FOSSIL FUEL SUBSIDIES AND THE ENVIRONMENT: A CROSS COUNTRY ANALYSIS OF REFORM OUTCOMES

BY

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FEBRUARY, 2026

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BEING A THESIS SUBMITTED TO THE DEPARTMENT OF ECONOMICS, FACULTY OF SOCIAL SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (PhD) DEGREE IN ECONOMICS.

FEBRUARY, 2026

DECLARATION

I the undersigned hereby declare that this thesis titled "**FOSSIL FUEL SUBSIDIES AND THE ENVIRONMENT: A CROSS COUNTRY ANALYSIS OF REFORM OUTCOMES"** is my original work and has not been submitted for any degree or professional qualification at any other academic institution. All sources of information and data utilized in this thesis have been duly acknowledged. I further declare that this thesis is the result of my own investigation and the opinions and conclusions drawn are my own except where otherwise stated and properly referenced.

__________________________ ________________________

Eseosa Joy SOWEMIMO **Date**

CERTIFICATION

This is to certify that this study was carried out by ESEOSA JOY SOWEMIMO in the Department of Economics, University of Benin, Benin City, Edo State, Nigeria.

Professor Aderoju Oyefusi **Chief Supervisor**	**Date**
Professor. S.O. Igbinedion **Co-Supervisor**	**Date**
Professor C.A.U. Ighodaro **Head of Department**	**Date**

DEDICATION

This thesis is dedicated to the Lord Jesus Christ for the abundance of his grace over me and my family. I thank my husband, Dr. Adeshina Sowemimo for his role and support through the various stages of my academic journey, I could not have done it without him, his words spurred me on even on days when I was tired, I knew I could not fail. May God continue to bless and cover him in his love. I also want to appreciate my siblings for their unconditional love and support. To Dr. Osazee Idemudia, always full of wisdom and sage advice. To Mrs. Osatohanmwen Idemudia-Karimu for being my sounding board, my crying board and my every board. God will continue to bless you both for me. To my mum, Mrs. Jane Enowamagbe Idemudia, for loving her children so passionately and for covering her family with prayers. To my Uncle, Barr. Solomon Isokpan the giant on whose shoulders I have stood on all my life, thank you for believing in me and for being proud of me. To my mother-in-law, Mrs. Rose Sowemimo and my sister-in-law, Mrs Iyabo Sowemimo; I thank them for their kindness and hospitality especially during the University of Ibadan phase of this journey, they will never lose their reward. A special thanks to my supervisor, Professor Sulaimon Aderoju Oyefusi, who went from being teacher, supervisor and mentor, to being my father. I greatly love and appreciate him. To my wonderful children, Oluwaseun Olaitan Sowemimo, Zoe Oluwatomisin Sowemimo and Gia Oyindamola Sowemimo, mummy loves them so much. I thank them for their understanding, patience and love. We all got this Ph.D. together.

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LIST OF ACRONYMS

EKC – Environmental Kuznets Curve

CO2 – Carbon dioxide emissions

GHG/GHGs – Greenhouse Gas emissions

IPAT – Impact, Population, Affluence and Technology

STIRPAT – Stochastic Impact by Regression on Population, Affluence, and **T**echnology

CSDID – Callaway and Sant'Anna Staggered Difference-in-Differences

Sys-GMM – System Generalized Method of Moments

ABSTRACT

Fossil fuel subsidies have long been recognized as a significant misalignment between energy pricing policies and environmental sustainability objectives, encouraging overconsumption of fossil fuels and slowing the transition to cleaner energy sources. While these subsidies are often justified on grounds of affordability and energy security, they tend to exacerbate greenhouse gas emissions, distort energy markets, and undermine climate policy commitments. The aim of this study is to examine the environmental consequences of fossil fuel subsidies and the impact of subsidy reforms across a geographically diverse sample of 68 countries.

The data utilized in this study span the periods 2010 to 2023. Of the 68 countries in the sample, 51 are identified as having implemented fossil fuel subsidy reforms between 2010 and 2023, while 17 serve as control countries that maintained their subsidy regimes without major reforms during this period. The study employed a combination of system generalized method of moments (GMM) estimation and the Callaway and Sant'Anna Difference-in-Differences method with staggered treatment to analyze the effects of fossil fuel subsidies and subsidy reforms on CO_2 and greenhouse gas emissions.

The result from the system GMM revealed that fossil fuel subsidies significantly increased emissions, with affluence moderating the effect such that higher-income countries experience a smaller emissions response to subsidies. The analysis found no evidence for the traditional Environmental Kuznets Curve (EKC); however, reform-augmented EKC analysis demonstrated that subsidy reforms can generate complex dynamics, including temporary "green paradox" effects, where emissions initially rise among low-income populations due to higher energy prices and limited access to clean alternatives. Over the longer term, the Staggered Difference in Difference results showed that subsidy reforms significantly reduced emissions, with earlier adopters achieving the greatest cumulative environmental gains. Based on these findings, the study recommended that policymakers calibrate subsidy strategies to income levels, phase out subsidies alongside investments in clean energy access, enact policies that protect the biomass and maintain reforms as continuous rather than one-off measures. The work contributed to knowledge by empirically validating the differential effects of fossil fuel subsidy reforms on emissions, highlighting the importance of context-sensitive climate policy.

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Fossil fuel subsidies are government policies that reduces the cost of energy production from fossil fuels, either by raising the price received by energy producers or reducing the price paid by energy consumers. Subsidies include both explicit financial support, such as direct government payments or tax breaks, and implicit subsidies, such as unpriced externalities like air pollution and climate damage. Countries adopt fossil fuel subsidy policies primarily as a means of addressing energy poverty, improving accessibility, stimulating domestic consumption and production activities with the goal of accelerating economic growth (Abdulwakil,et al. 2022). Nonetheless, fossil fuel subsidies are quite controversial with concerns about its impact falling into four broad categories. They include issues of fiscal sustainability and the significant budgetary pressure it engenders; the fact that it diverts resources away from investments in critical public services and efficient energy sources. It also creates problems of inequity since richer households are believed to benefit more from fossil fuel subsidies relative to poorer households (Coady et al 2017; Kuehl et al 2021). Lastly, fossil fuel subsidies have provoked considerable environmental concerns because they aggravate local air pollution, exacerbates congestion in transport systems, increases carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions thereby fueling the climate crisis (Coady et al, 2017; Ferraresi, et al, 2018; Adetutu & Weyman-Jones, 2019; Keuhl et al, 2021).

