22767.

- Ghosh, S. (2022). Renewable energy and CO₂ emissions: the economics and geopolitical implications, experiences from the BRICS nations. *International Journal of Energy Sector Management*, 16(6), 1064-1090.
- Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy strategy reviews*, 24, 38-50.
- Godil, D. I., Yu, Z., Sharif, A., Usman, R., & Khan, S. A. R. (2021). Investigate the role of technology innovation and renewable energy in reducing transport sector CO₂ emission in China: A path toward sustainable development. *Sustainable Development*, 29(4), 694-707.
- Golley, J., & Meng, X. (2012). Income inequality and carbon dioxide emissions: the case of Chinese urban households. *Energy Economics*, 34(6), 1864-1872.
- Golmohamadi, H. (2022). Demand-side management in industrial sector: A review of heavy industries. *Renewable and Sustainable Energy Reviews*, 156, 111963.
- Golpîra, H., Sadeghi, H., & Magazzino, C. (2023). The Impact of Economic Growth, Population, and Energy Consumption on Environmental Degradation: Evidence from OECD Countries.
- Gourevitch, P. (1978). The second image reversed: the international sources of domestic politics. *International organization*, 32(4), 881-912.
- Gozgor, G., Mahalik, M. K., Demir, E., & Padhan, H. (2020). The impact of economic globalization on renewable energy in the OECD countries. *Energy Policy*, 139, 111365.
- Gozgor, G., Mahalik, M. K., Demir, E., & Padhan, H. (2020). The impact of economic globalization on renewable energy in the OECD countries. *Energy Policy*, 139, 111365.
- Grangeia, C., Santos, L., & Lazaro, L. L. B. (2022). The Brazilian biofuel policy (RenovaBio) and its uncertainties: An assessment of technical, socioeconomic and institutional aspects. *Energy Conversion and Management: X*, 13, 100156.
- Grunst, A. S., Grunst, M. L., Grémillet, D., Kato, A., Bustamante, P., Albert, C., ... & Fort, J. (2023). Mercury contamination challenges the behavioral response of a keystone species to Arctic climate change. *Environmental Science & Technology*, 57(5), 2054-2063.
- Gu, X., Alamri, A. M., Ahmad, M., Alsagr, N., Zhong, X., & Wu, T. (2023). Natural resources extraction and green finance: Dutch disease and COP27 targets for OECD countries. *Resources Policy*, 81, 103404.
- Gugushvili, A., Reeves, A., & Jarosz, E. (2020). How do perceived changes in inequality affect health? *Health & Place*, 62, 102276.

- Guloglu, B., Caglar, A. E., & Pata, U. K. (2023). Analyzing the determinants of the load capacity factor in OECD countries: Evidence from advanced quantile panel data methods. *Gondwana Research*, 118, 92-104.
- Güney, T. (2019). Renewable energy, non-renewable energy and sustainable development. *International Journal of Sustainable Development & World Ecology*, 26(5), 389-397.
- Guo, Y., Yu, C., Zhang, H., & Cheng, H. (2021). Asymmetric between oil prices and renewable energy consumption in the G7 countries. *Energy*, 226, 120319.
- Gyamfi, S., Derkyi, N. S., Asuamah, E. Y., & Aduako, I. J. (2018). Renewable energy and sustainable development. In *Sustainable Hydropower in West Africa* (pp. 75-94). Academic Press.
- Hailiang, Z., Iqbal, W., Yin Chau, K., Raza Shah, S. A., Ahmad, W., & Hua, H. (2023). Green finance, renewable energy investment, and environmental protection: empirical evidence from BRICS countries. *Economic research-Ekonomska istraživanja*, 36(2).
- Hainsch, K., Löffler, K., Burandt, T., Auer, H., del Granado, P. C., Pisciella, P., & Zwickl-Bernhard, S. (2022). Energy transition scenarios: What policies, societal attitudes, and technology developments will realize the EU Green Deal? *Energy*, 239, 122067.
- Han, J., Zeeshan, M., Ullah, I., Rehman, A., & Afridi, F. E. A. (2022). Trade openness and urbanization impact on renewable and non-renewable energy consumption in China. *Environmental Science and Pollution Research*, 29(27), 41653-41668.
- Han, J., Zeeshan, M., Ullah, I., Rehman, A., & Afridi, F. E. A. (2022). Trade openness and urbanization impact on renewable and non-renewable energy consumption in China. *Environmental Science and Pollution Research*, 29(27), 41653-41668.
- Haralayya, B., & Aithal, P. (2021). Analysis of bank productivity using panel causality test.
- Haseeb, M., Abidin, I. S. Z., Hye, Q. M. A., & Hartani, N. H. (2019). The impact of renewable energy on economic well-being of Malaysia: Fresh evidence from auto regressive distributed lag bound testing approach. *International Journal of Energy Economics and Policy*, 9(1), 269.
- Hassan, S. T., Batool, B., Wang, P., Zhu, B., & Sadiq, M. (2023). Impact of economic complexity index, globalization, and nuclear energy consumption on ecological footprint: First insights in OECD context. *Energy*, 263, 125628.
- Hayat, S., Safi, A., Wahab, S., Shahzad, K., & Chen, Y. (2023). Renewable energy R&D and natural resources: A success story of environmentally friendly financing in OECD economies. *Resources Policy*, 83, 103655.

- He, Y., Li, X., Huang, P., & Wang, J. (2022). Exploring the road toward environmental sustainability: natural resources, renewable energy consumption, economic growth, and greenhouse gas emissions. *Sustainability*, *14*(3), 1579.
- He, Z. X., Xu, S. C., Li, Q. B., & Zhao, B. (2018). Factors that influence renewable energy technological innovation in China: A dynamic panel approach. *Sustainability*, *10*(1), 124.
- Heino, J., Culp, J. M., Erkinaro, J., Goedkoop, W., Lento, J., Rühland, K. M., & Smol, J. P. (2020). Abruptly and irreversibly changing Arctic freshwaters urgently require standardized monitoring. *Journal of Applied Ecology*, *57*(7), 1192-1198.
- Hieu, V. M., & Mai, N. H. (2023). Impact of renewable energy on economic growth? Novel evidence from developing countries through MMQR estimations. *Environmental Science and Pollution Research*, *30*(1), 578-593.
- Ho, S. Y., & Iyke, B. N. (2019). Trade openness and carbon emissions: evidence from central and eastern European countries. *Review of Economics*, *70*(1), 41-67.
- Hou, H., Lu, W., Liu, B., Hassanein, Z., Mahmood, H., & Khalid, S. (2023). Exploring the role of fossil fuels and renewable energy in determining environmental sustainability: Evidence from OECD countries. *Sustainability*, *15*(3), 2048.
- Hsiao, C. Y. L., Lin, W., Wei, X., Yan, G., Li, S., & Sheng, N. (2019). The impact of international oil prices on the stock price fluctuations of China's renewable energy enterprises. *Energies*, *12*(24), 4630.
- Hu, Y., Cheng, H., & Tao, S. (2022). Opportunity and challenges in large-scale geothermal energy exploitation in China. *Critical Reviews in Environmental Science and Technology*, *52*(21), 3813-3834.
- Huang, Y., Ahmad, M., Ali, S., & Kirikkaleli, D. (2022). Does eco-innovation promote cleaner energy? Analyzing the role of energy price and human capital. *Energy*, *239*, 122268.
- Huilan, W., Akadiri, S. S., Haouas, I., Awosusi, A. A., & Odu, A. T. (2022). Impact of trade liberalization and renewable energy on load capacity factor: Evidence from novel dual adjustment approach. *Energy & Environment*, 0958305X221137559.
- Hysa, E., Kruja, A., Rehman, N. U., & Laurenti, R. (2020). Circular economy innovation and environmental sustainability impact on economic growth: An integrated model for sustainable development. *Sustainability*, *12*(12), 4831.
- Ibrahim, R. L., & Ajide, K. B. (2021). Nonrenewable and renewable energy consumption, trade openness, and environmental quality in G-7 countries: the conditional role of technological progress. *Environmental Science and Pollution Research*, *28*, 45212-45229.

- Ibrahim, R. L., Adebayo, T. S., Awosusi, A. A., Ajide, K. B., Adewuyi, A. O., & Bolarinwa, F. O. (2022). Investigating the asymmetric effects of renewable energy-carbon neutrality nexus: Can technological innovation, trade openness, and transport services deliver the target for Germany?. *Energy & Environment*, 0958305X221127020.
- IEA (International Energy Agency). (2021). Net zero by 2050. <https://www.iea.org/reports/net-zero-by-2050> (Accessed 05 July 2022).
- IEA, World energy outlook 2019, part of world energy outlook. (Accessed 12 July 2022).
- IEA. International Energy Agency, world energy outlook (2015). <https://www.iea.org/publications/freepublications/publication/WEO2015.pdf> (Accessed 10 July 2022).
- IEA. International Energy Agency, world energy outlook (2020). <https://www.iea.org/reports/world-energy-outlook-2020> (Accessed 10 July 2022).
- Intergovernmental Panel on Climate Change (IPCC), Global Warming of 1.5 °C (2018), United Nations, New York.
- International Energy Agency (IEA) (2022). <https://www.iea.org/> (Accessed 10 January 2023).
- International Energy Agency (IEA), 2022, World Energy Balances 2021: Extended Energy Balances, <https://www.iea.org/data-and-statistics/dataproduct/world-energy-balances> (Accessed 10 January 2023).
- IPCC (2019), Intergovernmental Panel on Climate Change annual report in 2029. <https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf> (Accessed 10 July 2022).
- IPCC Working Group III, Climate change 2014-mitigation of climate change: synthesis report, Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (2014).
- Iqbal, A., Tang, X., & Rasool, S. F. (2023). Investigating the nexus between CO2 emissions, renewable energy consumption, FDI, exports and economic growth: evidence from BRICS countries. *Environment, Development and Sustainability*, 25(3), 2234-2263.
- Irandoost, M. (2016). The renewable energy-growth nexus with carbon emissions and technological innovation: Evidence from the Nordic countries. *Ecological indicators*, 69, 118-125.
- Irandoost, M. (2018). Innovations and renewables in the Nordic countries: A panel causality approach. *Technology in Society*, 54, 87-92.

