Federal University of Paraiba - UFPB
Center for Applied Social Sciences - CCSA
Graduate Program in Economics - PPGE

Essays in Environmental Economics

Bruno Felipe Lenin Souza Bezerra

João Pessoa - PB
2025

Bruno Felipe Lenin Souza Bezerra

Essays in Environmental Economics

Doctoral dissertation presented to the Graduate Program in Economics at the Federal University of Paraíba (UFPB) as part of the requirements for obtaining the title of Doctor of Economics.

Federal University of Paraiba - UFPB

Center for Applied Social Sciences - CCSA

Graduate Program in Economics - PPGE

Advisor: Dr. Jevuks Matheus de Araujo

João Pessoa - PB

2025

Catalogação na publicação
Seção de Catalogação e Classificação

B574e Bezerra, Bruno Felipe Lenin Souza.
Essays in environmental economics / Bruno Felipe Lenin Souza Bezerra. - João Pessoa, 2025.
90 f. : il.

Orientação: Jevuks Matheus de Araujo.
Tese (Doutorado) - UFPB/CCSA.

1. Desastre natural - Economia. 2. Energia renovável. 3. Transição energética. 4. Geração de energia - Incêndios. 5. Meio ambiente - Amazônia Legal. I. Araujo, Jevuks Matheus de. II. Título.

UFPB/BC CDU 338.14(043)

Elaborado por Walqueline da Silva Araújo - CRB-15/514

Universidade Federal da Paraíba
Centro de Ciências Sociais Aplicadas
Programa de Pós-Graduação em Economia

Campus Universitário I – Cidade Universitária – CEP 58.059-900 – João Pessoa – Paraíba
Tel: (83) 3216-7482 – https://sigaa.ufpb.br/sigaa/public/programa/portal.jsf?id=1875 – E-mail: ppge.ccsa@gmail.com

Ata da reunião da Banca Examinadora designada para avaliar o trabalho de Tese do Doutorando **BRUNO FELIPE LENIN SOUZA BEZERRA**, submetida para obtenção do grau de doutor em Economia, área de concentração em **Economia Aplicada.**

Aos dezenove dia, do mês de junho, do ano dois mil e vinte e cinco, às quatorze horas, no Programa de Pós-Graduação em Economia, do Centro de Ciências Sociais Aplicadas, da Universidade Federal da Paraíba, reuniram-se, em cerimônia pública, os membros da Banca Examinadora, constituída pelos professores doutores **Jevuks Matheus de Araújo** (Orientador), da Universidade Federal da Paraíba; **Adriano Firmino Valdevino de Araújo** (Examinador Interno), da Universidade Federal da Paraíba; **José Luis da Silva Netto Júnior** (Examinador Interno), da Universidade Federal da Paraíba; **Pedro Jorge Holanda Figueiredo Alves** (Examinador Externo), do Instituto de Pesquisa Econômica Aplicada IPEA; **Bruno Chaves Morone Pinto** (Examinador Externo) da University of Arkansas, a fim de examinarem o candidato ao grau de doutor em Economia, área de concentração em **Economia Aplicada**, **Bruno Felipe Lenin Souza Bezerra.** Além dos examinadores e do examinando, compareceram também, representantes do Corpo Docente e do Corpo discente. Iniciando a sessão, o professor **Jevuks Matheus de Araújo**, na qualidade de presidente da Banca Examinadora, comunicou aos presentes a finalidade da reunião e os procedimentos de encaminhamento desta. A seguir, concedeu a palavra ao candidato, para que fizesse oralmente a exposição do trabalho, apresentado sob o título: **"Ensaios em Economia Ambiental."** Concluída a exposição, o senhor presidente solicitou que fosse feita a arguição por cada um dos examinadores. A seguir foi concedida a palavra ao candidato, para que respondesse e esclarecesse as questões levantadas. Terminadas as arguições, a Banca Examinadora passou a proceder à avaliação e ao julgamento do candidato. Em seguida, o senhor presidente comunicou aos presentes que a Banca Examinadora, por unanimidade, **aprovou** a Tese apresentada e defendida com o conceito **APROVADO**, concedendo assim, o grau de **Doutor em Economia**, área de concentração em **Economia Aplicada**, ao doutorando **Bruno Felipe Lenin Souza Bezerra.** E, para constar, eu, **Ivone Dias da Silva**, secretária *ad hoc* do Programa de Pós-Graduação em Economia, lavrei a presente ata, que assino junto com os membros da Banca Examinadora. João Pessoa, 19 de junho de 2025.

Jevuks Araujo
Assinado digitalmente via ZapSign por
Jevuks Araujo
Data 19/06/2025 16:34:16.626 (UTC-0300)

***Prof. Dr.* Jevuks Matheus de Araújo**
Orientador – UFPB

***Prof. Dr.* Adriano Firmino Valdevino de Araújo**
Examinador Interno – UFPB

Assinado digitalmente via ZapSign por
Adriano Firmino V. de Araújo
Data 19/06/2025 17:16:48.679 (UTC-03

Assinado digitalmente via ZapSign por
José Luis da Silva Netto Junior
Data 20/06/2025 10:03:36.318 (UTC-0300)

***Prof.* José Luis da Silva Netto Júnior**
Examinador Interno – UFPB

***Prof.* Pedro Jorge Holanda Figueiredo Alves**
Examinador Externo – IPEA

Pedro Jorge Holanda Figueiredo Alves
Assinado digitalmente via ZapSign por
Pedro Jorge Holanda Figueiredo Alves
Data 19/06/2025 16:32:39.876 (UTC-03

Bruno Chaves Morone Pinto
Assinado digitalmente via ZapSign por
Bruno Chaves Morone Pinto
Data 23/06/2025 15:29:40.558 (UTC-0300)

***Prof.* Bruno Chaves Morone Pinto**
Examinador Externo – University of Arkansas

Ivone Dias da Silva
Secretária *Ad Hoc* – PPGE/ UFPB

Relatório de Assinaturas

Datas e horários em UTC-0300 (America/Sao_Paulo)
Última atualização em 23 Junho 2025, 15:29:41

ZapSign By Truora

Status: Assinado
Documento: Ata De Defesa De Tese - Bruno Lenin.Pdf
Número: de783925-f74a-4354-b2bb-050322810d77
Data da criação: 19 Junho 2025, 12:43:52
Hash do documento original (SHA256): e08c5febccc306d8a7313e4def2a0bbf29b044dd6693ca3830534bb74d23d9b6

Assinaturas

5 de 5 Assinaturas

Assinado | via ZapSign by Truora

BRUNO CHAVES MORONE PINTO
Data e hora da assinatura: 23/06/2025 15:29:40
Token: 70dd14c6-c27c-4777-a0d2-2acdb4ff0c4a

Assinatura
Bruno Chaves Morone Pinto
Bruno Chaves Morone Pinto

Pontos de autenticação:
Telefone: + 14028753741
E-mail: brunoc@uark.edu
Nível de segurança: Validado por código único enviado por e-mail

IP: 107.204.242.228
Dispositivo: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/137.0.0.0 Safari/537.36 Edg/137.0.0.0

Assinado | via ZapSign by Truora

JEVUKS ARAUJO
Data e hora da assinatura: 19/06/2025 16:34:16
Token: f5636249-9290-49b9-b67a-c0d5d9f7b453

Assinatura
Jevuks Araujo
Jevuks Araujo

Pontos de autenticação:
Telefone: + 5583999509996
E-mail: jevuks.araujo@academico.ufpb.br
Nível de segurança: Validado por código único enviado por e-mail

Localização aproximada: -7.153254, -34.829107
IP: 187.19.179.183
Dispositivo: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/137.0.0.0 Safari/537.36

Assinado | via ZapSign by Truora

PEDRO JORGE HOLANDA FIGUEIREDO ALVES
Data e hora da assinatura: 19/06/2025 16:32:39
Token: 36849192-f72b-4155-951b-9f73e9cbd669

Assinatura
Pedro Jorge Holanda Figueiredo Alves
Pedro Jorge Holanda Figueiredo Alves

Pontos de autenticação:
Telefone: + 5561992517799
E-mail: pedrojorge_holanda@hotmail.com
Nível de segurança: Validado por código único enviado por e-mail

IP: 187.19.178.201
Dispositivo: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/137.0.0.0 Safari/537.36

Relatório de Assinaturas

Datas e horários em UTC-0300 (America/Sao_Paulo)
Última atualização em 23 Junho 2025, 15:29:41

ZapSign
By Truora

Assinado | via ZapSign by Truora

ADRIANO FIRMINO V. DE ARAÚJO

Data e hora da assinatura: 19/06/2025 17:16:48
Token: 81e28d7d-2b77-4e2a-abf2-e01237bd3b4e

Assinatura

Adriano Firmino V. de Araújo

Pontos de autenticação:

Telefone: + 5583999128595
E-mail: afva@academico.ufpb.br

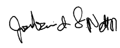
IP: 45.174.32.71
Dispositivo: Mozilla/5.0 (Linux; Android 10; K) AppleWebKit/537.36 (KHTML, like Gecko) SamsungBrowser/28.0 Chrome/130.0.0.0 Mobile Safari/537.36

Assinado | via ZapSign by Truora

JOSÉ LUIS DA SILVA NETTO JUNIOR

Data e hora da assinatura: 20/06/2025 10:03:36
Token: 9103e473-ded7-4db8-aa27-89205831c3aa

Assinatura



José Luis da Silva Netto Junior

Pontos de autenticação:

Telefone: + 5583987130579
E-mail: jose.junior@academico.ufpb.br

IP: 168.0.235.172
Dispositivo: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_15_7) AppleWebKit/605.1.15 (KHTML, like Gecko) Version/18.5 Safari/605.1.15

INTEGRIDADE CERTIFICADA - ICP-BRASIL

Assinaturas eletrônicas e físicas têm igual validade legal, conforme MP 2.200-2/2001 e Lei 14.063/2020.
Confirme a integridade do documento aqui.

Este Log é exclusivo e parte integrante do documento número de783925-f74a-4354-b2bb-050322810d77, segundo os Termos de Uso da ZapSign, disponíveis em zapsign.com.br

Acknowledgment

Inicialmente agradeço a Deus. Sem Ele nada disto seria possível.

Gostaria de agradecer primeiramente a minha esposa, Margarida, que me suporta desde a graduação. Agradeço sua dedicação e apoio durante a graduação, o mestrado e durante o desenvolvimento e conclusão deste doutorado. Você é a minha maior incentivadora, além de ser alguém que eu me espelho a seguir. Certeza que este doutorado é muito mais seu do que meu. Obrigado por tudo. Agradeço também a minha filha, Sofia, que serviu como incentivo para prosseguir e persistir na vida acadêmica.

Obrigado ao meu orientador, Jevuks, que além de orientador se tornou um amigo durante meus anos de academia. Suas sugestões e ajuda fizeram possível a entrega deste trabalho.

Também dedico um agradecimento especial aos meus familiares. Aqui citarei alguns nomes, mas saibam que todos estão em meus pensamentos. Josmar e Cassia, primeiramente, sem eles eu não estaria aqui. Vinicius, Raul e Caio pelos momentos de lazer e por fazerem parte desta jornada. Agradeço também a Seu Hernandes, Dona Margarida, Dona Célia e Seu Noel pelo suporte ao longo dos ultimos anos, sou grato por tudo. Vinicinhus, Maria, Gael, Murilo e João, vocês servem como motivação pra prosseguir melhorando.

Gostaria de agradecer aos amigos e colegas que fiz durante os anos de universidade: Noelia, Ana, Pedro, Bruno e Luciano que são os mais próximos e que estavam a par de toda essa jornada. Também agradeço a todos os Clubista Fabiano que promoveram calorosas discussões ao longo de todo esse tempo.

Por fim, agradeço a todos que me motivaram, ajudaram, estavam presente durante esses ultimos 4 anos. Infelizmente não tenho espaço para agradecer a todo mundo, mas saibam que todos foram importantes para a obtenção deste título.

List of Tables

List of Figures

Summary

1 Introduction

Over the last decades, the accelerating effects of environmental degradation and climate change have placed sustainability at the core of global economic discussions. The urgency to adapt production systems, institutional frameworks, and policy mechanisms to these environmental challenges has led to an increased interest in understanding the role of economic instruments in promoting sustainability. Within this context, environmental economics emerges as an important field for understanding the interactions between economic development and environmental stability, as well as for evaluating the efficiency and equity of policies designed to mitigate environmental issues (MUNASINGHE, 1993; HANLEY et al., 2019).

This thesis is situated within the field of environmental economics and explores three interrelated essays that address key issues: the global energy transition, the vulnerability of energy systems to climate-induced natural disasters, and the effectiveness of environmental enforcement policies. The research investigates both international and domestic contexts, applying advanced econometric techniques in order to produce robust empirical evidence.

The first essay investigates the determinants of renewable energy expansion in developed, developing, and BRICS countries, trying to understand how globalization, financial development, and macroeconomic factors influence energy transitions. The second essay analyzes the impact of billion-dollar natural disasters on energy generation across U.S. states, focusing on the heterogeneous effects of climate shocks such as wildfires and storms on renewable and non-renewable energy sources. Finally, the third essay evaluates the effectiveness of the "Green Brazil Operation"in combating wildfire outbreaks in the Legal Amazon, providing policy-relevant insights into the enforcement of environmental laws and interventions.

These essays seek to advance the literature by uncovering the economic dynamics that shape climate and environmental policy outcomes. They identify key institutional constraints that may hinder policy effectiveness and offer empirical evidence to support the design and evaluation of public interventions. By integrating cross-country analysis with detailed case studies from Brazil and the United States, the dissertation provides a multidimensional perspective on environmental challenges and the policy responses needed to address them effectively.

The thesis is organized into four chapters. Following this introductory chapter, Chapter 2 presents the first essay, which investigates the drivers of renewable energy adoption across developed, developing, and BRICS countries. Chapter 3 explores how natural disasters impact energy generation in the United States, emphasizing differences across states and energy sources. Chapter 4 examines the effectiveness of Brazil's Green Brazil Operation in reducing wildfires in the Legal Amazon.

2 Energy Transition Process: Evidence from Developed, Developing, and BRICS Countries

Resumo

Este artigo tem o objetivo de analisar o processo de transição energética através de dados para países desenvolvidos, em desenvolvimento e BRICS. Visto a importância do setor de energia renovável no mundo, é importante analisar e entender os principais determinantes do aumento desde setor na matriz energética mundial. Para tanto, utilizaremos os métodos de painel MQO Dinâmico (DOLS), MQO Totalmente Modificao (FMOLS) e Canonical Cointegrating Regression (CCR) para averiguar os principais determinantes para o setor de energia renovável. Os resultados sugerem que uma forte relação entre globalização e o implemento de energia limpa para os países desenvolvidos. Além de que destaca-se que para os países pertencentes aos BRICS, o mercado financeiro desenvolve papel importante na adoção de uma matriz energética renovável.

Palavras-Chave: Energia Renovável, Transição Energética, FMOLS, DOLS, CCR

Abstract

This article aims to provide a study of the energy transition process through the analysis of data for developed, developing countries and BRICS. Seen the importance of the renewable energy sector in the world, it is important to analyze the main factors of the increase of this sector in the world energy matrix. To this end, we will use Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS) and Canonical Cointegrating Regression (CCR) panel methods to investigate the main determinants for the renewable energy sector. The results suggest a strong relationship between globalization and the implementation of clean energy for developed countries. In addition, it is worth highlighting that for the BRICS countries, the financial market plays an important role in the adoption of a renewable energy matrix.

Keywords: Renewable Energy, Energy Transition, FMOLS, DOLS, CCR

2.1 Introduction

Energy is an essential resource for carrying out social and economic activities, such as the operation of industries, schools, hospitals, and it is crucial for the quality of life of the population in their households. Over the past decade, the world has seen an increase in energy generation, with a growth between 30% to 76% estimated by 2050 (AGENCY, 2023). In 2022, the majority of energy generated came from non-renewable sources such as oil, coal, and natural gas, accounting for 30.2%, 27.6%, and 23.1% of the global energy matrix, respectively (IEA, 2024).

The structures of non-renewable energy consumption, primarily based on oil and coal, have contributed to the global economy and the accelerated economic growth of the last century (WANG et al., 2019). However, due to the severity of problems related to climate change, environmental pressure has increased for investments that promote a transition to low-carbon economies (YORK; BELL, 2019; XIONG et al., 2020).

Renewable energy plays a significant role in the transition to low-carbon economies (GLASNOVIC; MARGETA, 2011; ARI; YIKMAZ, 2019; GIELEN et al., 2019). This role has gained greater prominence since the 1990s, with the emergence of the first international climate agreements and conferences, such as the United Nations Framework Convention on Climate Change, ratified in 1994, the Kyoto Protocol, signed in 1997, and the Paris Agreement in 2015 (KUYPER; SCHROEDER; LINNÉR, 2018). Given this shift in the structure of global climate policy, countries are incentivized to invest more in renewable energy sources (hydropower, solar, geothermal, wind, etc.) in order to meet the carbon reduction targets agreed upon in international climate conferences, thereby accelerating the process of energy transition (MOUTINHO; MOREIRA; SILVA, 2015; ARANTEGUI; JÄGER-WALDAU, 2018; MIYAMOTO; TAKEUCHI, 2019).

Factors such as the increase in global energy demand, particularly in emerging countries, the development of new technologies, and the commitment of nations to climate pollution reduction agendas will assign renewable energies a more significant role in the global energy matrix in both the short and long term (ANTON; NUCU, 2020). In the year 2000, solar and wind energy represented only 0.01% and 0.20% of the total electricity generation worldwide. By 2021, this figure rose to over 10% of the total electricity generation, according to OECD data. Furthermore, when examining the percentage of renewable energy generation relative to total energy production, regions like the OECD report that 49% of this electricity comes from renewable sources, highlighting the importance of the sector in the economies of these countries.

Given the importance of the renewable energy sector for long-term sustainable growth, it is crucial to understand the main determinants of the increase in renewable energy consumption worldwide in order to present potential policy implications for the energy sector. This study, therefore, aims to investigate the factors influencing renewable energy consumption, analyzing the period from 1990 to 2021 for developed and developing countries belonging to the OECD and BRICS.

One influential factor is the economic activity and development level of a nation. There is a well-documented connection between economic growth and renewable energy consumption. Authors such as Gozgor et al. (2020), Salim e Rafiq (2012), Pao e Fu (2013), Omri, Daly e Nguyen (2015) argue that an increase in energy consumption is necessary to generate economic growth, thus expecting that the growth of economic activity will positively impact the share of renewable energy in a country's total energy consumption. Furthermore, certain factors are crucial for analyzing economic activity like globalization and financial development.

The second important factor that could influence the increase of renewable energy is globalization. According to Dreher (2006), globalization enhances long-term economic performance in both developing and developed nations through mechanisms such as capital flows and foreign direct investment. Additionally, Gozgor et al. (2020) emphasizes that high-level technology adoption is critical for renewable energy investments, while capital flows provide essential inputs for the development of the energy sector.

Building on this, Anton e Nucu (2020) argue that public investments alone are insufficient for driving the energy transition. Instead, the financial sector plays a central role by supporting companies, mitigating liquidity risks, and facilitating fundraising for sustainable energy technologies. Well-developed capital markets not only contribute to greater sector growth and cost reductions but also lead to increased renewable energy generation and demand. As we can see from Wang e Taghizadeh-Hesary (2023), financial instruments like green bonds help mobilize private investments in renewable energy, particularly wind and hydro. Similarly, Ansaram e Petitjean (2024) highlight that stock markets play a crucial role by reallocating capital from fossil fuels to renewables, strengthening the financial foundation for a low-carbon economy.

Another significant factor is that, given the distinction between renewable and non-renewable energy sources, oil prices can influence renewable energy consumption, as fossil fuels often act as substitutes for clean energy, leading to an expected negative correlation. Additionally, Gozgor et al. (2020) suggests that CO2 emissions are a key driver of renewable energy generation. The growing societal concern about climate change can lead to a demand for cleaner environments, causing carbon emissions to have a significant and positive impact on renewable energy consumption and generation (OMRI; DALY; NGUYEN, 2015).

Finally, renewable energy consumption helps reduce the vulnerability of economies to exogenous oil supply instability (RENTSCHLER, 2013), stabilizes energy prices (SHEN et al., 2010), and increases efficiency levels in the energy market (MURSHED, 2020). According to the report from the International Renewable Energy Agency, the global average costs of solar and wind energy significantly decreased between 2010 and 2018, almost equaling the corresponding costs of electricity generation from fossil fuels Costs (2018). This demonstrates that analyzing the price of renewable energy is also an essential factor in understanding changes in the generation and consumption of clean energy.

This article contributes to the existing empirical literature in two significant ways. First, while most empirical studies focus on developed countries, this study employs a mixed dataset of developed and developing countries, which may generate new insights for economic policymakers, considering that results can vary when comparing emerging and developed countries. Second, we advance the analysis conducted by Gozgor et al. (2020) by introducing the level of financial market development as a key variable to explain the higher level of investment attraction and development in the renewable energy sector of a region, as well as incorporating the price of energy inputs as a control variable in the model.

Our results highlight distinct drivers of renewable energy adoption between developed and developing countries, specifically the OECD and BRICS groups. The findings confirm that globalization significantly promotes renewable energy consumption in developed nations. These results align with the literature, such as Gozgor et al. (2020), which emphasizes globalization's role in attracting investments for cleaner energy solutions. Additionally, in BRICS nations, the development of financial markets plays a critical role in renewable energy adoption, this results aligns with Paramati, Alam e Apergis (2018), who found that developed capital markets are essential for accessing international investments and implementing sustainable energy projects. Moreover, we find a negative relationship between CO2 emissions and renewable energy production, supporting Menegaki (2011) assertion that an increase in emissions from fossil fuels undermines the growth of renewable energy. This contrasts with findings like those of Omri, Daly e Nguyen (2015), who observed a positive relationship between CO2 emission and renewable energy consumption.

These differences underscore the importance of policy approaches: while developed nations benefit from leveraging globalization to enhance renewable energy use, emerging economies in BRICS require robust financial systems to attract the capital necessary for renewable energy investments. Understand these differences enriches the literature and provides insights for energy policymakers worldwide.

This article is organized as follows: Section 2 aims to contextualize the development of the energy sector in the OECD, BRICS, and globally, to analyze the trajectory of the variables. Section 3 presents the dataset used, along with the theoretical and empirical modeling employed in this study. The final section provides the results of the empirical analysis.

2.2 Contextualization

Firstly, it is necessary to understand how the process of electricity generation from renewable and non-renewable sources evolved during the period analyzed in this article (see Figure 1). Global data suggest a certain stability in energy production from non-renewable sources between 2000 and 2012. From then on, there is a slight but continuous reduction in energy generation derived from fossil resources. This trend is also observed in the countries comprising the OECD and BRICS. The increase in investments in clean energy sources may explain this change.

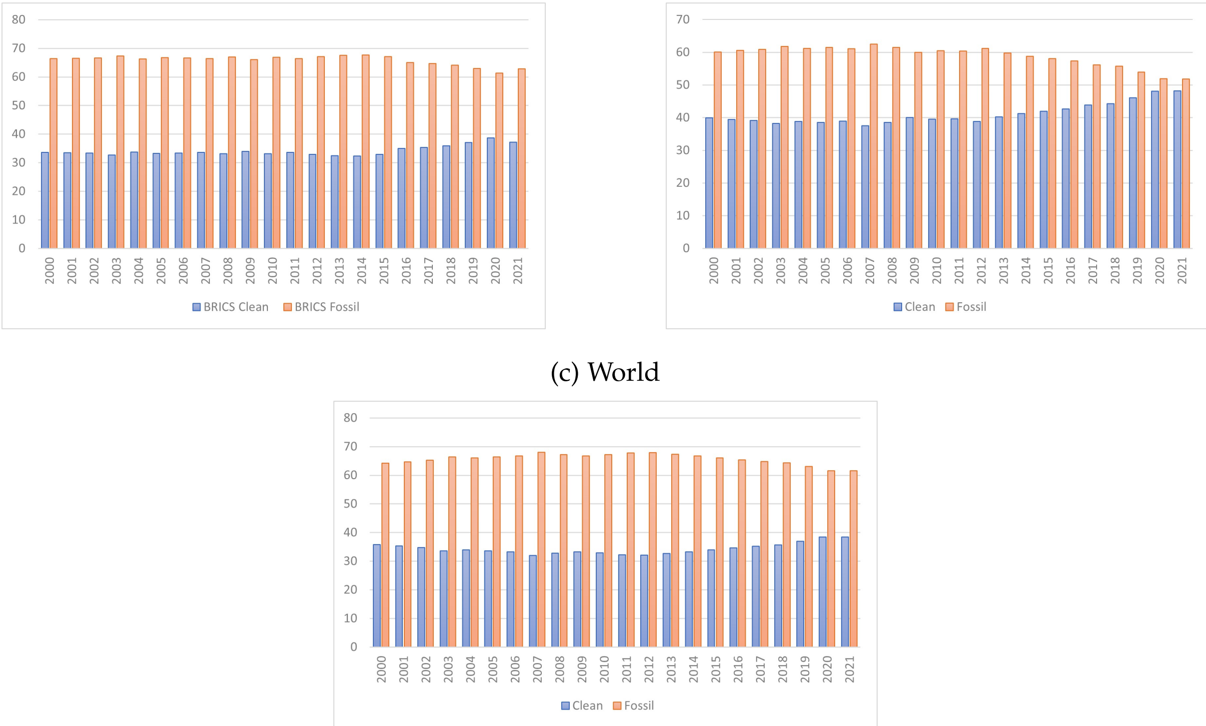
According to the energy report published by BRICS (2021), the share of renewable resources in total energy consumption has increased significantly in recent years, indicating the efforts of these countries in transitioning to low-carbon energy. In 2019, China was the largest investor in clean energy worldwide (US$ 83.4 billion), while India (US$ 9.3 billion) and Brazil (US$ 6.5 billion) ranked fourth and fifth globally, respectively (STATISTA, 2022).

Furthermore, to assist emerging countries in Latin America and Asia in securing financial resources for investments in clean and renewable energy production, the OECD developed the Clean Energy Finance and Investment Mobilisation (CEFIM) program [1].

[1] The Clean Energy Finance and Investment Mobilisation program aims to strengthen the internal conditions of countries to attract financing and investments in renewable energy, energy efficiency, and industrial decarbonization in emerging economies. The program supports countries in developing policies and instruments for clean energy projects. CEFIM is directly supported by the governments of Denmark, Egypt, and Germany.

Figure 1 – Renewable and non-renewable electricity generation

(a) BRICS (b) OECD



Source: Own Elaboration

Evaluating by specific energy source, global electricity production from polluting sources such as coal and oil decreased during the 2000–2021 period (see Table 1). This reduction is particularly notable in OECD countries, with variations of 48% and 66% between the first and last periods, respectively. The data suggest a substitution process from these energy production sources to natural gas, especially in OECD countries. According to the Energy Information Administration, this is a reasonable short-term alternative, as CO2 emissions from natural gas are significantly lower compared to the two previously mentioned sources.

Furthermore, investments in clean electricity production sources appear to be yielding initial results. An increase in the share of generation sources such as hydro, solar, and wind energy can be observed throughout the entire period. In 2021, when considered together, these sources accounted for approximately 25%, 27%, and 28% of total electricity production worldwide, in OECD countries, and in BRICS countries, respectively. This result suggests that countries may indeed be undergoing a transition in their energy production processes.

Table 1 – Electricity generation by resource type

Region	Year	Coal	Gas	Hydro	Solar	Wind	Oil	Nuclear	Others Ren.
WORLD	2000	38.46	17.82	17.00	0.01	0.20	7.98	16.58	1.19
	2010	40.01	22.65	15.89	0.16	1.61	4.41	12.83	1.76
	2021	35.99	22.90	15.01	3.63	6.54	2.53	9.84	2.68
OECD	2000	37.37	15.88	14.73	0.01	0.30	6.85	23.16	1.69
	2010	32.87	23.92	13.15	0.28	2.55	3.57	21.13	2.53
	2021	19.58	29.57	13.37	4.89	9.06	2.36	17.33	3.85
BRICS	2000	52.30	10.72	27.27	0.00	0.06	3.35	5.36	0.59
	2010	51.27	14.39	24.63	0.01	0.74	1.10	5.74	1.70
	2021	48.77	12.63	19.83	2.76	5.26	1.00	6.61	2.54

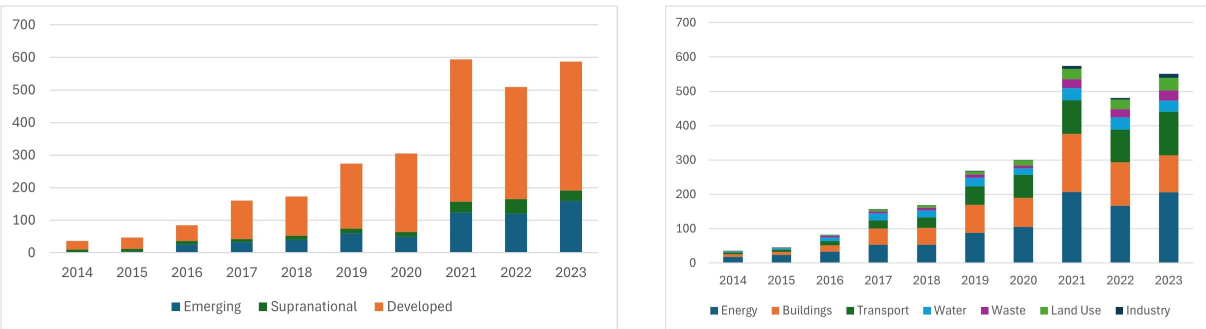
Source: Own elaboration based on EIA data.

Another important aspect of the paper is understanding the role of the financial market in the process of energy transition. One mechanism through which the financial market can generate higher investments in renewable energy is through Climate Bonds Investments (WANG; TAGHIZADEH-HESARY, 2023). According to the Climate Bonds Initiative (2024), climate bonds are a type of fixed-income security created to generate funding for projects that address climate change solutions. Figure 2 illustrates the total amount of climate bond investments, categorized by market/region of investment and use of investment. The data show a significant increase in capital flows toward climate-related projects, emphasizing the growing role of financial markets in supporting sustainable energy transitions.

Figure 2 – Climate Bonds Investment - Total Amount (Billion USD)

(a) Market/Region of Investment

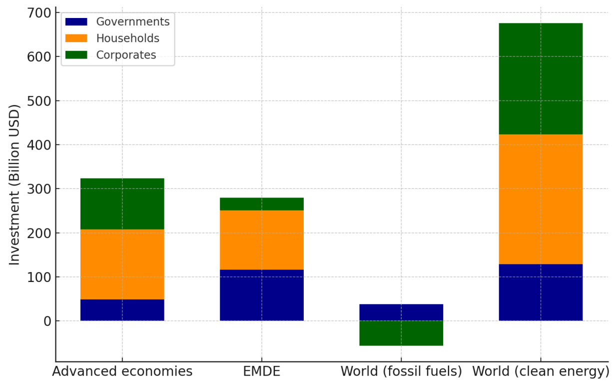
(b) Use of the Investment



Source: Own Elaboration from Climate Bonds Initiative (2024)

Regional variations in investment patterns suggest that developed economies, particularly those in the OECD, have been leading in climate bond investment, with a total investment of $396.5 billion in 2023. However, emerging economies, including BRICS nations, are gradually expanding their participation in climate financing, with a growth rate of 19,850% between 2014 and 2023, while developed countries experienced an increase of 1,380% over the same period. A substantial share is directed toward renewable energy projects, representing more than 34% of the total amount invested between 2014 and 2023. These trends reinforce the importance of financial mechanisms in accelerating the transition away from fossil fuels and enhancing climate resilience.