While the first three categories of fossil fuel subsidy concerns have serious implications for economic and social outcomes at the local level, the environmental dimension poses a critical challenge at both the local and global level, and is the focus of this study. According to the 2023 Global Climate Report, 2023 was the warmest year since global records began in 1850. The earth's temperature has risen by an average of 0.06^0 Celsius per decade since 1850. Whereas some of this has been due to natural causes, a major contributory factor has been the emissions of CO_2 and other GHGs like methane. Human activities, especially the burning of fossil fuels, and to a lesser degree, cutting down of forests adds about 40 billion metric tons of CO_2 to the atmosphere annually which is above what natural processes can remove, thereby accelerating global warming (NOAA, 2023; IPCC, 2023).

One of the most common measurements of fossil fuel subsidy is arrived at by taking the difference between the price paid by consumers and the financial costs of supplying the fuel. This definition, variously known as explicit or pre-tax subsidy, has been classified as inefficient as it does not account for environment cost. This is in contrast to post-tax or implicit subsidies which arises when consumer prices are lower than supply costs plus a Pigouvian tax that reflects environmental damages as well as the general consumer tax. Nonetheless, accounting for the environmental costs of fossil fuels is difficult to operationalize in reality due to the substantial complexity in measuring environmental damages. Consequently, most empirical measurements of fossil fuel subsidies focus on pre-tax subsidy. In a sense, the award of pre-tax fossil fuel subsidy may be considered a double tragedy as it not only fails to accommodate the externalities associated with fossil fuel production and utilization in determining the market price, but also allows people to use the resource at a price less than the market determined price.

Fossil fuel subsidy (pre-tax subsidy) may impact on the environment directly through greater emission of CO_2 and other GHGs as a result of increased usage. It may also have indirect impact through its interaction with population (demographic structure), income and the technology of production and consumption adopted in the society (Ehrlich & Holdren 1971; Dietz & Rosa, 1994). Fossil fuel subsidies may also alter the relationship between economic development and environmental degradation by altering the progress along the path of the Environmental Kuznets Curve (EKC). In particular, fossil fuel subsidy may delay or hasten the turning point on the EKC (the point at which society transit from higher to lower environmental degradation as income grows) depending on the relative strength of the substitution and income effect of subsidies on fossil fuel consumption. Thus, given the current focus on climate change and the urgency of keeping global warming within the limit of 1.5^0 and 2.0^0 Celsius, it has been argued that subsidy reform is one way to scale down the use of fossil fuels and thus reduce GHG emissions (Coady et al, 2017; Kuehl et al, 2021).

This discussion around fossil fuel subsidies and the necessity of reforms have also raised significant ethical and practical considerations. Many argue that developing nations, given their historically low contributions to global greenhouse gas emissions, should not bear the burden for addressing climate change; in this case through subsidy removal (Mayer, 2018; Sovacool & Linnér, 2016). Instead, the onus should be on developed countries that have historically emitted the largest shares of pollutants, as they possess the resources and infrastructure to drive emissions reductions more effectively (Perry, 2020). Furthermore, it is considered unjust for developing nations, which often grapple with economic constraints, to impose additional hardships on their citizens by eliminating subsidies that support energy access and economic development (Beaton et al., 2013). Proponents of maintaining subsidies especially in the Global South further highlight that developed nations themselves provide substantial subsidies in critical sectors, such as agriculture and energy, as a means of bolstering their economies and mitigating the impact of inflation on households (IEA, 2021; Newell & Simms, 2019). The argument posits that if wealthy nations are permitted such subsidies, it would seem inequitable to expect developing nations to forgo similar economic supports especially when these subsidies can promote growth and enhance quality of life (Dasgupta & Roy, 2020). However, retaining fossil fuel subsidies also poses potential long-term risks for both the environment and economic stability, reinforcing the need for all countries, irrespective of their development stage, to seek balanced and innovative solutions for energy transition in the context of climate change (Collier & Venables, 2019).

This study thus seeks to undertake an evidence-based analysis of the impact of fossil fuel subsidy reforms on the environment.

1.2 Statement of the Research Problem

Fossil fuel subsidies represent a significant global challenge, with the International Monetary Fund estimating their value at $7.4 trillion in 2022 which is approximately 7.1% of global GDP (Black et al., 2023). These subsidies have far-reaching implications for climate change mitigation, public finance sustainability, and social equity. The urgency of addressing this issue is accentuated by the fact that fossil fuel combustion accounts for approximately 73% of global greenhouse gas emissions, with coal, oil, and gas being the primary contributors. Furthermore, the World Health Organization (WHO, 2021) attributes approximately 7 million premature deaths annually to air pollution (both ambient and household) particularly in low- and middle-income countries. These fatalities are linked to ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and acute respiratory infections, with a significant portion stemming from pollutants generated by fossil fuel combustion.

Despite substantial research examining the environmental effects of fossil fuel subsidies, critical gaps remain in the literature. Existing studies (e.g., Akinyemi et al., 2017; Li et al., 2017; Coxhead & Grainger, 2018; Agboje, 2022) have primarily analyzed subsidies within the broader context of their economic impacts. While Solarin (2020) and Arzaghi & Squalli (2023) have appropriately identified fossil fuel subsidies as drivers of environmental degradation, these studies have not explored the potential interactions between subsidies and other established determinants of environmental impact, as originally identified by Ehrlich & Holdren (1971) in their seminal IPAT framework. Such interactions may generate indirect effects that differ substantially from the direct environmental impacts of subsidies (Girma et al., 2020), and failure to account for these mechanisms may underestimate the full environmental consequences of subsidy policies.

The relationship between fossil fuel subsidies and environmental outcomes is more nuanced than often acknowledged. A less prominent perspective suggests that in developing countries, fossil fuel subsidies might paradoxically reduce certain forms of environmental degradation by enabling citizens to transition away from traditional energy sources, thereby decreasing reliance on biomass for production and consumption (United Nations Environmental Programme, 2002; Lin & Jiang, 2011). Conversely, other scholars (Fischer & Toman, 2001; Holton, 2012) argue that subsidies distort market prices, disincentivizing investment in the energy sector as firms struggle to attract resources for productivity enhancement, capacity building, and environmental improvements. This creates a self-reinforcing cycle that produces uncompetitive industries and ultimately reduces GDP per capita, with attendant environmental implications.