- Ivanovski, K., & Marinucci, N. (2021). Policy uncertainty and renewable energy: Exploring the implications for global energy transitions, energy security, and environmental risk management. *Energy Research & Social Science*, 82, 102415.
- Ivanovski, K., Hailemariam, A., & Smyth, R. (2021). The effect of renewable and non-renewable energy consumption on economic growth: non-parametric evidence. *Journal of Cleaner Production*, 286, 124956.
- Jaforullah, M., & King, A. (2015). Does the use of renewable energy sources mitigate CO2 emissions? A reassessment of the US evidence. *Energy Economics*, 49, 711-717.
- Jain, P., Raina, G., Sinha, S., Malik, P., & Mathur, S. (2021). Agrovoltatics: Step towards sustainable energy-food combination. *Bioresource Technology Reports*, 15, 100766.
- Jamil, K., Liu, D., Gul, R. F., Hussain, Z., Mohsin, M., Qin, G., & Khan, F. U. (2022). Do remittance and renewable energy affect CO2 emissions? An empirical evidence from selected G-20 countries. *Energy & Environment*, 33(5), 916-932.
- Jardón, A., Kuik, O., & Tol, R. S. (2017). Economic growth and carbon dioxide emissions: An analysis of Latin America and the Caribbean. *Atmósfera*, 30(2), 87-100.
- Jebli, M. B., & Youssef, S. B. (2017). The role of renewable energy and agriculture in reducing CO2 emissions: Evidence for North Africa countries. *Ecological indicators*, 74, 295-301.
- Jebli, M. B., Farhani, S., & Guesmi, K. (2020). Renewable energy, CO2 emissions and value added: Empirical evidence from countries with different income levels. *Structural Change and Economic Dynamics*.
- Jeswani, H. K., Chilvers, A., & Azapagic, A. (2020). Environmental sustainability of biofuels: a review. *Proceedings of the Royal Society A*, 476(2243), 20200351.
- Jiang, J., Hu, B., Wang, R. Z., Deng, N., Cao, F., & Wang, C. C. (2022). A review and perspective on industry high-temperature heat pumps. *Renewable and Sustainable Energy Reviews*, 161, 112106.
- Jiang, T., Zhang, Y., Olayiwola, S., Lau, C., Fan, M., Ng, K., & Tan, G. (2022). Biomass-derived porous carbons support in phase change materials for building energy efficiency: a review. *Materials Today Energy*, 23, 100905.
- Jin, C., Lv, Z., Li, Z., & Sun, K. (2023). Green finance, renewable energy and carbon neutrality in OECD countries. *Renewable Energy*, 211, 279-284.

- Joof, F., Samour, A., Tursoy, T., & Ali, M. (2023). Climate change, insurance market, renewable energy, and biodiversity: double-materiality concept from BRICS countries. *Environmental Science and Pollution Research*, 30(11), 28676-28689.
- Jorgenson, A. K. (2015). Inequality and the carbon intensity of human well-being. *Journal of Environmental Studies and Sciences*, 5(3), 277-282.
- Julio, A. A. V., Milessi, T. S., Maya, D. M. Y., Lora, E. S., & Palacio, J. C. E. (2023). Assessment of the sustainability and economic potential of hydrotreated vegetable oils to complement diesel and biodiesel blends in Brazil. *Biofuels, Bioproducts and Biorefining*, 17(2), 312-323.
- Kahia, M., Aïssa, M. S. B., & Lanouar, C. (2017). Renewable and non-renewable energy use-economic growth nexus: The case of MENA Net Oil Importing Countries. *Renewable and Sustainable Energy Reviews*, 71, 127-140.
- Karacan, R., Mukhtarov, S., Barış, İ., İşleyen, A., & Yardımcı, M. E. (2021). The impact of oil price on transition toward renewable energy consumption? Evidence from Russia. *Energies*, 14(10), 2947.
- Karakurt, I., & Aydin, G. (2023). Development of regression models to forecast the CO₂ emissions from fossil fuels in the BRICS and MINT countries. *Energy*, 263, 125650.
- Karlilar, S., Balcilar, M., & Emir, F. (2023). Environmental sustainability in the OECD: The power of digitalization, green innovation, renewable energy and financial development. *Telecommunications Policy*, 47(6), 102568.
- Katircioglu, S., & Katircioglu, S. (2023). The effects of environmental taxation on stock returns of renewable energy producers: Evidence from Turkey. *Renewable Energy*, 208, 311-323.
- Kaur, H., Singh, K., Kumar, P., & Kaur, A. (2023, February). Assessing the environmental sustainability corridor: An empirical study of Renewable energy consumption in BRICS nation. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1110, No. 1, p. 012053). IOP Publishing.
- Kazemzadeh, E., Fuinhas, J. A., Koengkan, M., & Shadmehri, M. T. A. (2023). Relationship between the share of renewable electricity consumption, economic complexity, financial development, and oil prices: A two-step club convergence and PVAR model approach. *International Economics*, 173, 260-275.
- Kebede, A. A., Kalogiannis, T., Van Mierlo, J., & Bercibar, M. (2022). A comprehensive review of stationary energy storage devices for large scale renewable energy sources grid integration. *Renewable and Sustainable Energy Reviews*, 159, 112213.

- Kemp, L., Xu, C., Depledge, J., Ebi, K. L., Gibbins, G., Kohler, T. A., ... & Lenton, T. M. (2022). Climate Endgame: Exploring catastrophic climate change scenarios. *Proceedings of the National Academy of Sciences*, *119*(34), e2108146119.
- Khan, A., Chenggang, Y., Hussain, J., & Kui, Z. (2021). Impact of technological innovation, financial development and foreign direct investment on renewable energy, non-renewable energy and the environment in belt & Road Initiative countries. *Renewable Energy*, *171*, 479-491.
- Khan, H., Khan, I., & BiBi, R. (2022). The role of innovations and renewable energy consumption in reducing environmental degradation in OECD countries: an investigation for Innovation Claudia Curve. *Environmental science and pollution research*, *29*(29), 43800-43813.
- Khan, H., Khan, U., Jiang, L. J., & Khan, M. A. (2020a). Impact of infrastructure on economic growth in South Asia: Evidence from pooled mean group estimation. *The Electricity Journal*, *33*(5), 106735.
- Khan, K., Su, C. W., Rehman, A. U., & Ullah, R. (2022). Is technological innovation a driver of renewable energy? *Technology in Society*, *70*, 102044.
- Khan, M. T. I., Yaseen, M. R., & Ali, Q. (2017). Dynamic relationship between financial development, energy consumption, trade and greenhouse gas: comparison of upper middle income countries from Asia, Europe, Africa and America. *Journal of cleaner production*, *161*, 567-580.
- Khan, Z., Ali, M., Jinyu, L., Shahbaz, M., & Siqun, Y. (2020). Consumption-based carbon emissions and trade nexus: evidence from nine oil exporting countries. *Energy Economics*, *89*, 104806.
- Khezri, M., Heshmati, A., & Khodaei, M. (2022). Environmental implications of economic complexity and its role in determining how renewable energies affect CO2 emissions. *Applied Energy*, *306*, 117948.
- Khobai, H. (2021). A Review of the Nexus Between Energy consumption and Economic growth in the Brics countries. *670216917*.
- Khurshid, A., Khan, K., Chen, Y., & Cifuentes-Faura, J. (2023). Do green transport and mitigation technologies drive OECD countries to sustainable path?. *Transportation Research Part D: Transport and Environment*, *118*, 103669.
- Kilinc-Ata, N. (2016). The evaluation of renewable energy policies across EU countries and US states: An econometric approach. *Energy for Sustainable Development*, *31*, 83-90.
- Kilinc-Ata, N., & Dolmatov, I. A. (2023). Which factors influence the decisions of renewable energy investors? Empirical evidence from OECD and BRICS countries. *Environmental Science and Pollution Research*, *30*(1), 1720-1736.

- Kim, J., & Park, K. (2016). Financial development and deployment of renewable energy technologies. *Energy Economics*, 59, 238-250.
- Kirikkaleli, D., & Adebayo, T. S. (2021). Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. *Sustainable Development*, 29(4), 583-594.
- Kolcava, D., Nguyen, Q., & Bernauer, T. (2019). Does trade liberalization lead to environmental burden shifting in the global economy? *Ecological Economics*, 163, 98-112.
- Kong, Y., Nketia, E. B., Antwi, S. K., & Musah, M. (2020). Scrutinizing the complex relationship between financial development gross fixed capital formation and economic growth in Africa by adopting CCEMG and AMG estimation techniques. *International Journal of Science and Business*, 4(11), 160-174.
- Kou, G., Yüksel, S., & Dinçer, H. (2022). Inventive problem-solving map of innovative carbon emission strategies for solar energy-based transportation investment projects. *Applied Energy*, 311, 118680.
- Krug, M., Di Nucci, M. R., Caldera, M., & De Luca, E. (2022). Mainstreaming Community Energy: Is the Renewable Energy Directive a Driver for Renewable Energy Communities in Germany and Italy? *Sustainability*, 14(12), 7181.
- Kumar, A., Pal, D., Kar, S. K., Mishra, S. K., & Bansal, R. (2022). An overview of wind energy development and policy initiatives in India. *Clean Technologies and Environmental Policy*, 1-22.
- Kyritsis, E., & Serletis, A. (2019). Oil prices and the renewable energy sector. *The Energy Journal*, 40 (The New Era of Energy Transition).
- Langevin, J., Harris, C. B., & Reyna, J. L. (2019). Assessing the potential to reduce US building CO2 emissions 80% by 2050. *Joule*, 3(10), 2403-2424.
- Laurent, E. (2015). Social-Ecology: exploring the missing link in sustainable development.
- Lee, C. C., Feng, Y., & Peng, D. (2022). A green path towards sustainable development: The impact of low-carbon city pilot on energy transition. *Energy Economics*, 115, 106343.
- Lee, C. C., Olasehinde-Williams, G., & Gyamfi, B. A. (2022). The synergistic effect of green trade and economic complexity on sustainable environment: A new perspective on the economic and ecological components of sustainable development. *Sustainable Development*.
- Li, S., & Shao, Q. (2021). Exploring the determinants of renewable energy innovation considering the institutional factors: A negative binomial analysis. *Technology in Society*, 67, 101680.