Figure 3 – Change in Energy Investment Volume from 2016 to 2023 (Billion USD)



Source: International Energy Agency (2024)

Another important aspect of the financial market's role in promoting energy transition is the evolution of energy investment, considering the type of energy and the entities investing in these sources. Figure 3 shows that between 2016 and 2023, investment in fossil fuels experienced a relative decline, primarily due to a decrease in corporate investment during this period. An important observation is that when analyzing the change in investment in clean energy, approximately 80% of the investment came from corporations and households. Also, given the importance of corporations and households, Ansaram e Petitjean (2024) found that the stock market plays a crucial role in the energy transition process, as investors have started shifting their focus from fossil fuels to renewable energy sources. This transition is reinforced by the increasing number of companies related to renewable energy in energy stock and carbon markets.

The findings from Table 1 and Figures 2 and 3 provide a comprehensive view of the ongoing global energy transition. The decline in coal usage, growth in renewable energy, and the increasing role of climate finance all suggest how financial instruments and investment strategies are evolving to support sustainable energy solutions.

2.3 Methodology

Following the model developed by Gozgor et al. (2020) and incorporating the financial sector variable, the factors affecting energy consumption can be described as follows:

LNCER = f(LNPIB, LNOIL, LNPER, LNCO2, LNGLOBI, LNGLOBIR, LNFIN) (2.1)

Where LNCER is the natural logarithm (ln) of renewable energy consumption, LNPIB is the ln of real GDP per capita, LNPER is the ln of the WTI oil price, LNPER serves as a proxy for renewable energy price, LNCO2 is the ln of carbon emissions, LNBLOBI and LNGLOBIR are the globalization indices, and LNFIN is the ln of the financial market development index.

The above function can be represented as follows:

$$\begin{aligned} LNCER_{it} = & \alpha_i + \beta_{1,i} LNPIB_{it} + \beta_{2,i} LNOIL_{it} + \beta_{3,i} LNCO2_{it} + \\ & \beta_{4,i} LNGLOBI_{it} + \beta_{5,i} LNGLOBIR_{it} + \beta_{6,i} LNFIN_{it} + \epsilon_{it} \end{aligned} \tag{2.2}$$

Where i represents the countries, t is the time period, and ϵ_{it} is the error term.

The econometric modeling will follow the four steps described in Gozgor et al. (2020). First, stationarity tests will be conducted using unit root tests. This will be followed by cointegration tests of the variables. Next, the long-term panel estimation will be carried out using FMOLS (Fully-Modified Ordinary Least Squares) and DOLS (Dynamic Ordinary Least Squares) methods. Finally, panel causality tests will be performed.

2.3.1 Unit Root and Cointegration

The first step in the modeling process is to determine whether the variables in the system are integrated of the same order. Several unit root tests have been developed to determine the order of integration of panel data variables. In this article, we will use the unit root tests developed by Levin, Lin e Chu (2002), Kruse (2011), and Kapetanios, Shin e Snell (2003). Given that the study variables become stationary after differencing, we will proceed with panel cointegration techniques developed by Pedroni (1999), Pedroni (2004) and Kao (1999).

The cointegration tests are based on the residuals of equation (2.2), where the null hypothesis is the absence of cointegration, meaning there is no shared long-term vector. The formula for the panel cointegration test by Pedroni (1999), Pedroni (2004) can be expressed as follows:

$$y_{it} = \alpha_i + \sigma_i t + \sum_{m} {}_{j=1} \beta_{ji} X_{j,it} + \epsilon_{it} \quad t = 1, ..., T, i = 1, ..., N \tag{2.3}$$

Where T represents the number of observations, N is the number os units, m is the number of regression variables, and y_{it} and β_{ji} are integrated of the first order.

The test by Kao (1999), in turn, introduces an Augmented Dickey-Fuller test for panel cointegration. Analyzing a bivariate case, the model is as follows:

$$y_{i,t} = \alpha_i + \beta x_{i,t} + \epsilon \quad i = 1, ..., N, t = 1, ..., T \tag{2.4}$$

Where $y_{i,t} = y_{i,t-1} + \mu_{i,t}$ e $x_{i,t} = x_{i,t-1} +_{i,t}$, α_i represents the fixed effect varying across cross-sectional observations, β is the slope parameter, and $y_{i,t}$ e $x_{i,t}$ are independent random walks for the entire set i.

2.3.2 FMOLS, DOLS and CCR

Finally, in the presence of cointegration among the variables, the parameters estimated using traditional OLS become biased and inconsistent due to issues such as endogeneity and serial correlation. To address this, alternative estimation methods such as Fully Modified OLS (FMOLS), Dynamic OLS (DOLS), and Canonical Cointegrating Regression (CCR) are employed. The FMOLS and DOLS panel methods were proposed by Pedroni (1999), Pedroni (2004) and Kao (1999), respectively. These estimators provide consistent estimates of the long-run relationships and allow for heterogeneity in cointegrating vectors across panel members.

The FMOLS estimators are given by the following equation:

$$\hat{\beta}_{FMOLS} = \frac{1}{N} \sum_{i=1}^{N} \left(\sum_{i=1}^{T} (x_{i,t} - \overline{x}_i)^2 \right)^{-1} \left(\sum_{i=1}^{T} (x_{i,t} - \overline{x}_i)\, y_{i,t}^{*} - T\hat{\gamma}_i \right) \tag{2.5}$$

Where $\hat{\gamma}_i$ corrects the serial correlation term resulting from dynamic heterogeneity, and $y_{i,t}^{*}$ is the transformation of $y_{i,t}$ that eliminates the endogeneity problem..

Similarly, the DOLS technique can eliminate the correlation between the error term and the regressors by including lagged and lead values in the cointegrating relationship. The Dynamic OLS estimator is given by:

$$\hat{\beta}_{DOLS} = \frac{1}{N} \sum_{i=1}^{N} \left(\sum_{i=1}^{T} Z_{i,t} Z_{i,t}' \right)^{-1} \left(\sum_{i=1}^{T} Z_{i,t} \left(y_{i,t} - \overline{y}_i \right) \right) \tag{2.6}$$

Where $Z_{i,t}$ represents $2(K+1)x1$ vectors of included explanatory variables $(x_{i,t} - \overline{x}_i, \Delta x_{i,t-k}, ..., \Delta x_{i,t+k})$.

Finally, the Canonical Cointegrating Regression (CCR) approach, introduced by Park (1992), transforms the data using long-run covariance matrices to correct for endogeneity and serial correlation, without the need to include leads or lags.

$$y_{i,t} = x'_{i,t}\beta_i + u_{i,t} \tag{2.7}$$

CCR modifies both $x_{i,t}$ and $y_{i,t}$ using estimates of the long-run covariance matrices to obtain transformed variables $(x^*_{i,t}, y^*_{i,t})$. The CCR estimator is then given by the following OLS regression:

$$\hat{\beta}_{CCR} = \left(\sum_{t=1}^{T} x^*_{i,t} x^{*\prime}_{i,t} \right)^{-1} \left(\sum_{t=1}^{T} x^*_{i,t} y^*_{i,t} \right) \tag{2.8}$$

2.3.3 Dataset

In this article, we work with panel data from 1990 to 2021, covering 21 developed countries, 15 developing countries, including 5 BRICS countries. The dependent variable is renewable energy consumption per capita (RENPC). Additionally, as control and independent variables, we use GDP per capita (GDPPC) and CO_2 emissions per capita (CO2PC), which were collected from Our World in Data. The globalization index (KOFGI) was obtained from the KOF Swiss Economic Institute, while the oil price (POIL) data was sourced from FRED. Finally, financial indicators, including the financial development index, institutional index, and market index, were collected from the International Monetary Fund (IMF) database.

Table 2 – Developed and Developing Countries Dataset

Developed			**Developing**		
Australia	Belgium	Canada	Argentina	Chile	China
Denmark	Finland	France	Colombia	Egypt	India
Germany	Greece	Italy	Indonesia	Iran	Mexico
Japan	Netherlands	New Zeland	Peru	Russia	Saudi Arabia
Norway	Poland	Portugal	South Africa	Turkey	UAE
South Korea	Spain	Sweden			
Switzerland	United Kingdom	United States			

Source: Own elaboration.

Following the approach proposed by Gozgor et al. (2020), we will use two indicators to measure the level of globalization in a country as the primary variable of interest: (i) the economic globalization index developed by Dreher (2006), and (ii) the revised economic globalization index created by Gygli et al. (2019). Unlike previous studies, we introduce the financial market development level of each country as a variable of interest. This variable can be considered an explanatory factor for the development and acquisition of resources for investments in renewable energy sources. This data will be collected from the IMF Data.

Table 3 – Dataset

Variable	Description	Frequency	Source
renpc	Renewable Energy Consumption per Capita	Annual	IEA
co2pc	CO_2 Emissions per Capita	Annual	OECD/World Bank
gdppc	Real Gross Domestic Product per Capita	Annual	OECD/World Bank
poil	WTI Crude Oil Spot Price	Annual	FRED
kofgi	Globalization Index	Annual	KOF Swiss Econ. Inst.
findev	Financial Development Index	Annual	IMF Data
fininst	Institutional Financial Index	Annual	IMF Data
finmark	Financial Market Development Index	Annual	IMF Data

Source: Own elaboration.

2.4 Results and Discussion

Table A.25, A.26 and A.27 in appendix highlights the descriptive statistics across developed, developing, and BRICS countries, showcasing notable variations in economic and energy-related indicators. Developed countries exhibit the highest mean GDP per capita (42,060.460) and mean renewable energy per capita (11.869), but also substantial variability in these indicators, as seen in their high standard deviations. In contrast, developing countries have significantly lower averages for GDP per capita (7,704.132) and renewable energy per capita (2.588), reflecting economic disparities and lower energy adoption. BRICS countries fall between these groups, with moderate GDP per capita (5,892.358) and renewable energy per capita (2.482), but greater variability in CO2 emissions. Across all groups, the globalization index shows relatively consistent levels, while financial indices reveal significant heterogeneity. These patterns emphasize the structural and developmental differences across country groups.

As we can see from Tables A.31, A.32, and A.33 in appendix, the colletation coefficient of renpc is positively and significantly correlated with gdppc, aligning with expectations that higher income levels are associated with increased renewable energy consumption. Also, renpc shows a weak correlation with co2pc, suggesting that higher renewable energy consumption does not necessarily align with lower carbon emissions across countries. To investigate the order of integration of the variables, we conducted unit root tests (tables A.28, A.29, and A.30 in appendix), including Levin, Lin & Chu, Choi Pm test, and Im, Pesaran & Shin, which revealed a mixed order of integration (I(0) and I(1)), which is appropriate for the models.

Table 4 – Fully Modified OLS - Average Result for Developed, BRICS, and Developing Countries

	Developed			BRICS			Developing		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
gdppc	1.54***	1.80***	1.64***	1.09***	1.34***	1.53***	0.93***	0.68***	1.01***
co2pc	-1.57***	-1.62***	-1.48***	-1.23***	-1.46***	-1.38***	-1.25***	-1.07***	-1.26***
kofgi	1.10***	0.51***	0.98***	-0.93***	-0.43***	-1.10***	2.33	0.97	3.04
findev	-0.11			0.58***			-0.28***		
fininst		-0.28**			0.27***			0.51***	
finmark			-0.1			0.32***			-0.23***

Source: Own elaboration.

In Table 4, we can observe the results for the Fully Modified OLS (FMOLS) estimation for developing countries, developed countries, and BRICS nations. It is evident that the per capita renewable energy production variable is significantly and positively influenced across all models and for all subgroups of countries. This result aligns with theory, suggesting that an increase in GDP leads to the development of the energy sector in general, which also positively impacts the use of renewable energy.

Interestingly, CO_2 emissions per capita are negatively associated with renewable energy consumption, contrasting with some previous findings Omri, Daly e Nguyen (2015), Salim e Rafiq (2012), but aligning with Menegaki (2011), Attiaoui et al. (2017). Since the global energy matrix predominantly relies on non-renewable energy sources, the increase in CO2 production is directly linked to the use of polluting energy. According to Menegaki (2011), due to the competition between carbon emissions and renewable energy, the increase in renewable energy use cannot be promoted when a country intensifies the utilization of CO2-emitting sources.

The FMOLS model identified that the globalization index has a significant and positive effect for the developed countries. Globalization influences the behavior of polluting companies, which may relocate from developed countries to those with weaker environmental regulations Copeland e Taylor (2004). Given that institutions are more developed in these countries, it is expected that the more globalized a country is, the more interested it will be in developing stricter environmental policies. Additionally, such countries are better equipped to acquire new technologies capable of promoting changes in their energy matrix, consequently leading to an increase in renewable energy consumption (GOZGOR et al., 2020).

Finally, the model shows that the three financial indexes has more impact in developing countries and BRICS, also the capital market index has a positive and significative effect for BRICS countries. According to Paramati, Alam e Apergis (2018), Younis et al. (2021), this result indicates that for a developing country to secure capital for a cleaner energy sector, investment in the capital market is necessary, as it plays a key role in attracting international capital. This outcome is evident when comparing the results for BRICS. On average, BRICS countries have more developed capital markets than the rest of the developing nations, enabling them to attract more capital and, consequently, leading to greater investment in clean energy.

Table 5 – Canonical Cointegrating Regression - Average Result for Developed, BRICS, and Developing Countries

	Developed			BRICS			Developing		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
gdppc	1.52***	1.74***	1.59***	1.18***	1.36***	1.59***	1.03***	0.75***	1.09***
co2pc	-1.55***	-1.62***	-1.45***	-1.29***	-1.47***	-1.42***	-1.29***	-1.07***	-1.30***
kofgi	1.08***	0.62***	1.05**	-0.96***	-0.44***	-1.15***	2.27	0.94	2.95**
findev	-0.11			0.55**			-0.27***		
fininst		-0.22**			0.27***			0.48***	
finmark			-0.1			0.32***			-0.22***

Source: Own elaboration.

To test the robustness of our FMOLS estimates, we re-estimated the model using the Canonical Cointegrating Regression approach. The results were qualitatively similar, supporting the robustness of the estimated cointegrating relationship. In Table 5, we present the results for the CCR model. We can observe that all effects maintain the same sign. The globalization index has a positive and significant influence on countries, whereas the financial indexes positively affects clean energy production in the BRICS.

Table 6 – Dynamic OLS - Average Result for Developed, BRICS, and Developing Countries

	Developed			BRICS			Developing		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
gdppc	1.76***	1.55***	1.67***	1.31***	-0.99***	2.08***	1.05***	1.04***	0.92***
co2pc	-1.24***	-1.78***	-0.96***	-2.55***	-1.73***	-2.58***	-2.05***	-2.92***	-1.86***
kofgi	1.35***	2.14***	0.98***	-1.69***	-0.50**	-1.67***	4.71	1.91	3.93**
findev	-0.47***			0.88			-0.75		
fininst		-1.14***			2.10***			2.72***	
finmark			-0.11**			0.25*			-0.41***

Source: Own elaboration.

Table 6 reports the estimates from the Dynamic Ordinary Least Squares (DOLS) models. These results also support the robustness of our findings. GDP per capita continues to exhibit a strong and positive impact on renewable energy consumption across all country groups, particularly in BRICS countries, where the coefficient is the highest among the models. CO_2 emissions have a consistently negative and statistically significant effect, and the magnitude of this effect is even stronger in the DOLS model than in FMOLS or CCR, indicating a more pronounced substitution effect between fossil and renewable energy sources.

The globalization index again displays heterogeneity: positive and significant in developed countries, negative in BRICS countries, and not significant in the broader group of developing nations. Financial indicators continue to be especially influential in BRICS countries, with the institutional and market indices showing strong positive effects.

This result implies that financial infrastructure in these countries plays a critical role in supporting the growth of renewable energy sectors. Financial markets are essential for providing the capital necessary for investments in clean energy technologies, which are often capital-intensive. A more developed financial market likely facilitates access to credit, investment, and financial instruments that can fund renewable energy projects. For BRICS countries, which include rapidly developing economies such as Brazil, Russia, India, China, and South Africa, the ability to leverage financial markets for such investments is particularly crucial.

2.5 Conclusion

This study aims to understand the factors that explain the growth of renewable energy production in developed, developing, and BRICS countries. As observed, economic growth plays a fundamental role in the use of renewable energy. Additionally, a negative relationship between CO2 emissions and the growth of renewable energy production was identified. This can be explained by the fact that these two types of energy are seen as substitute goods.

This study also emphasized the importance of globalization for developed countries and the development of capital markets as a crucial factor for the growth of clean energy production in developing countries, specifically in BRICS nations. Since developing countries are not necessarily integrated into global trade, strengthening capital markets is an important factor for attracting foreign capital and making the necessary investments in infrastructure to promote the transition to clean energy sources.

In conclusion, this research contributes to the literature by analyzing the determinants of renewable energy consumption across a diverse mix of developed and developing countries. The results indicate that economic development and CO2 emissions affect all countries in a homogeneous manner, altering only the magnitude of the impact felt, not its direction. Globalization and capital markets, however, have a heterogeneous effect when analyzing all countries. Developed countries are more influenced by the globalization index, while the renewable energy sector in BRICS countries is impacted by the capital market index. Therefore, it is important for policymakers to change their strategies to these factors, focusing on enhancing financial systems in emerging markets.

3 Impacts of Natural Disasters on Energy Generation in the United States: A State-Level and Energy Source Analysis

Resumo

Dada a importância do clima no setor de energia e que nas últimas décadas o clima mundial vem sofrendo alterações e provocando aumento na frequência e intensidade dos eventos climáticos, este artigo tem como objetivo investigar todos os desastres de Bilhões de Dólares ocorridos nos últimos 20 anos nos Estados Unidos e os impactos sentidos no setor de geração de energia. Para tanto, utilizaremos uma modelagem ARDL para detectar esses impactos a nível de estado e de fonte energética. Os resultados do modelo sugerem que os impactos na geração de energia são heterogêneos e são dependentes do tipo do desastre natural (incêndios ou tempestades severas), do tipo de fonte energética (solar, hidroelétrica, biomassa, eólica, carvão, petróleo, nuclear e gás natural) e de caracteristicas individuas estaduais.

Palavras-Chave: Desastre Natural, Geração de Energia, GMM

Abstract

Given the importance of climate in the energy sector and that in recent decades the world climate has been changing and causing an increase in the frequency and intensity of climatic events (natural disasters), this paper aims to investigate all Billion-Dollar disasters that occurred in the last 20 years in the United States and the impacts of these events in the energy generation sector. To do so, we will use ARDL modeling to detect these impacts at the state and energy source levels. The model results suggest that the impacts on energy generation are heterogeneous and are dependent on the type of natural disaster (fires or severe storms), the type of energy source (solar, hydroelectric, biomass, wind, coal, oil, nuclear and natural gas) and individual state characteristics.

Keywords: Natural Disaster, Energy Generation, GMM

3.1 Introduction

In recent decades, evidence has grown that the global climate is changing and that the main cause of this change is emissions caused by human activity (PÖRTNER et al., 2022). Climate change is primarily responsible for the increase in the frequency and intensity of natural disasters in recent years (AALST, 2006; BANHOLZER; KOSSIN; DONNER, 2014). According to Reidmiller et al. (2017), the quantity and costs of natural disasters are increasing due to the combination of three distinct factors: greater exposure, with a larger number of assets at risk; vulnerability, meaning how much damage a climatic event can cause in a given location; and climate change, which is responsible for the rise in extreme events, leading to billions of dollars in losses for the U.S. economy.

The total cost of natural disasters in the United States over the past five years (2017-2021) amounted to $724.1 billion, with an average annual cost of $148.4 billion. In comparison, during the 1980s (1980-1989), the average annual cost was $19 billion, and in the 2010s (2010-2019), it was $87.3 billion, demonstrating how the costs arising from natural disasters have been increasing over time in the United States. Analyzing billion-dollar events that occurred between 1980 and 2021, the greatest damages were caused by tropical cyclones ($1,148.0 billion) with the highest cost per event ($20.5 billion). Severe storms were the most frequent, occurring 143 times, with a total cost of $330.7 billion, while winter storms resulted in a final cost of $78.6 billion (NCEI, 2021).

In addition to the accounting cost, it is important to analyze natural disasters and measure their short- and long-term impact on economic variables (LEE et al., 2021). Noy (2009) found that the damages resulting from a natural disaster and its economic impact are multifaceted. Several studies assert that the variation in impacts is due to economic and social factors, as well as the quality of infrastructure and the level of development of a country (SUTANTA; RAJABIFARD; BISHOP, 2013; BERLEMANN; WENZEL, 2018; BENALI; SAIDI, 2017; LEE; CHEN, 2020; BROWN et al., 2018). The economic effects of disasters are categorized into two types: direct and indirect (BENALI; SAIDI, 2017). Direct effects are those that necessarily depend on a country's level of development, while indirect effects refer to the short- and long-term impacts on the economic growth of an economy that experienced the disaster shock (NOY, 2009).

Given that the level of development of a country is important for analyzing the impact of natural disasters, it is widely accepted in the literature that electricity is an essential factor in indicating a nation's stage of development (FERGUSON; WILKINSON; HILL, 2000). Energy consumption increases with the degree of industrialization and technological progress of a country, and this increase is correlated with higher production levels and, consequently, an improved quality of life. Climate is one of the factors that affects energy consumption, as climate shocks are responsible for short- and long-term changes in consumption patterns (AUFFHAMMER; MANSUR, 2014). Some studies specifically focus on the connection between natural disasters and electricity. Chang et al. (2007) analyzed power grid disruptions following extreme events, demonstrating a negative correlation between them. Lee et al. (2021) show that natural disasters have a significant negative impact on the consumption of oil, renewable energy, and nuclear energy.

Analyzing various types of natural disasters, Felbermayr e Gröschl (2014) conclude that the natural correlation between natural disasters and their effects on short-term economic growth variables is inherently negative. The focus on short-term analysis for climate shocks stems from the presumption of the standard neoclassical growth theory that a natural disaster shock does not affect long-term per capita GDP (BERLEMANN; WENZEL, 2018). According to neoclassical theory, these shocks would lead to a temporary increase in the per capita savings rate, resulting in a rise in the per capita capital level until it returns to the pre-shock level.

In practice, the neoclassical assumption that natural disaster shocks do not affect a region's long-term growth may be flawed (BERLEMANN; WENZEL, 2018). One justification is that repeated disasters in a given locality can prevent the country from reaching its natural long-term equilibrium. Individuals may increase their individual savings as a consequence of the higher frequency of natural disasters, thereby raising precautionary savings due to the heightened expectation of greater capital losses. On the other hand, individuals may fail to smooth consumption over their lifetime, resulting in reduced savings due to the increased risk to life (ROSON; CALZADILLA; PAULI, 2006). These factors can be exacerbated by the global warming process of recent decades, driven by human activity, which in turn leads to a greater number of natural disasters.

The contribution of this study is to investigate the effects of natural disasters on the electricity supply in the United States, analyzing at both the energy source level and the state level for each billion-dollar natural disaster over the past 20 years. Although the literature on natural disasters is well-developed, few studies examine the shock to energy generation. Using this dataset may yield new insights into the duration of impact of a given natural disaster, thereby enabling better decision-making by policymakers.

Our results demonstrate that the impacts of natural disasters on energy generation in the United States are heterogeneous, varying significantly by the type of disaster, energy source, and state characteristics. Wildfires predominantly affected renewable energy sources, such as solar and wind energy, with strong impacts observed in states like California, which experienced frequent and intense wildfire activity. Severe storms impacted both renewable and non-renewable energy sources, with significant negative effects on coal and natural gas generation in states like Alabama and Missouri. These findings align with prior studies, such as those by Chang et al. (2007), Pryor e Barthelmie (2010), which emphasize the vulnerability of renewable infrastructure to climatic variability and the physical damage storms inflict on energy systems.

These results emphasize the need for policies promoting resilient renewable energy technologies and decentralized recovery strategies to address state-specific vulnerabilities and reduce dependence on non-renewable sources post-disaster.

This article is organized as follows: Section 2 aims to contextualize the impacts of a natural disaster in terms of quantity and the economic impact among the states and the country. Section 3 presents the dataset used, along with the empirical modeling employed in this study. The final section provides the results and discussion of the empirical analysis

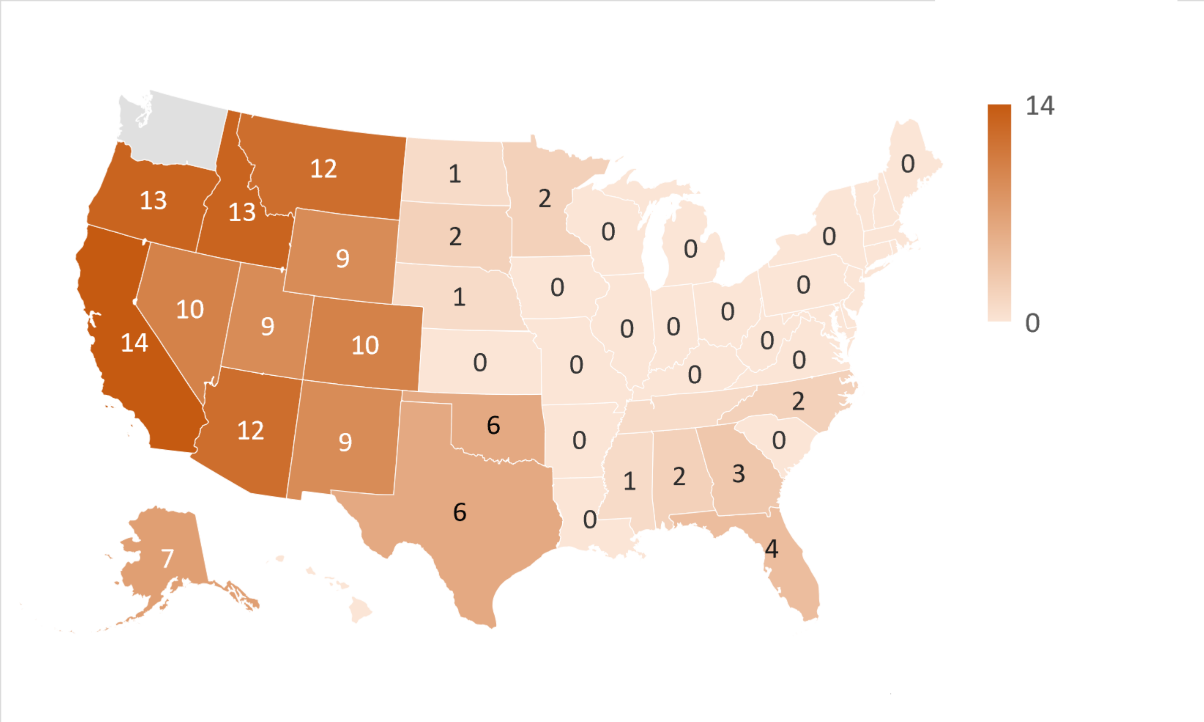
3.2 Contextualization

Electricity distribution systems have always been heavily impacted by natural disasters, and climate change observed in recent decades may exacerbate this issue (HILL et al., 2021). Extreme temperatures, heat waves, or cold snaps lead to increased energy demand, which can negatively affect the operation and distribution of equipment within the electrical system. This situation can result in greater market price volatility and even lead to energy supply shortages.

The increasing intensity and frequency of blackouts caused by climatic events, in addition to the damage inflicted on the population and the economy, remains the greatest vulnerability of electrical infrastructures (MOHAMED et al., 2019). For instance, in 2012, Hurricane Sandy disrupted power for over 9.1 million customers across more than 20 U.S. states, with estimated repairs to the power grid costing over $3.5 billion, and an overall economic impact of approximately $72.0 billion (FORECASTING, 2013).

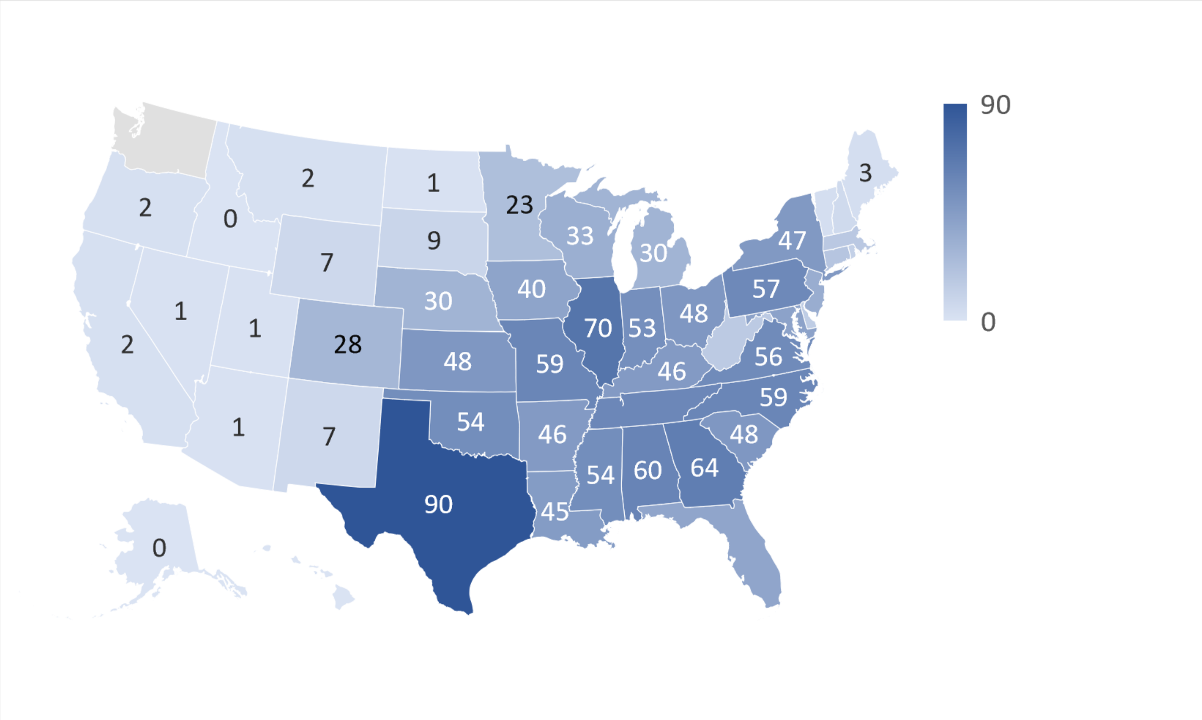
In Figures 2 and 3, we can observe the spatial distribution of these extreme events in the United States. The Northwest and Southwest regions experience a higher incidence of billion-dollar disasters caused by wildfires, whereas the South-Central and Southeast regions show a greater incidence of storms that have resulted in billion-dollar economic losses. This spatial distribution by type of extreme event highlights the need for decentralized disaster impact analyses. As suggested by Ward (2013), Auffhammer e Mansur (2014), Mohamed et al. (2019), studies on the impact of natural disasters on the electrical system should consider the type of natural disaster, the level of development and integration of the region's energy system, as well as the magnitude of the disaster.

Figure 4 – Billion-Dollar Wildfires Events in The U.S. between 2000 and 2022



Source: Own Elaboration.

Figure 5 – Billion-Dollar Storms Events in The U.S. between 2000 and 2022



Source: Own Elaboration.

Table 7 shows the frequency of events that cost more than 1 billion in the United States. It is evident that the number of events has been increasing over the decades. From the period 1980-1989 to 1990-1999, there was a growth of 94.4%; from 1990-1999 to 2000-2009, an increase of 31.42% was observed; and between 2000-2009 and 2010-2019, the number of billion-dollar events rose by 104.3%. This consistent increase in the frequency of natural disasters can be attributed to climate change, as highlighted in the IPCC climate report (SENEVIRATNE et al., 2021).