The literature has identified several moderating factors in the relationship between fossil fuel subsidies and environmental outcomes, including urbanization, human capital development, energy intensity, energy structure, industrial capacity, investment, resource rents, and globalization (Solarin, 2020; Gani, 2021; Arzaghi & Squalli, 2023). However, two potentially crucial variables have received inadequate attention: (1) governance quality, particularly state capacity to maintain law and order, regulate economic activities, provide public services, and ensure transparency and accountability; and (2) the existence and enforcement of environmental protection policies. These factors may play decisive roles in determining the environmental outcomes of subsidy reforms.

A frequently overlooked challenge is that subsidy reforms may trigger unintended negative consequences, particularly in low-income countries. For instance, the abrupt removal of cooking fuel subsidies might compel households to revert to biomass for cooking and heating, thereby accelerating forest degradation and compromising indoor air quality (Omotosho, 2020). This raises a critical question: does income level mediate the environmental outcomes of fossil fuel subsidy reforms? More specifically, might reform impacts be negative at lower income levels but positive at higher income levels, suggesting the existence of a reform-augmented Environmental Kuznets Curve?

According to Sanchez et al. (2020), data from the International Institute of Sustainable Development indicate that more than forty countries have implemented fossil fuel subsidy reforms over the past two decades, employing diverse strategies including gradualist approaches, strategic timing considerations, attention to country-specific socio-economic and political contexts, pivoting toward renewable energy support, and provision of social safety nets for vulnerable populations. Despite this rich diversity of reform experiences and the heterogeneity of approaches, no systematic empirical study has comprehensively assessed the environmental impacts of these reforms.

This study addresses these gaps by employing the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model to examine both the direct and indirect effects of fossil fuel subsidies on environmental outcomes. Specifically, the study contributes to the literature by analyzing the interaction effects between fossil fuel subsidies and established drivers of environmental impact, thereby capturing indirect mechanisms often overlooked in previous research. The study also conducts a robust empirical analysis of subsidy reform impacts within a dynamic panel framework that accounts for temporal dependencies and endogeneity concerns. In addition, the study investigates whether the environmental effects of subsidy reforms vary systematically with income levels and thus, tests for the existence of a reform-augmented Environmental Kuznets Curve.

1.3 Research Questions

This study raises the following research questions.

i. Do fossil fuel subsidies have an indirect effect on the environment?

ii. To what extent does fossil fuel subsidies affect the validity and shape of the Environmental Kuznets Curve?

iii. Is there evidence of the existence of a reform-augmented Environmental Kuznets Curve?

iv. Do fossil fuel subsidy reforms have an effect on the environment?

1.4 Research Objectives

The broad objective of this study is to assess the impact of fossil fuel subsidies and fossil fuel subsidy reforms on environmental outcomes in 68 selected countries. The specific objectives are to;

i. Ascertain the direct and indirect effects of fossil fuel subsidies on the environment.

ii. Evaluate the extent to which fossil fuel subsidies influence the validity and shape of the Environmental Kuznets Curve.

iii. Assess the evidence for the existence of a reform-augmented Environmental Kuznets Curve.

iv. Determine the impact of fossil fuel subsidy reform on the environment.

1.5 Research Hypotheses

The following are the hypothesis to be tested for this study:

i. There are no direct and indirect effects of fossil fuel subsidy on the environment.

ii. Fossil fuel subsidies does not influence the validity or the shape of the Environmental Kuznets Curve.

iii. There is no reform - augmented Environmental Kuznets Curve.

iv. Fossil fuel subsidy reform has no impact on the environment.

1.6 Scope of the Study

The study examines the environmental impact of fossil fuel subsidies through multiple analytical frameworks across 68 countries, focusing on both direct and indirect effects of subsidies as well as the causal impacts of subsidy reforms. Of the 68 countries in the sample, 51 are identified as having implemented fossil fuel subsidy reforms between 2010 and 2023, while 17 serve as control countries that maintained their subsidy regimes without major reforms during this period.

The data utilized span the period 2010-2023 for the following reform-enacting countries: Algeria, Angola, Argentina, Bahrain, Bangladesh, Brazil, Brunei, Canada, Chile, China, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, France, Gabon, Ghana, Indonesia, India, Iran, Jordan, Kenya, Kuwait, Namibia, Nigeria, Niger, Mauritania, Malaysia, Mexico, Morocco, Oman, Pakistan, Peru, Philippines, Qatar, Rwanda, Saudi Arabia, Sierra Leone, Sri Lanka, Sudan, Thailand, Trinidad and Tobago, Tanzania, Uganda, Ukraine, United Arab Emirates, Venezuela, Vietnam, Yemen, Zambia and Zimbabwe. While these countries differ in their geographical locations and socio-economic characteristics, they share the common experience of having undertaken documented fossil fuel subsidy reforms within the study period.

To enable rigorous causal analysis of reform impacts using the Staggered Difference-in-Differences framework, 17 additional countries were included as pure controls; countries that maintained stable subsidy regimes without implementing major reforms during the study period. The time span was also extended to 2005 -2023 to provide sufficient pre-treatment periods necessary for the CSDID estimation, allowing for proper identification of treatment effects by establishing robust baseline trends before reform implementation. These control countries are: Albania, Cameroon, Comoros, Croatia, Kiribati, Libya, Madagascar, Mali, Mauritius, Panama, Puerto Rico, Sao Tome and Principe, Tajikistan, Timor-Leste, Turkmenistan, Tunisia, and Lebanon.

Country selection was based on publicly available information compiled by the IMF, the International Institute for Sustainable Development's Global Subsidies Initiative (IISD-GSI), and documented evidence from peer-reviewed journal articles. Data were sourced from multiple reputable databases including the IMF, IISD-GSI, EDGAR, World Development Indicators (WDI), and the Worldwide Governance Indicators (WGI).

1.7 Significance for the Study

The significance of this study is directly linked to the gaps it aims to fill in the literature. First, the possible effect of the interactions between fossil fuel subsidies and other established drivers of environmental impact is worth investigating. While it may be expected that fossil fuel subsidies and income variables will have a negative effect on environmental impact, the impact of the interaction of these two variables is not so straight forward. Its effect is likely to depend on the level of income and the size of the subsidies plus a host of other political-economy issues. Identifying these factors and how to address them are important for the design of reform packages.

Second, this study contributes to knowledge by examining empirically if the presence of fossil fuel subsidies hastens or delays a country's progress on the Environmental Kuznets Curve and thus, the time of attaining the turning point and as a corollary, whether there exists a reform - augmented Environmental Kuznets Curve is novel to this study. One can postulate that the level of income determines the environmental impact of fossil fuel subsidy reforms. In other words, just as the level of income matter for a country to transit along the normal Environmental Kuznets curve, we argue that the degree of success of fossil fuel subsidy reform policies may also be determined by the level of income in a particular country.