- Li, Y., Li, M., Sang, P., Chen, P. H., & Li, C. (2022). Stakeholder studies of green buildings: A literature review. *Journal of Building Engineering*, 54, 104667.
- Li, Y., Wang, R., Li, Y., Zhang, M., & Long, C. (2023). Wind power forecasting considering data privacy protection: A federated deep reinforcement learning approach. *Applied Energy*, 329, 120291.
- Li, Z., Khajepour, A., & Song, J. (2019). A comprehensive review of the key technologies for pure electric vehicles. *Energy*, 182, 824-839.
- Liao, J., Liu, X., Zhou, X., & Tursunova, N. R. (2023). Analyzing the role of renewable energy transition and industrialization on ecological sustainability: Can green innovation matter in OECD countries. *Renewable Energy*, 204, 141-151.
- Lin, B., & Omoju, O. E. (2017). Focusing on the right targets: Economic factors driving non-hydro renewable energy transition. *Renewable Energy*, 113, 52-63.
- Lin, B., & Omoju, O. E. (2017). Focusing on the right targets: Economic factors driving non-hydro renewable energy transition. *Renewable Energy*, 113, 52-63.
- Lin, B., & Zhu, J. (2019). Determinants of renewable energy technological innovation in China under CO₂ emissions constraint. *Journal of environmental management*, 247, 662-671.
- 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, 1082-1091.
- Liu, F., Feng, J., Zhai, G., & Razzaq, A. (2022). Influence of fiscal decentralization and renewable energy investment on ecological sustainability in EU: What is the moderating role of institutional governance? *Renewable Energy*, 200, 1265-1274.
- Liu, M., & Lee, C. C. (2021). Capturing the dynamics of the China crude oil futures: Markov switching, co-movement, and volatility forecasting. *Energy Economics*, 103, 105622.
- Liu, T., Chen, Z., & Xu, J. (2022). Empirical evidence-based effectiveness assessment of policy regimes for wind power development in China. *Renewable and Sustainable Energy Reviews*, 164, 112535.
- Liu, Z., Lan, J., Chien, F., Sadiq, M., & Nawaz, M. A. (2022). Role of tourism development in environmental degradation: A step towards emission reduction. *Journal of environmental management*, 303, 114078.
- Lohani, S. P., Gurung, P., Gautam, B., Kafle, U., Fulford, D., & Jeuland, M. (2023). Current status, prospects, and implications of renewable energy for achieving sustainable development goals in Nepal. *Sustainable Development*, 31(1), 572-585.

- Lu, W.C. (2017). Renewable energy, carbon emissions, and economic growth in 24 Asian countries: evidence from panel cointegration analysis. *Environmental Science and Pollution Research*, 24(33), 26006-26015.
- Lucas, J. N. V., Francés, G. E., & González, E. S. M. (2016). Energy security and renewable energy deployment in the EU: Liaisons dangereuses or virtuous circle?. *Renewable and sustainable energy reviews*, 62, 1032-1046.
- Luo, Z., Wang, X., Wen, H., & Pei, A. (2022). Hydrogen production from offshore wind power in South China. *International Journal of Hydrogen Energy*, 47(58), 24558-24568.
- Mac Domhnaill, C., & Ryan, L. (2020). Towards renewable electricity in Europe: Revisiting the determinants of renewable electricity in the European Union. *Renewable Energy*, 154, 955-965.
- Magazzino, C., Mele, M., & Schneider, N. (2021). A machine learning approach on the relationship among solar and wind energy production, coal consumption, GDP, and CO2 emissions. *Renewable Energy*, 167, 99-115.
- Magoti, E., Mabula, S., & Ngong'ho, S. B. (2020). Triple Deficit Hypothesis: A Panel ARDL and Dumitrescu-Hurlin Panel Causality for East African Countries. *African Journal of Economic Review*, 8(1), 144-161.
- Mahalik, M. K., Mallick, H., & Padhan, H. (2021). Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective. *Renewable Energy*, 164, 419-432.
- Mahalik, M. K., Mallick, H., & Padhan, H. (2021). Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective. *Renewable Energy*, 164, 419-432.
- Mahalik, M. K., Patel, G., Sahoo, B. K., & Rahman, M. M. (2023). Impact of income inequality on renewable energy demand in south Asian economies. *Energy Policy*, 180, 113628.
- Majid, M. A. (2020). Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities. *Energy, Sustainability and Society*, 10(1), 1-36.
- Marijanovic, Z., Theile, P., & Czock, B. H. (2022). Value of short-term heating system flexibility—A case study for residential heat pumps on the German intraday market. *Energy*, 249, 123664.
- Marques, A. C., & Fuinhas, J. A. (2011). Do energy efficiency measures promote the use of renewable sources?. *Environmental Science & Policy*, 14(4), 471-481.

- Marques, A. C., & Fuinhas, J. A. (2011). Drivers promoting renewable energy: A dynamic panel approach. *Renewable and sustainable energy reviews*, 15(3), 1601-1608.
- Marques, A. C., & Fuinhas, J. A. (2012). Are public policies towards renewables successful? Evidence from European countries. *Renewable Energy*, 44, 109-118.
- Marques, A. C., Fuinhas, J. A., & Manso, J. P. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy policy*, 38(11), 6877-6885.
- Marques, A. C., Fuinhas, J. A., & Manso, J. P. (2011). A quantile approach to identify factors promoting renewable energy in European countries. *Environmental and Resource Economics*, 49(3), 351-366.
- Mbarek, M. B., Saidi, K., & Rahman, M. M. (2018). Renewable and non-renewable energy consumption, environmental degradation and economic growth in Tunisia. *Quality & Quantity*, 52(3), 1105-1119.
- McGee, J. A., & Greiner, P. T. (2019). Renewable energy injustice: The socio-environmental implications of renewable energy consumption. *Energy Research & Social Science*, 56, 101214.
- Mehrara, M., Rezaei, S., & Razi, D. H. (2015). Determinants of renewable energy consumption among ECO countries; based on Bayesian model averaging and weighted-average least square. *International Letters of Social and Humanistic Sciences*, 54, 96-109.
- Mehrenjani, J. R., Gharehghani, A., Nasrabadi, A. M., & Moghimi, M. (2022). Design, modeling and optimization of a renewable-based system for power generation and hydrogen production. *International Journal of Hydrogen Energy*, 47(31), 14225-14242.
- Meles, T. H., & Ryan, L. (2022). Adoption of renewable home heating systems: An agent-based model of heat pumps in Ireland. *Renewable and Sustainable Energy Reviews*, 169, 112853.
- Melnyk, L. H., Sommer, H., Kubatko, O. V., Rabe, M., & Fedyna, S. M. (2020). The economic and social drivers of renewable energy development in OECD countries.
- Menegaki, A. N. (2011). Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy economics*, 33(2), 257-263.
- Mills, B. H., Ho, C. K., Schroeder, N. R., Shaeffer, R., Laubscher, H. F., & Albrecht, K. J. (2022). Design evaluation of a next-generation high-temperature particle receiver for concentrating solar thermal applications. *Energies*, 15(5), 1657.

- Mohamed Yusoff, N. Y., Ridzuan, A. R., Soseco, T., Narmaditya, B. S., & Ann, L. C. (2023). Comprehensive Outlook on Macroeconomic Determinants for Renewable Energy in Malaysia. *Sustainability*, *15*(5), 3891.
- Montoya-Duque, L., Arango-Aramburo, S., & Arias-Gaviria, J. (2022). Simulating the effect of the Pay-as-you-go scheme for solar energy diffusion in Colombian off-grid regions. *Energy*, *244*, 123197.
- Monyei, C. G., Akpeji, K. O., Oladeji, O., Babatunde, O. M., Aholu, O. C., Adegoke, D., & Imafidon, J. O. (2022). Regional cooperation for mitigating energy poverty in sub-Saharan Africa: a context-based approach through the tripartite lenses of access, sufficiency, and mobility. *Renewable and Sustainable Energy Reviews*, *159*, 112209.
- Muhammad, I., Ozcan, R., Jain, V., Sharma, P., & Shabbir, M. S. (2022). Does environmental sustainability affect the renewable energy consumption? Nexus among trade openness, CO2 emissions, income inequality, renewable energy, and economic growth in OECD countries. *Environmental Science and Pollution Research*, 1-11.
- Muhammad, I., Shabbir, M. S., Saleem, S., Bilal, K., & Ulucak, R. (2021). Nexus between willingness to pay for renewable energy sources: Evidence from Turkey. *Environmental Science and Pollution Research*, *28*(3), 2972-2986.
- Mujtaba, A., Jena, P. K., Bekun, F. V., & Sahu, P. K. (2022). Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. *Renewable and Sustainable Energy Reviews*, *160*, 112300.
- Mujtaba, A., Jena, P. K., Bekun, F. V., & Sahu, P. K. (2022). Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. *Renewable and Sustainable Energy Reviews*, *160*, 112300.
- Mukhtarov, S., Mikayilov, J. I., Humbatova, S., & Muradov, V. (2020). Do high oil prices obstruct the transition to renewable energy consumption? *Sustainability*, *12*(11), 4689.
- Murshed, M. (2018). Does improvement in trade openness facilitate renewable energy transition? Evidence from selected South Asian economies. *South Asia Economic Journal*, *19*(2), 151-170.
- Murshed, M. (2020). Are Trade Liberalization policies aligned with Renewable Energy Transition in low and middle income countries? An Instrumental Variable approach. *Renewable Energy*, *151*, 1110-1123.
- Murshed, M., & Tanha, M. M. (2021). Oil price shocks and renewable energy transition: Empirical evidence from net oil-importing South Asian economies. *Energy, Ecology and Environment*, *6*(3), 183-203.

- Muza, O., & Thomas, V. M. (2022). Cultural norms to support gender equity in energy development: Grounding the productive use agenda in Rwanda. *Energy Research & Social Science*, 89, 102543.
- Nadolny, A., Cheng, C., Lu, B., Blakers, A., & Stocks, M. (2022). Fully electrified land transport in 100% renewable electricity networks dominated by variable generation. *Renewable Energy*, 182, 562-577.
- Nakhli, M. S., Shahbaz, M., Jebli, M. B., & Wang, S. (2022). Nexus between economic policy uncertainty, renewable & non-renewable energy and carbon emissions: contextual evidence in carbon neutrality dream of USA. *Renewable Energy*, 185, 75-85.
- Namahoro, J. P., Wu, Q., Zhou, N., & Xue, S. (2021). Impact of energy intensity, renewable energy, and economic growth on CO2 emissions: Evidence from Africa across regions and income levels. *Renewable and Sustainable Energy Reviews*, 147, 111233.
- Nan, S., Huang, J., Wu, J., & Li, C. (2022). Does globalization change the renewable energy consumption and CO2 emissions nexus for OECD countries? New evidence based on the nonlinear PSTR model. *Energy Strategy Reviews*, 44, 100995.
- Naqvi, S. A. A., Hussain, M., Hussain, B., Shah, S. A. R., Nazir, J., & Usman, M. (2023). Environmental sustainability and biomass energy consumption through the lens of pollution Haven hypothesis and renewable energy-environmental kuznets curve. *Renewable Energy*, 212, 621-631.
- Narbel, P. A. (2013). What is really behind the adoption of new renewable electricity generating technologies?. *Energy for Sustainable Development*, 17(4), 386-390.
- Nathaniel, S. P., Yalçiner, K., & Bekun, F. V. (2021). Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. *Resources Policy*, 70, 101924.
- Nazir, M. S., Bilal, M., Sohail, H. M., Liu, B., Chen, W., & Iqbal, H. M. (2020). Impacts of renewable energy atlas: Reaping the benefits of renewables and biodiversity threats. *International Journal of Hydrogen Energy*, 45(41), 22113-22124.
- New Development Bank (NDB) (2018) Developing Solutions for A Sustainable Future Annual Report 2017.
https://www.ndb.int/wpcontent/uploads/2018/07/NDB_AR2017.pdf (Accessed 10 June 2022)
- Nguyen, K. H., & Kakinaka, M. (2019). Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. *Renewable Energy*, 132, 1049-1057.