Following the same trend as the frequency of disasters, it is possible to observe a positive correlation between disasters and costs, as well as between disasters and the number of deaths. Despite increased awareness and the expansion of insurance services against natural disasters, the total number of deaths caused by billion-dollar natural disasters has increased nearly 4.5 times over the past 30 years, rising from 831 deaths during the 1980s to 4,535 deaths in the 2010s. Meanwhile, the cost of disasters has increased more than tenfold over the same period, from $60.8 billion to $694.4 billion. The greater rise in costs compared to deaths is explained by Reidmiller et al. (2017), where the authors highlight factors responsible for the increased costs, including greater exposure and the vulnerability of urban areas.

Table 7 – Frequency of Billion-Dollar Events by State (1980 - 2019)

Years	Billion-Dollar Disasters	Events/Year	Cost	% of Total Cost	Cost/Year	Deaths	Deaths/Year
1980-1989	18	1,8	$60.8B	3.7	$6.1B	831	83
1990-1999	35	3.5	$189.3B	11.5	$18.9B	1,232	123
2000-2009	46	4.6	$471.2B	28.7	$47.1B	2,745	275
2010-2019	94	9.4	$694.4B	42.3	$69.4B	4,535	454

Source: Own elaboration based on EIA data.

While Table 7 provides a general analysis of billion-dollar events in the United States, Table 8 examines each natural disaster individually between 1980 and 2021 in the United States. It can be observed that the most common events are severe storms, accounting for 60.3% of all events; however, they cause the least damage per event ($2.3 billion). The disaster causing the highest damage per event is tropical cyclones, with a total cost of $20.5 billion per event, followed by wildfires, which incur a cost of $6.3 billion per event.

Analyzing the total deaths by type of event, tropical cyclones were responsible for 6,697 deaths between 1980 and 2021, representing an average of 159 deaths per year in the United States. The second most deadly events were severe storms, causing 1,880 deaths, followed by winter storms with 1,277 deaths, and wildfires with 401 deaths.

Table 8 – Billion-Dollar Events in the United States (1980 - 2021)

Disaster	Events	Events/Year	Total Cost	Cost/Event	Cost/Year	Deaths	Deaths/Year
Severe Storm	143	3.4	$330.7B	$2.3B	$7.9B	1,880	45
Tropical Cyclone	56	1.3	$1,148.0B	$20.5B	$27.3B	6,697	159
Winter Storm	19	0.5	$78.6B	$4.1B	$1.9B	1,277	30
Wildfire	19	0.5	$120.2B	$6.3B	$2.9B	401	10
Total	237	5.7	$1,677.5B	$8.3B	$40.0B	10,255	244

Source: Own elaboration based on EM-DATA.

3.3 Methodology

3.3.1 Model

In this article, we will use a dynamic modeling approach to analyze the potential impacts of natural disasters on energy generation. This type of approach is widely used in the natural disaster literature when studying the impacts on energy consumption or economic growth (LEE; CHEN, 2020; PANWAR; SEN, 2019). This approach takes into account the dynamic effects that disasters may have on energy generation; however, dynamic analysis can pose estimation challenges, potentially limiting the robustness of the coefficient estimates.

One of the challenges of using a dynamic panel is the problem of endogeneity, meaning there is a correlation between the estimators and the error term. It is important to note that several authors argue for the possible presence of endogeneity when using EM-DATA, due to the way disaster intensity is calculated—based on total monetary damages, an economic indicator correlated with the region's GDP (PANWAR; SEN, 2019; BERLEMANN; WENZEL, 2018; FELBERMAYR; GRÖSCHL, 2014; BOTZEN; DESCHENES; SANDERS, 2020). Given this issue, standard OLS techniques become inconsistent and unreliable.

To address this problem, this study will employ the ARDL (Autoregressive Distributed Lag) model to detect the short- and long-term dynamics of natural disaster shocks on energy generation. According to Bhat e Mishra (2018), the main advantage of this methodology is that it does not require the assumption that natural disasters and their impacts are exogenous. Another advantage of the ARDL model is its flexibility in handling models where variables are integrated of different orders (I(0) and I(1)). For this purpose, unit root tests were applied to assess the degree of integration of the variables.

The ARDL model is given as follows:

$$Y_t = \varphi + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_j X_{t-j} + \sum_{k=0}^{r} \delta_k Z_{t-k} + \epsilon_t \tag{3.1}$$

where Y_t is the dependent variable (energy generation), X is a dummy variable representing natural disasters, and Z represents the other covariates in the model (GDP, number of consumers, and energy price).

The unrestricted dynamic error correction model (UECM), as described in Pesaran, Shin e Smith (2001), can be represented as:

$$\begin{aligned} \Delta GE_t = \varphi &+ \sum_{j=1}^{p} \phi_2 \Delta GE_{t-j} + \sum_{j=0}^{p} \beta_2 \Delta DN_{t-j} + \sum_{j=0}^{p} \gamma_2 \Delta PIB_{t-j} + \sum_{j=0}^{p} \theta_2 \Delta CON_{t-j} \\ &+ \sum_{j=0}^{p} \delta_2 \Delta PRICE_{t-j} + \alpha_1 Y_{t-j} + \alpha_2 DN_{t-j} + \alpha_3 PIB_{t-j} + \alpha_4 CON_{t-j} \\ &+ \alpha_5 \text{PRICE}_{t-j} + \epsilon_t \end{aligned} \tag{3.2}$$

where GE represents energy generation, DN represents natural disasters, and $CON, PIB, PRICE$ are the covariates in the model: number of consumers, state GDP, and energy price, respectively. Additionally, the equation above can be divided into two distinct segments: $\phi_2, \beta_2, \Delta_2, \gamma_2 e \theta_2$ represent the short-term components; and $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ represent the long-term components of the model. The variable p is the optimal lag of the model, selected using the AIC criterion for each state and for each type of energy generated.

3.3.2 Dataset

In this study, we use monthly data on energy generation and natural disasters. The energy generation data were obtained from the Energy Information Administration and include: hydropower energy (generation from hydropower sources), solar energy (generation from solar sources), nuclear energy (generation from nuclear sources), wind energy (generation from wind sources), oil-based energy (generation from petroleum), biomass energy (generation from biomass), natural gas energy (generation from natural gas), and geothermal energy (generation from geothermal sources). Additionally, electricity prices (residential, commercial, and industrial) were collected for each state.

Natural disaster data were sourced from The International Disasters Database (EM-DATA), which also provided information on the deaths and costs associated with each disaster. Data on population, the number of consumers, and state-level production were collected from the Federal Reserve Economic Data (FRED). The dataset covers the period from January 2000 to December 2021.

Table 9 – Dataset Overview

Variable	Description	Type	Frequency	Source
hydro_energy	Energy generation from hydropower	Numeric	Monthly	EIA
solar_energy	Energy generation from solar sources	Numeric	Monthly	EIA
nuclear_energy	Energy generation from nuclear sources	Numeric	Monthly	EIA
wind_energy	Energy generation from wind sources	Numeric	Monthly	EIA
coal_energy	Energy generation from coal	Numeric	Monthly	EIA
oil_energy	Energy generation from petroleum	Numeric	Monthly	EIA
bio_energy	Energy generation from biomass	Numeric	Monthly	EIA
gas_energy	Energy generation from natural gas	Numeric	Monthly	EIA
disasters	Extreme natural disasters	Dummy	Monthly	EM-DATA
con	Number of consumers in the state	Integer	Monthly	EIA
poil	Crude oil price	Numeric	Monthly	BP
PRICE	Electricity price	Numeric	Monthly	EIA
GDP	Gross Domestic Product	Numeric	Monthly	FRED

Source: Own elaboration.

3.4 Results and Discussion

In this section, we will discuss the results of the model by analyzing the aggregated impact of disasters on the energy generation sector. Subsequently, the analysis will proceed with a more granular approach, detailing both the type of disaster and disaggregating by energy source. This approach is necessary because, in many cases, the resilience of the energy sector can vary depending on the energy source and the type of disaster that occurred in the state.

Before that, we conducted unit root tests using the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and KPSS tests to assess the stationarity of the variables across all states. The results indicate a mix of I(0) and I(1) variables, where some series are stationary at level, while others become stationary only after first differencing. Therefore, the ARDL approach is appropriate for modeling the relationships between these variables while accounting for both short-run and long-run dynamics. Besides that, all models were estimated using the Akaike Information Criterion (AIC) to determine the optimal number of lags for each variable in the model.

Table 10 – ARDL Model: Impact of Natural Disaster in Energy Generation

	Total Non Renewable			**Total Renewable**		
State	Disaster	L(Disaster, 1)	L(Disaster, 2)	Disaster	L(Disaster, 1)	L(Disaster, 2)
Alabama	-0.022	-0.034*	0.036**	-0.014	-0.064*	
Alaska	-0.085*	0.091**		-0.005		
Arizona	-0.002	0.033	-0.038*	0.005		
Arkansas	-0.045*	0.015	0.029	0.008		
California	0.023	0.052	-0.019	-0.002	-0.023	-0.008
Colorado	-0.012	0.035*	-0.001	-0.013	-0.015	0.053
Connecticut	0.003	-0.018	-0.018	-0.022		
Delaware	0.177**	-0.184**		0.09**	-0.016	-0.048
Florida	-0.013	0.009	-0.001	-0.002		
Georgia	0.000	-0.003	0.013	0.002	-0.066***	
Idaho	0.039	0.068	0.183	0.049	-0.016	-0.097**
Illinois	-0.022*	0.008	0.021	0.005	-0.067	-0.078*
Indiana	-0.028	0.017	0.02	0.037	-0.118**	-0.094*
Iowa	-0.043			0.031	-0.036	-0.028
Kansas	0.018	-0.025	0.087***	0.072*	-0.075	-0.045
Kentucky	-0.038*	0.008	0.011	-0.027		
Louisiana	-0.03	-0.011	0.029	0.012	-0.024	
Maine	0.299*	-0.416***		-0.023		
Maryland	0.004			0.061		
Massachusetts	0.043	-0.136***	0.115**	-0.005		
Michigan	-0.007			0.009		
Minnesota	-0.003	-0.072**	0.039	0.052	-0.065	-0.001
Mississippi	0.029	-0.047	0.021	-0.001		
Missouri	-0.01	0.005	0.031	0.062		
Montana	-0.208***	0.078	0.173***	0.083**	-0.059	-0.042
Nebraska	-0.034*	-0.027	0.008	0.006	-0.049*	
New Hampshire	-0.11	0.125		0.034	-0.076	0.102**
New Jersey	-0.042**			0.015		
New York	0.017	-0.041**	0.022	-0.023**	-0.001	-0.013
North Carolina	-0.011	0.014	-0.003	0.017		
North Dakota	-0.002	-0.031	0.028	-0.009		
Ohio	-0.013	-0.003	0.011	0.016	-0.065**	
Oklahoma	0.005	0.007	0.085***	0.015	-0.012	-0.073*
Oregon	-0.003	0.102	0.092	0.003	0.002	-0.081*
Pennsylvania	-0.022	0.016	0.002	0.021	-0.04	-0.029
Rhode Island	-0.033			0.006		
South Carolina	0.005	-0.023	0.032**	-0.029	-0.059**	
South Dakota	0.052			0.04		
Tennessee	-0.004	0.02	0.014	-0.054		
Texas	-0.016	0.047**	0.032	0.053	-0.035	-0.061*
Utah	0.046**			0.048	-0.057	-0.052
Vermont	0.23	0.232	-0.508*	-0.05		
Virginia	-0.026	0.009	-0.019	-0.011	-0.029	-0.019
Washington	0.094	0.074	-0.046	0.003	0.039	-0.093**
West Virginia	-0.042	0.062	-0.051	-0.099*		
Wisconsin	-0.006	-0.001	0.037*	0.013	-0.004	-0.039
Wyoming	-0.002	0.047	-0.001	0.03		

Source Own Elaboration.

Table 10 presents the overall results of the impacts of natural disasters on total non-renewable and renewable energy generation across all U.S. states that experienced disasters during the analyzed period. It is observed that in states like Alabama and

Illinois, there is a significant negative impact on non-renewable energy production when a disaster occurs, suggesting that the energy infrastructure in these states is sensitive to such events. Specifically, in Alabama, the effect of disasters appears to persist, with only partial recovery occurring two lags after the initial event.

Additionally, states vary in their responses to disasters, as observed in Delaware and Montana. In Delaware, there is a positive but short-lived impact, indicating that local conditions allow for rapid adaptation and recovery. In Montana, a mixed pattern emerges where disasters initially have a negative impact on non-renewable energy production, but a significant recovery occurs in the subsequent lag.

For renewable energy, the response to disasters is more negative and significant in many states. States like Indiana and Oregon exhibit persistent negative effects over the lags, indicating that renewable energy generation is particularly sensitive to adverse climatic events. This sensitivity may be due to the nature of these sources, such as solar and wind energy, which rely heavily on favorable environmental conditions (PRYOR; BARTHELMIE, 2010; SCHAEFFER et al., 2012). This heightened sensitivity underscores the need for policies aimed at improving the resilience of renewable energy sources, including investments in weather-resistant technologies and mitigation strategies to prevent prolonged disruptions.

Since the results vary significantly from state to state, this difference may be due to the aggregation of the energy production sector or the aggregation of environmental impacts. Mideksa e Kallbekken (2010), Schaeffer et al. (2012) argue that energy production and distribution, the technologies used for input generation, and the entire energy system can be influenced by environmental variables, including extreme events. Moreover, these factors and their related impacts differ across states and types of energy generation. Therefore, it is essential to conduct an analysis that disaggregates factors both at the energy source level and by the type of disaster.

Table 11 – ARDL Model: Impact of Wildfire

	Total Non Renewable			Total Renewable		
	Wildfire	L(wildfire, 1)	L(Wildfire, 2)	Wildfire	L(wildfire, 1)	L(Wildfire, 2)
Arizona	0.002	0.030	-0.058**	-0.035		
	(0923)	(0.373)	(0.024)	(0.124)		
California	0.028	0.082**	-0.043	-0.111***	0.097***	-0.065**
	(0.296)	(0.020)	(0.122)	(0.000)	(0.006)	(0.017)
Colorado	-0.006	0.045	-0.015	-0.031	-0.008	0.033
	(0.778)	(0.130)	(0.536)	(0.458)	(0.876)	(0.453)
Idaho	0.241**			-0.075	0.059	-0.040
	(0.017)			(0.108)	(0.335)	(0.396)
Montana	-0.046	0.226***		-0.010	0.063	-0.114**
	(0.475)	(0.000)		(0.815)	(0.265)	(0.010)
Oregon	-0.038	0.141	0.045	-0.035	-0.027	-0.001
	(0.751)	(0.361)	(0.706)	(0.371)	(0.582)	(0.961)
Texas	-0.017	0.103**	-0.079**	-0.061		
	(0.611)	(0.015)	(0.015)	(0.104)		
Utah	0.087***			-0.081**		
	(0.001)			(0.034)		
Washington	0.181	-0.058	-0.033	-0.037	0.053	-0.052
	(0.102)	(0.694)	(0.772)	(0.371)	(0.335)	(0.231)
Wyoming	0.041	0.032	0.088	0.003	-0.059	0.159***
	(0.160)	(0.419)	(0.997)	(0.954)	(0.434)	(0.007)

Source: Own Elaboration.

Following the analysis that the effects of a disaster can be more pronounced when disaggregated by energy source or type of natural disaster, Table 11 presents the impacts of billion-dollar wildfires on renewable and non-renewable energy generation. This table includes only the 10 states with the highest number of such disasters during the analyzed period.

In Arizona and California, wildfires have significant negative impacts on renewable energy production, suggesting that the infrastructure for clean energy sources is highly susceptible to wildfires. In particular, in California, a state frequently affected by wildfires, adverse effects are observed both at the time of the event and in subsequent lags. This prolonged impact reflects not only the frequency of wildfires but also the nature of the damage they cause, underscoring the importance of rapid prevention and recovery strategies. For California, Wang et al. (2021) demonstrate that the increasing frequency and intensity of wildfires will exponentially affect the state's electric transmission lines, estimating that within 30 years, 40% of the transmission network will be located in high-risk areas.

Idaho and Utah, on the other hand, show a positive impact on non-renewable energy following wildfires, which can be interpreted as an increase in production to compensate for losses in renewable sources. This compensatory effect suggests that the non-renewable energy infrastructure in these states is relatively adaptable, enabling a rapid increase in production when other sources fail. However, the positive impact may also indicate an undesirable dependence on non-renewable sources during critical moments, raising concerns about sustainability.

Table 12 – ARDL Model: Impact of Severe Storm

	Total Non Renewable			Total Renewable		
	Storm	L(Storm, 1)	L(Storm, 2)	Storm	L(Storm, 1)	L(Storm, 2)
Alabama	-0.079***	-0.036*	0.002	0.057	-0.077*	
	(0.000)	(0.080)	(0.913)	(0.184)	(0.074)	
Arkansas	-0.089***	-0.001	-0.010	0.055		
	(0.005)	(0.959)	(0.737)	(0.148)		
Georgia	-0.029	-0.010	0.030	0.007		
	(0.173)	(0.620)	(0.147)	(0.741)		
Illinois	-0.026*	0.022	0.022	-0.052	-0.111**	-0.103**
	(0.058)	(0.106)	(0.107)	(0.269)	(0.020)	(0.028)
Indiana	-0.041*	0.026	0.023	0.022	-0.142***	-0.152***
	(0.068)	(0.244)	(0.299)	(0.654)	(0.004)	(0.003)
Kansas	0.043	-0.002	0.106***	-0.060	-0.021	-0.101**
	(0.122)	(0.935)	(0.000)	(0.122)	(0.615)	(0.018)
Missouri	-0.047**	0.021	0.024	0.058		
	(0.026)	(0.335)	(0.250)	(0.271)		
Oklahoma	0.001	0.020	0.107***	0.020	0.031	-0.084**
	(0.957)	(0.535)	(0.001)	(0.618)	(0.459)	(0.040)
Tennessee	-0.070**	0.064**	-0.022	-0.037	-0.080	
	(0.013)	(0.028)	(0.438)	(0.135)	(0.671)	
Texas	-0.022	0.051***	0.067***	0.084***		
	(0.206)	(0.005)	(0.000)	(0.004)		

Source: Own Elaboration.

Following the same analysis as Table 11, Table 12 shows the impacts of severe storms on renewable and non-renewable energy generation in U.S. states. For this analysis, the 10 states with the highest occurrence of severe storms during the analyzed period were selected.

As seen in Table 8, severe storms (including storms and tropical cyclones) are the most frequent events over the past 40 years, as well as those causing the greatest monetary losses to states. Given the high degree of damage caused by these events, a significant negative impact on non-renewable energy production is observed during and after the storms for almost all states in the sample. This may indicate that infrastructure in these states is vulnerable to physical damage caused by strong winds and heavy rainfall. The slow recovery following the storm suggests that these regions may face challenges in restoring generation capacity, possibly due to resource limitations or difficulties in immediate repairs (REED; POWELL; WESTERMAN, 2010; WARD, 2013).

It is possible to observe that in Illinois, the effect is more persistent, impacting production over multiple lags, which suggests that the renewable energy infrastructure is less adaptable to extreme weather events. On the other hand, in Indiana, the negative impact is significant in the initial lags but seems to ease over time, indicating a faster recovery. This difference highlights how local policies and infrastructure vary between states and can influence post-disaster recovery.

In Texas, non-renewable energy production shows a significant positive recovery in the lags following a severe storm, indicating that the state is capable of quickly restoring production. However, this may also reflect a high dependence on non-renewable sources to meet energy demand after disasters, as the disaster has a positive and significant effect on this type of energy source.

According to Leslie (2021), Busby et al. (2021), the positive parameters associated with Texas may be due to the fact that energy producers in the state are compensated only when energy is generated, not for investments in stored energy capacity. This suggests that disasters may prompt producers to increase output to compensate for momentary blackouts. In other words, the positive effect may not necessarily be tied to the resilience of the energy sector.

Table 13 – ARDL Model: Impact of Wildfire on Various Renewable Energy Generation Sources

	Hydro			Solar			Wind			Biomass		
	Wildfire	L(,1)	L(,2)	Wildfire	L(,1)	L(,2)	Wildfire	L(,1)	L(,2)	Wildfire	L(,1)	L(,2)
Arizona	0.005			-0.027			0.121	-0.179	0.156	0.107	-0.513***	0.217
	(0.841)			(0.579)			(0.247)	(0.185)	(0.128)	(0.471)	(0.008)	(0.141)
California	-0.128***	0.185***	-0.108**	-0.029	0.007	-0.320***	-0.169**	0.044	-0.083	-0.000		
	(0.009)	(0.002)	(0.021)	(0.806)	(0.962)	(0.009)	(0.021)	(0.626)	(0.259)	(0.979)		
Colorado	-0.057			-0.131**	0.102	-0.134**	-0.007			-0.033*		
	(0.618)			(0.036)	(0.206)	(0.039)	(0.536)			(0.072)		
Idaho	-0.066	0.070	-0.071				0.031			-0.016		
	(0.267)	(0.360)	(0.231)				(0.450)			(0.497)		
Montana	0.029	0.009	-0.175***				-0.112	0.014	0.105	0.100	-0.037	-0.045
	(0.597)	(0.167)	(0.002)				(0.115)	(0.869)	(0.140)	(0.317)	(0.777)	(0.662)
Oregon	-0.080	-0.005	0.048	-0.158***			0.098	-0.119	-0.138	0.019		
	(0.107)	(0.930)	(0.324)	(0.000)			(0.258)	(0.285)	(0.124)	(0.499)		
Texas	-0.226			-0.043			-0.060			-0.013		
	(0.127)			(0.436)			(0.144)			(0.668)		
Utah	-0.079**						-0.026			0.027	-0.053	0.018
	(0.025)						(0.761)			(0.334)	(0.166)	(0.537)
Washington	-0.039	0.055	-0.049	-0.019	-0.077	0.020	0.036			0.021	0.093*	-0.096***
	(0.409)	(0.382)	(0.315)	(0.651)	(0.190)	(0.643)	(0.630)			(0.545)	(0.052)	(0.009)
Wyoming	-0.030	0.106	-0.144				-0.003	-0.048	0.188**			
	(0.746)	(0.394)	(0.138)				(0.960)	(0.604)	(0.010)			

Source: Own Elaboration.

The results in Table 13 show that wildfires distinctly affect renewable energy sources. It is observed that California is the most sensitive state to disasters of this nature. The impact on energy generation is negative and significant for all renewable sources, except for biomass energy. This result can be attributed to the fact that California was the most affected state by wildfires during the analyzed period, as evidenced by Figure 1 in the appendix. Furthermore, since California is the state that imports the most electricity from other states, both the transmission system and the energy imports themselves can be disrupted by wildfires within the state or in the regions from which energy is imported (U.S. Energy Information Administration (EIA), 2024).

Additionally, states like Colorado and Oregon showed negative impacts on solar energy generation, while Utah and Montana recorded negative impacts on hydropower generation. These disaggregated results highlight how energy mixes vary across states and how certain types of energy sources or electrical systems may be more sensitive to environmental impacts. When comparing these results with those in Table 12, it is noted that, while some states do not show significant impacts on aggregated renewable energy, specific generation sources, such as those in Colorado and Oregon, are sensitive to wildfires.

Table 14 – ARDL Model: Impact of Wildfire on Various Non-Renewable Energy Generation Sources

	Coal			Petroleum			Nuclear			Natural Gas		
	Wildfire	L(,1)	L(,2)	Wildfire	L(,1)	L(,2)	Wildfire	L(,1)	L(,2)	Wildfire	L(,1)	L(,2)
Arizona	-0.008			0.061			-0.049	0.052	-0.008	0.093	0.014	-0.171
	(0.740)			(0.343)			(0.204)	(0.292)	(0.817)	(0.156)	(0.863)	(0.863)
California	-0.036			0.132			-0.043	0.162**	-0.145**	0.044	0.072	-0.039
	(0.571)			(0.149)			(0.474)	(0.034)	(0.015)	(0.210)	(0.114)	(0.276)
Colorado	-0.027	0.041	0.010	-0.032						0.037		
	(0.358)	(0.276)	(0.745)	(0.504)						(0.281)		
Idaho	0.158**									0.246**		
	(0.029)									(0.021)		
Montana	-0.044	0.233***		0.149						-0.029		
	(0.529)	(0.000)		(0.216)						(0.813)		
Oregon	1.024***			0.096						-0.098	0.199	0.044
	(0.001)			(0.150)						(0.453)	(0.235)	(0.735)
Texas	-0.014	0.042	-0.046	-0.089	-0.374*	0.330**	-0.029			-0.010	0.114*	-0.101**
	(0.738)	(0.432)	(0.261)	(0.554)	(0.057)	(0.029)	(0.391)			(0.816)	(0.052)	(0.023)
Utah	0.099***			-0.002						0.069		
	(0.000)			(0.964)						(0.123)		
Washington	0.575	0.027	0.594	-0.015			0.125			0.154	-0.047	-0.096
	(0.137)	(0.995)	(0.144)	(0.840)			(0.376)			(0.314)	(0.819)	(0.545)
Wyoming	0.040	0.036	-0.001	0.020						0.028		
	(0.187)	(0.374)	(0.977)	(0.312)						(0.526)		

Source: Own Elaboration.

Unlike what is observed in Table 13, Table 14 reveals that non-renewable energy generation is more resilient to wildfires in California. This result can be explained by external factors, such as the low level of non-renewable energy generation in the state (U.S. Energy Information Administration (EIA), 2024). Another interesting point in this table is that states like Oregon, Utah, and Idaho show positive and significant impacts on coal-based energy generation. One possible explanation for this increase in energy production is the need to compensate for losses in renewable sources. These results suggest that the non-renewable sector may be more resilient in these states. These findings are consistent with the results in Table 11, which show that wildfires lead to an increase in aggregated non-renewable energy generation.

Table 15 – ARDL Model: Impact of Storm on Various Renewable Energy Generation Sources

	Hydro			Solar			Wind			Biomass		
	Storm	L(,1)	L(,2)	Storm	L(,1)	L(,2)	Storm	L(,1)	L(,2)	Storm	L(,1)	L(,2)
Alabama	0.077	-0.151**								0.054		
	(0.223)	(0.019)								(0.530)		
Arkansas	0.130*									-0.061***		
	(0.055)									(0.000)		
Georgia	-0.014	-0.118***								-0.016		
	(0.692)	(0.001)								(0.237)		
Illinois	0.104*			0.078**	0.084**		-0.062	-0.109**	-0.115**	0.042*		
	(0.080)			(0.047)	(0.036)		(0.231)	(0.037)	(0.028)	(0.054)		
Indiana	-0.035						0.007	-0.189**	-0.333***	0.025		
	(0.696)						(0.912)	(0.010)	(0.000)	(0.146)		
Kansas	0.045						-0.060	-0.021	-0.102**	-0.218***	-0.034	-0.030
	(0.326)						(0.128)	(0.614)	(0.018)	(0.001)	(0.635)	(0.674)
Missouri	0.168*						0.015	0.003	-0.077	0.011		
	(0.069)						(0.764)	(0.948)	(0.118)	(0.804)		
Oklahoma	0.158						0.019	0.007	-0.147***	-0.092	-0.162**	
	(0.150)						(0.656)	(0.868)	(0.002)	(0.178)	(0.020)	
Tennessee	-0.061	-0.086	0.041				-0.004	-0.092		0.032		
	(0.301)	(0.148)	(0.478)				(0.937)	(0.118)		(0.138)		
Texas	0.225*	0.138	-0.102	0.116***			0.053*	0.000	-0.063**	-0.011		
	(0.051)	(0.241)	(0.380)	(0.004)			(0.087)	(0.975)	(0.040)	(0.642)		

Source: Own Elaboration.

In Tables 15 and 16, we analyze the impacts of severe storms on different types of energy generation. In general, wind energy is the most negatively affected by this type of disaster. States like Texas, Illinois, Indiana, Kansas, and Oklahoma show significant negative effects in at least one of the model's lags. One factor that may explain this negative impact on wind energy generation is the physical infrastructure required for its production. Jung et al. (2017) argue that if wind speeds become too high, it is necessary to shut down equipment to prevent structural damage.

Table 16 – ARDL Model: Impact of Storm on Various Non-Renewable Energy Generation Sources

	Coal			Petroleum			Nuclear			Natural Gas		
	Storm	L(,1)	L(,2)	Storm	L(,1)	L(,2)	Storm	L(,1)	L(,2)	Storm	L(,1)	L(,2)
Alabama	-0.119***			-0.151**			-0.023	-0.070***		-0.073**		
	(0.000)			(0.069)			(0.331)	(0.004)		(0.025)		
Arkansas	-0.144***			-0.101			0.039	-0.127		-0.037		
	(0.006)			(0.334)			(0.658)	(0.149)		(0.553)		
Georgia	-0.039			-0.056	-0.036	0.129	-0.033*	-0.042**	0.026	-0.037	0.004	0.001
	(0.449)			(0.707)	(0.810)	(0.392)	(0.098)	(0.039)	(0.197)	(0.228)	(0.887)	(0.958)
Illinois	-0.070**	0.075***		0.017			-0.002	0.019*	0.019*	0.216***	0.268***	0.196**
	(0.011)	(0.007)		(0.757)			(0.843)	(0.063)	(0.053)	(0.003)	(0.000)	(0.010)
Indiana	-0.062**	0.028	0.021	0.026						0.052	0.110**	
	(0.028)	(0.311)	(0.446)	(0.660)						(0.346)	(0.049)	
Kansas	0.045	-0.023	0.114***	0.034	0.155	-0.259***	-0.013	0.531	0.659*	0.177**	0.086	0.135*
	(0.164)	(0.497)	(0.001)	(0.704)	(0.111)	(0.008)	(0.968)	(0.136)	(0.066)	(0.016)	(0.273)	(0.090)
Missouri	-0.059***	0.029	0.011	-0.285***	-0.048	-0.261***	0.044	0.211	0.060	-0.083		
	(0.008)	(0.221)	(0.582)	(0.005)	(0.634)	(0.009)	(0.861)	(0.427)	(0.824)	(0.307)		
Oklahoma	-0.069			-0.069	-0.046	0.025				0.037	0.073*	0.153***
	(0.295)			(0.480)	(0.655)	(0.798)				(0.355)	(0.088)	(0.000)
Tennessee	-0.079	0.087		0.063			-0.071**			0.040	-0.003	-0.148
	(0.154)	(0.114)		(0.542)			(0.016)			(0.722)	(0.979)	(0.198)
Texas	-0.005	0.056**	0.047**	0.158**	-0.017	-0.066	-0.050*			0.006	0.053**	0.075***
	(0.786)	(0.011)	(0.035)	(0.045)	(0.832)	(0.395)	(0.050)			(0.780)	(0.019)	(0.001)

Source: Own Elaboration.

When analyzing the impacts on non-renewable energy sources, it is observed that this type of source is more sensitive to severe storms than renewable sources. Table 16 shows that Alabama, Arkansas, Illinois, Indiana, and Missouri record negative and significant impacts on coal-based energy generation. Additionally, in the state of Alabama, all four energy sources analyzed experience negative and significant effects, indicating that the state is not resilient to this type of disaster. These results are more pronounced for non-renewable energy because, in general, these states have energy mixes predominantly based on polluting sources.