Finally, perhaps, the environmental benefit of fossil fuel subsidy reform is its strongest selling point especially in the face of the climate crisis and the urgency in keeping global warming within the limits of 1.5^0 C to 2.0^0 C. This is because governments in fossil fuel subsidizing economies tend to face significant opposition when discussions of reforms arise due to the hike in prices that accompanies implementation. Citizens may be more willing to bear the welfare loss if they understand and value the potential environmental benefits that accrue. A study such as this that examines the impact of reforms on the environment can provide an evidence-based report to assist both policymakers and civil society to better appraise these tough choices.

1.8 Structure of the Study

The study is structured into six chapters. Chapter one introduces the work. Chapter two provides a background to the study by examining the scope and scale of fossil fuel subsidies across the regions of interest. It also presents a trend analysis of the key variables utilized in the study in order to determine if there are co-movements that provides preliminary justification for the study. Chapter three is the literature review; here relevant concepts are clarified and the key theoretical and empirical literature are discussed. Chapter four presents a discussion of the theoretical framework adopted for this study. Furthermore, the model specified and methodology employed are discussed. Chapter five presents the empirical results, discussion of findings and policy implications while chapter six contains the summary of findings, conclusion, policy recommendations and suggestions for extension of the study.

CHAPTER TWO

BACKGROUND TO THE STUDY

2.1 The Scope and Scale of Fossil Fuel Subsidies

Historically, oil gained prominence around the mid-20th century in the economic and social life of most societies, in turn, governments provided fossil fuel subsidies as a measure to support energy production, ensure access and security. Subsidies may be in form of direct payments; tax breaks or even favorable regulations. The last two decades have seen a growing concern about environmental sustainability and climate change with a focus on the role of fossil fuel subsidies. Critics have argued that subsidies distort market prices, fosters overconsumption and hinder the development of alternative renewable energy sources (Coady et al, 2017). According to the International Monetary Fund (IMF), when governments underprice fossil fuels, they not only forego a valuable source of revenue, they also undermine their distributional and poverty alleviation objective given that subsidies are not pro-poor (Black et al, 2023).

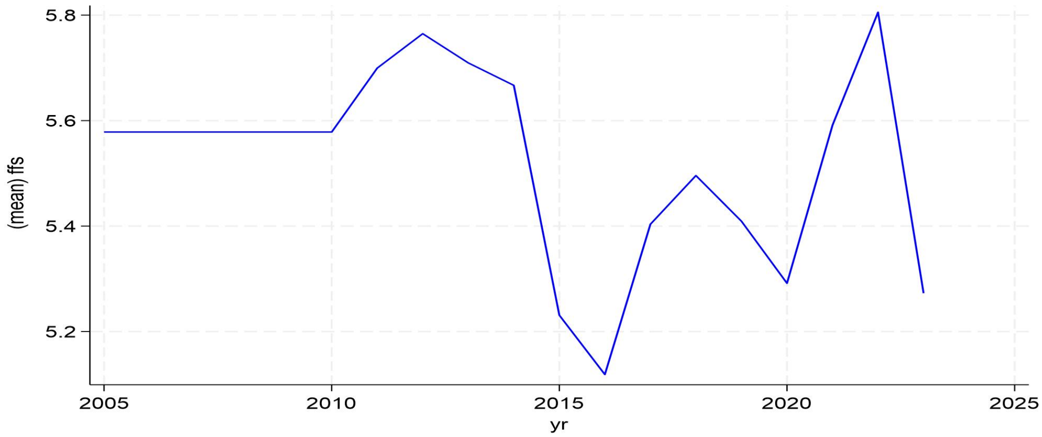
In terms of measurement, subsidies may be classed as either implicit or explicit. The former occurs when the retail price of fossil fuels does not account for external costs or include the consumption tax of the fuel. External costs consist of the impact on climate change through greenhouse gas emissions, local air pollutants, traffic congestions, etc. To get the true cost of fossil fuels, these costs must be fully factored into fossil fuel prices. Explicit subsidies apply where the retail price is below the fuel's supply cost. They can occur for both a tradable product like oil or a non-tradable product like electricity. Data from the IMF states that globally, total fossil fuel subsidies were nearly 7.1% of global gross domestic product, an amount equivalent to $7.4 trillion dollars in 2022 with explicit costs accounting for 18% of the total and implicit costs accounting for 82% (Black et al., 2023).

While fossil fuels come in different products with the popular ones being petrol, diesel, kerosene, LPG, natural gas, electricity, coal and other oil products, their combustion generate ambient air pollution and contribute to global warming. Take the case of Nigeria, a large proportion of her subsidy payments goes to petrol and diesel. Officially, subsidies on diesel were removed in 2012, yet data from international sources like the International Monetary Fund (IMF) show that Nigeria is still subsidizing the product. Their calculations are based on the difference the retail price of the fuel and the supply cost where the implicit and explicit costs are fully accounted for.

Table 2.1 and the trend line in Figure 2.1 below show the variation in fossil fuel subsidies over time for the period 2005 to 2023. The chart show that fossil fuel subsidy was stable between 2005 and 2010.

Table 2.1: Trend in Fossil Fuel Subsidies in 51 reform enacting countries

YEAR	FOSSIL FUEL SUBSIDIES (FFS)	% CHANGE
2005	5.57828	—
2006	5.57828	0.00%
2007	5.57828	0.00%
2008	5.57828	0.00%
2009	5.57828	0.00%
2010	5.57828	0.00%
2011	5.69960	2.17%
2012	5.76482	1.14%
2013	5.70945	-0.96%
2014	5.66685	-0.75%
2015	5.23103	-7.69%
2016	5.11864	-2.15%
2017	5.40357	5.56%
2018	5.49581	1.70%
2019	5.40920	-1.57%
2020	5.29159	-2.17%
2021	5.59135	5.66%
2022	5.80548	3.83%
2023	5.27287	-9.17%



Source: Figure is based on data from IMF

Figure 2.1: Trend in Fossil Fuel Subsidies in 51 reform enacting countries

There is a noticeable sharp rise between 2010 and 2013, peaking in 2013. A significant decline is seen from 2014 to 2016 likely due to more and more countries carrying out reforms. However, from 2016 to 2023, the trend become unstable with noticeable dips and spikes.