- Niaz, H., Shams, M. H., Liu, J. J., & You, F. (2022). Mining bitcoins with carbon capture and renewable energy for carbon neutrality across states in the USA. *Energy & Environmental Science*, 15(9), 3551-3570.
- Nicolini, M., & Tavoni, M. (2017). Are renewable energy subsidies effective? Evidence from Europe. *Renewable and Sustainable Energy Reviews*, 74, 412-423.
- Nicolli, F., & Vona, F. (2019). Energy market liberalization and renewable energy policies in OECD countries. *Energy Policy*, 128, 853-867.
- Nilsson, M. M. (2019). The Effect of Oil Prices on Patents in Renewable Energy: A DTC Approach.
- Nwani, C., Alola, A. A., Omoke, C. P., Adeleye, B. N., & Bekun, F. V. (2022). Responding to the environmental effects of remittances and trade liberalization in net-importing economies: the role of renewable energy in Sub-Saharan Africa. *Economic Change and Restructuring*, 55(4), 2631-2661.
- Nyiwul, L. (2017). Economic performance, environmental concerns, and renewable energy consumption: drivers of renewable energy development in Sub-Saharan Africa. *Clean Technologies and Environmental Policy*, 19(2), 437-450.
- Ocal, O., & Aslan, A. (2013). Renewable energy consumption–economic growth nexus in Turkey. *Renewable and sustainable energy reviews*, 28, 494-499.
- OECD (2017). OECD and the sustainable development goals: delivering on universal goals and targets. Available at: <http://www.oecd.org/development/sustainabledevelopment-goals.html> (Accessed 10 June 2022)
- OECD (2019). Measuring Distance to the SDG Targets 2019: an Assessment of where OECD Countries Stand. Organisation for Economic Co-operation and Development.
- Ofori, E. K., Onifade, S. T., Ali, E. B., Alola, A. A., & Zhang, J. (2023). Achieving carbon neutrality in post COP26 in BRICS, MINT, and G7 economies: The role of financial development and governance indicators. *Journal of Cleaner Production*, 387, 135853.
- Olabi, A. G., & Abdelkareem, M. A. (2022). Renewable energy and climate change. *Renewable and Sustainable Energy Reviews*, 158, 112111.
- Olabi, A. G., Abdelkareem, M. A., Wilberforce, T., & Sayed, E. T. (2021). Application of graphene in energy storage device—A review. *Renewable and Sustainable Energy Reviews*, 135, 110026.
- Olanrewaju, V. O., Irfan, M., Altuntaş, M., Agyekum, E. B., Kamel, S., & El-Naggar, M. F. (2022). Towards sustainable environment in G7 nations: The role of

renewable energy consumption, eco-innovation and trade openness. *Frontiers in Environmental Science*, 10, 925822.

Omri, A., & Nguyen, D. K. (2014). On the determinants of renewable energy consumption: International evidence. *Energy*, 72, 554-560.

Onifade, S. T., Erdoğan, S., Alagöz, M., & Bekun, F. V. (2021). Renewables as a pathway to environmental sustainability targets in the era of trade liberalization: empirical evidence from Turkey and the Caspian countries. *Environmental Science and Pollution Research*, 28, 41663-41674.

Ozcan, B., & Bozoklu, S. (2021). Dynamics of ecological balance in OECD countries: Sustainable or unsustainable? *Sustainable Production and Consumption*, 26, 638-647.

Padilla-Pérez, R., & Gaudin, Y. (2014). Science, technology and innovation policies in small and developing economies: The case of Central America. *Research Policy*, 43(4), 749-759.

Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. *Renewable and sustainable energy reviews*, 15(3), 1513-1524.

Pao, H. T., & Tsai, C. M. (2010). CO2 emissions, energy consumption and economic growth in BRIC countries. *Energy policy*, 38(12), 7850-7860.

Paramati, S. R., & Roca, E. (2019). Does tourism drive house prices in the OECD economies? Evidence from augmented mean group estimator. *Tourism Management*, 74, 392-395.

Paris, B., Vandorou, F., Balafoutis, A. T., Vaiopoulos, K., Kyriakarakos, G., Manolakos, D., & Papadakis, G. (2022). Energy use in open-field agriculture in the EU: A critical review recommending energy efficiency measures and renewable energy sources adoption. *Renewable and Sustainable Energy Reviews*, 158, 112098.

Pata, U. K., & Samour, A. (2023). Assessing the role of the insurance market and renewable energy in the load capacity factor of OECD countries. *Environmental Science and Pollution Research*, 30(16), 48604-48616.

Pata, U. K., Dam, M. M., & Kaya, F. (2023). How effective are renewable energy, tourism, trade openness, and foreign direct investment on CO2 emissions? An EKC analysis for ASEAN countries. *Environmental Science and Pollution Research*, 30(6), 14821-14837.

Perera, F., & Nadeau, K. (2022). Climate change, fossil-fuel pollution, and children's health. *New England Journal of Medicine*, 386(24), 2303-2314.

- Perin, G., & Jones, P. R. (2019). Economic feasibility and long-term sustainability criteria on the path to enable a transition from fossil fuels to biofuels. *Current opinion in biotechnology*, 57, 175-182.
- Pesaran, M. H. (2004). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 1-38.
- Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, 22(2), 265-312.
- Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric reviews*, 34(6-10), 1089-1117.
- Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of econometrics*, 142(1), 50-93.
- Pfeiffer, B., & Mulder, P. (2013). Explaining the diffusion of renewable energy technology in developing countries. *Energy Economics*, 40, 285-296.
- Philibert, C. (2017). Renewable energy for industry. Paris: International Energy Agency, 65.
- Phillips, P. C., & Sul, D. (2003). Dynamic panel estimation and homogeneity testing under cross section dependence. *The Econometrics Journal*, 6(1), 217-259.
- Popp, D., Hascic, I., & Medhi, N. (2011). Technology and the diffusion of renewable energy. *Energy Economics*, 33(4), 648-662.
- Przychodzen, W., & Przychodzen, J. (2020). Determinants of renewable energy production in transition economies: A panel data approach. *Energy*, 191, 116583.
- Qamruzzaman, M., & Jianguo, W. (2020). The asymmetric relationship between financial development, trade openness, foreign capital flows, and renewable energy consumption: Fresh evidence from panel NARDL investigation. *Renewable Energy*, 159, 827-842.
- Qi, M., Dai, X., Zhang, B., Li, J., & Liu, B. (2023). The Evolution and Future Prospects of China's Wave Energy Policy from the Perspective of Renewable Energy: Facing Problems, Governance Optimization and Effectiveness Logic. *Sustainability*, 15(4), 3274.
- Qing, L., Dagestani, A. A., Shinwari, R., & Chun, D. (2023). Novel research methods to evaluate renewable energy and energy-related greenhouse gases: evidence from BRICS economies. *Economic research-Ekonomska istraživanja*, 36(1), 960-976.
- Quaranta, E., & Davies, P. (2022). Emerging and innovative materials for hydropower engineering applications: Turbines, bearings, sealing, dams and waterways, and ocean power. *Engineering*, 8, 148-158.

- Rabbat, C., Awad, S., Villot, A., Rollet, D., & Andrès, Y. (2022). Sustainability of biomass-based insulation materials in buildings: Current status in France, end-of-life projections and energy recovery potentials. *Renewable and Sustainable Energy Reviews*, 156, 111962.
- Radmehr, R., Henneberry, S. R., & Shayanmehr, S. (2021). Renewable energy consumption, CO2 emissions, and economic growth nexus: a simultaneity spatial modeling analysis of EU countries. *Structural Change and Economic Dynamics*, 57, 13-27.
- Radulescu, M., Balsalobre-Lorente, D., Joof, F., Samour, A., & Türsoy, T. (2022). Exploring the impacts of banking development, and renewable energy on ecological footprint in OECD: new evidence from method of moments quantile regression. *Energies*, 15(24), 9290.
- Rafiq, S., Bloch, H., & Salim, R. (2014). Determinants of renewable energy adoption in China and India: a comparative analysis. *Applied Economics*, 46(22), 2700-2710.
- Rahman, M. M., Khan, I., Field, D. L., Techato, K., & Alameh, K. (2022). Powering agriculture: Present status, future potential, and challenges of renewable energy applications. *Renewable Energy*, 188, 731-749.
- Raihan, A., & Tuspekova, A. (2022). The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: new insights from Peru. *Energy Nexus*, 6, 100067.
- Rasoulinezhad, E., & Saboori, B. (2018). Panel estimation for renewable and non-renewable energy consumption, economic growth, CO2 emissions, the composite trade intensity, and financial openness of the commonwealth of independent states. *Environmental Science and Pollution Research*, 25(18), 17354-17370.
- Reboredo, J. C. (2015). Is there dependence and systemic risk between oil and renewable energy stock prices?. *Energy Economics*, 48, 32-45.
- Rehman, A., Alam, M. M., Ozturk, I., Alvarado, R., Murshed, M., Işık, C., & Ma, H. (2023). Globalization and renewable energy use: how are they contributing to upsurge the CO2 emissions? A global perspective. *Environmental Science and Pollution Research*, 30(4), 9699-9712.
- REN21, Renewables 2017 Global status report, Paris, 2017.
<https://www.ren21.net/gsr-4792017/> (Accessed 10 June 2022)
- REN21, Renewables. Global status report (GSR) Paris: REN21 secretariate (2020).
https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf (Accessed 10 July 2022)