Finally, it is observed that the aggregated results for Texas remain consistent when the sample is disaggregated by energy type. The positive and significant result for Texas may be related to the unique characteristics of the state's electrical system. Unlike the rest of the country, Texas has its own power generation and transmission system, without integration with other systems. Additionally, there are no incentives for producers to store energy, so a disaster is followed by an increase in electricity production to avoid blackouts in cities or to compensate for damage to the distribution network.

3.5 Conclusion

The analysis of the impacts of natural disasters on energy generation in the United States reveals that these events have significant and differentiated effects on renewable and non-renewable energy sources, depending on the type of disaster and the affected state. The ARDL methodology used allowed for the identification of how each energy type responds to extreme weather events, from wildfires to severe storms. These results shows the vulnerability of U.S. energy infrastructure, particularly in relation to natural disasters that, becoming more frequent and intense, directly impact the resilience and continuity of energy generation.

The impacts vary according to the energy source. In California, renewable energy generation was particularly susceptible to wildfires, while severe storms negatively affected energy generation in almost all states (the top 10 states most affected by this type of disaster). These effects highlight the need for climate adaptation policies that consider local specifics and different energy sources. Additionally, the results suggest a possible dependence on non-renewable sources as a compensation mechanism, given that is possible to notice the increase of the consumption of this type of source some periods ahead after the disaster, which raises concerns about long-term energy sustainability.

Another important point for future studies is the role of infrastructure and the recovery capacity of each state. States with more robust and adaptable infrastructure could demonstrate greater recovery capacity after disasters, which shows the importance of investments in resilient technologies and mitigation strategies, especially for renewable sources, which, due to their nature, are more vulnerable to climate variations.

This study contributes to the understanding of the impacts of natural disasters on energy generation in the United States, both at the state level and by energy source. The ARDL modeling applied is a valuable tool for analyzing variations in different types of energy generation caused by various natural disasters. Therefore, this research is important as it provides new insights for policymakers, helping them design new strategies to enhance energy resilience and mitigate the impacts of future disasters.

4 Did The Green Brazil Operation Have an Effect on Reducing Wildfires in the Legal Amazon?

Resumo

A Amazônia Legal, um importante bioma para a estabilidade climática global, tem experimentado um aumento significativo em incêndios florestais, impulsionados por fatores naturais e humanos. Em resposta, o governo brasileiro elaborou as Operações Verde Brasil (1 e 2) para combater o desmatamento ilegal e incêndios florestais. Este estudo avalia a eficácia dessas operações na redução de ocorrências de incêndios florestais usando uma metodologia Difference-in-Differences (DiD) através de dados em painel mensal durante o período de 2017–2023. Os resultados indicam que nenhuma das operações reduziu significativamente os focos de incêndio. Além disso, ao contrário dos objetivos da política, o número de multas ambientais diminuiu durante os períodos operacionais. Essas descobertas destacam as limitações das Operações Verde Brasil em abordar as causas principais dos incêndios florestais e ressaltam a necessidade de estratégias mais abrangentes e integradas que alinhem a fiscalização com as realidades socioeconômicas na região.

Palavras-Chave: Incêndios, Meio Ambiente, Amazônia Legal, DiD

Abstract

The Legal Amazon, a critical biome for global climate stability, has experienced a significant increase in wildfires, driven by both natural and human factors. In response, the Brazilian government launched the Green Brazil Operations (1 and 2) to combat illegal deforestation and wildfires. This study evaluates the effectiveness of these operations in reducing wildfire occurrences using a Difference-in-Differences (DiD) methodology on a monthly panel dataset spanning 2017–2023. Results indicate that neither operation significantly reduced fire outbreaks. Additionally, contrary to policy objectives, the number of environmental fines decreased during the operational periods. These findings highlight the limitations of the Green Brazil Operations in addressing the root causes of wildfires and underscore the need for more comprehensive, integrated strategies that align enforcement with socio-economic realities in the region.

Keywords: Wildfire, Environment, Legal Amazon, DiD

4.1 Introduction

Established in 1953, the Legal Amazon is a region corresponding to 59% of the Brazilian territory, representing a total area of 5.0 million km². This region was established due to the need to plan and promote the economic and sustainable development of the region. Although wildfires in the Amazon rainforest have become more common, in recent years, there has been an increase in these fires above the historical average (109,042 fire outbreaks per year between 1998 and 2023). According to data from RAISG (Georeferenced Amazon Socio-Environmental Information Network), fires expanded by 256,000 km² in 2019, 271,000 km² in 2020 and 173,000 km² in 2021. During these three years, the surface area affected by wildfires reached a cumulative total of approximately 700,000 km², equivalent to a territory larger than France.

Forest fires occurring in the Amazon come from natural factors, such as prolonged droughts, and factors linked to human activities, such as deforestation for agriculture or livestock farming in the region or the use of burning techniques for soil preparation (COCHRANE; BARBER, 2009; JONES et al., 2022). According to data from RAISG, between 2019 and 2021, 59% of the affected areas were considered new fire areas. That is, they are areas that have never had recorded fires. This data could indicate human involvement in the region's increased fire incidents (BERLINCK; BATISTA, 2020).

Given this, the Brazilian government launched two policies with the purpose of combating and preventing environmental crimes in the Legal Amazon, with a primary focus on illegal deforestation and wildfires. The first policy, called 'Verde Brasil 1' (Green Brazil 1), was carried out between the period from August 24, 2019, to September 24, 2019, while the second environmental policy, called 'Verde Brasil 2' (Green Brazil 2), lasted for almost a year, from May 6, 2020, to April 31, 2021. These operations involved the presence of the Brazilian army, working together with environmental agencies in cities, environmental reserves, and border regions of the Amazon to combat illegal environmental practices and prevent wildfires. Considering the issues caused by wildfires, it is important to assess whether the Green Brazil 1 and Green Brazil 2 operations effectively prevented and combat wildfires in the Brazilian Legal Amazon.

The main objective of this study is to evaluate the effectiveness of the operation "Verde Brasil 1"and "Verde Brasil 2"policies in combating and preventing wildfires in the Legal Amazon and the capacity of these policies in reducing CO2 emissions resulting from wildfires.

Since Brazil contains 60% of the Amazon rainforest, considered the largest tropical forest in the world, the increase in the number of wildfires caused by human activities can result in regional and global problems. Silva et al. (2020) showed that the fires in Amazon in 2019 were responsible for the emission of 295 million tons of CO2 into the atmosphere, representing 16% of the country's emissions and potentially causing long-term issues like global warming. At the regional level, wildfires can disrupt the natural rainfall cycle of a region, consequently affecting soil fertility and the quantity and quality of water in rivers and basins in the region. Gas emissions from fires can also lead to health problems in local communities (PIVELLO et al., 2021).

Fires are seen as one of the main causes of the destruction of forest ecosystems worldwide, posing a threat not only to the loss of local biodiversity but also to local communities, the economy, and public health. Given the importance of the Amazon region in the global climate, several environmental policies have been implemented to reduce and combat fires in the region.

According to Aragao et al. (2008), deforestation in the Amazon region reaches its peak during July and September, which is the period of cutting and agricultural burning in the region. In summary, after cutting, there is enough time for the fallen wood to dry until the driest month, when farmers set fire to the dry material on the ground. As also noted by Li et al. (2007), fires resulting from human, intentional, or accidental ignitions can grow to significant proportions due to the Amazon's summer climate, as there will be drier tree biomass available for the spread of the fire.

Reinforcing this connection, Marle et al. (2017) using data of fire emissions identified that 31% of the fires in the Amazon, between 1973 and 2014, were attributed to deforestation, while natural factors or human actions caused 69% of the cases. Given that human activities has an important impact in the spread of wildfires, Morello et al. (2020) emphasize that wildfire prevention policies in the Legal Amazon were developed specifically to mitigate these impacts. These policies include the prohibition of fire use for agriculture at the state level, subsidies for farmers who choose not to use fire, and environmental education programs aimed at protecting the biome. The authors highlight that the strategic allocation of federal and state firefighters can help mitigate the spread of fires in large areas of the Amazon region.

Even though the importance of wildfire prevention policies is well established in the literature, Schmidt e Eloy (2020) show that the fires that occurred during the year 2019 in Brazil were influenced by changes resulting from the political scenario in Brazil. The authors emphasize that reductions in investments in environmental protection, the weakening of punitive laws for environmental crimes, and certain political decisions were key factors contributing to the increase in the number of fires recorded in the Amazon in recent years. Also, in connection with the political scenario, Eufemia et al. (2022) argue that, given the complexity and size of the region, these policies face significant challenges in containing or reversing deforestation and wildfire trends. These findings align with the results of this study, which show that municipalities receiving the policy did not experience a reduction in fire outbreaks compared to those that did not.

Our findings show that neither operation significantly reduced fire outbreaks, and, in fact, there was a decline in the number of environmental fines during the policy periods, which contradicts the policy's objectives. Furthermore, the results confirm that temperature and precipitation remain significant predictors of fire outbreaks, consistent with earlier findings by (COCHRANE; BARBER, 2009) and (FONSECA et al., 2019). The analysis also reveals that human activities, particularly increases in planted area, continue to be important drivers of wildfire occurrences.

These results suggest that enforcement-based environmental interventions, when not connected with socio-economic strategies, may fall short of addressing the root causes of Amazonian wildfire. The chapter proceeds as follows: Section 3.2 provides context on the policy background; Section 3.3 outlines data and empirical strategy; Section 3.4 presents the results; and Section 3.5 concludes with implications and directions for future policy design.

4.2 Policy Background

The Legal Amazon has witnessed a significant increase in wildfires in recent years, surpassing historical averages. These fires in the region are a result of a complex interaction between natural factors, such as droughts, and human activities, including deforestation for agriculture, livestock farming, and the use of burning techniques for soil preparation. This increase in wildfires on Amazon has raised concerns due to its potential regional and global consequences.

Operation Green Brazil was created in response to the escalating deforestation and wildfires within the Amazon region. The primary goal of this operation was to mobilize the Armed Forces, along with public security and environmental agencies, to combat these illegal activities. The deployment of the Armed Forces was regulated by Decree 9,985/2019 and 10,341/2020, which determined the cooperation between the military and public security agencies, including the Federal Police, the National Public Security Force, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), and the Chico Mendes Institute for Biodiversity Conservation (ICMBio). (DECREE. . . , 2019; DECREE. . . , 2020)

The selection of municipalities for intervention was based on three primary criteria. First, historical data on deforestation and fires was analyzed, with municipalities experiencing significant rates prioritized for military intervention, although the specific thresholds or indicators used for this assessment are not disclosed in the available documentation. Second, due to the region's vast and remote nature, areas known to have the presence of armed groups involved in illegal activities were targeted by the operation to ensure the safety of both personnel and local residents, yet no detailed methodology for identifying such areas is provided. Finally, the capacity of local enforcement agencies was assessed, and military support was deployed to areas where their resources were insufficient to combat deforestation and wildfires.

Also, the selection of municipalities for intervention under the operation was coordinated by the Grupo de Integração para a Proteção da Amazônia (GIPAM), operating from the CENSIPAM facilities in Brasilia. The prioritization of areas was based on a multidisciplinary methodology, which included representatives from agencies such as IBAMA, ICMBio, the Federal Police, ABIN, INCRA, and others. The methodology relied on remote sensing technologies—such as satellite imagery, radar, and aerial surveillance using remotely piloted aircraft systems (SARP) to identify polygons of illegal deforestation and fire activity. These polygons were prioritized based on several criteria: (i) location within protected areas such as conservation units or indigenous lands; (ii) proximity to remaining forest fragments; (iii) accessibility and closeness to urban centers or road networks; (iv) spatial relation to existing deforestation zones; and (v) rate of expansion (OFFICIAL. . . , 2021).

Table 17 – Fire Outbreak by State

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Amapa	1,946	1,206	1,277	750	676	990	2,552
Acre	6,295	6,626	6,802	9,193	8,828	11,840	6,562
Amazonas	11,685	11,446	12,676	16,729	14,848	21,217	19,604
Maranhao	25,576	13,892	18,521	16,817	16,077	20,224	21,113
Mato Grosso	30,911	18,032	31,169	47,708	22,520	29,039	21,723
Para	49,770	22,080	30,165	38,603	22,876	41,421	41,719
Rondonia	11,313	10,255	11,230	11,145	10,030	12,460	7,417
Roraima	1,565	2,383	4,784	1,930	989	1,223	2,659
Tocantins	15,673	8,033	13,625	12,093	10,007	12,145	9,641
Total	154,734	93,953	130,249	154,968	106,851	150,559	132,990

Source: Own elaboration

Table 17 provides a detailed overview of fire outbreaks in different states within the Legal Amazon region over a seven-year period, from 2017 to 2023. The total number of fire outbreaks in the region shows considerable variation, with a peak in 2020 (154,968 outbreaks) and a notable decrease in 2023 (132,990 outbreaks). The trend suggests cyclical patterns, likely influenced by varying environmental conditions, regulatory measures, and human activities. In particular, we see an increase in fire outbreaks from 2018 to 2020, rising from 93,953 in 2018 to 130,249 in 2019, and reaching 154,968 in 2020. This represents a 64.92% increase in fire outbreaks during this period. This increase was a key factor in the implementation of Operation Green Brazil.

Based on the three key criteria, Operation Green Brazil 1 was implemented in 71 municipalities, while Operation Green Brazil 2 expanded its reach to 129 municipalities. Both operations were carried out across all states of the Legal Amazon. The duration and intensity of these operations varied, with Operation Green Brazil 1 averaging 54 days per municipality, while Green Brazil 2 extended to 292 days per municipality. Another difference is that the daily deployment of military personnel increased between the operations, from 1,411 to 2,500, indicating an escalation in operational scale and resource allocation in the region.

Table 18 – Number of municipalities and regions by State

	Total	**Green Brazil 1**	**Green Brazil 2**	**Both Operations**	**Only Green Brazil 2**
Acre	22	8	16	7	9
Amapa	16	1	2	1	1
Amazonas	62	17	24	10	14
Rondonia	52	2	19	2	17
Roraima	15	7	9	3	6
Tocantins	139	1	0	0	0
Para	144	8	28	2	26
Maranhao	79	1	4	0	4
Mato Grosso	141	11	15	5	10
Total	670	71	129	33	96

Source: Own elaboration

As shown in Table 18, the state most targeted by Operation Green Brazil 1 was Amazonas, with 17 municipalities and regions, whereas for Operation Green Brazil 2, the state of Para had the most units included in the program, with 28 in total. Another factor in our analysis is that out of the 129 municipalities targeted by Operation Green Brazil 2, 33 of these municipalities were also included in Operation Green Brazil 1. The Legal Amazon region comprises a total of 670 municipalities.

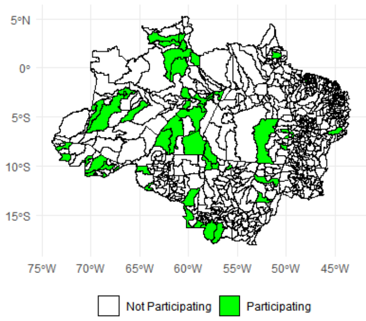
Table 19 – Distribution of Fire Outbreak by Municipalities Targeted by the Policy

State	Mean_FO_0	Mean_FO_1	Total_FO_0	Total_FO_1	Number_Mun_0	Number_Mun_1
Acre	2,825.200	2,085.765	14,126	35,458	5	17
Amapa	366.143	859.500	5,126	1,719	14	2
Amazonas	571.889	2,615.885	20,588	68,013	36	26
Maranhao	489.174	1,728.250	104,194	6,913	213	4
Mato Grosso	1,023.925	2,690.857	122,871	56,508	120	21
Pará	936.969	5,603.067	120,869	84,046	129	15
Rondonia	342.647	3,043.500	11,650	54,783	34	18
Roraima	279.500	947.308	559	12,315	2	13
Tocantins	514.935	0	71,576	0	139	0

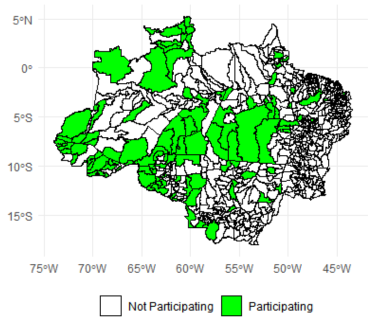
Note: FO_0 denotes fire outbreaks in municipalities that was not target by the policy; FO_1 denotes fire outbreaks in municipalities that was targeted by the policy; Number_Mun_0 and Number_Mun_1 is the number of municipalities that do not have the policy and has the policy.

The Table 19 presents a summary of fire outbreaks across states in the Brazilian Legal Amazon, distinguishing between municipalities that ever participated in the policy intervention and those that never did. For each state, it shows the average number of fire outbreaks per municipality, the total number of fire outbreaks, and the number of municipalities in each group. As we can see, states like Para, Rondonia, and Amazonas show higher average fire outbreaks per municipality in areas that had the policy, suggesting these municipalities may have had more severe fire activity or were prioritized for intervention due to elevated risk.

Figure 6 – Participation by Municipality



Operation Green Brazil 1



Operation Green Brazil 2

Figures 6 illustrate the spatial distribution of municipalities involved in Operation Green Brazil 1 and Operation Green Brazil 2, respectively. Although only 19.3% of the region's municipalities were targeted by Operation Green Brazil 2, approximately 50.0% of the Legal Amazon region was covered by the operation.

4.3 Methods and Data Sources

This proposal is based on a monthly municipality panel dataset covering the period from January 2017 to April 2023. Data on wildfires were generated via satellite and collected from INPE (National Institute for Space Research) and is measured in number of fire outbreaks. Following Assunção et al. (2020), there are two sets of control variables: the first related to agriculture and livestock, which have a relationship with the increase of wildfires in the Amazon Biome, the second control group is related to conservation policies that were present in the municipality during the progress of the Operation Green Brazil 1 and 2, and we will introduce a third control group that are environment variables.

The model includes several co-variables related to environmental and economic factors at the municipal level as we can see from Table 20. Population, obtained from IBGE, is annual data reflecting the total number of inhabitants in each municipality. Planted

Area and Total Quantity of Cattle, also from IBGE and PPM respectively, are recorded annually, with the latter being expressed as the logarithm of the total number of cattle.

Climate-related variables include Temperature and Precipitation, originally recorded as daily data from INPE. These were aggregated into monthly values to align with the analysis framework. Environmental Fines, sourced from IBAMA, were also initially daily data but were converted into monthly values, considering the total amount of fines issued for environmental violations. Lastly, the Priority Municipality variable, provided by the Ministry of the Environment, is a binary indicator identifying whether a municipality is classified as a priority for environmental policies and interventions. This combination of variables enables a comprehensive assessment of the environmental and economic dynamics at the municipal level.

Table 20 – Variables

Variables	**Source**	**Details**
Fire Outbreak	INPE	Total number of fire outbreaks in the municipality
Population	IBGE	Population of the municipality
Planted Area	IBGE	total planted area of the municipality
Total Quantity of cattle	PPM	Logarithm of total number of cattle
Temperature	INPE	Mean of the temperature in Celsius
Precipitation	INPE	Accumulated precipitation
Environmental fines	IBAMA	Logarithm of the total amount of environmental fines
Priority Municipality	Ministry of the Environment	If the municipality is a priority

Source: Own elaboration

In this proposal, we evaluate the impacts of Operations Green Brazil 1 and 2 on wildfires. To do so, we utilize the fact that these operations were applied on environmental reserves and border regions of the Amazon biome. This provides us with clusters of municipalities inside the biome that were subject to the operations and those that were not. This clustering allows us to create a treatment group, consisting of the municipalities inside of the Amazon biome that were covered by the policy, and a control group, composed of the municipalities belonging to the Legal Amazon but not covered by the Operations Green Brazil 1 and 2. We then combine this geographic difference caused by environmental policy with monthly city-level data to conduct a Difference-in-Differences (DiD) analysis.

A generalization of the Difference-in-Differences approach is the Two-way Fixed Effect Model. Imai e Kim (2021) argue that this method is commonly used to estimate causal relationships in applied research for causal the standard. However, the authors says that these models has limitations when it comes to accurately determining cause and effect, arguing that it is impossible to adjust for unknown factors affecting both groups and time periods simultaneously. Given that, Imai e Kim (2021) shows that a Difference-in-differences estimator with multi period is similar to the weighted two-way fixed effect estimator.

Using the analysis from Imai e Kim (2021), we estimated the following equation:

$$Y_{it} = \mu_i + \beta_i Pol_{it} + \gamma Z_{it} + \lambda_t + \epsilon_{it} \tag{4.1}$$

where Y_{it} is the dependent variable representing wildfires and environmental fines in municipality i at time t. μ_i denotes the fixed effect of each municipality, which contains initial conditions and municipality characteristics, such as infrastructure and others. The term λ_t is the monthly fixed effect to control time trends, such as political cycles, macroeconomic trend, seasonal fluctuations, and others. The term Pol is a dummy variable that has the value of 1 (one) if the municipality receives the policy and the value of 0 (zero) if the municipality does not receive the policy. The parameter of interest β is the causal effect of Operation Green Brazil 1 and 2 on the dependent variable. The term Z_{it} is a vector of covariates and ϵ is the error of the estimation.

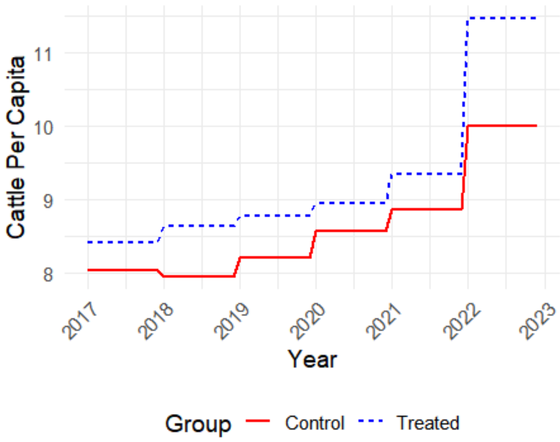
The validity of DiD specification relies on two key conditions: the method should be robust to the varying impacts of regional shocks, ensuring that our analysis is not biased by these shocks, and pre-trends for control and treatment groups must be parallel. In other words, the method requires that the trend of the outcome variables for both the control and treated groups grow in parallel before the intervention (MEYER, 1995; ASSUNÇÃO et al., 2020). Based on this empirical approach, or goal is to examine the impact of the Operations Green Brazil 1 and 2 on the wildfires in the Legal Amazon.

We have also used the difference-in-difference specification with the Propensity Score Matching (PSM) approach. This approach allows us to match treated and untreated municipalities based on similar observable characteristics measured before the program was implemented. We performed nearest neighbor matching with replacement, using five control units per treated unit (ratio = 5). Matching was conducted separately for the full sample and for the restricted sample excluding Green Brazil 1 municipalities. After matching, we re-estimated the two-way fixed effects model on the matched data to account for time and unit-specific effects.

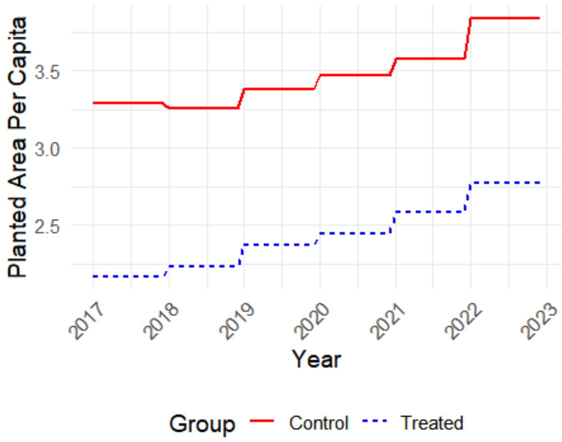
4.4 Results

Before analyzing the results for the Two-Way Fixed Effect Model, it is important to analyze the trend of the variables in the model. Figure 7 shows the trend of the variables for the municipalities that participated in the policy and those that did not. For all variables, these municipalities exhibit parallel trends. However, it is possible to observe that, for the number of cattle per capita, the municipalities that participated in the policy have higher values, and for planted area per capita the municipalities that was not target by the policy has more agricultural areas. The same pattern is visible for the number of fire outbreaks, where the municipalities that participated in the program has the same trend but have more outliers related to wildfires. These figures could provide an explanation as to why these municipalities were chosen to participate in Operation Green Brazil, given that an increase in wildfires or the number of cattle are important factors considered by policymakers. And the graph shows that the treated and not treated municipalities has similar characteristics.

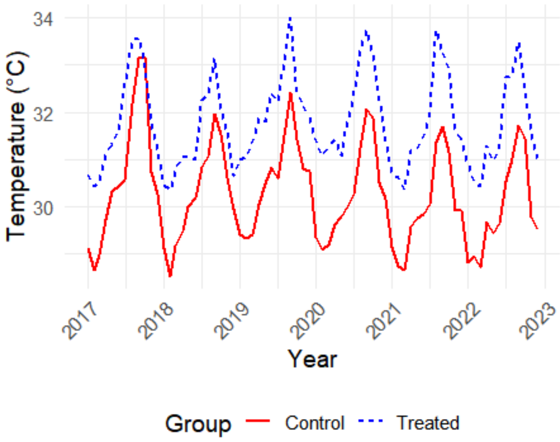
Figure 7 – Parallel Trend



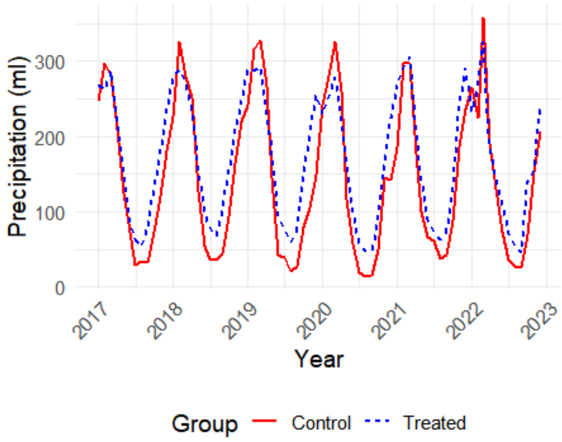
Cattle



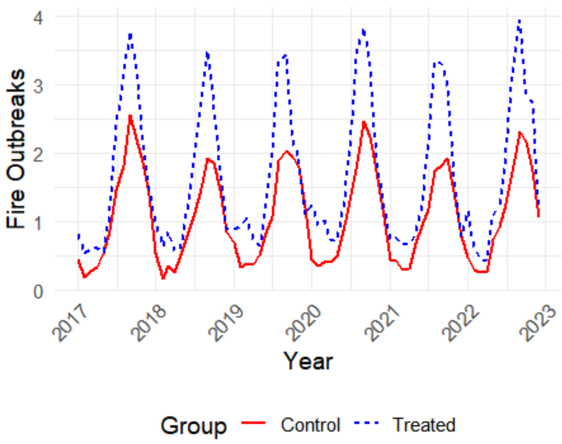
Planted Area



Temperature



Precipitation



Wildfire

Source: Own elaboration

Table 21 presents descriptive statistics (means and standard deviations) for the main variables included in the model, the results are separated by group and period. Municipalities are classified as Control (pre) if they were never treated and are observed before the policy was implemented; as Control (post) if they are never treated and the observations are collected after the policy began; as Treated if they were exposed to the policy during its active implementation period; and as Treated (post) if they are observed after the treatment period ended in their municipality.

Table 21 – Descriptive Statistics by Exposure Group

Variable	Stat	Control (pre)	Control (post)	Treated	Treated (post)
Fire Outbreaks	**Mean**	1.004	1.176	1.895	1.962
	S.D.	0.681	0.772	0.874	0.826
Temperature	**Mean**	30.347	30.154	31.763	31.681
	S.D.	7.161	7.111	1.023	1.011
Precipitation	**Mean**	160.703	127.887	157.435	154.449
	S.D.	66.049	58.994	53.449	42.287
Env. Fines	**Mean**	1.032	0.860	3.758	4.729
	S.D.	1.667	1.653	4.479	4.493
Cattle PC	**Mean**	8.119	9.217	8.909	10.557
	S.D.	12.054	13.217	10.852	12.960
Planted Area PC	**Mean**	2.326	2.649	1.446	1.702
	S.D.	7.125	7.783	4.749	5.513
Population	**Mean**	27,661.969	27,689.051	76,791.970	74,448.738
	S.D.	70,434.812	69,741.309	165,077.027	157,563.993

Note: The variables *Fire Outbreaks* and *Env. Fines* are in logarithmic form; PC refers to per capita variables; S.D. denotes standard deviation.

Treated municipalities show higher means values for these fire outbreak and for environmental fines during and after the treatment period compared to control municipalities. For example, the mean logarithm number of fire outbreaks has a value of 1.004 in pre-treatment controls and 1.895 during the treatment period in treated municipalities, suggesting potential policy-targeting of higher-risk areas.

Temperature and precipitation appear relatively balanced across groups and periods, though treated municipalities show slightly higher average temperatures and slightly lower precipitation values. Agricultural activity, measured by Cattle per Capita and Planted Area per Capita, has different relationship when comparing treated and control groups. Control groups has high values for planted area per Capita and Treated groups has a bigger value for cattle per Capita. Population size is markedly higher in treated municipalities, reflecting possible targeting of more populous or economically active regions. These patterns underscore the importance of the DiD design and the inclusion of fixed effects to account for both observable and unobservable differences across municipalities over time.

In the results, we are analyzing four different models: Model 1 is the Two-Way Linear Fixed Effect Model for the entire sample; Model 2 is the Two-Way Linear Fixed Effect Model for the entire sample, excluding the municipalities that participated in Operation Green Brazil 1; Model 3 is the Propensity Score Matching (PSM) model for the entire sample; and Model 4 is the Propensity Score Matching (PSM) model for the entire sample, excluding the municipalities that participated in Operation Green Brazil 1.

As shown in Table 22, for all models, temperature and precipitation have a significant impact on fire outbreaks in the Legal Amazon region. Temperature has a positive impact, and precipitation has a negative impact. These results align with the literature, which suggests that higher temperatures are one of the causes of fires in the Amazon biome, while the quantity of precipitation is negatively correlated with these events(SILVESTRINI et al., 2011; COCHRANE; BARBER, 2009; FONSECA et al., 2019).

For all models, the operation does not have a significant effect, meaning there is no difference between the treated and non-treated groups. Another interesting result is that in the model 1, 2 and 3 the cattle per capita has a significant and positive impact on the number of fire outbreaks in this region. This result corroborates the findings of Morton et al. (2008), Barbosa et al. (2021), Eufemia et al. (2022), where the authors argue that part of the wildfires in the Amazon are explained by human actions, often undertaken to expand agricultural areas.

Table 22 – Regression Results: Fire Outbreaks

	Dependent variable:			
	Fire Outbreaks			
	Full Sample	Without GB1	PSM Full	PSM Without GB1
	(1)	(2)	(3)	(4)
operation	−0.004	−0.012	−0.121	−0.096
	(0.036)	(0.038)	(0.080)	(0.089)
temperature	0.172***	0.165***	0.240***	0.244***
	(0.004)	(0.004)	(0.020)	(0.022)
precipitation	−0.001***	−0.001***	−0.001***	−0.001***
	(0.00005)	(0.00005)	(0.0002)	(0.0002)
log(cattle/pop)	0.046*	0.046*	0.770***	−0.016
	(0.025)	(0.025)	(0.108)	(0.124)
log(planted_area/pop)	−0.022	−0.027	0.034	0.196
	(0.039)	(0.039)	(0.327)	(0.320)
Observations	56,016	54,432	4,758	4,278
R^2	0.581	0.581	0.711	0.723
Adjusted R^2	0.575	0.574	0.654	0.664
Residual Std. Error	0.905 (df = 55162)	0.901 (df = 53600)	237.454 (df = 3973)	242.076 (df = 3533)
Note:				*p<0.1; **p<0.05; ***p<0.01

Another important goal of Operation Green Brazil 1 and 2 was to increase the number of environmental fines as a means to reduce illegal activities in the region. Table 23 shows that the operation had a significant impact on the number of environmental fines; however, contrary to the policy's objective, the impact was negative. These results indicate that the municipalities targeted by the policy saw a decrease in environmental fines during the analysis period. This finding could imply that the policy was not effective in stopping or delaying illegal activities in the Legal Amazon. This result is consistent with the findings of Cabral, Filho e Borges (2013), where the authors argue that, despite specific legislation for the Amazon region, the lack of control and supervision contributes to the increase in fires. Additionally, Morton et al. (2008) demonstrated that policies implemented for the region, given the complexity of the area and the various roles assigned to different levels of public administration, can lead to a lack of coordination in public policies for the region, resulting in inefficient fire-fighting practices.