2.2 Analysis of trends in CO_2 and Greenhouse Gas Emissions

The link between fossil fuel subsidies and greenhouse gas emissions is not in dispute. Coal, oil and gas are considered to be the largest contributor to global climate change as they account for more than 75% of the global greenhouse gas emissions and approximately 90% of CO_2 emissions (Siddik et al., 2021).

Table 2.2: Lifecycle Greenhouse Gas Emissions of Fossil Fuels and Low-Carbon Alternatives

Fuel Type	Median Lifecycle Emissions (gCO_2e/kWh)
Coal	1050
Oil	850
Petroleum Coke	870
Peat	820
Natural Gas	500
Biomass (inefficient)	400
Nuclear	20
Hydropower	24
Solar PV	45
Wind	10
Geothermal	20
Renewables Mix	15

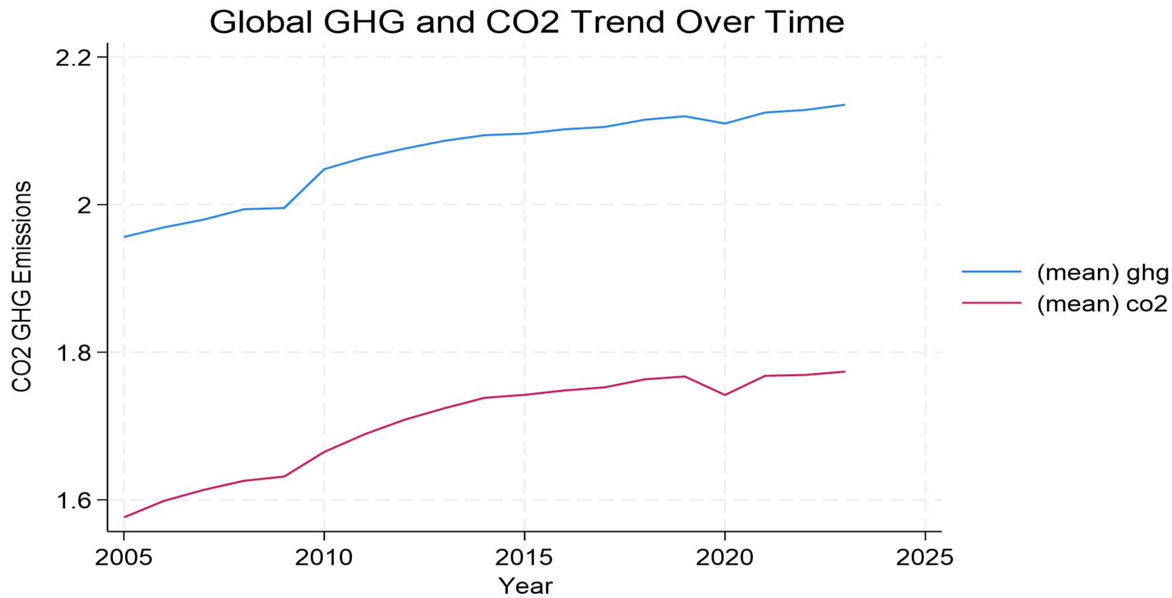
Source: Heath (2013), IPCC(2014), IEA (2020), WNA(2021)

Table 2.2. provides a snapshot ranking of various fossil fuels compared with low-carbon energy sources, and their median lifecycle greenhouse gas emissions expressed in grams of carbon dioxide equivalent per kilowatt (gCO_2e/kWh). Lifecycle emissions account for all stages of energy production including resource extraction, processing, plant construction, operation, maintenance and decommissioning, thus providing a comprehensive measure of environmental impact. From the Table, coal is shown to be the most carbon-intensive fuel, with median lifecycle emissions exceeding 1,000 gCO_2e/kWh, followed by petroleum coke, oil, and peat, all of which have high combustion emissions and substantial upstream impacts. Natural gas performs better than other fossil fuels but still emits roughly ten times more than most renewable sources. In contrast, wind, solar PV, geothermal, hydropower, and nuclear energy display very low lifecycle emissions, with most impacts arising from manufacturing and infrastructure rather than operation.

Table 2.3: Global GHG and CO_2 Emissions Trends (2005–2023)

YEAR	GHG EMISSIONS	% CHANGE	CO_2 EMISSIONS	% CHANGE
2005	1.9563	-	1.57628	-
2006	1.9692	0.67	1.59864	1.42
2007	1.97985	0.54	1.61367	0.94
2008	1.99382	0.71	1.62590	0.76
2009	1.99546	0.08	1.63163	0.35
2010	2.04807	2.64	1.66496	2.04
2011	2.06387	0.77	1.68876	1.43
2012	2.07585	0.58	1.70856	1.17
2013	2.08649	0.51	1.72420	0.91
2014	2.09405	0.36	1.73828	0.82
2015	2.09625	0.11	1.74232	0.23
2016	2.10213	0.28	1.74826	0.34
2017	2.10530	0.15	1.75253	0.24
2018	2.11511	0.47	1.76339	0.62
2019	2.11975	0.22	1.76714	0.21
2020	2.10992	-0.46	1.74213	-1.41
2021	2.12480	0.71	1.76811	1.49
2022	2.12824	0.16	1.76930	0.07
2023	2.13540	0.34	1.77381	0.26

Source: Author's using data from EDGAR, 2024



Source: Based on data from EDGAR, 2024

Figure 2.2: Global GHG and CO2 Trend Over Time

Table 2.3 provides the average trend in CO_2 and greenhouse gas emissions from 2005 to 2023 for the 51 countries adopted for this study. From the underlying chart, it can be seen that both variables show a generally increasing trend overtime. While CO_2 emissions rose from 1.57628 in 2005 to 1.77381 in 2023, GHG emissions increased from 1.9563 to 2.1354 in the same period. It can also be seen that the rate of increase in GHG emissions is slightly higher than that of CO_2 emissions suggesting that other gases like methane and nitrous oxide are also driving GHG emissions.

Another interesting finding here is the deep in both emissions in 2020, on face value, this was most likely driven by the COVID 19 pandemic and the slow-down in mobility and other economic activities. However, by observing the percentage changes in CO_2 and GHG emissions, it can be seen that pre 2010 when the first wave of fossil fuel subsidy reforms took place, emissions were rising at an average of 1.5% to 2.5%, this gradually slowed down with

CO_2 emissions in particular growing below 1% per year after 2013. While the sharp drop in 2020 can be attributed chiefly to the impact of COVID 19, yet the post-pandemic trend shows that despite the rebound in 2021, growth remain weak suggesting a structural shift in emissions patterns.