- REN21, Renewables. Global status report (GSR) Paris: REN21 secretariate (2022). https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf (Accessed 10 January 2023)
- Romano, A. A., & Scandurra, G. (2011). The investments in renewable energy sources: do low carbon economies better invest in green technologies? *International Journal of Energy Economics and Policy*, 1(4), 107-115.
- Romano, A. A., & Scandurra, G. (2016). “Nuclear” and “nonnuclear” countries: Divergences on investment decisions in renewable energy sources. *Energy Sources, Part B: Economics, Planning, and Policy*, 11(6), 518-525.
- Romano, A. A., & Scandurra, G. (2016). Divergences in the determinants of investments in renewable energy sources: hydroelectric vs. other renewable sources. *Journal of Applied Statistics*, 43(13), 2363-2376.
- Romano, A. A., & Scandurra, G. (2016). Investments in renewable energy sources in countries grouped by income level. *Energy Sources, Part B: Economics, Planning, and Policy*, 11(10), 929-935.
- Romano, A. A., Scandurra, G., Carfora, A., & Fodor, M. (2017). Renewable investments: The impact of green policies in developing and developed countries. *Renewable and Sustainable Energy Reviews*, 68, 738-747.
- Romano, A., & Scandurra, G. (2014). Investments in renewable energy sources in OPEC members: a dynamic panel approach. *Advances in Methodology and Statistics*, 11(2), 93-106.
- Rout, S. K., Gupta, M., & Sahoo, M. (2022). The role of technological innovation and diffusion, energy consumption and financial development in affecting ecological footprint in BRICS: an empirical analysis. *Environmental Science and Pollution Research*, 1-18.
- Saboori, B., Gholipour, H. F., Rasoulinezhad, E., & Ranjbar, O. (2022). Renewable energy sources and unemployment rate: Evidence from the US states. *Energy Policy*, 168, 113155.
- Sachan, A., Sahu, U. K., Pradhan, A. K., & Thomas, R. (2023). Examining the drivers of renewable energy consumption: Evidence from BRICS nations. *Renewable Energy*, 202, 1402-1411.
- SACREEE, REN21 (2018). SADC Renewable Energy and Energy Efficiency Status Report. Windhoek: 2018.
- Sadiqa, B. A., Zaman, K., Rehman, F. U., Nassani, A. A., Haffar, M., & Abro, M. M. Q. (2022). Evaluating race-to-the-top/bottom hypothesis in high-income countries: controlling emissions cap trading, inbound FDI, renewable energy

- demand, and trade openness. *Environmental Science and Pollution Research*, 29(33), 50552-50565.
- Sadorsky, P. (2009). Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. *Energy Economics*, 31(3), 456-462.
- Sadorsky, P. (2012). Energy consumption, output and trade in South America. *Energy Economics*, 34(2), 476-488.
- Sadorsky, P.(2009b). Renewable energy consumption and income in emerging economies. *Energy policy*, 37(10), 4021-4028.
- Sager, L. (2019). Income inequality and carbon consumption: Evidence from Environmental Engel curves. *Energy Economics*, 84, 104507.
- Saibu, O. M., & Omoju, O. E. (2016). Macroeconomic determinants of renewable electricity technology adoption in Nigeria. *Economic and Environmental Studies (E&ES)*, 16(1), 65-83.
- Saint Akadiri, S., Bekun, F. V., & Sarkodie, S. A. (2019). Contemporaneous interaction between energy consumption, economic growth and environmental sustainability in South Africa: what drives what? *Science of the total environment*, 686, 468-475.
- Saleem, H., Khan, M. B., Shabbir, M. S., Khan, G. Y., & Usman, M. (2022). Nexus between non-renewable energy production, CO2 emissions, and healthcare spending in OECD economies. *Environmental Science and Pollution Research*, 29(31), 47286-47297.
- Salim, R. A., & Rafiq, S. (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy? *Energy Economics*, 34(4), 1051-1057.
- Salvarli, M. S., & Salvarli, H. (2020). For sustainable development: Future trends in renewable energy and enabling technologies. In *Renewable Energy-Resources, Challenges and Applications*. IntechOpen.
- Samour, A., & Pata, U. K. (2022). The impact of the US interest rate and oil prices on renewable energy in Turkey: a bootstrap ARDL approach. *Environmental Science and Pollution Research*, 1-10.
- Samour, A., Baskaya, M. M., & Tursoy, T. (2022). The impact of financial development and FDI on renewable energy in the UAE: a path towards sustainable development. *Sustainability*, 14(3), 1208.
- 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*.

- Sandberg, M., Klockars, K., & Wilén, K. (2019). Green growth or degrowth? Assessing the normative justifications for environmental sustainability and economic growth through critical social theory. *Journal of Cleaner Production*, 206, 133-141.
- Sarafidis, V., & Wansbeek, T. (2012). Cross-sectional dependence in panel data analysis. *Econometric Reviews*, 31(5), 483-531.
- Sarkar, B., Mridha, B., Pareek, S., Sarkar, M., & Thangavelu, L. (2021). A flexible biofuel and bioenergy production system with transportation disruption under a sustainable supply chain network. *Journal of Cleaner Production*, 317, 128079.
- Sarwat, S., Godil, D. I., Ali, L., Ahmad, B., Dinca, G., & Khan, S. A. R. (2022). The role of natural resources, renewable energy, and globalization in testing EKC Theory in BRICS countries: Method of Moments Quantile. *Environmental Science and Pollution Research*, 1-13.
- Sayed, E. T., Abdelkareem, M. A., Bahaa, A., Eisa, T., Alawadhi, H., Al-Asheh, S., ... & Olabi, A. G. (2021). Synthesis and performance evaluation of various metal chalcogenides as active anodes for direct urea fuel cells. *Renewable and Sustainable Energy Reviews*, 150, 111470.
- Sbia, R., Shahbaz, M., & Hamdi, H. (2014). A contribution of foreign direct investment, clean energy, trade openness, carbon emissions and economic growth to energy demand in UAE. *Economic modelling*, 36, 191-197.
- Schleussner, C. F., Ganti, G., Rogelj, J., & Gidden, M. J. (2022). An emission pathway classification reflecting the Paris Agreement climate objectives. *Communications Earth & Environment*, 3(1), 135.
- Sebri, M., & Ben-Salha, O. (2014). On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries. *Renewable and Sustainable Energy Reviews*, 39, 14-23.
- Semančíková, J. (2016). Trade, trade openness and macroeconomic performance. *Procedia-Social and Behavioral Sciences*, 220, 407-416.
- Senyapar, H. N. D. (2023). Renewable Energy Literature in Turkey: Mapping Analysis of the Field and Future Study Suggestions on Overlooked Issues. *International Journal of Renewable Energy Research (IJRER)*, 13(1), 221-235.
- Sequeira, T. N., & Santos, M. S. (2018). Renewable energy and politics: A systematic review and new evidence. *Journal of Cleaner Production*, 192, 553-568.
- Shafiei, S., & Salim, R. A. (2014). Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: a comparative analysis. *Energy policy*, 66, 547-556.

- Shah, I. H., Hiles, C., & Morley, B. (2018). How do oil prices, macroeconomic factors and policies affect the market for renewable energy?. *Applied energy*, 215, 87-97.
- Shah, M. I., AbdulKareem, H. K., & Abbas, S. (2022). Examining the agriculture induced Environmental Kuznets Curve hypothesis in BRICS economies: The role of renewable energy as a moderator. *Renewable Energy*, 198, 343-351.
- Shahbaz, M., Nasreen, S., Ling, C. H., & Sbia, R. (2014). Causality between trade openness and energy consumption: What causes what in high, middle and low income countries. *Energy Policy*, 70, 126-143.
- Shahbaz, M., Rizvi, S. K. A., Dong, K., & Vo, X. V. (2022). Fiscal decentralization as new determinant of renewable energy demand in China: The role of income inequality and urbanization. *Renewable Energy*, 187, 68-80.
- Shahzad, U. (2020). Environmental taxes, energy consumption, and environmental quality: Theoretical survey with policy implications. *Environmental Science and Pollution Research*, 27(20), 24848-24862.
- 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, 121777.
- Sharif, A., Baris-Tuzemen, O., Uzuner, G., Ozturk, I., & Sinha, A. (2020). Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: Evidence from Quantile ARDL approach. *Sustainable Cities and Society*, 57, 102138.
- Sharif, A., Jammazi, R., Raza, S. A., & Shahzad, S. J. H. (2017). Electricity and growth nexus dynamics in Singapore: Fresh insights based on wavelet approach. *Energy Policy*, 110, 686-692.
- Sharif, A., Raza, S. A., Ozturk, I., & Afshan, S. (2019). The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. *Renewable energy*, 133, 685-691.
- Sharma, R., & Rajpurohit, S. S. (2022). Nexus between income inequality and consumption of renewable energy in India: a nonlinear examination. *Economic Change and Restructuring*, 1-22.
- Shayanmehr, S., Radmehr, R., Ali, E. B., Ofori, E. K., Adebayo, T. S., & Gyamfi, B. A. (2023). How do environmental tax and renewable energy contribute to ecological sustainability? New evidence from top renewable energy countries. *International Journal of Sustainable Development & World Ecology*, 1-21.
- Shayanmehr, S., Rastegari Henneberry, S., Sabouhi Sabouni, M., & Shahnoushi Foroushani, N. (2020). Drought, climate change, and dryland wheat yield

response: An econometric approach. *International Journal of Environmental Research and Public Health*, 17(14), 5264.