As observed for fire outbreaks, the importance of temperature and precipitation is also evident in relation to environmental fines. There is a significant and positive relationship between temperature and fines in Models 1 and 2, and also we have a significant and positive impact of the number of cattle in the municipality and the quantity of environmental fines.

Table 23 – Regression Results: Environmental Fires

	Dependent variable:			
	Environmental Fines			
	Full Sample	Without GB1	PSM Full	PSM Without GB1
	(1)	(2)	(3)	(4)
operation	-0.206^{*}	-0.302^{**}	-0.988^{***}	-0.750^{**}
	(0.124)	(0.130)	(0.331)	(0.368)
temperature	0.068^{***}	0.069^{***}	-0.047	-0.099
	(0.015)	(0.015)	(0.082)	(0.091)
precipitation	-0.0001	-0.0001	0.0002	-0.001
	(0.0002)	(0.0002)	(0.001)	(0.001)
log(cattle/pop)	0.158^{*}	0.184^{**}	2.622^{***}	0.675
	(0.084)	(0.084)	(0.470)	(0.542)
log(planted_area/pop)	-0.195	-0.197	-1.459	-1.354
	(0.132)	(0.133)	(1.379)	(1.320)
Observations	56,016	54,432	4,666	4,190
R^2	0.328	0.330	0.577	0.604
Adjusted R^2	0.318	0.320	0.492	0.518
Residual Std. Error	3.092	3.056	943.174	950.089
	(df = 55162)	(df = 53600)	(df = 3881)	(df = 3445)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 24 illustrates environmental variables for all the municipalities that participated in Operation Green Brazil 2. It shows the mean and median values for these variables (wildfire occurrences, fines, temperature, and precipitation) before, during, and after the policy.

The number of fire outbreaks shows a positive trend throughout the period. Before the policy, there were a total of 33,750 fire outbreaks; during the policy, the total rose to 43,893; and after the policy, it increased to 54,667. This indicates that wildfires in the region continued to escalate despite the adoption of the policy by these municipalities. However, unlike the number of fire outbreaks, the total value of environmental fines in Brazilian Reals did not follow a positive trend across the periods. Before the policy, these municipalities had an average of R$1,887,104 in fines. During the policy, the total value of fines decreased by 21.4% to R$1,482,576. After the policy, the total value of fines increased again to R$2,505,682.

Table 24 – Green Brazil 2 - Municipalities

	Quantity of Wildfire			**Fines in Real**		
	Mean	Median	Coef. Var.	Mean	Median	Coef. Var.
Before Policy	33.750	2.000	4.172	1887104	0	16.510
During Policy	43.893	3.000	4.098	1482576	0	5.649
After Policy	54.667	4.000	3.947	2505682	0	4.771

	Temperature in Celcius			**Rain Precipitation in ml**		
	Mean	Median	Coef. Var.	Mean	Median	Coef. Var
Before Policy	31.502	31.132	0.054	184.734	184.850	0.682
During Policy	31.694	31.462	0.049	162.794	143.908	0.800
After Policy	31.696	31.406	0.051	153.868	128.628	0.844

Note: Own Elaboration.

Looking at environmental variables such as temperature and precipitation, which could explain the difference in fines and fire outbreaks shown in Table 22, we observe that the average temperature before, during, and after the policy remained consistent (31.50°C, 31.69°C, and 31.69°C, respectively), meaning temperature alone does not explain the trend in fire outbreaks. However, precipitation appears to be an important factor, as it exhibits a negative trend over the periods, indicating that precipitation plays a significant role in explaining the high number of wildfires in the region.

4.5 Conclusion

The analysis of the Operation Green Brazil 1 and 2 aimed to understand their effectiveness in reducing wildfire and mitigating environmental issues in the Legal Amazon. The results indicate that the operations did not have a significant impact on reducing fire outbreaks. While temperature and precipitation have a significant influence on the occurrence of wildfires, with higher temperatures increasing fire outbreaks and precipitation reducing them, the policy itself did not show a meaningful difference between the treated and non-treated municipalities.

Additionally, the policy's goal of increasing environmental fines to prevent illegal activities was also not achieved. In fact, the results show a significant decrease in fines during the policy period, which raises concerns about the effectiveness of enforcement measures in policy illegal activities in the region. Despite the resources allocated and the prolonged presence of military forces (360 days on average for the Operation Green

Brazil 2), the operations did not produce the desired outcomes in terms of reducing wildfires.

The evidence suggests that, while environmental variables like temperature and precipitation continue to play a crucial role in wildfire dynamics in this region, the Green Brazil Operations were insufficient in combating the main causes of these environmental issues. Moreover, the increase in wildfires during and after the policy period show the challenges in implementing effective fire prevention in the Amazon biome. This raises concerns about the design and implementation of such policies, highlighting the need for more robust and integrated approaches to environmental protection in the Legal Amazon.

In conclusion, while the Green Brazil Operations aimed to combat wildfire and environmental issues in the Legal Amazon, the results indicate that they were not sufficiently effective in achieving their objectives. To move forward, a more comprehensive strategy is needed that not only enforces regulations but also addresses the underlying socio-economic factors contributing to deforestation and land use practices. Additionally, further research is essential to evaluate the impact of these policies on combating illegal deforestation in the region, as this remains a key goal of the Green Brazil Operations.

References

AALST, M. K. V. The impacts of climate change on the risk of natural disasters. *Disasters*, Wiley Online Library, v. 30, n. 1, p. 5–18, 2006.

AGENCY, I. E. *World Energy Outlook 2023*. Paris: OECD Publishing, 2023.

ANSARAM, K.; PETITJEAN, M. A global perspective on the nexus between energy and stock markets in light of the rise of renewable energy. *Energy Economics*, Elsevier, v. 131, p. 107406, 2024.

ANTON, S. G.; NUCU, A. E. A. The effect of financial development on renewable energy consumption. a panel data approach. *Renewable Energy*, Elsevier, v. 147, p. 330–338, 2020.

ARAGAO, L. E. O. et al. Interactions between rainfall, deforestation and fires during recent years in the brazilian amazonia. *Philosophical Transactions of the Royal Society B: Biological Sciences*, The Royal Society London, v. 363, n. 1498, p. 1779–1785, 2008.

ARANTEGUI, R. L.; JÄGER-WALDAU, A. Photovoltaics and wind status in the european union after the paris agreement. *Renewable and Sustainable Energy Reviews*, Elsevier, v. 81, p. 2460–2471, 2018.

ARI, I.; YIKMAZ, R. F. The role of renewable energy in achieving turkey's indc. *Renewable and Sustainable Energy Reviews*, Elsevier, v. 105, p. 244–251, 2019.

ASSUNÇÃO, J. et al. The effect of rural credit on deforestation: Evidence from the brazilian amazon. *The Economic Journal*, Oxford University Press, v. 130, n. 626, p. 290–330, 2020.

ATTIAOUI, I. et al. Causality links among renewable energy consumption, co 2 emissions, and economic growth in africa: evidence from a panel ardl-pmg approach. *Environmental science and pollution research*, Springer, v. 24, p. 13036–13048, 2017.

AUFFHAMMER, M.; MANSUR, E. T. Measuring climatic impacts on energy consumption: A review of the empirical literature. *Energy Economics*, Elsevier, v. 46, p. 522–530, 2014.

BANHOLZER, S.; KOSSIN, J.; DONNER, S. The impact of climate change on natural disasters. In: *Reducing disaster: Early warning systems for climate change*. [S.l.]: Springer, 2014. p. 21–49.

BARBOSA, M. L. F. et al. Recent trends in the fire dynamics in brazilian legal amazon: Interaction between the enso phenomenon, climate and land use. *Environmental Development*, Elsevier, v. 39, p. 100648, 2021.

BENALI, N.; SAIDI, K. A robust analysis of the relationship between natural disasters, electricity and economic growth in 41 countries. *Journal of Economic Development*, v. 42, n. 3, 2017.

BERLEMANN, M.; WENZEL, D. Hurricanes, economic growth and transmission channels: Empirical evidence for countries on differing levels of development. *World Development*, Elsevier, v. 105, p. 231–247, 2018.

BERLINCK, C. N.; BATISTA, E. K. Good fire, bad fire: It depends on who burns. *Flora*, Elsevier, v. 268, p. 151610, 2020.

BHAT, A. A.; MISHRA, P. P. Interaction between natural disasters and economic growth: Ardl approach. *IUP Journal of Applied Economics*, v. 17, n. 4, 2018.

BOTZEN, W. W.; DESCHENES, O.; SANDERS, M. The economic impacts of natural disasters: A review of models and empirical studies. *Review of Environmental Economics and Policy*, The University of Chicago Press, 2020.

BRICS. *BRICS Energy Report*. 2021. Disponível em: <https://brics2021.gov.in/brics/public/uploads/docpdf/getdocu-41.pdf>.

BROWN, P. et al. Natural disasters, social protection, and risk perceptions. *World development*, Elsevier, v. 104, p. 310–325, 2018.

BUSBY, J. W. et al. Cascading risks: Understanding the 2021 winter blackout in texas. *Energy Research & Social Science*, Elsevier, v. 77, p. 102106, 2021.

CABRAL, A. L. A.; FILHO, L. O. M.; BORGES, L. A. C. Uso do fogo na agricultura: legislação, impactos ambientais e realidade na amazônia. *Periódico Eletrônico Fórum Ambiental da Alta Paulista*, v. 9, n. 5, 2013.

CHANG, S. E. et al. Infrastructure failure interdependencies in extreme events: power outage consequences in the 1998 ice storm. *Natural Hazards*, Springer, v. 41, n. 2, p. 337–358, 2007.

Climate Bonds Initiative. *Market Data*. 2024. Accessed: 01-30-2025. Disponível em: <https://www.climatebonds.net/market/data/>.

COCHRANE, M. A.; BARBER, C. P. Climate change, human land use and future fires in the amazon. *Global Change Biology*, Wiley Online Library, v. 15, n. 3, p. 601–612, 2009.

COPELAND, B. R.; TAYLOR, M. S. Trade, growth, and the environment. *Journal of Economic literature*, American Economic Association, v. 42, n. 1, p. 7–71, 2004.

COSTS, I. R. P. G. International renewable energy agency, 2019. *Google Scholar There is no corresponding record for this reference*, 2018.

DECREE nº 10,341, from 6 of may of 2020. 2020. <https://www.planalto.gov.br/ccivil_03/_Ato2019-2022/2020/Decreto/D10341.htm>. Presidência da República do Brasil. Diário Oficial da União.

DECREE nº 9,985, from 23 of august of 2019. 2019. <https://www.planalto.gov.br/ccivil_03/_Ato2019-2022/2019/Decreto/D9985.htm>. Presidência da República do Brasil. Diário Oficial da União.

DREHER, A. Does globalization affect growth? evidence from a new index of globalization. *Applied economics*, Taylor & Francis, v. 38, n. 10, p. 1091–1110, 2006.

EUFEMIA, L. et al. Fires in the amazon region: Quick policy review. *Development Policy Review*, Wiley Online Library, v. 40, n. 5, p. e12620, 2022.

FELBERMAYR, G.; GRÖSCHL, J. Naturally negative: The growth effects of natural disasters. *Journal of development economics*, Elsevier, v. 111, p. 92–106, 2014.

FERGUSON, R.; WILKINSON, W.; HILL, R. Electricity use and economic development. *Energy policy*, Elsevier, v. 28, n. 13, p. 923–934, 2000.

FONSECA, M. G. et al. Effects of climate and land-use change scenarios on fire probability during the 21st century in the brazilian amazon. *Global change biology*, Wiley Online Library, v. 25, n. 9, p. 2931–2946, 2019.

FORECASTING, I. Hurricane sandy event recap report. *Rep., Aon Benfield*, v. 50, 2013.

GIELEN, D. et al. The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, Elsevier, v. 24, p. 38–50, 2019.

GLASNOVIC, Z.; MARGETA, J. Vision of total renewable electricity scenario. *Renewable and Sustainable Energy Reviews*, Elsevier, v. 15, n. 4, p. 1873–1884, 2011.

GOZGOR, G. et al. The impact of economic globalization on renewable energy in the oecd countries. *Energy Policy*, Elsevier, v. 139, p. 111365, 2020.

GYGLI, S. et al. The kof globalisation index–revisited. *The Review of International Organizations*, Springer, v. 14, n. 3, p. 543–574, 2019.

HANLEY, N. et al. *Introduction to environmental economics*. [S.l.]: Oxford University Press, 2019.

HILL, J. et al. The effects of climate change on interregional electricity market dynamics on the us west coast. *Earth's Future*, Wiley Online Library, v. 9, n. 12, p. e2021EF002400, 2021.

IEA. *World Energy Statistics and Balances*. 2024. Accessed: 2024-02-26. Disponível em: <https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances>.

IMAI, K.; KIM, I. S. On the use of two-way fixed effects regression models for causal inference with panel data. *Political Analysis*, Cambridge University Press, v. 29, n. 3, p. 405–415, 2021.

International Energy Agency. *World Energy Investment 2024*. Paris, 2024. Licence: CC BY 4.0, Accessed: 01-30-2025. Disponível em: <https://www.iea.org/reports/world-energy-investment-2024>.

JONES, M. W. et al. Global and regional trends and drivers of fire under climate change. *Reviews of Geophysics*, Wiley Online Library, v. 60, n. 3, p. e2020RG000726, 2022.

JUNG, C. et al. Global gust climate evaluation and its influence on wind turbines. *Energies*, MDPI, v. 10, n. 10, p. 1474, 2017.

KAO, C. Spurious regression and residual-based tests for cointegration in panel data. *Journal of econometrics*, Elsevier, v. 90, n. 1, p. 1–44, 1999.

KAPETANIOS, G.; SHIN, Y.; SNELL, A. Testing for a unit root in the nonlinear star framework. *Journal of econometrics*, Elsevier, v. 112, n. 2, p. 359–379, 2003.

KRUSE, R. A new unit root test against estar based on a class of modified statistics. *Statistical Papers*, Springer, v. 52, n. 1, p. 71–85, 2011.

KUYPER, J.; SCHROEDER, H.; LINNÉR, B.-O. The evolution of the unfccc. *Annual Review of Environment and Resources*, Annual Reviews, v. 43, p. 343–368, 2018.

LEE, C.-C.; CHEN, M.-P. Do natural disasters and geopolitical risks matter for cross-border country exchange-traded fund returns? *The North American Journal of Economics and Finance*, Elsevier, v. 51, p. 101054, 2020.

LEE, C.-C. et al. The impact of natural disaster on energy consumption: International evidence. *Energy Economics*, Elsevier, v. 97, p. 105021, 2021.

LESLIE, M. *Texas crisis highlights grid vulnerabilities*. [S.l.]: Elsevier, 2021.

LEVIN, A.; LIN, C.-F.; CHU, C.-S. J. Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of econometrics*, Elsevier, v. 108, n. 1, p. 1–24, 2002.

LI, W. et al. Causes of recent changes of rainfall variabilities and implications to the future climate in the amazon region. In: *AGU Fall Meeting Abstracts*. [S.l.: s.n.], 2007. v. 2007, p. GC44A–09.

MARLE, M. J. van et al. Fire and deforestation dynamics in amazonia (1973–2014). *Global biogeochemical cycles*, Wiley Online Library, v. 31, n. 1, p. 24–38, 2017.

MENEGAKI, A. N. Growth and renewable energy in europe: A random effect model with evidence for neutrality hypothesis. *Energy economics*, Elsevier, v. 33, n. 2, p. 257–263, 2011.

MEYER, B. D. Natural and quasi-experiments in economics. *Journal of business & economic statistics*, Taylor & Francis, v. 13, n. 2, p. 151–161, 1995.

MIDEKSA, T. K.; KALLBEKKEN, S. The impact of climate change on the electricity market: A review. *Energy policy*, Elsevier, v. 38, n. 7, p. 3579–3585, 2010.

MIYAMOTO, M.; TAKEUCHI, K. Climate agreement and technology diffusion: Impact of the kyoto protocol on international patent applications for renewable energy technologies. *Energy policy*, Elsevier, v. 129, p. 1331–1338, 2019.

MOHAMED, M. A. et al. Proactive resilience of power systems against natural disasters: A literature review. *IEEE Access*, IEEE, v. 7, p. 163778–163795, 2019.

MORELLO, T. F. et al. Predicting fires for policy making: Improving accuracy of fire brigade allocation in the brazilian amazon. *Ecological Economics*, Elsevier, v. 169, p. 106501, 2020.

MORTON, D. et al. Agricultural intensification increases deforestation fire activity in amazonia. *Global Change Biology*, Wiley Online Library, v. 14, n. 10, p. 2262–2275, 2008.

MOUTINHO, V.; MOREIRA, A. C.; SILVA, P. M. The driving forces of change in energy-related co2 emissions in eastern, western, northern and southern europe: The lmdi approach to decomposition analysis. *Renewable and Sustainable Energy Reviews*, Elsevier, v. 50, p. 1485–1499, 2015.

MUNASINGHE, M. *Environmental economics and sustainable development*. [S.l.]: World Bank Publications, 1993. v. 3.

MURSHED, M. Electricity conservation opportunities within private university campuses in bangladesh. *Energy & Environment*, SAGE Publications Sage UK: London, England, v. 31, n. 2, p. 256–274, 2020.

NCEI, N. *US billion-dollar weather and climate disasters*. [S.l.]: Retrieved 22/10/22 from https://www.ncdc.noaa.gov/billions, 2021.

NOY, I. The macroeconomic consequences of disasters. *Journal of Development economics*, Elsevier, v. 88, n. 2, p. 221–231, 2009.

OFFICIAL Letter No. 20248/GM-MD, dated August 9, 2021 – Response to Request No. 2534 of 2020. 2021. Available in: <https://www25.senado.leg.br/web/atividade/materias/-/materia/145173>. Access in: 20 maio 2025. Federal Senate of Brazil.

OMRI, A.; DALY, S.; NGUYEN, D. K. A robust analysis of the relationship between renewable energy consumption and its main drivers. *Applied Economics*, Taylor & Francis, v. 47, n. 28, p. 2913–2923, 2015.

PANWAR, V.; SEN, S. Economic impact of natural disasters: An empirical re-examination. *Margin: The Journal of Applied Economic Research*, SAGE Publications Sage India: New Delhi, India, v. 13, n. 1, p. 109–139, 2019.

PAO, H.-T.; FU, H.-C. Renewable energy, non-renewable energy and economic growth in brazil. *Renewable and Sustainable Energy Reviews*, Elsevier, v. 25, p. 381–392, 2013.

PARAMATI, S. R.; ALAM, M. S.; APERGIS, N. The role of stock markets on environmental degradation: A comparative study of developed and emerging market economies across the globe. *Emerging Markets Review*, Elsevier, v. 35, p. 19–30, 2018.

PARK, J. Y. Canonical cointegrating regressions. *Econometrica: Journal of the Econometric Society*, JSTOR, p. 119–143, 1992.

PEDRONI, P. Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and statistics*, Wiley Online Library, v. 61, n. S1, p. 653–670, 1999.

PEDRONI, P. Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the ppp hypothesis. *Econometric theory*, Cambridge University Press, v. 20, n. 3, p. 597–625, 2004.

PESARAN, M. H.; SHIN, Y.; SMITH, R. J. Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, Wiley Online Library, v. 16, n. 3, p. 289–326, 2001.

PIVELLO, V. R. et al. Understanding brazil's catastrophic fires: Causes, consequences and policy needed to prevent future tragedies. *Perspectives in Ecology and Conservation*, Elsevier, v. 19, n. 3, p. 233–255, 2021.

PÖRTNER, H.-O. et al. Climate change 2022: Impacts, adaptation and vulnerability. *IPCC Sixth Assessment Report*, 2022.

PRYOR, S. C.; BARTHELMIE, R. J. Climate change impacts on wind energy: A review. *Renewable and sustainable energy reviews*, Elsevier, v. 14, n. 1, p. 430–437, 2010.

REED, D. A.; POWELL, M. D.; WESTERMAN, J. M. Energy supply system performance for hurricane katrina. *Journal of Energy Engineering*, American Society of Civil Engineers, v. 136, n. 4, p. 95–102, 2010.

REIDMILLER, D. R. et al. Impacts, risks, and adaptation in the united states: Fourth national climate assessment, volume ii. 2017.

RENTSCHLER, J. E. *Oil price volatility, economic growth and the hedging role of renewable energy*. [S.l.]: The World Bank, 2013.

ROSON, R.; CALZADILLA, A.; PAULI, F. Climate change and extreme events: an assessment of economic implications. FEEM Working Paper, 2006.

SALIM, R. A.; RAFIQ, S. Why do some emerging economies proactively accelerate the adoption of renewable energy? *Energy economics*, Elsevier, v. 34, n. 4, p. 1051–1057, 2012.

SCHAEFFER, R. et al. Energy sector vulnerability to climate change: A review. *Energy*, Elsevier, v. 38, n. 1, p. 1–12, 2012.

SCHMIDT, I. B.; ELOY, L. Fire regime in the brazilian savanna: Recent changes, policy and management. *Flora*, Elsevier, v. 268, p. 151613, 2020.

SENEVIRATNE, S. I. et al. Weather and climate extreme events in a changing climate. In: MASSON-DELMOTTE, V. et al. (Ed.). *Climate Change 2021: The Physical Science Basis*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2021. p. 1513–1766.

SHEN, Y.-C. et al. An assessment of exploiting renewable energy sources with concerns of policy and technology. *Energy Policy*, Elsevier, v. 38, n. 8, p. 4604–4616, 2010.

SILVA, I. et al. A wildfire warning system applied to the state of acre in the brazilian amazon. *Applied Soft Computing*, Elsevier, v. 89, p. 106075, 2020.

SILVESTRINI, R. A. et al. Simulating fire regimes in the amazon in response to climate change and deforestation. *Ecological Applications*, Wiley Online Library, v. 21, n. 5, p. 1573–1590, 2011.

STATISTA. *Investment in clean energy globally in 2019, by select country*. 2022. Disponível em: <https://www.statista.com/statistics/799098/global-clean-energy-investment-by-country/>.

SUTANTA, H.; RAJABIFARD, A.; BISHOP, I. D. Disaster risk reduction using acceptable risk measures for spatial planning. *Journal of Environmental Planning and Management*, Taylor & Francis, v. 56, n. 6, p. 761–785, 2013.

U.S. Energy Information Administration (EIA). *California State Profile and Energy Estimates*. 2024. Accessed: 2024-11-15. Disponível em: <https://www.eia.gov/state/analysis.php?sid=CA>.

WANG, D. et al. Economic footprint of california wildfires in 2018. *Nature Sustainability*, Nature Publishing Group UK London, v. 4, n. 3, p. 252–260, 2021.

WANG, Y.; TAGHIZADEH-HESARY, F. Green bonds markets and renewable energy development: Policy integration for achieving carbon neutrality. *Energy Economics*, Elsevier, v. 123, p. 106725, 2023.

WANG, Z. et al. Natural gas consumption forecasting model based on coal-to-gas project in china. *Global Energy Interconnection*, Elsevier, v. 2, n. 5, p. 429–435, 2019.

WARD, D. M. The effect of weather on grid systems and the reliability of electricity supply. *Climatic Change*, Springer, v. 121, n. 1, p. 103–113, 2013.

XIONG, W. et al. Substitution effect of natural gas and the energy consumption structure transition in china. *Sustainability*, MDPI, v. 12, n. 19, p. 7853, 2020.

YORK, R.; BELL, S. E. Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. *Energy Research & Social Science*, Elsevier, v. 51, p. 40–43, 2019.

YOUNIS, I. et al. Impact of stock market, renewable energy consumption and urbanization on environmental degradation: new evidence from brics countries. *Environmental Science and Pollution Research*, Springer, v. 28, p. 31549–31565, 2021.

A Appendix: Supplementary material for all papers

A.1 Supplementary Material for Paper 1

Table A.25 – Descriptive Statistics - Developing Countries

	renpc	**gdppc**	**co2pc**	**kofgi**	**findev**	**fininst**	**finmark**
Mean	2.588	7704.132	4.739	64.938	0.452	0.457	0.431
Median	2.486	8320.239	4.223	65.000	0.460	0.424	0.412
Maximum	7.817	14200.270	11.798	77.000	0.672	0.731	0.701
Minimum	0.081	757.669	0.919	46.000	0.242	0.134	0.184
Std. Deviation	1.955	3431.689	2.982	6.209	0.104	0.139	0.125
X-squared (JB Test)	19.12	3.669	28.989	5.067	5.809	10.052	10.665
p-value (JB Test)	0.0000	0.1597	0.0000	0.0794	0.0548	0.0066	0.0048

Table A.26 – Descriptive Statistics - BRICS

	renpc	gdppc	co2pc	kofgi	findev	fininst	finmark
Mean	2.482	5892.358	5.789	63.362	0.516	0.509	0.503
Median	1.613	6209.366	6.391	64.000	0.503	0.538	0.521
Maximum	7.817	10370.360	11.798	72.000	0.672	0.731	0.701
Minimum	0.081	757.669	0.919	46.000	0.350	0.256	0.302
Std. Deviation	2.424	2925.679	3.796	5.486	0.081	0.138	0.100
X-squared (JB Test)	12.32	8.256	10.698	6.693	6.022	7.755	4.556
p-value (JB Test)	0.0021	0.0161	0.0048	0.0352	0.0492	0.0207	0.1025

Table A.27 – Descriptive Statistics - Developed Countries

	renpc	gdppc	co2pc	kofgi	findev	fininst	finmark
Mean	11.869	42060.460	9.568	83.313	0.754	0.779	0.702
Median	5.168	40851.160	8.839	84.000	0.754	0.796	0.741
Maximum	93.408	88413.200	21.304	91.000	1.000	1.000	1.000
Minimum	0.151	16992.480	3.522	67.000	0.455	0.427	0.319
Std. Deviation	16.540	15281.170	3.942	5.329	0.122	0.123	0.157
X-squared (JB Test)	1728.2	64.469	95.257	50.700	12.567	21.234	27.169
p-value (JB Test)	0.0000	0.0000	0.0000	0.0000	0.0018	0.0000	0.0000

Table A.28 – Unit Root Tests - Developed Countries

		Im-Pesaran-Shin		Levin-Lin-Chu		Choi (Pm test)	
		Statistic	**p-value**	**Statistic**	**p-value**	**Statistic**	**p-value**
Level	**renpc**	-3.043	0.001	1.896	0.971	1.333	0.091
	gdppc	-0.354	0.361	-2.573	0.005	-0.979	0.836
	co2pc	-2.568	0.005	-2.692	0.003	2.197	0.013
	kofgi	-0.296	0.383	-13.591	0.000	25.846	0.000
	findev	-2.260	0.011	-3.528	0.000	0.783	0.216
	fininst	-3.747	0.000	-1.076	0.140	-1.093	0.862
	finmark	-2.654	0.003	-4.806	0.000	5.380	0.000
First Difference	**renpc**	-20.1	0.000	-21.055	0.000	69.233	0.000
	gdppc	-12.463	0.000	-12.650	0.000	34.017	0.000
	co2pc	-16.504	0.000	-17.892	0.000	56.746	0.000
	kofgi	-22.350	0.000	-11.902	0.000	39.240	0.000
	findev	-20.446	0.000	-20.038	0.000	63.494	0.000
	fininst	-17.309	0.000	-20.230	0.000	65.494	0.000
	finmark	-17.363	0.000	-16.528	0.000	50.613	0.000

Table A.29 – Unit Root Tests - BRICS

		Im-Pesaran-Shin		Levin-Lin-Chu		Choi (Pm test)	
		Statistic	**p-value**	**Statistic**	**p-value**	**Statistic**	**p-value**
Level	**renpc**	-1.489	0.068	0.998	0.84	-0.794	0.786
	gdppc	0.384	0.649	-1.802	0.035	-1.204	0.885
	co2pc	-2.593	0.004	-1.351	0.088	3.425	0.000
	kofgi	0.861	0.805	-10.835	0.000	32.136	0.000
	findev	-1.822	0.034	-2.287	0.011	0.202	0.419
	fininst	-3.089	0.001	-0.833	0.202	0.653	0.256
	finmark	-1.396	0.081	-2.568	0.005	1.599	0.054
First Difference	**renpc**	-11.875	0.000	-13.217	0.000	41.816	0.000
	gdppc	-4.974	0.000	-5.423	0.000	12.950	0.000
	co2pc	-6.992	0.000	-7.659	0.000	20.976	0.000
	kofgi	-13.453	0.000	-1.090	0.137	1.096	0.136
	findev	-10.899	0.000	-9.833	0.000	29.139	0.000
	fininst	-12.618	0.000	-10.640	0.000	32.055	0.000
	finmark	-9.161	0.000	-10.640	0.000	30.714	0.000

Table A.30 – Unit Root Tests - Developing Countries

		Im-Pesaran-Shin		Levin-Lin-Chu		Choi (Pm test)	
		Statistic	**p-value**	**Statistic**	**p-value**	**Statistic**	**p-value**
Level	**renpc**	-4.2452	0.000	0.202	0.580	1.828	0.033
	gdppc	1.1127	0.867	-5.273	0.000	1.727	0.042
	co2pc	3.935	1.000	6.810	1.000	-2.773	0.997
	kofgi	-6.493	0.000	-17.101	0.000	33.762	0.000
	findev	1.512	0.934	-6.947	0.000	5.064	0.000
	fininst	2.977	0.998	-2.158	0.015	0.158	0.437
	finmark	-1.436	0.075	-9.007	0.000	18.378	0.000
First Difference	**renpc**	-23.891	0.000	-24.631	0.000	91.357	0.000
	gdppc	-18.094	0.000	-16.253	0.000	51.848	0.000
	co2pc	-22.242	0.000	-17.984	0.000	58.782	0.000
	kofgi	-22.416	0.000	-21.414	0.000	64.692	0.000
	findev	-19.242	0.000	-16.836	0.000	51.556	0.000
	fininst	-21.594	0.000	-23.550	0.000	74.617	0.000
	finmark	-18.593	0.000	-15.423	0.000	51.107	0.000

Table A.31 – Correlation Matrix - Developed Countries

	renpc	**gdppc**	**co2pc**	**kofgi**	**findev**	**fininst**	**finmark**
renpc	1						
gdppc	0.566	1					
co2pc	-0.153	0.046	1				
kofgi	0.339	0.770	-0.146	1			
findev	0.187	0.570	0.079	0.492	1		
fininst	0.035	0.430	0.114	0.341	0.803	1	
finmark	0.254	0.508	0.026	0.487	0.875	0.428	1

Table A.32 – Correlation Matrix - BRICS

	renpc	**gdppc**	**co2pc**	**kofgi**	**findev**	**fininst**	**finmark**
renpc	1						
gdppc	0.583	1					
co2pc	0.102	0.715	1				
kofgi	0.400	0.664	0.519	1			
findev	0.394	0.460	0.229	0.787	1		
fininst	0.299	0.542	0.218	0.618	0.684	1	
finmark	0.246	0.120	0.114	0.558	0.788	0.105	1