2.3 Overview of fossil fuel subsidy reforms in selected Countries

Table 2.4 presents a selection of some of the countries analysed in this study. It highlights when reforms were introduced in the country based on available data.

Table 2.4: Timing of fossil fuel subsidy reforms in selected countries

	Country	Reform
1	Algeria	Gradual increase in fuel prices as part of fiscal reforms starting in 2016
2	Angola	Implemented significant fuel subsidy reductions in 2016 due to fiscal pressures
3	Argentina	Introduced a gradual reduction in electricity and natural gas subsidies in 2016
4	Bahrain	Increased domestic fuel prices as part of subsidy reforms in 2015. Reduced oil subsidies by 89% in 2016
5	Bangladesh	Started reducing subsidies on fuel products in 2013
6	Brunei	Announced plans to review and adjust fuel subsidies in 2015
7	Canada	Various provinces have implemented carbon pricing and reduced subsidies, with notable actions in 2016 and 2018.
8	Denmark	Phased out fossil fuel subsidies and introduced carbon taxes between the 1990s and 2000s
9	Dominican Republic	Adjusted fuel prices to reflect international prices more accurately in 2011
10	Ecuador	Announced the reduction of fuel subsidies but faced significant public protests between 2018-2019 but faced significant protests.
11	Egypt	Initiated substantial cuts so that fuel and gas prices increased 40-78% in 2014. Reduced subsidies further in 2019.
12	El-Salvador	Began reducing subsidies on LPG in 2011
13	Estonia	Phased out fossil fuel subsidies as part of transition to a market economy in the 1990s
14	France	Implemented policies to reduce fossil fuel subsidies, including tax incentives for renewable energy in 2018
15	Gabon	Began subsidy reforms to address fiscal deficits in 2014
16	Ghana	Raised prices of gasoline and diesel in 2013 but had a policy reversal. Petroleum prices liberalized 2015
17	India	Liberalized gasoline prices in 2010. Deregulated diesel prices in 2014. Abolished gasoline subsidies in 2015 and by 2016, continued to reduce subsidies on kerosene and LPG
18	Indonesia	Major reforms to reduce subsidies on diesel and gasoline between 2014 and 2015.

		Abolished gasoline subsidies in 2015.
19	Iran	Liberalized prices in 2010 with gasoline going up fourfold and the price of natural gas, eightfold.
20	Kenya	It adjusted fuel pricing mechanism to reduce subsidies in 2014
21	Kuwait	Implemented fuel price increases as part of subsidy reform in 2016
22	Nigeria	Attempted to remove fuel subsidies in 2012, partial reinstatement due to public backlash. But price for petrol still went up by 49%. Announced removal of fuel subsidies amidst broader economic reforms in 2020. Policy adopted in 2023.
23	Niger	Reduced subsidies to align fuel prices with international market levels in 2012.
24	Malaysia	Removed gasoline and diesel subsidies, moving to a managed float system in 2014 hence prices for gasoline and diesel set monthly to reflect international prices
25	Morocco	Began phasing out fuel subsidies in 2013 with phaseout completed in 2015
26	Philippines	Deregulated the downstream oil industry to reduce subsidies in 1996
27	Qatar	Increased domestic fuel prices as part of subsidy reforms in 2016. Oil price went up by 6%
28	Rwanda	Started adjusting fuel prices in 2014 to better reflect international prices
29	Saudi Arabia	Gasoline price increased 51% and gas by 47% in 2016. Continued increasing fuel prices in 2018 under Vision 2030.
30	Sierra Leone	Adjusted fuel prices and reduced subsidies in 2018.
31	Sri Lanka	Introduced a pricing formula to reflect global oil prices in 2018, reducing subsidies.
32	Sudan	Implemented fuel price hikes as part of subsidy reforms in 2013
33	Thailand	Began reducing subsidies for LPG and other fuels in 2014
34	Trinidad and Tobago	Announced plans to gradually reduce fuel subsidies in 2016
35	Tanzania	Adjusted fuel prices to reduce subsidies in 2011
36	United Arab Emirates	Deregulated fuel prices in 2015, linking them to global oil prices
37	Venezuela	Increased fuel prices for the first time in two decades in 2016
38	Vietnam	Began adjusting fuel prices to reflect market rates more accurately in 2011
39	Zambia	Reduced fuel subsidies to address fiscal challenges in 2013
40	Zimbabwe	Increased fuel prices significantly as part of subsidy reforms in 2019

Source: compilation from various internet sources

Although, Table 2.4 confirms that some countries implemented some form of reforms in the 1990s, (e.g. Philippines, Denmark, Estonia, e.t.c), various publically available database compile subsidies from 2010. Based on this, this study utilizes 2010 as the base year for reforms. Table 2.4 shows the year of reform for each of the 51 countries in this study.

Table 2.5: Timing of Reforms Across Countries

YEAR	COUNTRIES
2010	Brazil, Chile, China, Denmark, India, Iran, Kenya, Mexico, Namibia, Peru, Philippines, Uganda, Venezuela, Yemen, Mauritania, Estonia
2011	El Salvador, Niger, Rwanda, Tanzania, Vietnam
2012	Jordan, Nigeria
2013	Bangladesh, Malaysia, Morocco, Pakistan, Sudan
2014	Egypt, Gabon, Oman, Thailand, Indonesia
2015	Bahrain, Brunei, Ghana, UAE
2016	Algeria, Angola, Argentina, Canada, Kuwait, Qatar, Saudi Arabia, Trinidad & Tobago
2017	Ukraine
2018	Ecuador, Sri Lanka
2019	Sierra Leone
2020	Zimbabwe
2021	Zambia

Source: Data on reform timing compiled from the International Monetary Fund's fossil fuel subsidy database and the OECD-IISD Fossil Fuel Subsidy Tracker

Table 2.4 and Table 2.5 presents summarized versions of the timing of subsidy reforms across the countries of interest in this study. A detailed discussion on the history and process of reforms in some of these countries are presented in Appendix 1.