- Shirwani, R., Gulzar, S., Asim, M., Umair, M., & Al-Rashid, M. A. (2020). Control of vehicular emission using innovative energy solutions comprising of hydrogen for transportation sector in Pakistan: A case study of Lahore City. *International Journal of Hydrogen Energy*, 45(32), 16287-16297.
- Sinha, A., & Shahbaz, M. (2018). Estimation of environmental Kuznets curve for CO2 emission: role of renewable energy generation in India. *Renewable energy*, 119, 703-711.
- Sinha, A., Shahbaz, M., & Balsalobre, D. (2017). Exploring the relationship between energy usage segregation and environmental degradation in N-11 countries. *Journal of cleaner production*, 168, 1217-1229.
- Sohag, K., Begum, R. A., Abdullah, S. M. S., & Jaafar, M. (2015). Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. *Energy*, 90, 1497-1507.
- Solt, F. (2019). Measuring income inequality across countries and over time: The standardized world income inequality database. SWIID Version 8.1, May 2019.
- Song, D., Liu, Y., Qin, T., Gu, H., Cao, Y., & Shi, H. (2022). Overview of the policy instruments for renewable energy development in China. *Energies*, 15(18), 6513.
- Stec, M., & Grzebyk, M. (2022). Statistical Analysis of the Level of Development of Renewable Energy Sources in the Countries of the European Union. *Energies*, 15(21), 8278.
- Stevens, K. A., Tang, T., & Hittinger, E. (2023). Innovation in complementary energy technologies from renewable energy policies. *Renewable Energy*, 209, 431-441.
- Strunz, S., Gawel, E., & Lehmann, P. (2016). The political economy of renewable energy policies in Germany and the EU. *Utilities Policy*, 42, 33-41.
- 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, 121798.
- Su, M., Yang, Z., Abbas, S., Bilan, Y., & Majewska, A. (2023). Toward enhancing environmental quality in OECD countries: Role of municipal waste, renewable energy, environmental innovation, and environmental policy. *Renewable Energy*, 211, 975-984.
- Suki, N. M., Sharif, A., Afshan, S., & Suki, N. M. (2020). Revisiting the Environmental Kuznets Curve in Malaysia: The role of globalization in sustainable environment. *Journal of Cleaner Production*, 264, 121669.

- Suki, N. M., Suki, N. M., Sharif, A., Afshan, S., & Jermsittiparsert, K. (2022). The role of technology innovation and renewable energy in reducing environmental degradation in Malaysia: A step towards sustainable environment. *Renewable Energy*, *182*, 245-253.
- Swamy, P. A. (1970). Efficient inference in a random coefficient regression model. *Econometrica: Journal of the Econometric Society*, 311-323.
- Tan, Y., & Uprasen, U. (2021). Carbon neutrality potential of the ASEAN-5 countries: Implications from asymmetric effects of income inequality on renewable energy consumption. *Journal of Environmental Management*, *299*, 113635.
- Tan, Y., & Uprasen, U. (2022). The effect of foreign direct investment on renewable energy consumption subject to the moderating effect of environmental regulation: Evidence from the BRICS countries. *Renewable Energy*, *201*, 135-149.
- Tanaka, K., Wilson, C., & Managi, S. (2022). Impact of feed-in tariffs on electricity consumption. *Environmental Economics and Policy Studies*, 1-24.
- Tang, C. F., & Tan, E. C. (2013). Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. *Applied Energy*, *104*, 297-305.
- Tawiah, V., Zakari, A., & Adedoyin, F. F. (2021). Determinants of green growth in developed and developing countries. *Environmental Science and Pollution Research*, *28*, 39227-39242.
- Teal, F., & Eberhardt, M. (2010). Productivity analysis in global manufacturing production.
- Thrän, D., Schaubach, K., Majer, S., & Horschig, T. (2020). Governance of sustainability in the German biogas sector—Adaptive management of the Renewable Energy Act between agriculture and the energy sector. *Energy, Sustainability and Society*, *10*, 1-18.
- Tiba, S., Omri, A., & Frikha, M. (2016). The four-way linkages between renewable energy, environmental quality, trade and economic growth: a comparative analysis between high and middle-income countries. *Energy Systems*, *7*(1), 103-144.
- Tiwari, A. K. (2011). A structural VAR analysis of renewable energy consumption, real GDP and CO2 emissions: evidence from India. *Economics Bulletin*, *31*(2), 1793-1806.
- Topcu, M., & Tugcu, C. T. (2020). The impact of renewable energy consumption on income inequality: Evidence from developed countries. *Renewable Energy*, *151*, 1134-1140.

- Tutak, M., & Brodny, J. (2022). Renewable energy consumption in economic sectors in the EU-27. The impact on economics, environment and conventional energy sources. A 20-year perspective. *Journal of Cleaner Production*, 345, 131076.
- Udeagha, M. C., & Muchapondwa, E. (2023). Green finance, fintech, and environmental sustainability: Fresh policy insights from the BRICS nations. *International Journal of Sustainable Development & World Ecology*, 1-17.
- Ullah, A., Zhang, Q., Raza, S. A., & Ali, S. (2021). Renewable energy: Is it a global challenge or opportunity? Focusing on different income level countries through Panel Smooth Transition Regression Model. *Renewable Energy*, 177, 689-699.
- UNFCCC (2015) Paris Agreement: Article 8 – the Paris outcome on loss and damage. https://unfccc.int/files/adaptation/groupscommittees/lossanddamageexecutivecommittee/application/pdf/ref_8_decision_xcp.21.pdf. Accessed 16th December 2022.
- UNFCCC (2022) Funding arrangements for responding to loss and damage associated with the adverse effects of climate change, including a focus on addressing loss and damage. Decision-/CP.27-/CMA.4. <https://unfccc.int/documents/624440> . (Accessed 19 December 2022)
- United Nations, World population prospects: the 2021 version.
- Usman, M., & Makhdum, M. S. A. (2021). What abates the ecological footprint in the BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area, and financial development. *Renewable Energy*, 179, 12-28.
- Usman, M., & Makhdum, M. S. A. (2021). What abates the ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area, and financial development. *Renewable Energy*, 179, 12-28.
- Usman, M., & Radulescu, M. (2022). Examining the role of nuclear and renewable energy in reducing carbon footprint: does the role of technological innovation really create some difference? *Science of The Total Environment*, 841, 156662.
- Uzar, U. (2020). Is income inequality a driver for renewable energy consumption? *Journal of Cleaner Production*, 255, 120287.
- Uzar, U., & Eyuboglu, K. (2019). The nexus between income inequality and CO2 emissions in Turkey. *Journal of Cleaner Production*, 227, 149-157.
- Vishnuram, P., & Nastasi, B. (2023). Wireless Chargers for Electric Vehicle: A Systematic Review on Converter Topologies, Environmental Assessment, and Review Policy. *Energies*, 16(4), 1731.

- Voumik, L. C., & Sultana, T. (2022). Impact of urbanization, industrialization, electrification and renewable energy on the environment in BRICS: Fresh evidence from novel CS-ARDL model. *Heliyon*, 8(11).
- Wahab, S., Imran, M., Safi, A., Wahab, Z., & Kirikkaleli, D. (2022). Role of financial stability, technological innovation, and renewable energy in achieving sustainable development goals in BRICS countries. *Environmental Science and Pollution Research*, 29(32), 48827-48838.
- Wahab, S., Imran, M., Safi, A., Wahab, Z., & Kirikkaleli, D. (2022). Role of financial stability, technological innovation, and renewable energy in achieving sustainable development goals in BRICS countries. *Environmental Science and Pollution Research*, 29(32), 48827-48838.
- Wan, J., Baylis, K., & Mulder, P. (2015). Trade-facilitated technology spillovers in energy productivity convergence processes across EU countries. *Energy Economics*, 48, 253-264.
- Wang, G., Sadiq, M., Bashir, T., Jain, V., Ali, S. A., & Shabbir, M. S. (2022). The dynamic association between different strategies of renewable energy sources and sustainable economic growth under SDGs. *Energy Strategy Reviews*, 42, 100886.
- Wang, J., & Dong, K. (2019). What drives environmental degradation? Evidence from 14 Sub-Saharan African countries. *Science of the Total Environment*, 656, 165-173.
- Wang, J., Dong, X., & Dong, K. (2021). How renewable energy reduces CO2 emissions? Decoupling and decomposition analysis for 25 countries along the Belt and Road. *Applied Economics*, 53(40), 4597-4613.
- Wang, Q., Dong, Z., Li, R., & Wang, L. (2022). Renewable energy and economic growth: new insight from country risks. *Energy*, 238, 122018.
- Wang, Q., Wang, L., & Li, R. (2022). Renewable energy and economic growth revisited: The dual roles of resource dependence and anticorruption regulation. *Journal of Cleaner Production*, 337, 130514.
- Wang, S., Jiang, J., Zhao, Q., & Wang, K. (2022). Effects of substrate type on variation of sludge organic compounds, bioelectric production and microbial community structure in bioelectrochemically-assisted sludge treatment wetland. *Journal of Environmental Management*, 307, 114548.
- Wang, W., Xiao, W., & Bai, C. (2022). Can renewable energy technology innovation alleviate energy poverty? Perspective from the marketization level. *Technology in Society*, 68, 101933.

- Wang, Z., Chandavuth, Y., Zhang, B., Ahmed, Z., & Ahmad, M. (2023). Environmental degradation, renewable energy, and economic growth nexus: Assessing the role of financial and political risks?. *Journal of Environmental Management*, 325, 116678.
- WDI, World Development Indicators, World Bank, (2020). <https://databank.worldbank.org/source/world-development-indicators> (Accessed 10 December 2021)
- WDI, World Development Indicators, World Bank, (2021). <https://databank.worldbank.org/source/world-development-indicator> (Accessed 10 July 2022)
- Wei, J., Wen, J., Wang, X. Y., Ma, J., & Chang, C. P. (2023). Green innovation, natural extreme events, and energy transition: Evidence from Asia-Pacific economies. *Energy Economics*, 121, 106638.
- Wei, S., Jiandong, W., & Saleem, H. (2023). The impact of renewable energy transition, green growth, green trade and green innovation on environmental quality: Evidence from top 10 green future countries. *Frontiers in Environmental Science*, 10, 2448.
- Wesseh, P. K., Benjamin, N. I., & Lin, B. (2022). The coordination of pumped hydro storage, electric vehicles, and climate policy in imperfect electricity markets: Insights from China. *Renewable and Sustainable Energy Reviews*, 160, 112275.
- Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and statistics*, 69(6), 709-748.
- Westerlund, J. (2008). Panel cointegration tests of the Fisher effect. *Journal of Applied Econometrics*, 23(2), 193-233.
- World Bank (2017). Annual Report 2017 End Extreme Poverty • Boost Shared Prosperity
- Wu, H. (2023). Evaluating the role of renewable energy investment resources and green finance on the economic performance: Evidence from OECD economies. *Resources Policy*, 80, 103149.
- Wu, L., & Broadstock, D. C. (2015). Does economic, financial and institutional development matter for renewable energy consumption? Evidence from emerging economies. *International Journal of Economic Policy in Emerging Economies*, 8(1), 20-39.
- Xia, T., Li, Y., Wu, X., Fan, Z., Shi, W., Liu, X., & Li, T. (2022). Performance of a new active solar heat storage–release system for Chinese assembled solar greenhouses used in high latitudes and cold regions. *Energy Reports*, 8, 784-797.