Table A.33 – Matrix Correlation - Developing Countries

	renpc	**gdppc**	**co2pc**	**kofgi**	**findev**	**fininst**	**finmark**
renpc	1						
gdppc	-0.367	1					
co2pc	-0.543	0.801	1				
kofgi	0.104	0.527	0.296	1			
findev	0.123	0.184	0.293	0.515	1		
fininst	0.167	0.207	0.246	0.337	0.716	1	
finmark	0.05	0.06	0.169	0.479	0.821	0.214	1

Table A.34 – Panel Cointegration Test - KAO and Pedroni

					KAO Test				
		Developed			Developing			BRICS	
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Modif. Dickey–Fuller t	2.3008***	2.747***	2.6208***	3.3363***	3.1265***	3.2228***	1.6271*	1.5738*	1.0913
Dickey–Fuller t	2.2673***	2.8065***	2.7107***	5.2146***	4.9059***	5.0535***	1.826***	1.8266***	1.0285
Aug. Dickey–Fuller t	2.9646***	3.4263***	3.2625***	5.4243***	5.1846***	5.1256***	2.7639***	2.7488***	2.1125***
Unadj. modif. Dickey–Fuller t	0.6579	1.2565	1.8773***	2.7952***	2.4518***	2.6221***	-5.0406***	-4.8159***	-5.2246***
Unadj. Dickey–Fuller t	0.5073	0.9818	1.7558***	4.095***	3.6848***	3.896***	-2.9852***	-2.7096***	-2.9678***

					Pedroni Test				
		Developed			Developing			BRICS	
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Modif. Phillips–Perron t	0.336	0.1291	0.1358	1.081	0.7546	1.1106	-0.939	-0.9074	-0.6526
Phillips–Perron t	-1.937***	-2.2086***	-2.3081***	-2.6812***	-3.0968***	-2.497***	-7.1005***	-7.0261***	-6.6526***
Aug. Dickey–Fuller t (ADF)	-2.2199***	-2.179***	-2.4211***	-2.6453***	-2.9462***	-2.2006***	-6.579***	-6.4909***	-6.366***

Table A.35 – Fully Modified OLS - BRICS Countries

	Model 1				Model 2				Model 3			
	gdppc	co2pc	kofgi	findev	gdppc	co2pc	kofgi	fininst	gdppc	co2pc	kofgi	finmark
BRA	0.76***	-0.35***	0.45**	0.08	0.94***	-0.41***	0.60***	-0.05	0.72***	-0.34***	0.26	0.11***
CHN	1.69***	-0.1	-2.18***	-0.33**	1.26***	0.06*	-1.62***	0.39***	1.57***	-0.04	-2.02***	-0.15**
IND	1.40***	-0.17	-1.30***	0.35*	1.43***	-0.46*	-1.39***	0.60***	1.58***	-0.34	-1.24***	0.13
RUS	0.53***	-1.13***	-1.27***	0.01	0.45***	-1.15***	-1.36***	0.08*	0.52***	-1.13***	-1.29***	-0.02
ZAF	1.08**	-4.38***	-0.35	2.78***	2.61***	-5.36***	1.62***	0.34	3.26***	-5.06***	-1.24***	1.54***

Table A.36 – Dynamic OLS - BRICS Countries

	Model 1				Model 2				Model 3			
	gdppc	co2pc	kofgi	findev	gdppc	co2pc	kofgi	fininst	gdppc	co2pc	kofgi	finmark
BRA	0.17	-0.66***	0.39*	0.59***	1.97***	-1.23***	1.14***	-0.73***	0.65***	-0.42***	0	0.16***
CHN	2.02***	-0.66***	-2.28***	-0.27**	0.49***	0.33***	-0.63***	1.40***	1.84***	-0.49***	-1.83***	-0.21***
IND	1.88***	-1.04***	-0.56***	-1.07***	2.38***	-1.14***	-1.36***	-0.41	1.39***	-0.47	-0.79**	-0.34**
RUS	0.94***	-1.92***	-2.61***	-0.18	0.81***	-2.75***	-3.80***	0.39***	1.05***	-2.31***	-3.11***	-0.15***
ZAF	1.52*	-8.45***	-3.38***	5.31***	-10.61***	-3.88***	2.17***	9.84***	5.46***	-9.21***	-2.61**	1.79***

Table A.37 – CCR Model - BRICS Countries

	Model 1				Model 2				Model 3			
	gdppc	co2pc	kofgi	findev	gdppc	co2pc	kofgi	fininst	gdppc	co2pc	kofgi	finmark
BRA	0.83***	-0.36***	0.44***	0.06	0.96***	-0.41***	0.60***	-0.07	0.76***	-0.35***	0.16	0.12**
CHN	1.75***	-0.16	-2.21***	-0.35*	1.26***	0.06	-1.61***	0.39***	1.60***	-0.08	-2.03***	-0.14*
IND	1.58***	-0.35	-1.38***	0.34	1.44***	-0.48	-1.42***	0.64***	1.70***	-0.47	-1.28***	0.1
RUS	0.54***	-1.13***	-1.30***	0	0.47***	-1.14***	-1.37***	0.07	0.53***	-1.14***	-1.31***	-0.02
ZAF	1.22*	-4.44***	-0.38	2.72***	2.69**	-5.39***	1.60***	0.3	3.35***	-5.06***	-1.31**	1.54***

Table A.38 – Fully Modified OLS - Developing Countries

	Model 1				Model 2				Model 3			
	gdppc	**co2pc**	**kofgi**	**findev**	**gdppc**	**co2pc**	**kofgi**	**fininst**	**gdppc**	**co2pc**	**kofgi**	**finmark**
ARG	-0.64***	0.27*	1.82***	0.19***	-0.26***	0.01	2.33***	-0.32***	-0.78**	0.5	2.20***	0.13*
BRA	0.76***	-0.35***	0.45***	0.08	0.94***	-0.41***	0.60***	-0.05	0.72***	-0.34***	0.26	0.11***
CHL	1.21***	-1.04***	0.55	-0.3	1.60***	-1.44***	1.13	-1.24**	1.14***	-0.96***	0.08	0.03
CHN	1.69***	-0.1	-2.18***	-0.33**	1.26***	0.06*	-1.62***	0.39***	1.57***	-0.04	-2.02***	-0.15**
COL	1.38***	-0.80***	-0.46**	-0.24***	1.63***	-0.65***	-0.86***	-0.30***	1.16***	-0.66***	-0.65***	-0.06***
EGY	0.48***	-0.98***	0.01	0.42***	-0.51***	-0.85***	1.84***	1.22***	0.52***	-0.92***	0.09	0.22***
IND	1.40***	-0.17	-1.30***	0.35*	1.43***	-0.46*	-1.39***	0.60***	1.58***	-0.34	-1.24***	0.13
IDN	1.04***	0.16	1.04***	-0.60***	1.71***	0.65***	-1.32***	-1.15***	0.69***	0.49	0.41	-0.04
IRN	-0.33	-1.84*	2.43	1.14**	-1.07	-1.88**	3.56**	1.07***	-0.65	-2.19**	3.95*	0.3
MEX	0.87**	-1.85***	-0.27	0.25	0.68***	-1.83***	0.03	0	0.73*	-1.90***	-0.1	0.27**
PER	0.75***	-0.61***	-0.16	0.35**	0.47***	-0.40***	-0.30*	0.31***	0.79***	-0.34**	0.11	-0.13
RUS	0.53***	-1.13***	-1.27***	0.01	0.45***	-1.15***	-1.36***	0.08*	0.52***	-1.13***	-1.29***	-0.02
SAU	11.33***	-1.49	17.20***	-3.61***	5.37***	0.71	6.30***	5.48***	8.39***	-0.07	18.58***	-2.92***
ZAF	1.08**	-4.38***	-0.35	2.78***	2.61***	-5.36***	1.62***	0.34	3.26***	-5.06***	-1.24***	1.54***
TUR	2.61***	-2.39***	-2.25***	0.58***	2.64***	-2.03***	-0.79**	-0.14***	2.78***	-2.13***	-2.81***	0.49***
UAE	-9.29***	-3.32***	21.97***	-5.54***	-8.05***	-2.10**	5.77**	1.82	-6.20***	-5.11***	32.24***	-3.61***

Table A.39 – Dynamic OLS - Developing Countries

	Model 1				Model 2				Model 3			
	gdppc	**co2pc**	**kofgi**	**findev**	**gdppc**	**co2pc**	**kofgi**	**fininst**	**gdppc**	**co2pc**	**kofgi**	**finmark**
ARG	-1.57***	1.20*	1.24***	0.38*	-0.81	0.51	2.18*	-0.4	-1.35**	1.17	1.36*	0.15
BRA	0.17	-0.66***	0.39*	0.59***	1.97***	-1.23***	1.14***	-0.73***	0.65***	-0.42***	0	0.16***
CHL	1.01***	-1.73***	1.59**	-0.08	1.49***	-1.95***	1.97***	-1.48***	1.24***	-1.70***	-0.03	0.46*
CHN	2.02***	-0.66***	-2.28***	-0.27**	0.49***	0.33***	-0.63***	1.40***	1.84***	-0.49***	-1.83***	-0.21***
COL	1.08***	-0.86***	0.81***	-0.40***	2.15***	-0.77***	0.03	-0.84***	0.45***	-0.66***	0.95***	-0.13***
EGY	0.48	-1.03**	0.13	0.36**	-0.68***	-1.14***	2.94***	1.33***	0.48***	-1.05***	0.61	0.17***
IND	1.88***	-1.04***	-0.56***	-1.07***	2.38***	-1.14***	-1.36***	-0.41	1.39***	-0.47	-0.79**	-0.34**
IDN	0.78*	0.87	-1.43*	-0.7	0.36	3.55***	-6.10***	-1.41***	-0.12	3.33***	-7.48***	1.41***
IRN	-3.02	-6.03***	8.40***	2.88***	-9.54**	-10.51**	17.41**	5.25***	-1.58	-1.98	2.4	1.49***
MEX	-0.27	-1.14**	0.35	0.07	-0.63	-0.86***	0.5	0.03	-0.13	-1.27***	0.25	0.48*
PER	0.37	-0.77***	-0.51*	1.09***	-0.23	-0.1	-0.80***	0.74***	0.36*	-0.24	0.73***	0
RUS	0.94***	-1.92***	-2.61***	-0.18	0.81***	-2.75***	-3.80***	0.39***	1.05***	-2.31***	-3.11***	-0.15***
SAU	16.58*	-3.83	30.34	-8.94	21.56*	-4.44	19.81**	0.26	13.67	-0.74	27.17	-4.97
ZAF	1.52*	-8.45***	-3.38***	5.31***	-10.61***	-3.88***	2.17***	9.84***	5.46***	-9.21***	-2.61**	1.79***
TUR	3.39***	-4.16***	-0.8	0.55	2.88***	-2.86***	0.85**	-0.18***	2.37***	-0.62	-5.71	0.79*
UAE	-8.61	-2.56**	43.75	-11.62***	4.99	-19.46***	-5.69	29.70***	-10.99**	-13.17***	50.96***	-7.73***

Table A.40 – CCR Model - Developing Countries

	Model 1				Model 2				Model 3			
	gdppc	**co2pc**	**kofgi**	**findev**	**gdppc**	**co2pc**	**kofgi**	**fininst**	**gdppc**	**co2pc**	**kofgi**	**finmark**
ARG	-0.64***	0.28	1.85***	0.21***	-0.25**	-0.01	2.37***	-0.33***	-0.82**	0.58	2.18***	0.13**
BRA	0.83***	-0.36***	0.44***	0.06	0.96***	-0.41***	0.60***	-0.07	0.76***	-0.35***	0.16	0.12***
CHL	1.27***	-1.04***	0.32	-0.25	1.72***	-1.54***	1.04*	-1.33**	1.18***	-0.98***	-0.03	0.04
CHN	1.75***	-0.16	-2.21***	-0.35*	1.26***	0.06*	-1.61***	0.39***	1.60***	-0.08	-2.03***	-0.14*
COL	1.40***	-0.82***	-0.46**	-0.25***	1.63***	-0.65***	-0.86***	-0.30***	1.18***	-0.70***	-0.62**	-0.07***
EGY	0.49***	-0.99***	0.01	0.42***	-0.52***	-0.86***	1.88***	1.23***	0.53***	-0.92***	0.08	0.22***
IND	1.58***	-0.35	-1.38***	0.34*	1.44***	-0.48*	-1.42***	0.64***	1.70***	-0.47	-1.28***	0.1
IDN	1.04***	0.16	1.00***	-0.60***	1.71***	0.65**	-1.33***	-1.15***	0.68**	0.51	0.33	-0.03
IRN	-0.05	-1.78*	2.21	1.15**	-0.76	-1.71*	3.14*	1.03***	-0.66	-2.20**	3.97*	0.3
MEX	0.90*	-1.87***	-0.3	0.26	0.69**	-1.83***	0.02	0.01	0.72	-1.89***	-0.09	0.25
PER	0.80***	-0.71***	-0.3	0.43**	0.48**	-0.42***	-0.37*	0.33***	0.85***	-0.39*	0.02	-0.11
RUS	0.54***	-1.13***	-1.30***	0	0.47***	-1.14***	-1.37***	0.07	0.53***	-1.14***	-1.31***	-0.02
SAU	12.03***	-1.80*	17.05***	-3.56***	5.83**	0.54	6.32***	5.37***	9.29***	-0.47	17.68***	-2.67***
ZAF	1.22*	-4.44***	-0.38	2.72***	2.69**	-5.39***	1.60***	0.3	3.35***	-5.06***	-1.31***	1.54***
TUR	2.61***	-2.39***	-2.25**	0.57**	2.65***	-2.04***	-0.79*	-0.13***	2.78***	-2.13***	-2.82***	0.49***
UAE	-9.28***	-3.31***	22.04***	-5.56***	-8.06***	-1.96**	5.89*	1.69	-6.22***	-5.11***	32.21***	-3.61***

Table A.41 – Fully Modified OLS - Developed Countries

	Model 1				Model 2				Model 3			
	gdppc	**co2pc**	**kofgi**	**findev**	**gdppc**	**co2pc**	**kofgi**	**fininst**	**gdppc**	**co2pc**	**kofgi**	**finmark**
AUS	1.06***	-3.64***	-0.57	0.57***	1.07***	-2.75***	2.18***	-1.80***	1.16***	-3.63***	-1.18	0.30***
BEL	4.78***	-5.25***	-4.90***	0.74***	5.70***	-5.02***	-4.26***	0.21	5.56***	-5.06***	-4.80***	0.11
CAN	-0.57***	0.23***	0.39*	0.17**	-0.50***	0.36***	0.68***	0.17***	-0.52***	0.13*	0.2	0.09*
DNK	2.88***	-0.93***	6.59***	1.20***	1.83*	-1.59***	5.88	3.37***	2.53***	-0.89***	10.46***	0.17**
FIN	0.30***	-0.51***	1.11***	-0.13**	0.27***	-0.50***	0.80***	-0.09	0.25**	-0.50***	0.89**	-0.01
FRA	-0.27	-1.12***	0.36	-0.36***	-0.6	-1.27***	1.01	-0.64***	-0.44**	-1.34***	-2.18***	0.06**
DEU	5.76***	-0.67**	2.74**	-0.56**	6.46***	-0.88***	0.23	0.3	5.97***	-0.79***	2.12**	-0.21**
GRC	0.38*	-2.06***	2.93***	0.91***	0.26*	-2.14***	4.83***	1.32***	0.59	-2.01***	2.45	0.41*
ITA	-0.71	-1.56***	1.19	0.37	-0.21	-1.73***	0.5	0.87***	-0.63	-1.30***	3.90**	-0.07
JAP	3.40***	-2.18***	-0.39	-0.47*	2.71***	-1.88***	-0.75*	0.38	2.92***	-1.94***	-0.19	-0.14**
KOR	6.69***	-2.03***	-1.91*	-0.84***	5.33***	-2.12***	-0.8	-0.88***	6.95***	-2.21***	-1.48	-0.33***
NLD	-0.98***	-0.73***	2.46***	-0.40***	-0.67***	-0.45***	1.35***	-0.26***	-0.83***	-0.56***	1.75***	-0.12***
NZL	0.2	0.34**	-0.62	-0.15	0.54**	0.08	-1.25*	-0.36***	-0.06	0.15	-1.15	0.06
NOR	3.33***	-0.08	-3.53***	1.46***	3.44***	0.37	-5.56***	1.32***	3.71***	0.97	-2.65***	0.45**
POL	-0.5	-1.97***	2.36***	1.28***	0.18	-2.05***	3.66***	1.36***	-0.54**	-1.82***	1.79***	0.49***
PRT	6.30***	-4.80***	1.06	-5.55***	10.17***	-6.14***	-5.38***	-11.13***	5.18***	-4.23***	1.48	-2.98***
ESP	0.44	-1.30***	2.58	0.6	0.94*	-1.57***	1.51	2.81***	0.71	-1.16***	2.62	0.22
SWE	-0.42**	-0.50***	-3.94***	0.86***	-0.50***	-0.42***	0.14	0.27***	0.44	-0.3	-4.93**	0.43**
SWZ	-0.92***	0.08	0.63	0.29***	-1.33***	0.12	2.79***	-0.52*	-0.89***	0.12	0.84	0.16***
UK	2.07***	-2.31***	13.61***	-2.53***	1.65***	-2.89***	4.30**	-0.73*	2.90***	-2.54***	12.17***	-1.48***
USA	-0.82***	-1.88***	0.90***	0.18***	1.04***	-1.44***	-1.24***	-1.84***	-0.55**	-2.10***	-1.55*	0.32***

Table A.42 – Dynamic OLS - Developed Countries

	Model 1				Model 2				Model 3			
	gdppc	**co2pc**	**kofgi**	**findev**	**gdppc**	**co2pc**	**kofgi**	**fininst**	**gdppc**	**co2pc**	**kofgi**	**finmark**
AUS	2.75*	-3.84***	-8.11	1.39*	1.74**	-2.36***	1.84	-3.39***	2.87***	-3.92***	-9.14**	0.73***
BEL	3.87***	-5.22***	-0.87	0.66	3.64***	-5.11***	2.2	0.66	6.37***	-4.73***	0.83	-0.61
CAN	-0.62***	0.11***	0.82***	0.13**	-0.70***	0.39***	0.94***	0.37***	-0.50***	0.10**	1.07***	0.03*
DNK	-0.34	-0.93***	19.37**	0.34	-0.21	-1.48***	14.08**	2.66**	-1.98	-1.16***	26.37**	-0.46
FIN	0.99***	-0.59***	0.63	-0.79***	1.04***	-0.57***	-2.86***	-0.94***	1.07***	-0.60***	-2.77**	-0.02
FRA	-0.68	-1.10**	2.34	-0.74*	-0.96	-1.27***	0.83	-0.85***	-3.3	-1.94***	-0.89	0.49**
DEU	6.79***	2.04***	7.04***	-2.02***	8.66***	2.12***	0.29	-0.61	7.15***	1.99***	6.59***	-0.89***
GRC	0.41	-2.71***	2.26**	1.44***	0.39	-2.79***	4.15***	2.09**	1.19*	-2.92***	0.03	0.86***
ITA	-1.06**	-2.76***	-12.71***	2.79***	-3.13***	-0.94***	2.47**	1.57***	-2.91***	-1.33***	-1.25	0.57***
JAP	0.48	-3.38***	1.15**	-0.07	0.38	-4.12***	1.63***	-1.30***	-0.24	-3.69***	1.00**	0.16**
KOR	11.59***	2.66***	-8.99***	-3.33***	4.07**	-2.29*	12.28**	2.31*	9.64***	1.33**	-0.3	-0.94***
NLD	-1.44***	-1.27***	4.30***	-0.85***	-1.00***	-1.07***	3.07***	-1.01***	-1.37***	-1.13***	3.38***	-0.36***
NZL	2.21***	1.07***	-3.35***	-0.86***	0.24	0.32*	1.69*	-0.36***	1.00***	1.36***	0.32	-0.50***
NOR	3.26***	-0.51	-4.68***	2.61***	3.29***	-2.01*	-12.01***	3.26***	3.59***	3.86*	-0.69	0.82*
POL	0.73	-1.82***	2.62**	-0.18	0.24	-1.44***	2.50**	-0.97**	0.24	-1.90***	2.87***	0.04
PRT	8.15***	-4.04**	-5.02	-7.01***	15.42***	-10.36**	-4.03	-23.59***	8.40***	-0.38	-14.42	-3.31**
ESP	-0.55	-0.70***	6.41***	0	-1.06***	-0.37	7.80***	-0.98	-0.38	-0.75***	5.98***	0.07
SWE	0.15	-0.34***	-6.46***	1.05***	0.24	-0.11	-2.94***	-0.03	2.36***	0.07	-16.19***	1.48***
SWZ	-1.26**	0.19*	0.23	0.44***	-2.35***	0.12	2.32	0.96**	-1.68***	0.18***	2.19***	0.21***
UK	1.23***	-1.47***	32.00***	-5.14***	0.87	-2.81***	9.26**	-0.7	2.55***	-2.25***	22.84***	-2.16***
USA	0.34	-1.43**	-0.55	0.23	1.79**	-1.25***	-0.5	-3.04***	1.02***	-2.36***	-7.17***	1.52***

Table A.43 – CCR Model - Developed Countries

	Model 1				Model 2				Model 3			
	gdppc	**co2pc**	**kofgi**	**findev**	**gdppc**	**co2pc**	**kofgi**	**fininst**	**gdppc**	**co2pc**	**kofgi**	**finmark**
AUS	1.25***	-3.66***	-1.29*	0.64**	1.14***	-2.73***	1.93***	-1.80***	1.34***	-3.66***	-1.83**	0.33***
BEL	4.72***	-5.23***	-4.35***	0.72***	5.53***	-4.99***	-3.29***	0.21	5.43***	-5.02***	-3.78***	0.1
CAN	-0.53***	0.23***	0.29*	0.17**	-0.49***	0.35***	0.64***	0.16***	-0.48***	0.12	0.05	0.09*
DNK	2.74***	-0.93***	7.22***	1.17***	1.16	-1.66***	7.38**	3.58***	2.51***	-0.89***	10.61***	0.17*
FIN	0.34***	-0.52***	0.92***	-0.13*	0.31***	-0.51***	0.62***	-0.1	0.31***	-0.51***	0.65**	-0.01
FRA	-0.21	-1.14***	0.1	-0.35***	-0.48	-1.29***	0.62	-0.63***	-0.41	-1.35***	-2.32***	0.06*
DEU	5.72***	-0.64**	2.99**	-0.59*	6.45***	-0.90**	0.33	0.37	5.92***	-0.77**	2.35**	-0.22*
GRC	0.34*	-2.02***	3.08***	0.89***	0.25*	-2.12***	4.87***	1.32***	0.5	-1.94***	2.59**	0.41*
ITA	-1.93*	-1.23*	1.73	0.52*	-0.6	-1.63***	0.65	0.98*	-1.71	-0.93*	5.22**	-0.09
JAP	3.71***	-2.16***	-0.46	-0.53**	2.96***	-1.88***	-0.89*	0.33	2.92***	-1.94***	-0.2	-0.14***
KOR	6.71***	-2.04***	-1.99*	-0.84***	5.35***	-2.15***	-0.92	-0.87*	6.96***	-2.21***	-1.52*	-0.33***
NLD	-1.02***	-0.75***	2.58***	-0.40***	-0.71***	-0.45***	1.43***	-0.24	-0.85***	-0.57***	1.81***	-0.12***
NZL	0.33	0.37**	-1.04	-0.18	0.52*	0.08	-1.26*	-0.35***	-0.01	0.2	-1.13	0.03
NOR	3.30***	-0.15	-3.48***	1.49***	3.39***	0.3	-5.50***	1.35***	3.68***	0.93	-2.59***	0.46*
POL	-0.5	-1.97***	2.36***	1.28***	0.23	-2.07***	3.63***	1.39***	-0.59*	-1.81***	1.92***	0.48***
PRT	6.31***	-4.81***	1.04	-5.55***	10.18***	-6.16***	-5.41***	-11.06***	5.20***	-4.24***	1.45	-2.98***
ESP	0.44	-1.30***	2.49*	0.62*	0.65	-1.67***	1.33	3.77***	0.55	-1.13***	2.75*	0.24
SWE	-0.44**	-0.51***	-3.87***	0.86***	-0.49***	-0.42***	0.1	0.27***	0.42	-0.3	-5.01**	0.47**
SWZ	-0.84***	0.08	0.42	0.30***	-1.30***	0.13	2.74***	-0.54*	-0.81***	0.13	0.64**	0.17***
UK	2.20***	-2.29***	13.22***	-2.59***	1.49***	-2.85***	5.23***	-0.82*	3.03***	-2.53***	11.95***	-1.51***
USA	-0.80***	-1.88***	0.77***	0.20***	1.03***	-1.44***	-1.20***	-1.83***	-0.53**	-2.10***	-1.64*	0.33***

A.2 Supplementary Material for Paper 2

Table A.44 – Number of Months with Disasters by State

	Wildfire	Drought	Cyclone	Severe Storm	Winter Storm	Flooding
Alabama	7	42	11	28	1	2
Alaska	18	0	0	0	0	0
Arizona	47	78	0	1	0	1
Arkansas	0	31	5	28	1	12
California	60	108	0	2	0	2
Colorado	46	78	0	20	1	2
Connecticut	0	12	7	6	5	1
Delaware	0	18	4	3	3	0
Florida	9	6	12	12	0	0
Georgia	7	42	14	30	3	4
Hawaii	0	0	0	0	0	0
Idaho	54	82	0	0	0	0
Illinois	0	27	1	43	4	12
Indiana	0	30	1	36	2	12
Iowa	0	47	0	28	0	11
Kansas	0	78	0	36	0	11
Kentucky	0	31	3	26	3	9
Louisiana	0	19	11	16	1	13
Maine	0	12	0	0	2	0
Maryland	0	30	8	23	5	2
Massachusetts	0	12	6	5	5	1
Michigan	0	21	0	19	2	5
Minnesota	0	46	0	13	0	4
Mississippi	0	43	10	23	2	9
Missouri	0	35	1	39	2	14
Montana	47	59	0	2	0	2
Nebraska	6	29	0	21	0	10
Nevada	0	0	0	0	0	0
New England	0	0	0	0	0	0
New Hampshire	0	12	2	0	3	0
New Jersey	0	24	7	15	6	2
New Mexico	0	0	0	0	0	0
New York	0	24	7	21	7	2
North Carolina	10	42	15	25	6	1
North Dakota	6	62	0	1	0	3
Ohio	0	24	2	26	3	9
Oklahoma	21	71	0	35	2	11
Oregon	54	84	0	1	1	0
Pennsylvania	0	18	7	26	7	1
Rhode Island	0	12	6	2	4	1
South Carolina	0	30	12	24	3	2
South Dakota	6	44	0	7	0	3
Tennessee	7	31	5	30	4	11
Texas	27	78	8	49	2	11
United States	0	0	0	0	0	0
Utah	28	72	0	1	0	0
Vermont	0	12	1	1	0	0
Virginia	0	30	13	27	6	2
Washington	48	77	0	1	1	0
West Virginia	0	6	3	10	1	1
Wisconsin	0	33	0	20	0	4
Wyoming	45	41	0	7	0	0

Figure 8 – Comparison of Number of Storms and Energy Production.

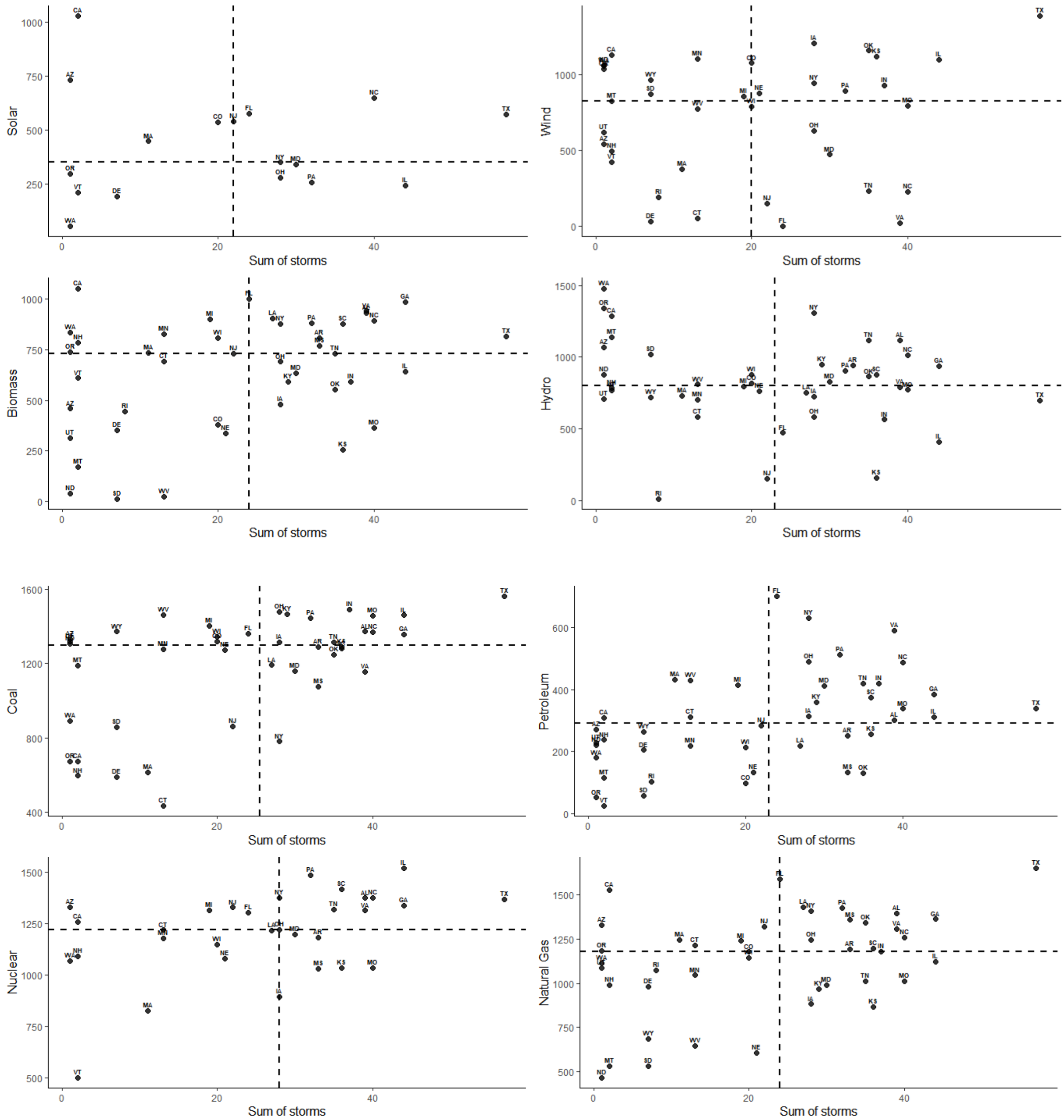


Figure 9 – Comparison of Number of Wildfire and Energy Production.