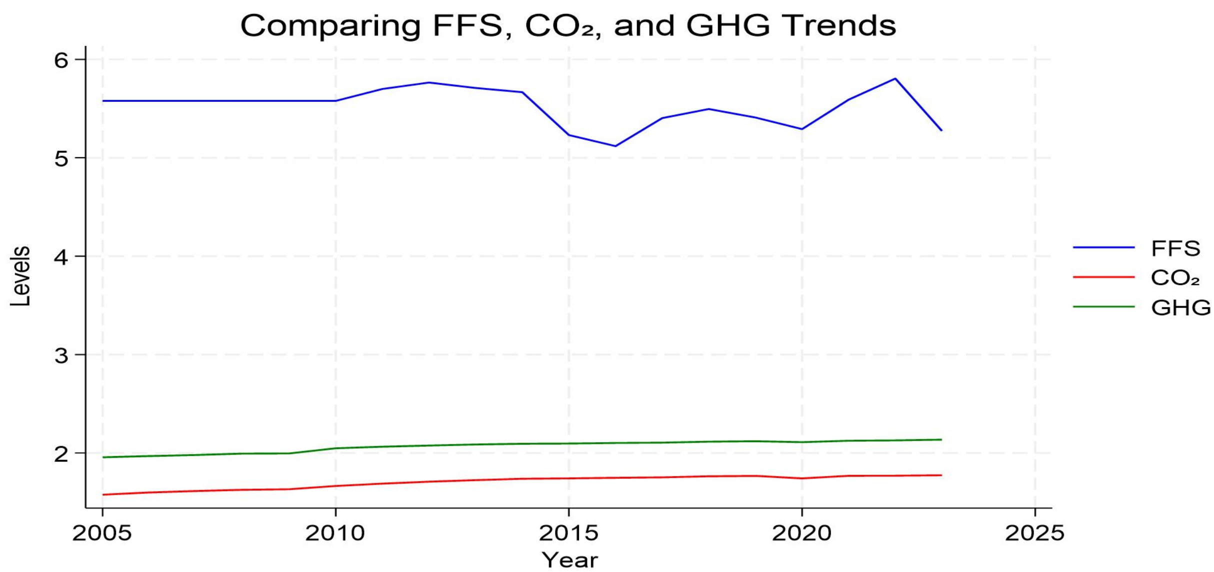
2.4 Analysis of trends in Fossil Fuel Subsidies and Emissions

Table 2.6 and Figure 2.3 show that fossil fuel subsidies exhibit notable fluctuations between 2005 and 2023, reflecting changing global energy prices, fiscal conditions, and policy reforms. Subsidies remain relatively stable until 2010, increase during the early 2010s, and decline sharply around 2015–2016, likely due to reform efforts and falling oil prices. A renewed increase after 2020 coincides with the COVID-19 pandemic and subsequent energy market disruptions, highlighting the continued reliance on subsidies as a policy tool during periods of economic and energy insecurity.

Table 2.6: Trend in Fossil fuel subsidies, CO2 and GHG emissions 2005 -2023

YEAR	FFS	CO_2	GHG
2005	5.57828	1.57628	1.95630
2006	5.57828	1.59864	1.96920
2007	5.57828	1.61367	1.97985
2008	5.57828	1.62590	1.99382
2009	5.57828	1.63163	1.99546
2010	5.57828	1.66496	2.04807
2011	5.69960	1.68876	2.06387
2012	5.76482	1.70856	2.07585
2013	5.70945	1.72420	2.08649
2014	5.66685	1.73828	2.09405
2015	5.23103	1.74232	2.09625
2016	5.11864	1.74826	2.10213
2017	5.40357	1.75253	2.10530
2018	5.49581	1.76339	2.11511
2019	5.40920	1.76714	2.11975
2020	5.29159	1.74213	2.10992
2021	5.59135	1.76811	2.12480
2022	5.80548	1.76930	2.12824
2023	5.27287	1.77381	2.13540

Source: Compiled using data from the IMF and EDGAR



Source: Compiled using data from the IMF and EDGAR

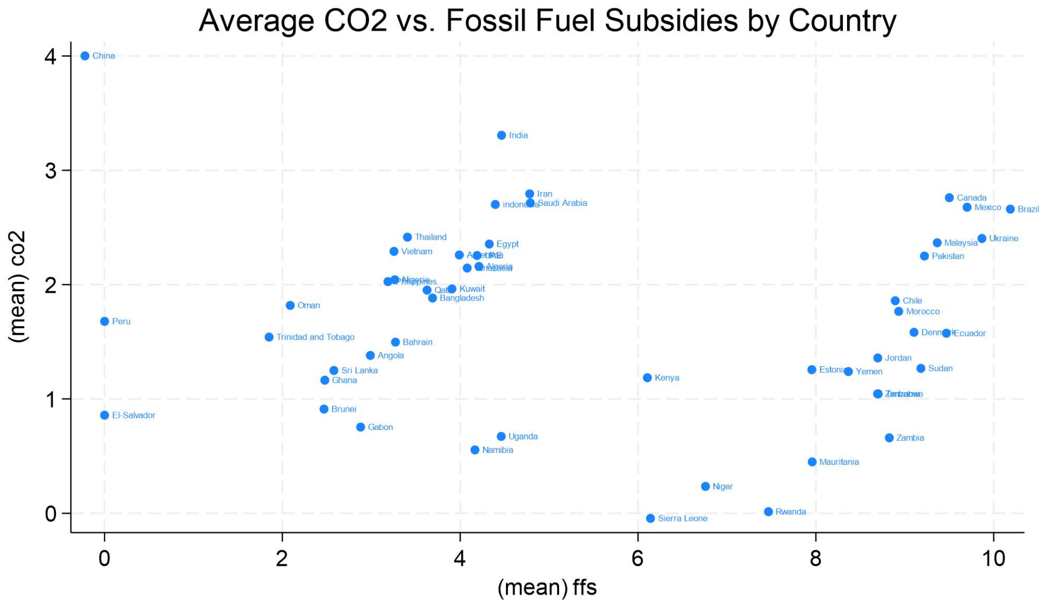
Figure 2.3: Comparing FFS, CO2 Emissions and GHG Trends

Over the same period, CO_2 and total GHG emissions display a generally upward trend, with only a temporary decline in 2020 followed by a rapid rebound. The parallel movement between higher subsidy levels and rising emissions suggests a positive association between fossil fuel support and environmental degradation, as subsidies lower energy prices and encourage fossil fuel consumption.

As a follow-up on the discussion in section 2.2, it can be observed that the reduction in fossil fuel subsidy around 2015 correlate with a reduction in the growth rate of CO_2 and GHG emissions suggesting that fossil fuel subsidy reforms may have helped to curb emissions. However, the continued rise in emissions even during periods of declining subsidies indicates that subsidy reform alone is insufficient for sustained emissions reduction, substantiating the role of broader structural factors such as economic growth, energy demand, and technological change.