- Xia, W., Doğan, B., Shahzad, U., Adedoyin, F. F., Popoola, A., & Bashir, M. A. (2022). An empirical investigation of tourism-led growth hypothesis in the European countries: evidence from augmented mean group estimator. *Portuguese Economic Journal*, 1-28.
- Xie, F., Liu, Y., Guan, F., & Wang, N. (2020). How to coordinate the relationship between renewable energy consumption and green economic development: from the perspective of technological advancement. *Environmental Sciences Europe*, 32(1), 1-15.
- Xu, X., Wei, Z., Ji, Q., Wang, C., & Gao, G. (2019). Global renewable energy development: Influencing factors, trend predictions and countermeasures. *Resources Policy*, 63, 101470.
- Yahya, F., & Lee, C. C. (2023). The asymmetric effect of agriculturalization toward climate neutrality targets. *Journal of Environmental Management*, 328, 116995.
- Yang, C., & Song, X. (2023). Assessing the determinants of renewable energy and energy efficiency on technological innovation: Role of human capital development and investment. *Environmental Science and Pollution Research*, 1-21.
- Yang, Z., Zhang, M., Liu, L., & Zhou, D. (2022). Can renewable energy investment reduce carbon dioxide emissions? Evidence from scale and structure. *Energy Economics*, 112, 106181.
- Yao, X., Fan, Y., Zhao, F., & Ma, S. C. (2022). Economic and climate benefits of vehicle-to-grid for low-carbon transitions of power systems: A case study of China's 2030 renewable energy target. *Journal of Cleaner Production*, 330, 129833.
- Yao, Y., Ivanovski, K., Inekwe, J., & Smyth, R. (2019). Human capital and energy consumption: Evidence from OECD countries. *Energy Economics*, 84, 104534.
- Yasmeen, H., Tan, Q., Zameer, H., Vo, X. V., & Shahbaz, M. (2021). Discovering the relationship between natural resources, energy consumption, gross capital formation with economic growth: can lower financial openness change the curse into blessing. *Resources Policy*, 71, 102013.
- Yasmeen, R., Tao, R., Jie, W., Padda, I. U. H., & Shah, W. U. H. (2022). The repercussions of business cycles on renewable & non-renewable energy consumption structure: Evidence from OECD countries. *Renewable Energy*, 190, 572-583.
- Yazdi, S. K., & Mastorakis, N. I. K. O. S. (2014). Renewable, CO2 emissions, trade openness, and economic growth in Iran. *Latest Trend in Energy, Environment and Development*, c, 25, 360-370.

- Yi, S., Raghutla, C., Chittedi, K. R., & Fareed, Z. (2023). How economic policy uncertainty and financial development contribute to renewable energy consumption? The importance of economic globalization. *Renewable Energy*, 202, 1357-1367.
- Yu, S., Hu, X., Li, L., & Chen, H. (2020). Does the development of renewable energy promote carbon reduction? Evidence from Chinese provinces. *Journal of environmental management*, 268, 110634.
- Yu, Z., Ridwan, I. L., Tanveer, M., & Khan, S. A. R. (2023). Investigating the nexuses between transportation Infrastructure, renewable energy Sources, and economic Growth: Striving towards sustainable development. *Ain Shams Engineering Journal*, 14(2), 101843.
- Yuan, M., Thellufsen, J. Z., Lund, H., & Liang, Y. (2021). The electrification of transportation in energy transition. *Energy*, 236, 121564.
- Zafar, M. W., Shahbaz, M., Hou, F., & Sinha, A. (2019). From nonrenewable to renewable energy and its impact on economic growth: the role of research & development expenditures in Asia-Pacific Economic Cooperation countries. *Journal of cleaner production*, 212, 1166-1178.
- Zahoor, A., Mehr, F., Mao, G., Yu, Y., & Sápi, A. (2023). The carbon neutrality feasibility of worldwide and in China's transportation sector by E-car and renewable energy sources before 2060. *Journal of Energy Storage*, 61, 106696.
- Zazoum, B. (2022). Solar photovoltaic power prediction using different machine learning methods. *Energy Reports*, 8, 19-25.
- Zeb, R., Salar, L., Awan, U., Zaman, K., & Shahbaz, M. (2014). Causal links between renewable energy, environmental degradation and economic growth in selected SAARC countries: progress towards green economy. *Renewable energy*, 71, 123-132.
- Zeraibi, A., Jahanger, A., Adebayo, T. S., Ramzan, M., & Yu, Y. (2023). Greenfield investments, economic complexity, and financial inclusion-environmental quality nexus in BRICS Countries: Does renewable energy transition matter?. *Gondwana Research*, 117, 139-154.
- Zeren, F., & Akkuş, H. T. (2020). The relationship between renewable energy consumption and trade openness: new evidence from emerging economies. *Renewable Energy*, 147, 322-329.
- Zhang, J., Lu, J., Pan, J., Tan, Y., Cheng, X., & Li, Y. (2022). Implications of the development and evolution of global wind power industry for China—An empirical analysis is based on public policy. *Energy Reports*, 8, 205-219.

- Zhang, L., Huang, F., Lu, L., Ni, X., & Iqbal, S. (2022). Energy financing for energy retrofit in COVID-19: recommendations for green bond financing. *Environmental Science and Pollution Research*, 29(16), 23105-23116.
- Zhang, M., Zhang, S., Lee, C. C., & Zhou, D. (2021). Effects of trade openness on renewable energy consumption in OECD countries: new insights from panel smooth transition regression modelling. *Energy Economics*, 104, 105649.
- Zhang, Q., & Wang, Q. (2023). Digitalization, Electricity Consumption and Carbon Emissions—Evidence from Manufacturing Industries in China. *International Journal of Environmental Research and Public Health*, 20(5), 3938.
- Zhang, R., Sharma, R., Tan, Z., & Kautish, P. (2022). Do export diversification and stock market development drive carbon intensity? The role of renewable energy solutions in top carbon emitter countries. *Renewable Energy*, 185, 1318-1328.
- Zhang, X., Shi, X., Khan, Y., Hassan, T., & Marie, M. (2023). Carbon Neutrality Challenge: Analyse the Role of Energy Productivity, Renewable Energy, and Collaboration in Climate Mitigation Technology in OECD Economies. *Sustainability*, 15(4), 3447.
- Zhao, J., Patwary, A. K., Qayyum, A., Alharthi, M., Bashir, F., Mohsin, M., ... & Abbas, Q. (2022). The determinants of renewable energy sources for the fueling of green and sustainable economy. *Energy*, 238, 122029.
- Zhao, Y., Tang, K. K., & Wang, L. L. (2013). Do renewable electricity policies promote renewable electricity generation? Evidence from panel data. *Energy policy*, 62, 887-897.
- Zhao, Z., Gozgor, G., Lau, M. C. K., Mahalik, M. K., Patel, G., & Khalfaoui, R. (2023). The impact of geopolitical risks on renewable energy demand in OECD countries. *Energy Economics*, 122, 106700.
- Zheng, J., Du, J., Wang, B., Klemeš, J. J., Liao, Q., & Liang, Y. (2023). A hybrid framework for forecasting power generation of multiple renewable energy sources. *Renewable and Sustainable Energy Reviews*, 172, 113046.
- Zheng, S., Zhou, F., & Wen, H. (2022). The relationship between trade liberalization and environmental pollution across enterprises with different levels of viability in China. *Emerging Markets Finance and Trade*, 58(8), 2125-2138.
- Zhou, A., & Li, J. (2022). How do trade liberalization and human capital affect renewable energy consumption? Evidence from the panel threshold model. *Renewable Energy*, 184, 332-342.
- Zhou, C., Ye, S., Ni, L., & Yao, Y. (2022). A review of heat pump research in China using bibliometric methods. *Journal of Renewable and Sustainable Energy*, 14(1), 012701.

Zoaka, J. D., Ekwueme, D. C., Güngör, H., & Alola, A. A. (2022). Will financial development and clean energy utilization rejuvenate the environment in BRICS economies?. *Business Strategy and the Environment*, 31(5), 2156-2170.



APPENDICES

APPENDIX A

Table A.1. List of 23 OECD Countries

Netherlands	Germany
Norway	Denmark
France	Spain
United States	United Kingdom
Belgium	Switzerland
Finland	Sweden
Greece	Chile
Japan	Colombia
Portugal	Hungary
Austria	Mexico
Canada	Turkey
New Zealand	

APPENDIX B

Table B.1. Variance Inflation Factors (VIF)

Variable	VIF	1/VIF
lnCO2	2.38	0.4207
LnGDP	3.58	0.2794
LnTO	1.55	0.6468
LnROP	1.16	0.8594
LnGN	3.59	0.2788
Mean VIF	2.45	

APPENDIX C

Table C.1. Studies on the Factors Influencing Renewable Energy Consumption

Author (s)	Time Period	Countries	Dependent Variable	Independent Variables	Methodology
Ackah and Kizys (2015)	1985-2010	12 African Countries	Level of Renewable electricity generation	Economic growth, capital stock, human capital, labor force, energy depletion, energy prices, CO2 emissions	One-way FE, One-way RE, GMM
Aguirre and Ibikunle (2014)	1990-2010	38 countries	Share of RE in total energy supply	CO2 emissions per capita, energy consumption, energy imports, population, economic growth, deregulations, commitment to renewables, Kyoto Protocol, electricity generation from nuclear and non-renewables, energy prices, RE potential, public policies	FEVD, PCSE, GLS
Akar (2016)	1998-2011	12 Balkan countries	Proportion of RE in overall energy demand	CO2 emissions per capita, economic growth, trade openness, natural gas, and oil rents	GMM
Anton and Nucu (2020)	1990-2015	28 EU countries	Proportion of RE in overall energy demand	Domestic credit to financial sector, private debt securities to GDP, stock market turnover ratio, GDP per capita, CPI, FDI inflows	FE
Apergis and Eleftheriou (2015)	1995-2011	16 Countries	Level of RE consumption	Effective legislative parties, green party, government size, trade freedom, regulatory restraints, property rights, GDP per capita, oil prices, education	FMOLS, DOLS, PMG, MG
Apergis and Payne (2014)	1980-2010	7 Central American countries	Level of Renewable electricity generation	GDP growth, carbon emissions, coal prices, oil prices	Cointegration techniques, Granger causality

Table C.1. (cont.)