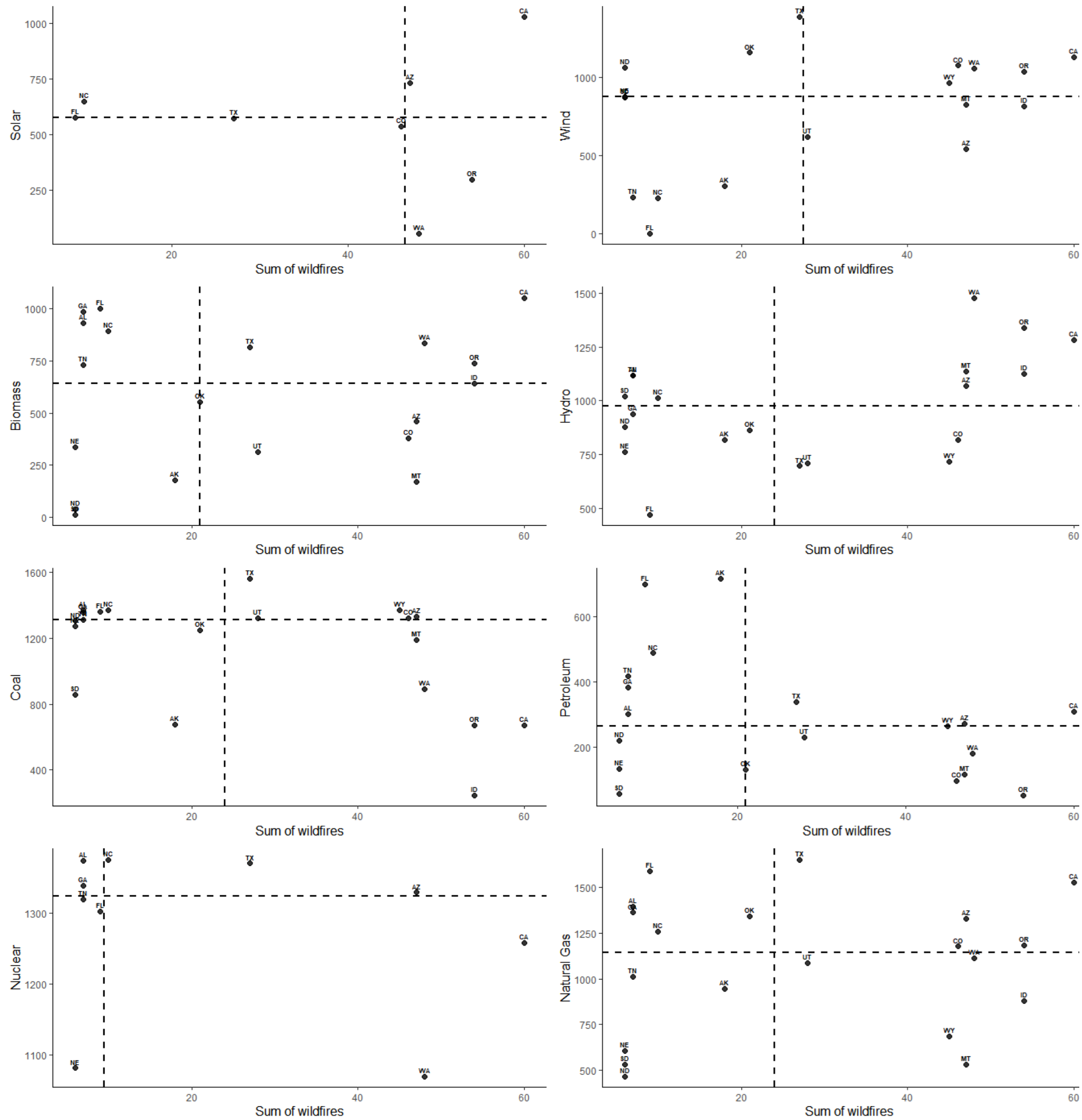


Table A.45 – ADF Test Results (Level)

State	total_renewables	total_non_renewables	solar	biomass	wind	nuclear	natural_gas	hydroelectric	coal	petroleum_liquids	all_fuels	pib	customer	retail_price
Alabama	-6.131***	-5.474***	NA	-0.840	NA	-4.907***	-3.742**	-6.145***	-5.318***	-4.933***	-4.756***	-1.586	-1.169	-6.894***
Alaska	-4.249***	-6.863***	NA	-2.325	-1.935	NA	-5.960***	-6.212***	-3.799**	-4.855***	-7.671***	-2.439	-3.090	-3.795**
Arizona	-7.111***	-9.249***	-0.880	-3.509**	-2.463	-4.731***	-5.924***	-4.697***	-3.351*	-4.322***	-9.415***	-2.902	-2.316	-10.635***
Arkansas	-4.539***	-4.201***	NA	-2.693	NA	-5.226***	-5.048***	-4.228***	-3.325*	-5.045***	-4.358***	0.134	-5.008***	-4.921***
California	-6.851***	-7.026***	-3.650**	-3.762**	-7.249***	-3.946**	-6.033***	-3.528**	-3.134	-3.877**	-11.629***	-3.410*	-6.468***	-6.053***
Colorado	-5.701***	-5.422***	-3.761**	-3.425*	-4.984***	NA	-2.950	-6.783***	-3.205*	-3.880**	-5.314***	-2.480	-3.629**	-5.479***
Connecticut	-3.501**	-4.139***	NA	-1.781	-2.487	-5.145***	-4.189***	-4.751***	-5.186***	-4.564***	-4.036***	-3.310*	-2.719	-2.261
Delaware	-3.964**	-3.960**	-1.890	-1.758	-7.738***	NA	-2.807	NA	-3.197*	-3.456**	-3.993**	-2.359	-1.574	-2.607
Florida	-2.329	-12.278***	-2.257	-2.872	-5.370***	-2.310	-8.854***	-5.525***	-4.035***	-3.948**	-12.413***	-2.422	-2.813	-2.697
Georgia	-3.107	-7.249***	NA	-2.536	NA	-6.435***	-3.569**	-3.982**	-4.915***	-4.338***	-7.019***	-2.854	-1.072	-6.030***
Hawaii	-6.106***	-9.068***	-3.224*	-6.704***	-4.842***	NA	NA	-4.248***	-5.324***	-8.328***	-12.372***	-2.809	-2.483	-2.322
Idaho	-6.625***	-5.927***	NA	-2.908	-2.204	NA	-5.900***	-7.210***	-5.663***	NA	-7.005***	-0.647	-0.371	-2.160
Illinois	-5.645***	-4.151***	-1.353	-5.783***	-5.330***	-6.615***	-4.819***	-5.687***	-2.429	-4.566***	-3.571**	-2.410	-5.315***	-2.838
Indiana	-4.887***	-3.298*	NA	-4.147***	-5.064***	NA	-2.158	-5.484***	-3.037	-3.105	-3.154*	-3.001	-1.987	-4.037***
Iowa	-5.443***	-3.657**	NA	-3.096	-5.415***	-1.258	-3.965**	-4.875***	-3.475**	-3.407*	-2.692	-2.940	-1.184	-9.264***
Kansas	-2.607	-5.466***	NA	-2.546	-2.604	-6.227***	-4.877***	-4.642***	-4.423***	-3.478**	-4.394***	-3.114	-3.934**	-2.669
Kentucky	-6.638***	-3.801**	NA	-4.781***	NA	NA	-4.191***	-6.624***	-2.936	-3.759**	-3.858**	-2.500	-2.268	-2.990
Louisiana	-3.591**	-5.736***	NA	-3.256*	NA	-5.593***	-5.871***	-6.160***	-2.942	-3.640**	-5.695***	-2.858	-3.614**	-3.963**
Maine	-7.993***	-3.266*	NA	-2.950	-4.052***	NA	-3.921**	-8.113***	-5.620***	-4.890***	-4.441***	0.152	-4.845***	-2.473
Maryland	-6.469***	-4.111***	-2.514	-3.865**	-1.830	-6.233***	-6.882***	-6.541***	-3.689**	-4.623***	-3.791**	-2.359	-1.609	-1.795
Massachusetts	-6.286***	-3.366*	-1.704	-0.002	-1.811	-1.728	-5.456***	-6.305***	-3.204*	-4.012***	-3.618**	-3.134	-3.584**	-2.131
Michigan	-4.023***	-4.742***	NA	-3.212*	-2.864	-4.847***	-3.811**	-7.392***	-3.335*	-6.795***	-4.557***	-3.474**	-2.101	-3.253*
Minnesota	-5.745***	-3.830**	NA	-2.144	-5.803***	-3.644**	-4.674***	-3.346*	-3.470**	-4.742***	-3.667**	-2.940	-1.715	-6.399***
Mississippi	-1.560	-6.180***	NA	1.951	NA	-4.995***	-3.777**	NA	-4.227***	-5.827***	-6.216***	-1.201	-2.904	-3.226*
Missouri	-3.153*	-3.571**	NA	-2.499	-2.869	-4.202***	-5.328***	-4.058***	-2.871	-5.375***	-3.374*	-1.644	-1.149	-6.538***
Montana	-5.574***	-6.177***	NA	-2.198	-5.999***	NA	-2.475	-6.039***	-6.189***	-4.544***	-4.329***	-1.799	-2.493	-3.646**
Nebraska	-2.910	-3.664**	NA	-3.806**	-3.270*	-4.455***	-7.225***	-2.934	-4.148***	-3.778**	-3.536**	-1.915	-4.495***	-3.947**
Nevada	-6.869***	-7.651***	-4.517***	-2.069	-1.799	NA	-6.599***	-6.784***	-3.936**	-5.356***	-7.585***	-2.613	-2.922	-4.786***
New Hampshire	-3.782**	-4.981***	NA	-1.421	-3.332*	-6.118***	-5.835***	-7.082***	-4.944***	-4.565***	-4.765***	-1.009	-4.223***	-2.387
New Jersey	-4.534***	-3.268*	-1.759	-2.397	-5.380***	-3.579**	-4.102***	-4.689***	-2.636	-5.231***	-3.320*	-2.380	-2.119	-5.018***
New Mexico	-3.852**	-6.597***	-1.360	-3.121	-3.748**	NA	-5.591***	-2.190	-5.623***	-3.584**	-4.686***	-1.249	-2.739	-4.717***
New York	-5.776***	-6.226***	-4.010***	-4.281***	-5.477***	-2.112	-5.588***	-3.748**	-2.007	-3.381*	-6.514***	-3.199*	-2.237	-3.914**
North Carolina	-4.056***	-4.716***	-1.165	-1.393	-1.933	-5.827***	-2.577	-4.804***	-5.528***	-3.758**	-4.790***	-1.854	-1.374	-3.544**
North Dakota	-4.649***	-5.675***	NA	-2.264	-5.232***	NA	-2.394	-3.179*	-5.733***	-4.423***	-5.199***	-1.689	-0.341	-2.261
Ohio	-3.565**	-3.237*	-4.303***	-3.013	-1.933	-6.362***	-2.752	-5.388***	-3.117	-3.274*	-3.160*	-2.973	-1.970	-3.429*
Oklahoma	-3.820**	-7.378***	NA	-4.448***	-2.432	NA	-5.493***	-4.568***	-2.958	-3.928**	-6.236***	-2.706	-1.501	-6.187***
Oregon	-6.145***	-6.711***	-2.576	-3.747**	-6.319***	NA	-6.209***	-5.776***	-5.079***	-5.540***	-5.885***	-2.551	-1.070	-2.021
Pennsylvania	-5.120***	-2.975	-3.153*	-2.052	-4.410***	-3.445**	-4.350***	-6.260***	-3.035	-3.402*	-2.892	-2.956	-1.367	-2.518
Rhode Island	-2.600	-7.099***	NA	-2.680	-2.611	NA	-7.081***	-3.938**	NA	-6.750***	-6.783***	-2.382	-5.020***	-2.711
South Carolina	-5.363***	-5.173***	NA	-1.998	NA	-6.200***	-5.054***	-4.513***	-4.261***	-4.156***	-4.589***	-2.727	-1.817	-3.815**
South Dakota	-3.548**	-3.998**	NA	-3.510**	-2.876	NA	-4.534***	-4.918***	-4.157***	-4.408***	-4.012***	-1.696	-4.755***	-3.246*
Tennessee	-5.350***	-4.381***	NA	-2.226	-3.523**	-3.844**	-1.880	-5.143***	-4.832***	-5.231***	-3.954**	-1.950	-2.886	-4.669***
Texas	-5.997***	-9.784***	-4.666***	-2.653	-5.678***	-4.860***	-8.643***	-4.811***	-4.777***	-7.041***	-10.645***	-2.613	-2.084	-2.669
Utah	-3.399*	-5.561***	NA	-2.943	-4.731***	NA	-3.283*	-3.892**	-6.043***	-2.494	-5.744***	-2.397	-2.164	-3.409*
Vermont	-7.638***	-2.048	-3.500**	-4.092***	-1.964	-1.979	NA	-6.905***	NA	-4.304***	-2.787	-1.876	-4.038***	-1.760
Virginia	-2.858	-2.892	NA	-1.377	-0.392	-4.572***	-3.416*	-5.082***	-2.444	-3.766**	-2.889	-1.175	-3.471**	-5.930***
Washington	-6.186***	-5.966***	-2.689	-3.660**	-5.460***	-4.665***	-5.661***	-6.267***	-7.132***	-5.186***	-5.487***	-2.353	-1.147	-4.623***
West Virginia	-7.128***	-3.634**	NA	-2.373	-5.997***	NA	-5.294***	-7.334***	-3.373*	-4.654***	-3.564**	-1.951	-2.602	-3.641**
Wisconsin	-4.666***	-5.505***	NA	-2.231	-6.540***	-3.674**	-3.681**	-5.418***	-3.520**	-3.574**	-5.440***	-2.781	-0.284	-3.421*
Wyoming	-3.993**	-5.065***	NA	NA	-4.574***	NA	-4.947***	-7.813***	-4.836***	-4.568***	-5.189***	-3.209*	-5.315***	-0.485

Table A.46 – PP Test Results (Level)

Variable State	all_fuels	biomass	coal	hydro	customer	natural_gas	nuclear	petroleum	pib	retail_price	solar	non_renewables	renewables	wind
Alabama	-63.289***	-163.866***	-52.417***	-53.481***	-9.796	-42.089***	-103.293***	-152.497***	-15.381	-70.384***	NA	-59.952***	-58.414***	NA
Alaska	-65.691***	-14.266	-75.402***	-75.743***	-17.369	-81.124***	NA	-124.446***	-9.533	-65.791***	NA	-71.321***	-69.443***	-29.729***
Arizona	-58.393***	-85.976***	-30.853***	-57.453***	-14.806	-52.095***	-89.139***	-155.062***	-6.214	-57.009***	-3.927	-57.811***	-53.408***	-14.421
Arkansas	-57.527***	-38.920***	-62.111***	-47.935***	-60.585***	-68.266***	-119.590***	-125.413***	-3.922	-59.260***	NA	-57.029***	-67.467***	NA
California	-62.056***	-67.144***	-44.895***	-36.173***	-245.668***	-52.432***	-63.219***	-120.755***	-14.867	-58.942***	-39.762***	-56.278***	-54.274***	-57.309***
Colorado	-59.008***	-25.817**	-51.061***	-125.010***	-8.529	-56.768***	NA	-193.801***	-10.364	-46.788***	-42.718***	-56.448***	-78.468***	-63.079***
Connecticut	-74.024***	-222.364***	-98.758***	-52.575***	-20.497*	-58.466***	-98.449***	-91.789***	-15.992	-17.094	NA	-73.602***	-109.644***	-24.322**
Delaware	-52.925***	-60.294***	-90.276***	NA	-5.538	-30.607***	NA	-81.813***	-13.098	-67.546***	-16.707	-52.616***	-126.589***	-122.051***
Florida	-61.730***	-60.475***	-42.119***	-84.130***	-76.946***	-57.171***	-60.150***	-98.578***	-6.926	-70.939***	-18.317*	-61.239***	-14.904	-167.292***
Georgia	-59.547***	-92.942***	-60.675***	-51.229***	-2.187	-37.116***	-88.845***	-144.302***	-12.104	-55.603***	NA	-59.240***	-52.818***	NA
Hawaii	-85.884***	-75.842***	-104.589***	-104.138***	-36.673***	NA	NA	-87.918***	-11.909	-10.317	-25.630**	-85.808***	-95.415***	-131.326***
Idaho	-60.838***	-80.930***	-56.452***	-56.512***	-1.329	-75.655***	NA	NA	-2.031	-20.679*	NA	-73.273***	-56.281***	-12.544
Illinois	-70.474***	-79.942***	-45.928***	-139.403***	-18.409*	-62.798***	-98.958***	-150.022***	-17.878*	-29.500***	-16.787	-65.495***	-51.195***	-49.013***
Indiana	-64.691***	-68.974***	-60.972***	-128.088***	-10.587	-52.001***	NA	-180.546***	-22.394**	-29.327***	NA	-62.056***	-36.139***	-28.239***
Iowa	-75.808***	-78.172***	-53.464***	-120.108***	-3.558	-52.658***	-20.112*	-114.201***	-19.688*	-54.393***	NA	-55.132***	-55.028***	-53.348***
Kansas	-59.590***	-39.642***	-56.540***	-98.366***	-16.057	-56.643***	-100.894***	-134.354***	-25.546**	-30.847***	NA	-57.336***	-50.679***	-51.299***
Kentucky	-61.174***	-103.429***	-55.713***	-65.876***	-8.048	-72.144***	NA	-149.415***	-26.623**	-35.752***	NA	-60.764***	-69.545***	NA
Louisiana	-58.219***	-45.659***	-54.995***	-53.067***	-166.319***	-58.918***	-90.590***	-151.868***	-12.958	-24.690**	NA	-58.403***	-66.580***	NA
Maine	-69.761***	-70.896***	-46.664***	-65.800***	-216.487***	-71.973***	NA	-93.601***	-2.332	-27.360**	NA	-81.706***	-62.102***	-36.627***
Maryland	-73.112***	-83.610***	-79.838***	-75.809***	-3.754	-64.191***	-93.157***	-113.392***	-19.717*	-36.191***	-21.858**	-70.998***	-67.900***	-12.383
Massachusetts	-61.432***	-87.854***	-47.315***	-65.012***	-140.136***	-58.690***	-9.332	-86.452***	-25.968**	-17.310	-14.154	-58.566***	-119.818***	-14.140
Michigan	-65.001***	-60.954***	-56.137***	-130.409***	-26.690**	-64.569***	-155.919***	-127.014***	-25.202**	-33.159***	NA	-62.781***	-45.014***	-24.772**
Minnesota	-65.138***	-44.666***	-53.166***	-44.559***	-13.936	-91.788***	-76.182***	-115.408***	-23.030**	-52.846***	NA	-60.828***	-67.560***	-63.309***
Mississippi	-66.040***	-53.206***	-88.147***	NA	-119.942***	-62.668***	-69.475***	-149.341***	-12.734	-29.484***	NA	-66.064***	-93.194***	NA
Missouri	-53.349***	-79.492***	-52.337***	-49.128***	-32.395***	-69.076***	-64.369***	-132.550***	-18.129*	-49.004***	NA	-53.127***	-52.140***	-33.423***
Montana	-67.431***	-17.853*	-58.346***	-54.100***	-12.428	-75.250***	NA	-163.583***	-11.144	-56.284***	NA	-58.287***	-53.409***	-63.758***
Nebraska	-57.767***	-70.529***	-55.925***	-26.183**	-95.873***	-82.710***	-123.480***	-94.119***	-18.518*	-40.182***	NA	-52.930***	-31.629***	-34.702***
Nevada	-54.434***	-11.201	-45.987***	-69.980***	-25.657**	-55.425***	NA	-119.836***	-11.871	-50.135***	-45.726***	-55.290***	-69.312***	-7.435
New Hampshire	-106.823***	-39.543***	-72.138***	-75.664***	-36.359***	-79.494***	-152.431***	-80.202***	-18.922*	-21.654**	NA	-108.987***	-55.674***	-20.328*
New Jersey	-55.864***	-52.001***	-58.486***	-73.896***	-138.542***	-43.968***	-91.958***	-84.092***	-16.871	-45.552***	-13.274	-55.660***	-51.666***	-72.584***
New Mexico	-66.459***	-73.082***	-65.661***	-22.701**	-31.672***	-63.485***	NA	-67.164***	-8.017	-43.626***	-6.269	-62.574***	-47.909***	-44.739***
New York	-64.466***	-78.132***	-59.905***	-76.961***	-110.178***	-52.880***	-58.025***	-72.788***	-32.327***	-39.497***	-34.162***	-58.227***	-84.502***	-58.326***
North Carolina	-60.313***	-52.974***	-76.105***	-63.410***	-10.024	-37.420***	-79.711***	-110.861***	-11.811	-43.051***	-10.065	-60.552***	-55.359***	-9.128
North Dakota	-82.023***	-33.379***	-64.602***	-45.905***	0.245	-38.927***	NA	-154.621***	-3.467	-31.944***	NA	-64.375***	-45.512***	-43.986***
Ohio	-57.237***	-97.785***	-66.415***	-108.742***	-7.640	-51.080***	-84.654***	-116.662***	-20.535*	-29.465***	-40.180***	-57.009***	-43.558***	-12.240
Oklahoma	-55.549***	-123.299***	-36.735***	-47.764***	-21.673**	-51.798***	NA	-151.754***	-10.541	-58.304***	NA	-54.042***	-71.712***	-55.951***
Oregon	-77.619***	-74.940***	-69.577***	-57.029***	-4.912	-61.461***	NA	-144.871***	-8.812	-10.894	-16.265	-58.171***	-57.991***	-70.591***
Pennsylvania	-57.404***	-56.129***	-58.729***	-64.369***	-5.331	-55.121***	-87.999***	-105.125***	-25.735**	-25.160**	-28.579***	-56.059***	-51.444***	-39.911***
Rhode Island	-68.228***	-38.343***	NA	-112.874***	-215.882***	-67.919***	NA	-97.165***	-29.163***	-46.738***	NA	-69.044***	-32.448***	-20.902*
South Carolina	-61.530***	-70.687***	-63.677***	-48.384***	-74.601***	-60.517***	-80.765***	-142.900***	-14.987	-59.593***	NA	-61.036***	-55.906***	NA
South Dakota	-59.749***	-47.542***	-68.587***	-61.299***	-156.068***	-88.625***	NA	-138.996***	-13.153	-36.934***	NA	-77.795***	-38.645***	-10.492
Tennessee	-64.961***	-48.639***	-70.805***	-60.894***	-12.392	-43.704***	-74.361***	-122.727***	-20.065*	-36.279***	NA	-64.300***	-59.109***	-39.697***
Texas	-57.119***	-83.464***	-43.151***	-84.799***	-9.259	-55.548***	-121.478***	-132.408***	-10.627	-33.008***	-42.509***	-55.615***	-86.541***	-82.931***
Utah	-58.285***	-14.573	-58.673***	-36.602***	-5.449	-52.208***	NA	-112.728***	-5.227	-34.860***	NA	-55.524***	-42.004***	-21.057**
Vermont	-32.091***	-114.367***	NA	-67.200***	-39.179***	NA	-9.952	-116.919***	-25.470**	-16.531	-33.818***	-11.362	-74.464***	-18.195*
Virginia	-54.463***	-33.706***	-86.027***	-82.100***	-81.759***	-62.012***	-82.574***	-102.530***	-14.837	-30.688***	NA	-54.756***	-49.741***	-4.179
Washington	-65.365***	-42.140***	-62.089***	-54.743***	-39.721***	-63.263***	-46.827***	-124.674***	-11.032	-43.316***	-14.896	-56.083***	-54.312***	-91.726***
West Virginia	-63.057***	-22.451**	-61.809***	-65.011***	-25.822**	-70.449***	NA	-147.064***	-16.501	-9.215	NA	-62.130***	-57.766***	-51.626***
Wisconsin	-54.303***	-39.889***	-51.366***	-95.719***	-58.866***	-79.938***	-112.957***	-130.716***	-27.441**	-34.209***	NA	-53.761***	-53.190***	-32.756***
Wyoming	-58.770***	NA	-56.520***	-56.294***	-107.075***	-86.907***	NA	-171.048***	-10.932	-8.121	NA	-57.532***	-31.311***	-33.047***

Table A.47 – KPSS Test Results (Level)

Variable State	all_fuels	biomass	coal	hydro	customer	natural_gas	nuclear	petroleum	pib	retail_price	solar	non_renewables	renewables	wind
Alabama	0.575**	0.166*	2.940***	0.515**	3.313***	1.878***	1.241***	3.242***	3.364***	2.224***	NA	0.706**	0.793***	NA
Alaska	0.842***	2.104***	0.409*	1.279***	0.240*	2.599***	NA	0.317*	0.202*	3.368***	NA	2.093***	2.206***	2.509***
Arizona	0.053*	0.255*	2.397***	0.357*	3.414***	0.703**	0.533**	0.298*	3.334***	1.485***	2.874***	0.302*	3.043***	2.246***
Arkansas	0.133*	2.308***	0.977***	0.337*	3.298***	1.829***	0.157*	0.125*	3.319***	1.919***	NA	0.150*	0.254*	NA
California	0.081*	0.619**	3.033***	0.198*	3.200***	0.704**	2.051***	0.843***	3.447***	2.893***	3.093***	1.632***	2.275***	1.638***
Colorado	1.508***	3.153***	2.469***	0.193*	3.264***	1.347***	NA	1.610***	3.427***	2.309***	3.287***	1.791***	3.213***	3.080***
Connecticut	2.408***	0.181*	2.375***	0.697**	3.199***	2.666***	0.050*	1.801***	3.226***	1.325***	NA	2.397***	1.213***	2.684***
Delaware	0.574**	2.445***	2.796***	NA	3.390***	1.183***	NA	1.775***	3.234***	2.639***	2.682***	0.578**	0.552**	0.554**
Florida	0.720**	0.483**	2.741***	0.164*	3.407***	2.225***	0.571**	2.419***	3.375***	0.832***	3.112***	0.497**	2.771***	0.212*
Georgia	0.092*	3.349***	2.644***	0.956***	3.311***	2.705***	0.543**	0.501**	3.452***	1.484***	NA	0.444*	3.067***	NA
Hawaii	2.204***	0.150*	1.917***	0.119*	3.487***	NA	NA	2.608***	3.238***	0.263*	3.394***	2.699***	2.735***	2.331***
Idaho	1.527***	0.457*	2.220***	0.050*	3.342***	1.654***	NA	NA	3.322***	2.769***	NA	1.590***	1.206***	2.386***
Illinois	1.857***	2.861***	2.791***	0.156*	3.367***	2.741***	0.965***	2.961***	3.393***	1.681***	2.516***	2.466***	2.618***	2.583***
Indiana	2.367***	2.927***	2.982***	1.575***	3.307***	3.010***	NA	1.364***	3.382***	3.308***	NA	2.557***	2.299***	1.823***
Iowa	1.824***	1.013***	2.429***	0.062*	3.422***	2.506***	0.997***	0.210*	3.369***	2.086***	NA	2.068***	2.901***	2.855***
Kansas	1.533***	1.515***	2.787***	2.205***	2.701***	0.447*	0.105*	0.488**	3.425***	2.772***	NA	2.450***	3.314***	3.316***
Kentucky	2.741***	0.130*	3.040***	2.093***	3.089***	3.099***	NA	2.024***	3.370***	3.167***	NA	2.800***	2.156***	NA
Louisiana	0.262*	0.722**	2.712***	0.227*	3.402***	2.053***	0.045*	2.534***	2.222***	0.168*	NA	0.253*	0.431*	NA
Maine	2.868***	3.039***	0.472**	1.213***	2.955***	2.745***	NA	2.248***	3.294***	1.089***	NA	2.888***	0.040*	2.914***
Maryland	0.684**	1.816***	2.746***	0.061*	3.402***	2.673***	0.602**	2.287***	3.451***	1.521***	3.341***	0.803***	1.555***	2.372***
Massachusetts	2.577***	1.137***	2.946***	0.336*	3.258***	1.184***	1.877***	1.546***	3.448***	2.563***	3.292***	2.568***	2.989***	2.551***
Michigan	0.406*	0.824***	2.810***	0.565**	2.972***	2.789***	0.446*	2.210***	3.379***	2.774***	NA	0.082*	3.021***	2.994***
Minnesota	1.733***	1.140***	2.095***	0.826***	3.412***	2.614***	1.141***	0.306*	3.429***	3.126***	NA	0.236*	2.808***	2.608***
Mississippi	2.090***	0.846***	2.477***	NA	3.378***	2.756***	0.204*	1.006***	3.245***	0.984***	NA	2.072***	0.198*	NA
Missouri	1.870***	2.531***	2.325***	0.433*	3.258***	1.454***	0.579**	0.456*	3.407***	2.078***	NA	2.130***	2.412***	2.689***
Montana	0.765***	0.684**	0.981***	0.115*	3.450***	1.671***	NA	0.409*	3.300***	3.072***	NA	0.928***	1.575***	2.751***
Nebraska	0.867***	2.096***	1.171***	1.132***	3.415***	1.344***	0.405*	1.257***	3.388***	2.228***	NA	1.622***	3.275***	3.296***
Nevada	0.836***	3.094***	2.025***	0.311*	3.242***	0.392*	NA	0.780***	3.255***	1.354***	3.335***	0.168*	3.352***	2.645***
New Hampshire	1.335***	0.613**	2.447***	0.316*	3.260***	0.948***	0.172*	0.152*	3.378***	2.716***	NA	1.234***	0.824***	2.485***
New Jersey	0.523**	1.029***	2.741***	0.356*	3.356***	1.608***	1.407***	1.221***	3.361***	1.046***	2.964***	0.432*	3.113***	0.706**
New Mexico	0.700**	0.434*	2.727***	1.140***	3.401***	1.599***	NA	0.118*	2.938***	1.635***	2.940***	2.325***	3.222***	3.005***
New York	0.574**	0.655**	3.094***	1.253***	3.427***	0.331*	0.765***	1.619***	3.447***	0.731**	3.289***	1.206***	2.595***	2.079***
North Carolina	0.637**	1.311***	2.846***	0.917***	3.339***	2.762***	0.957***	0.875***	3.432***	2.132***	3.358***	0.147*	3.229***	2.689***
North Dakota	2.654***	2.467***	1.500***	1.115***	3.387***	3.256***	NA	0.791***	2.618***	2.571***	NA	0.762***	3.039***	3.001***
Ohio	1.708***	0.530**	3.161***	0.264*	2.895***	2.798***	0.630**	2.288***	3.398***	2.097***	2.981***	1.888***	2.926***	2.642***
Oklahoma	0.666**	0.576**	2.313***	0.392*	3.454***	0.344*	NA	0.624**	2.826***	0.704**	NA	1.805***	3.365***	3.297***
Oregon	0.822***	1.264***	1.221***	0.221*	3.372***	0.543**	NA	0.302*	3.428***	2.944***	3.196***	0.216*	0.627**	1.793***
Pennsylvania	0.340*	1.226***	3.211***	0.374*	3.327***	3.054***	0.538**	1.938***	3.404***	0.356*	2.825***	0.309*	1.734***	2.070***
Rhode Island	0.182*	0.796***	NA	0.163*	2.932***	0.150*	NA	0.405*	3.371***	2.382***	NA	0.143*	1.801***	3.047***
South Carolina	0.300*	1.665***	3.037***	1.127***	3.330***	2.530***	0.471**	1.010***	3.457***	2.866***	NA	0.692**	2.141***	NA
South Dakota	2.154***	0.278*	0.548**	0.763***	3.465***	2.540***	NA	0.114*	3.302***	3.180***	NA	0.173*	2.314***	2.232***
Tennessee	0.248*	0.778***	2.627***	0.751***	3.262***	2.640***	1.818***	1.332***	3.433***	2.006***	NA	0.387*	0.726**	0.895***
Texas	1.205***	0.465**	2.056***	0.836***	3.367***	1.002***	0.134*	1.647***	3.295***	1.597***	3.425***	0.053*	3.343***	3.314***
Utah	0.611**	2.127***	2.093***	0.295*	3.416***	1.370***	NA	0.503**	3.414***	2.132***	NA	1.289***	2.945***	1.820***
Vermont	2.636***	0.366*	NA	0.256*	3.389***	NA	2.890***	0.421*	3.338***	3.021***	3.281***	2.903***	1.519***	2.769***
Virginia	2.835***	2.197***	2.654***	0.849***	3.346***	3.092***	0.768***	0.945***	3.413***	1.514***	NA	2.663***	2.928***	0.929***
Washington	0.175*	0.517**	0.128*	0.136*	3.411***	0.910***	0.262*	1.618***	3.448***	3.341***	1.873***	0.304*	0.133*	2.025***
West Virginia	1.707***	0.245*	1.989***	0.227*	0.724**	3.061***	NA	0.495**	3.013***	2.425***	NA	1.772***	1.550***	1.853***
Wisconsin	0.132*	1.014***	1.984***	1.982***	3.404***	2.988***	1.641***	0.853***	3.433***	2.582***	NA	0.027*	1.840***	1.197***
Wyoming	0.770***	NA	1.671***	0.262*	3.466***	2.849***	NA	0.095*	0.161*	2.990***	NA	1.512***	1.650***	1.533***