Apergis and Payne (2015)	1980-2010	11 countries	Level of Renewable electricity generation per capita	Carbon emissions, oil prices, economic growth	Pooled regression, FE
Baldwin et al. (2017)	1990-2010	149 countries	Level of non-hydro Renewable electricity generation	Renewable portfolio standard, RE subsidies, electricity consumption, fossil fuel imports, FIT, fossil fuel rents, political freedom, relative political extraction, aid to RE, CDM, population, GDP per capita, trade openness, political rights, private credit, bank deposits, RE regulatory framework	FE
Bengochea and Faet (2012)	1990-2004	15 EU countries	Level of RE supply	Fossil fuel price index, CO2 emissions	OLS, FE, RE, PCSE, FGLS
Best (2017)	1998-2013	137 countries	Proportion of RE in energy supply	Economic growth, forest area, non-renewable reserves, land area, average temperature, energy usage, financial capital	OLS, FE
Biresselioglu and Karaibrahimoglu (2012)	1999-2009	30 EU countries	Share of RE in total energy consumption	Energy production, government orientation, energy intensity, GDP per capita, population, energy dependency, nuclear energy supply, EU membership, target share, target set	ANOVA

Table C.1. (cont.)

Brunnschweiler (2010)	1980-2006	119 countries	Proportion of RE in overall electricity generation	Domestic credit to private sector, power sector reforms, Kyoto Protocol, GDP, FDI, fossil fuel energy prices, fossil fuel energy production, transition shock, financial crisis, economic freedom, financial development	GLS, GMM
Cadoret and Padovano (2016)	2004-2011	26 EU countries	Proportion of RE in overall energy demand	Influence of lobbies, government ideology, corruption, GDP, energy prices, energy dependency, CO2 emissions, environmental taxes	Two-step estimation techniques: LSDV, OLS
Carley et al. (2017)	1990-2010	164 countries	Proportion of RE in overall electricity generation	Fossil fuel revenues, aid to renewables, CDM funding, FDI, GDP per capita, population growth, electricity consumption, fossil fuel expenditures, FIT, renewable portfolio standard, RE regulatory framework, RE subsidies, political freedom, political ideology	Differences-in-Differences estimator
Gan and Smith (2011)	1994-2003	26 countries	Level of RE production	GDP per capita, R&D expenditure, CPI of energy, land area, RE research policies, market-based RE strategies, RE market deployment strategies	One-way FE
Geng and Ji (2016)	1980-2010	6 countries	Level of non-hydro RE in energy demand	CO2 emissions, economic growth, crude oil prices, renewable energy technology innovations	FMOLS, Granger causality

Table C.1. (cont.)

Jebli et al. (2020)	1990-2015	102 countries	Level of RE consumption	GDP, industrial value added, service value-added, CO2 emissions per capita	GMM, Granger causality
Killinc-Ata (2016)	1990-2008	27 EU countries	Proportion of non-hydro RE in overall electricity production	GDP growth, tenders, FIT, quotas, tax incentives, thermal energy, nuclear energy, energy imports, electricity imports, coal prices, gas prices, electricity consumption, CO2 emissions per capita	FE
Kim and Park (2016)	2000-2013	30 countries	Installed capacity of non-hydro electricity	Financial development, GDP per capita, FIT, renewable sectors' share of electricity generation	OLS, Tobit
Lin and Omoju (2017)	1980-2011	46 countries	Proportion of non-hydro RE in overall electricity supply	FDI, GDP per capita, trade openness, financial development, oil prices, gross fixed capital formation, oil rents, Kyoto Protocol ratification	FMOLS, DOLS, Dynamic FE
Lu (2017)	1990-2012	24 Asian countries	Level of RE consumption	Economic growth, carbon emissions	CCEMG, Granger causality
Marques and Fuinhas (2011a)	1990-2006	21 EU countries	Proportion of RE in overall energy production	CO2 emissions per capita, energy dependency, fossil fuel electricity generation, nuclear electricity generation, coal prices, oil prices, gas prices, energy efficiency policies and measures	OLS, Quantile Regression
Marques and Fuinhas (2011b)	1990-2006	24 EU countries	Proportion of RE in overall energy production	Carbon emissions, commitment to RE, energy usage, fossil fuel electricity generation, nuclear electricity generation, real GDP, fossil fuel energy prices, energy dependency	Difference and system GMM, LSDVC, FE

Table C.1. (cont.)

Marques and Fuinhas (2012)	1990-2007	23 countries	Proportion of RE in overall energy production	Carbon emissions, energy usage, energy dependency, fossil fuel electricity generation, nuclear electricity generation, RE policies, subsidies, policy processes, education and outreach, financial development, public investment, tradeable permits, voluntary agreements	RE, FE, PCSE
Marques et al. (2010)	1990-2006	24 countries	Proportion of RE in overall energy production	Carbon emissions, energy usage, energy dependency, share of fossil fuels and nuclear in total electricity generation, surface area, fossil fuel prices, EU membership, real GDP, commitment to RE	OLS, RE, FE, FEVD
Marques et al. (2011)	1990-2006	24 countries	Proportion of RE in overall energy production	Carbon emissions, energy usage, energy security, share of non-renewables and nuclear energy in total electricity supply, geographic area, fossil fuel prices, EU membership, real GDP, EU directive	OLS, quantile regression
Murshed (2019)	2000-2017	71 countries	Level of RE consumption, RE intensity	Trade openness, access to electricity, CO2 emissions, oil prices, FDI inflows, net official development assistance, international remittances, real GDP, domestic rate of Inflation	Regression Analysis (IV-2SLS)

Table C.1. (cont.)

Narbel (2013)	2007-2009	107 countries	Proportion of non-hydro RE in total electricity production	GDP growth, electricity production from domestic fossil fuel sources, electricity generation from imported non-renewables, electricity generation from hydro and nuclear energy sources	Cross-section Analysis: OLS
Nicolini and Tavoni (2017)	2000-2010	5 countries	Installed capacity of incentivized RE	GDP growth, carbon emissions, share of fossil fuels in electricity generation, net value of electricity exports, government political orientation, incentives/Tariff	RE, FE, Pooled OLS
Nyiwul (2017)	1980-2011	27 countries	Level of RE consumption	Real GDP, population size, CO2 emissions, share of industrial sector, oil prices	DOLS, FMOLS, FE
Omri and Nguyen (2014)	1990-2011	64 countries	Level of non-hydro RE consumption	Carbon emissions, economic growth, real oil prices, trade openness	Dynamic GMM
Pfeiffer and Mulder (2013)	1980-2010	108 countries	Level of non-hydro RE production	Green energy policy, Share of hydro and fossil fuels in electricity generation, economic instruments, regulatory instruments, policy support, Kyoto protocol, GDP per capita, electricity consumption, trade openness, FDI, net official development assistance, deposit money bank assets, energy mix, polity2	OLS, Probit
Romano and Scandura (2011)	1980-2008	29 countries	Proportion of RE in overall electricity supply	GDP, CO2 emissions, energy intensity, nuclear energy production	GMM

Table C.1. (cont.)

Romano and Scandura (2014)	1980-2009	6 countries	Proportion of RE in overall electricity supply	Carbon emissions, GDP growth, energy consumption, oil supply, energy intensity	GMM
Romano and Scandura (2016a)	2000-2008	32 countries	Proportion of RE in overall electricity supply	CO2 emissions, RE policy, nuclear and thermal energy production, energy efficiency, Electricity demand, GDP growth, energy security	GMM
Romano and Scandura (2016b)	1980-2008	60 countries	Proportion of RE in overall electricity supply	Economic growth, carbon emissions, nuclear electricity net usage, energy security, policy mechanism adoption, energy intensity, electricity usage	GMM
Romano and Scandura (2016c)	1980-2008	32 countries	Proportion of RE in overall electricity supply	Carbon emissions, FIT, energy efficiency, economic growth, energy demand, energy security	GMM
Romano et al. (2017)	2004-2013	56 countries	Proportion of non-hydro RE in overall electricity supply	Proportion of non-renewables in electricity production, energy intensity, net energy imports, electricity demand, gas supply, oil supply, GDP, electricity prices, female population, FDI, regulatory policies, public financing, public investments	PCSE
Sadorsky (2009)	1980-2005	G-7 Countries	Level of RE usage	Economic growth, carbon emissions, oil prices	FMOLS, DOLS, Granger causality
Salim and Rafiq (2012)	1980-2006	6 countries	Level of RE usage	Economic growth, oil prices, carbon emissions	DOLS, FMOLS, Granger causality
Valdes Lucas et al. (2016)	1990-2013	21 EU countries	Proportion of RE in overall energy generation	Energy prices, GDP per capita, environmental sustainability, energy security, regulatory policies	FGLS, PCSE, RE

Table C.1. (cont.)

Wu and Broadstock (2015)	1990-2010	22 countries	Level of RE usage	GDP growth, financial development, institutional quality, CO2 emissions, population, trade openness, oil prices	GMM
Zeb et al. (2014)	1975-2010	5 countries	Level of Renewable electricity generation	Natural resource depletion, carbon emissions, GDP growth, poverty	FMOLS, Granger causality
Zhao et al. (2013)	1980-2010	122 countries	Proportion of RE in overall electricity supply	Investment incentives, tax incentives, RE policy, CO2 intensity, energy imports, financial development, FDI, human capital, population	Poisson pseudo-maximum likelihood, OLS

CURRICULUM VITAE

Personal Information:

Iftikhar Muhammad

E-mail (1):

E-mail (2):

Education:

2010 – 2014 BS in Economics and Finance, International Islamic University
Islamabad, Pakistan.

2016 – 2018 MA in Economics, Erciyes University, Turkey

Work Experience:

2017 – 2018 Research Assistant, The Scientific and Technological Research Council
of Turkey (TÜBİTAK), Turkey

Publications:

1. The dynamic impact of foreign portfolio investment on stock prices in Pakistan, 2019, *Transnational Corporations Review*, 11(2), 166-178.
2. Assessment of Turkish citizen's willingness to pay for green electricity, 2019, *The Electricity Journal*, 32(10), 106677.
3. Nexus between willingness to pay for renewable energy sources: Evidence from Turkey. *Environmental Science and Pollution Research*, 28(3), 2972-2986.
4. Does environmental sustainability affect the renewable energy consumption? Nexus among trade openness, CO2 emissions, income inequality, renewable energy, and economic growth in OECD countries, 2022, *Environmental Science and Pollution Research*, 29(60), 90147-90157.
5. Do drivers of renewable energy consumption matter for BRICS economies? Nexus among technological innovation, environmental degradation, economic growth, and income inequality, 2022. *Environmental Science and Pollution Research*, 1-11.