Table A.48 – ADF Test Results (First Difference)

Variable State	all_fuels	biomass	coal	hydro	customer	natural_gas	nuclear	petroleum	pib	retail_price	solar	non_renewables	renewables	wind
Alabama	-7.328***	-3.838**	-6.375***	-7.935***	-7.036***	-8.095***	-9.897***	-9.178***	-5.624***	-7.675***	NA	-6.582***	-7.795***	NA
Alaska	-8.053***	-5.938***	-7.785***	-7.869***	-5.092***	-8.957***	NA	-7.100***	-5.120***	-7.185***	NA	-8.375***	-8.003***	-7.480***
Arizona	-6.942***	-8.170***	-7.140***	-7.504***	-8.270***	-8.302***	-21.704***	-9.142***	-6.846***	-10.978***	-6.074***	-6.895***	-9.286***	-6.402***
Arkansas	-7.577***	-7.264***	-7.320***	-6.707***	-7.625***	-7.564***	-9.834***	-7.712***	-7.197***	-7.744***	NA	-7.366***	-7.460***	NA
California	-8.188***	-8.331***	-7.559***	-9.733***	-8.229***	-7.432***	-7.691***	-7.355***	-6.850***	-7.290***	-7.947***	-7.419***	-11.249***	-9.498***
Colorado	-11.863***	-6.242***	-9.045***	-7.898***	-4.296***	-8.828***	NA	-8.686***	-6.902***	-8.836***	-7.287***	-9.542***	-7.444***	-7.375***
Connecticut	-9.863***	-8.981***	-7.173***	-7.827***	-7.220***	-8.277***	-11.343***	-7.690***	-6.027***	-6.489***	NA	-9.234***	-9.539***	-7.490***
Delaware	-7.544***	-7.298***	-9.275***	NA	-7.710***	-8.150***	NA	-8.546***	-5.776***	-8.678***	-8.194***	-7.527***	-7.422***	-8.008***
Florida	-7.932***	-6.858***	-7.572***	-7.992***	-11.533***	-8.893***	-10.327***	-7.813***	-7.598***	-6.253***	-7.142***	-8.008***	-6.317***	-9.073***
Georgia	-7.612***	-8.656***	-7.471***	-6.825***	-7.018***	-8.230***	-9.748***	-8.257***	-6.851***	-6.743***	NA	-7.510***	-7.513***	NA
Hawaii	-6.828***	-7.347***	-7.775***	-9.150***	-7.473***	NA	NA	-6.468***	-5.019***	-5.383***	-7.195***	-7.101***	-7.974***	-8.477***
Idaho	-8.067***	-9.054***	-8.318***	-8.451***	-5.712***	-8.047***	NA	NA	-7.446***	-8.170***	NA	-9.293***	-9.362***	-7.444***
Illinois	-12.150***	-7.480***	-10.344***	-7.477***	-6.973***	-7.118***	-12.145***	-9.015***	-6.274***	-6.976***	-7.068***	-11.570***	-6.517***	-6.607***
Indiana	-10.065***	-7.174***	-8.262***	-8.232***	-6.760***	-8.709***	NA	-8.049***	-6.494***	-6.428***	NA	-9.200***	-6.834***	-6.202***
Iowa	-10.585***	-8.031***	-7.015***	-8.474***	-7.538***	-7.378***	-6.684***	-8.151***	-6.038***	-7.288***	NA	-7.273***	-6.762***	-6.670***
Kansas	-7.419***	-5.879***	-7.020***	-7.596***	-6.845***	-8.148***	-8.393***	-8.654***	-7.095***	-9.547***	NA	-7.296***	-8.345***	-8.350***
Kentucky	-7.574***	-8.090***	-8.185***	-8.198***	-3.645**	-7.989***	NA	-8.902***	-6.570***	-7.475***	NA	-7.882***	-8.302***	NA
Louisiana	-7.156***	-7.312***	-6.958***	-7.573***	-7.645***	-7.611***	-7.666***	-9.451***	-4.544***	-6.253***	NA	-7.102***	-8.251***	NA
Maine	-9.416***	-8.164***	-7.616***	-8.405***	-9.331***	-8.435***	NA	-8.320***	-7.873***	-6.646***	NA	-9.201***	-7.802***	-7.877***
Maryland	-7.587***	-7.830***	-9.011***	-8.188***	-6.212***	-8.703***	-9.996***	-7.932***	-7.050***	-7.677***	-7.779***	-7.867***	-7.987***	-7.586***
Massachusetts	-7.027***	-11.192***	-7.583***	-7.639***	-7.159***	-6.545***	-5.817***	-7.578***	-6.181***	-6.472***	-7.995***	-6.732***	-7.776***	-7.624***
Michigan	-8.967***	-7.018***	-8.894***	-7.651***	-8.829***	-7.800***	-9.123***	-7.833***	-6.654***	-8.277***	NA	-8.616***	-7.395***	-8.085***
Minnesota	-11.049***	-7.006***	-7.238***	-6.475***	-6.400***	-7.936***	-9.309***	-8.318***	-6.715***	-8.237***	NA	-10.765***	-6.865***	-7.012***
Mississippi	-8.116***	-8.036***	-8.148***	NA	-8.145***	-7.547***	-8.187***	-7.333***	-7.207***	-8.229***	NA	-8.076***	-9.666***	NA
Missouri	-7.323***	-9.181***	-10.159***	-7.512***	-8.814***	-7.964***	-6.054***	-7.944***	-7.217***	-7.331***	NA	-7.177***	-8.070***	-7.445***
Montana	-7.739***	-5.798***	-7.867***	-7.605***	-7.807***	-6.922***	NA	-9.544***	-6.053***	-8.070***	NA	-7.992***	-6.669***	-7.245***
Nebraska	-8.633***	-6.882***	-7.867***	-7.240***	-9.244***	-8.056***	-8.386***	-8.390***	-7.061***	-7.454***	NA	-7.790***	-8.109***	-7.914***
Nevada	-7.498***	-5.665***	-6.230***	-8.223***	-4.786***	-6.623***	NA	-7.445***	-6.048***	-6.174***	-8.219***	-6.553***	-8.114***	-5.327***
New Hampshire	-9.518***	-9.442***	-7.675***	-7.944***	-6.467***	-7.879***	-8.684***	-7.866***	-8.012***	-8.024***	NA	-9.159***	-8.261***	-7.110***
New Jersey	-7.942***	-8.193***	-7.563***	-7.492***	-8.272***	-7.872***	-9.786***	-7.259***	-6.860***	-6.798***	-7.919***	-8.048***	-8.481***	-7.302***
New Mexico	-7.850***	-6.365***	-7.237***	-6.277***	-3.586**	-8.107***	NA	-7.640***	-6.167***	-7.095***	-6.620***	-7.507***	-7.440***	-7.979***
New York	-8.026***	-7.742***	-9.199***	-6.620***	-9.236***	-7.458***	-8.551***	-8.925***	-6.879***	-7.647***	-7.259***	-7.482***	-8.003***	-7.365***
North Carolina	-7.985***	-9.093***	-9.356***	-7.112***	-7.214***	-8.275***	-11.500***	-7.808***	-7.499***	-9.471***	-6.989***	-7.430***	-7.066***	-6.663***
North Dakota	-9.062***	-7.713***	-9.696***	-6.968***	-4.375***	-6.891***	NA	-7.854***	-4.400***	-10.934***	NA	-10.232***	-7.134***	-6.483***
Ohio	-9.653***	-8.584***	-9.442***	-8.033***	-6.646***	-8.131***	-9.020***	-7.901***	-6.743***	-7.411***	-7.472***	-9.970***	-7.591***	-6.712***
Oklahoma	-6.729***	-8.235***	-6.615***	-7.607***	-7.114***	-6.954***	NA	-7.705***	-4.933***	-8.484***	NA	-6.567***	-7.552***	-7.613***
Oregon	-6.484***	-7.483***	-7.655***	-8.179***	-8.616***	-8.257***	NA	-8.660***	-6.991***	-7.120***	-7.704***	-8.055***	-7.092***	-8.325***
Pennsylvania	-10.260***	-8.069***	-11.176***	-8.112***	-7.987***	-8.002***	-11.811***	-8.791***	-6.591***	-5.941***	-7.480***	-10.838***	-7.307***	-7.568***
Rhode Island	-8.410***	-6.683***	NA	-8.344***	-9.381***	-8.724***	NA	-8.012***	-7.235***	-6.815***	NA	-8.408***	-6.604***	-6.515***
South Carolina	-10.644***	-9.802***	-9.235***	-7.553***	-9.515***	-9.053***	-11.305***	-9.241***	-7.353***	-8.998***	NA	-9.900***	-7.206***	NA
South Dakota	-8.355***	-6.532***	-7.394***	-7.277***	-7.684***	-7.890***	NA	-8.054***	-6.761***	-9.304***	NA	-8.389***	-7.835***	-6.497***
Tennessee	-9.336***	-7.403***	-8.243***	-7.522***	-5.101***	-7.534***	-9.798***	-9.004***	-7.493***	-5.749***	NA	-9.328***	-7.539***	-6.938***
Texas	-6.909***	-8.324***	-7.243***	-7.563***	-7.412***	-7.335***	-9.159***	-8.913***	-5.203***	-7.735***	-7.357***	-7.010***	-8.277***	-8.745***
Utah	-7.538***	-6.463***	-7.491***	-7.385***	-3.862**	-9.241***	NA	-10.025***	-7.049***	-8.174***	NA	-7.463***	-7.690***	-8.452***
Vermont	-7.207***	-10.339***	NA	-7.499***	-7.872***	NA	-5.613***	-8.755***	-7.190***	-6.908***	-7.920***	-5.313***	-8.279***	-6.442***
Virginia	-14.446***	-8.817***	-10.568***	-7.572***	-7.386***	-10.429***	-11.733***	-9.349***	-7.244***	-8.808***	NA	-15.530***	-7.154***	-6.441***
Washington	-8.667***	-8.438***	-7.868***	-7.915***	-11.765***	-8.953***	-7.552***	-9.157***	-9.013***	-7.516***	-6.207***	-8.025***	-8.011***	-8.309***
West Virginia	-7.887***	-6.527***	-10.252***	-8.133***	-6.445***	-7.888***	NA	-10.163***	-6.508***	-6.477***	NA	-8.371***	-8.480***	-7.692***
Wisconsin	-8.646***	-7.754***	-7.738***	-8.284***	-11.711***	-8.123***	-10.439***	-7.013***	-6.771***	-7.862***	NA	-8.398***	-7.170***	-6.619***
Wyoming	-8.390***	NA	-7.844***	-9.834***	-7.862***	-8.327***	NA	-8.813***	-5.039***	-7.405***	NA	-8.249***	-7.271***	-8.146***

Table A.49 – PP Test Results (First Difference)

Variable State	all_fuels	biomass	coal	hydro	customer	natural_gas	nuclear	petroleum	pib	retail_price	solar	non_renewables	renewables	wind
Alabama	-102.861***	-208.395***	-118.387***	-147.672***	-213.811***	-134.624***	-148.826***	-197.143***	-154.133***	-190.326***	NA	-101.943***	-155.798***	NA
Alaska	-162.229***	-170.174***	-166.568***	-172.103***	-168.080***	-159.075***	NA	-188.963***	-168.382***	-194.801***	NA	-160.144***	-175.925***	-154.716***
Arizona	-160.978***	-251.839***	-172.187***	-169.524***	-168.075***	-163.770***	-161.258***	-193.162***	-167.863***	-162.997***	-171.428***	-160.853***	-179.324***	-178.346***
Arkansas	-86.764***	-169.807***	-119.341***	-178.170***	-168.104***	-134.870***	-181.195***	-192.255***	-167.846***	-164.993***	NA	-89.759***	-175.177***	NA
California	-158.382***	-166.423***	-135.045***	-112.695***	-174.325***	-136.581***	-155.804***	-200.376***	-168.066***	-144.540***	-146.206***	-127.749***	-145.378***	-165.860***
Colorado	-116.764***	-167.421***	-162.284***	-183.739***	-167.939***	-136.915***	NA	-229.598***	-167.944***	-171.487***	-180.076***	-88.980***	-167.141***	-164.656***
Connecticut	-113.939***	-278.396***	-165.494***	-147.616***	-168.155***	-138.442***	-164.928***	-133.983***	-168.018***	-170.009***	NA	-111.197***	-167.053***	-166.812***
Delaware	-148.209***	-160.213***	-148.658***	NA	-168.012***	-166.223***	NA	-134.234***	-167.857***	-165.190***	-187.027***	-148.051***	-153.309***	-222.309***
Florida	-171.015***	-173.130***	-164.413***	-208.897***	-167.759***	-171.953***	-167.063***	-192.137***	-167.873***	-207.751***	-188.055***	-170.783***	-173.363***	-193.143***
Georgia	-96.302***	-180.499***	-135.525***	-166.559***	-168.276***	-120.439***	-130.436***	-231.389***	-167.814***	-149.823***	NA	-96.449***	-171.783***	NA
Hawaii	-167.161***	-170.185***	-160.537***	-163.406***	-167.862***	NA	NA	-171.705***	-167.956***	-158.412***	-171.930***	-168.612***	-161.892***	-208.122***
Idaho	-118.327***	-162.523***	-156.869***	-164.126***	-168.451***	-146.678***	NA	NA	-167.185***	-165.276***	NA	-136.378***	-145.783***	-165.648***
Illinois	-160.511***	-191.429***	-165.519***	-182.683***	-168.391***	-129.462***	-169.313***	-195.028***	-168.051***	-198.095***	-176.934***	-163.833***	-117.893***	-113.448***
Indiana	-101.086***	-181.738***	-118.398***	-192.130***	-168.296***	-126.834***	NA	-195.990***	-167.748***	-173.348***	NA	-95.166***	-135.458***	-154.456***
Iowa	-125.885***	-202.759***	-88.286***	-179.397***	-167.567***	-112.722***	-182.533***	-193.943***	-167.737***	-102.540***	NA	-89.807***	-137.744***	-134.614***
Kansas	-99.415***	-212.756***	-94.315***	-172.238***	-180.124***	-136.079***	-160.567***	-195.840***	-166.148***	-146.986***	NA	-88.415***	-162.609***	-162.562***
Kentucky	-104.640***	-173.622***	-128.722***	-157.719***	-167.770***	-144.445***	NA	-198.861***	-161.569***	-161.910***	NA	-120.353***	-159.542***	NA
Louisiana	-121.687***	-179.518***	-135.517***	-159.885***	-219.459***	-156.679***	-171.495***	-202.849***	-173.878***	-176.490***	NA	-122.968***	-190.750***	NA
Maine	-146.754***	-137.236***	-174.759***	-143.682***	-170.988***	-166.088***	NA	-159.198***	-167.932***	-159.420***	NA	-161.852***	-158.031***	-176.618***
Maryland	-155.848***	-173.672***	-155.730***	-200.241***	-167.902***	-158.529***	-169.712***	-174.745***	-168.203***	-184.019***	-159.359***	-158.699***	-174.028***	-160.669***
Massachusetts	-118.902***	-160.505***	-181.388***	-142.802***	-182.916***	-123.434***	-171.615***	-167.618***	-164.313***	-160.875***	-163.135***	-115.755***	-198.322***	-174.078***
Michigan	-150.678***	-171.485***	-168.553***	-209.941***	-167.817***	-154.478***	-189.626***	-185.113***	-165.371***	-161.515***	NA	-147.609***	-145.533***	-162.220***
Minnesota	-108.835***	-180.402***	-98.762***	-147.836***	-168.955***	-166.531***	-121.970***	-202.608***	-167.465***	-148.018***	NA	-96.987***	-150.221***	-141.529***
Mississippi	-102.984***	-247.551***	-156.775***	NA	-168.533***	NA	-153.406***	-200.978***	-167.784***	-157.882***	NA	-105.742***	-172.119***	NA
Missouri	-78.285***	-177.523***	-137.577***	-159.864***	-167.633***	-118.505***	-183.157***	-196.095***	-167.313***	-112.966***	NA	-77.366***	-150.058***	-176.279***
Montana	-147.504***	-200.666***	-127.024***	-89.023***	-168.181***	-195.232***	NA	-202.477***	-167.943***	-172.637***	NA	-128.707***	-87.586***	-171.156***
Nebraska	-87.254***	-179.056***	-104.206***	-164.953***	-167.590***	-184.668***	-175.840***	-185.557***	-166.849***	-142.188***	NA	-101.664***	-160.945***	-147.961***
Nevada	-108.325***	-171.829***	-117.614***	-183.424***	-193.133***	-160.843***	NA	-209.347***	-161.037***	-124.709***	-84.344***	-101.408***	-169.974***	-170.194***
New Hampshire	-169.347***	-162.366***	-119.072***	-146.872***	-167.907***	-171.176***	-203.696***	-131.095***	-167.867***	-164.876***	NA	-171.508***	-159.314***	-170.194***
New Jersey	-133.736***	-207.222***	-125.112***	-193.530***	-166.328***	-165.409***	-153.302***	-150.967***	-167.784***	-120.058***	-157.468***	-134.674***	-182.817***	-159.793***
New Mexico	-133.401***	-176.909***	-155.189***	-185.500***	-167.826***	-127.020***	NA	-188.588***	NA	-139.537***	-161.713***	-122.124***	-172.427***	-171.154***
New York	-141.414***	-172.745***	-138.056***	-172.172***	-168.084***	-127.290***	-168.771***	-123.332***	-168.124***	-124.376***	-172.147***	-130.628***	-183.683***	-160.561***
North Carolina	-93.701***	-156.427***	-159.649***	-163.112***	-168.689***	-126.359***	-128.041***	-179.158***	-167.829***	-161.104***	-174.201***	-97.926***	-158.709***	-164.222***
North Dakota	-153.477***	-164.921***	-94.763***	-153.915***	-167.887***	-169.305***	NA	-210.783***	-167.805***	-193.857***	NA	-120.613***	-157.010***	-156.287***
Ohio	-115.553***	-168.913***	-128.628***	-181.890***	-168.017***	-159.290***	-156.680***	-186.572***	-167.976***	-119.816***	-129.709***	-129.187***	-158.343***	-164.190***
Oklahoma	-89.280***	-185.975***	-142.704***	-152.632***	-168.132***	-91.822***	NA	-193.242***	-168.131***	-185.963***	NA	-78.684***	-183.053***	-183.559***
Oregon	-151.570***	-162.387***	-172.893***	-153.808***	-168.430***	-113.417***	NA	-208.237***	-166.417***	-161.073***	-144.055***	-98.103***	-131.206***	-181.042***
Pennsylvania	-123.281***	-188.504***	-161.692***	-165.435***	-167.834***	-144.268***	-170.273***	-176.543***	-167.578***	-105.425***	-170.201***	-149.074***	-152.863***	-137.167***
Rhode Island	-165.363***	-159.946***	NA	-172.321***	-170.686***	-169.062***	NA	-168.505***	-167.885***	-209.799***	NA	-165.832***	-158.100***	-169.738***
South Carolina	-157.130***	-167.324***	-162.580***	-160.856***	-168.105***	-200.545***	-166.491***	-206.556***	-167.832***	-159.486***	NA	-157.288***	-172.754***	NA
South Dakota	-164.925***	-173.930***	-149.405***	-176.558***	-168.769***	-170.691***	NA	-221.729***	-167.837***	-173.707***	NA	-141.234***	-181.689***	-171.194***
Tennessee	-134.888***	-169.901***	-152.571***	-146.594***	-167.744***	-134.888***	-171.641***	-170.885***	-167.715***	-148.975***	NA	-157.138***	-160.645***	-163.457***
Texas	-145.394***	-176.750***	-144.751***	-186.835***	-167.555***	-149.746***	-180.505***	-200.301***	-168.632***	-141.842***	-174.601***	-136.109***	-178.198***	-166.977***
Utah	-158.712***	-168.021***	-152.203***	-161.816***	-167.942***	-153.812***	NA	-175.517***	-167.975***	-148.367***	NA	-156.439***	-164.226***	-167.217***
Vermont	-165.482***	-157.868***	NA	-130.881***	-167.963***	NA	-174.772***	-180.660***	-167.795***	-165.826***	-136.185***	-212.387***	-171.448***	-182.068***
Virginia	-141.731***	-164.076***	-155.526***	-189.592***	-168.015***	-153.530***	-167.427***	-164.023***	-168.068***	-162.086***	NA	-163.116***	-189.729***	-163.866***
Washington	-114.747***	-148.541***	-137.881***	-148.677***	-172.523***	-111.433***	-154.093***	-178.924***	-166.529***	-164.471***	-127.300***	-112.333***	-136.127***	-179.456***
West Virginia	-102.609***	-165.492***	-147.491***	-168.961***	-168.037***	-156.389***	NA	-194.719***	-167.823***	-175.508***	NA	-119.824***	-156.564***	-164.694***
Wisconsin	-71.793***	-167.020***	-82.410***	-176.792***	-168.288***	-146.356***	-165.736***	-193.319***	-168.010***	-151.168***	NA	-70.610***	-176.070***	-143.706***
Wyoming	-111.973***	NA	-112.653***	-112.209***	-168.059***	-181.693***	NA	-211.018***	-168.429***	-171.487***	NA	-106.793***	-167.988***	-158.883***

Table A.50 – KPSS Test Results (First Difference)

Variable State	all_fuels	biomass	coal	hydro	customer	natural_gas	nuclear	petroleum	pib	retail_price	solar	non_renewables	renewables	wind
Alabama	0.021*	0.017*	0.023*	0.014*	0.283*	0.028*	0.016*	0.020*	0.295*	0.025*	NA	0.017*	0.014*	NA
Alaska	0.321*	0.251*	0.324*	0.225*	0.044*	0.278*	0.332*	0.185*	0.349*	0.225*	NA	0.310*	0.252*	0.046*
Arizona	0.260*	0.193*	0.319*	0.119*	0.325*	0.077*	0.333*	0.141*	0.256*	0.143*	0.244*	0.270*	0.094*	0.055*
Arkansas	0.068*	0.347*	0.036*	0.040*	0.336*	0.060*	0.037*	0.025*	0.374*	0.110*	0.332*	0.054*	0.111*	0.332*
California	0.124*	0.349*	0.129*	0.085*	0.332*	0.110*	0.033*	0.017*	0.304*	0.049*	0.107*	0.058*	0.138*	0.212*
Colorado	0.287*	0.285*	0.329*	0.054*	0.346*	0.204*	0.332*	0.069*	0.366*	0.223*	0.242*	0.142*	0.283*	0.151*
Connecticut	0.122*	0.050*	0.057*	0.070*	0.356*	0.030*	0.322*	0.116*	0.453*	0.174*	0.332*	0.042*	0.332*	0.336*
Delaware	0.072*	0.269*	0.088*	0.332*	0.342*	0.054*	0.332*	0.047*	0.340*	0.274*	0.082*	0.067*	0.247*	0.044*
Florida	0.311*	0.346*	0.306*	0.089*	0.326*	0.316*	0.304*	0.120*	0.281*	0.120*	0.066*	0.311*	0.258*	0.240*
Georgia	0.084*	0.081*	0.069*	0.187*	0.354*	0.112*	0.019*	0.054*	0.397*	0.068*	0.332*	0.066*	0.239*	NA
Hawaii	0.309*	0.219*	0.240*	0.088*	0.333*	0.332*	0.332*	0.308*	0.338*	0.215*	0.060*	0.309*	0.219*	0.203*
Idaho	0.016*	0.104*	0.034*	0.257*	0.284*	0.100*	NA	0.332*	0.568**	0.263*	0.332*	0.040*	0.106*	0.080*
Illinois	0.310*	0.053*	0.328*	0.242*	0.327*	0.019*	0.333*	0.255*	0.310*	0.038*	0.100*	0.323*	0.043*	0.014*
Indiana	0.129*	0.038*	0.108*	0.048*	0.345*	0.116*	0.332*	0.355*	0.378*	0.183*	0.332*	0.075*	0.105*	0.062*
Iowa	0.265*	0.097*	0.025*	0.037*	0.346*	0.136*	0.297*	0.072*	0.355*	0.048*	NA	0.050*	0.040*	0.036*
Kansas	0.127*	0.094*	0.041*	0.275*	0.528**	0.029*	0.052*	0.060*	0.416*	0.023*	NA	0.046*	0.230*	0.230*
Kentucky	0.059*	0.095*	0.236*	0.205*	0.315*	0.039*	0.332*	0.039*	0.423*	0.194*	NA	0.156*	0.237*	0.332*
Louisiana	0.019*	0.294*	0.038*	0.073*	0.126*	0.074*	0.322*	0.025*	0.200*	0.125*	NA	0.020*	0.024*	NA
Maine	0.291*	0.126*	0.247*	0.057*	0.337*	0.135*	0.332*	0.061*	0.379*	0.090*	NA	0.194*	0.075*	0.214*
Maryland	0.115*	0.106*	0.199*	0.016*	0.325*	0.021*	0.322*	0.032*	0.324*	0.191*	0.049*	0.187*	0.104*	0.148*
Massachusetts	0.024*	0.284*	0.024*	0.017*	0.263*	0.041*	0.103*	0.059*	0.427*	0.060*	0.212*	0.024*	0.042*	0.133*
Michigan	0.211*	0.335*	0.321*	0.013*	0.292*	0.042*	0.222*	0.174*	0.418*	0.253*	0.332*	0.216*	0.015*	0.027*
Minnesota	0.279*	0.038*	0.046*	0.067*	0.344*	0.132*	0.137*	0.024*	0.372*	0.158*	NA	0.202*	0.071*	0.052*
Mississippi	0.055*	0.212*	0.036*	0.332*	0.341*	0.055*	0.017*	0.016*	0.369*	0.137*	NA	0.023*	0.238*	0.332*
Missouri	0.037*	0.204*	0.291*	0.113*	0.326*	0.122*	0.020*	0.048*	0.259*	0.023*	NA	0.031*	0.032*	0.236*
Montana	0.236*	0.065*	0.073*	0.093*	0.340*	0.129*	0.332*	0.101*	0.356*	0.120*	NA	0.093*	0.062*	0.153*
Nebraska	0.031*	0.260*	0.070*	0.168*	0.313*	0.013*	0.207*	0.049*	0.221*	0.034*	NA	0.169*	0.226*	0.177*
Nevada	0.019*	0.240*	0.040*	0.029*	0.095*	0.290*	0.332*	0.018*	0.578**	0.025*	0.118*	0.013*	0.149*	0.246*
New Hampshire	0.193*	0.168*	0.036*	0.049*	0.336*	0.054*	0.021*	0.175*	0.349*	0.271*	0.332*	0.145*	0.211*	0.137*
New Jersey	0.214*	0.043*	0.052*	0.190*	0.330*	0.247*	0.188*	0.098*	0.289*	0.117*	0.103*	0.227*	0.100*	0.256*
New Mexico	0.096*	0.306*	0.227*	0.234*	0.329*	0.072*	0.332*	0.063*	0.360*	0.140*	0.167*	0.035*	0.067*	0.163*
New York	0.223*	0.344*	0.040*	0.326*	0.330*	0.163*	0.347*	0.060*	0.322*	0.132*	0.283*	0.204*	0.017*	0.101*
North Carolina	0.037*	0.072*	0.277*	0.118*	0.349*	0.068*	0.039*	0.093*	0.380*	0.200*	0.217*	0.026*	0.227*	0.355*
North Dakota	0.290*	0.336*	0.040*	0.124*	0.327*	0.257*	0.332*	0.080*	0.307*	0.048*	0.332*	0.261*	0.111*	0.106*
Ohio	0.139*	0.353*	0.154*	0.067*	0.329*	0.074*	0.297*	0.320*	0.302*	0.051*	0.018*	0.194*	0.241*	0.192*
Oklahoma	0.094*	0.039*	0.028*	0.029*	0.338*	0.040*	0.332*	0.022*	0.355*	0.059*	0.332*	0.047*	0.023*	0.037*
Oregon	0.108*	0.074*	0.015*	0.146*	0.416*	0.026*	NA	0.037*	0.564**	0.137*	0.069*	0.025*	0.048*	0.090*
Pennsylvania	0.205*	0.377*	0.312*	0.117*	0.327*	0.014*	0.331*	0.073*	0.275*	0.075*	0.223*	0.282*	0.155*	0.069*
Rhode Island	0.210*	0.160*	0.332*	0.301*	0.332*	0.161*	0.332*	0.059*	0.342*	0.036*	0.332*	0.197*	0.220*	0.341*
South Carolina	0.295*	0.328*	0.302*	0.211*	0.321*	0.015*	0.326*	0.049*	0.252*	0.235*	NA	0.293*	0.099*	0.332*
South Dakota	0.265*	0.299*	0.027*	0.017*	0.333*	0.094*	0.332*	0.123*	0.356*	0.108*	NA	0.168*	0.079*	0.437*
Tennessee	0.168*	0.347*	0.169*	0.016*	0.326*	0.032*	0.315*	0.086*	0.282*	0.065*	NA	0.247*	0.070*	0.196*
Texas	0.179*	0.113*	0.212*	0.087*	0.303*	0.182*	0.019*	0.044*	0.260*	0.054*	0.030*	0.167*	0.086*	0.318*
Utah	0.318*	0.281*	0.266*	0.283*	0.336*	0.340*	0.332*	0.310*	0.351*	0.094*	0.332*	0.310*	0.272*	0.163*
Vermont	0.125*	0.093*	0.332*	0.012*	0.332*	0.332*	0.231*	0.047*	0.345*	0.344*	0.032*	0.075*	0.078*	0.162*
Virginia	0.295*	0.225*	0.239*	0.015*	0.330*	0.393*	0.319*	0.073*	0.318*	0.199*	0.332*	0.324*	0.029*	0.458*
Washington	0.024*	0.073*	0.013*	0.227*	0.379*	0.047*	0.027*	0.192*	0.445*	0.337*	0.070*	0.038*	0.160*	0.236*
West Virginia	0.100*	0.279*	0.240*	0.211*	0.333*	0.155*	0.332*	0.080*	0.336*	0.106*	NA	0.096*	0.182*	0.092*
Wisconsin	0.059*	0.347*	0.063*	0.016*	0.325*	0.032*	0.330*	0.057*	0.297*	0.026*	NA	0.057*	0.020*	0.025*
Wyoming	0.071*	0.332*	0.063*	0.039*	0.331*	0.304*	0.332*	0.077*	0.377*	0.198*	NA	0.036*	0.075*	0.031*