2.5 Scatterplots of Fossil Fuel Subsidies and Emissions in selected countries

The scatterplot in Figure 2.4 illustrates the relationship between CO_2 emissions and fossil fuel subsidies in selected countries for the periods 2005 – 2023. The scatterplot provides very interesting insights into the correlations between the average CO_2 emissions and fossil fuel subsidies by country.

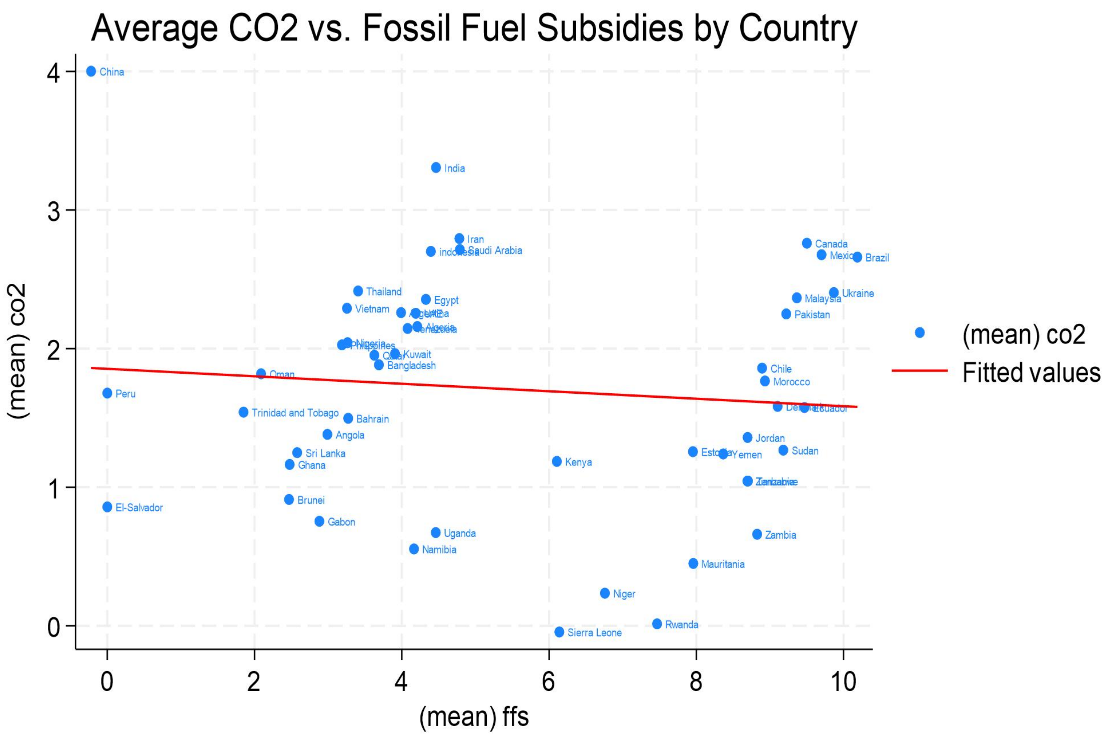


Source: Scatterplots based on data from the IEA (2023) and EDGAR (2023)

Figure 2.4: Average CO_2 vs. fossil fuel Subsidy by Country

In terms of specifics, certain patterns can be observed, there are a few countries with high emissions and low or no subsidies. For instance, Qatar has zero subsidies and a relatively high emissions level. While Chile and Ecuador has high subsidies but relatively lower emissions. This indicates that emissions in those places are driven by factors other than subsidies. Countries like China, India, Mexico and Malaysia has high emissions and comparably high subsidies. In contrast, countries like Sierra Leone, Rwanda, Burundi and Niger have very low CO_2 emissions and fossil fuel subsidies.

In general, a visual inspection of the scatterplot suggests a positive correlation between fossil fuel subsidies and CO_2 emissions implying that countries with higher subsidies tend to have higher emissions. However, the relationship appears weak and not strictly linear suggesting that other factors may also affect emission levels.

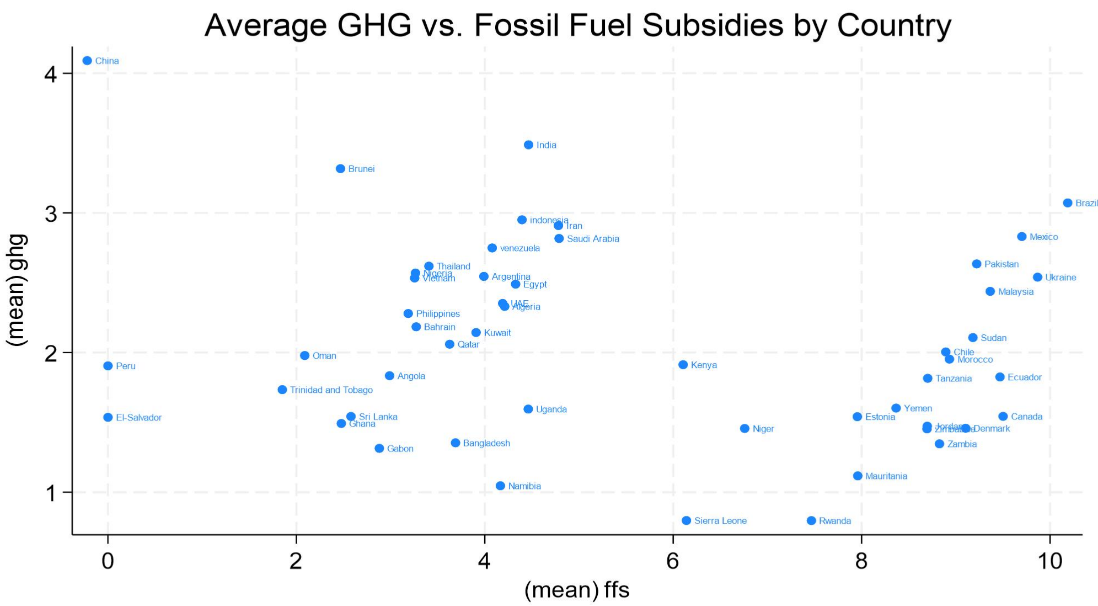


Source: Scatterplots based on data from the IEA (2023) and EDGAR (2023)

Figure 2.5. Average CO_2 vs. fossil fuel Subsidy by Country with trend line.

Thus, in other to be ascertain the exact direction of relationship between the two variables, a trend line was fitted to help quantify the relationship between subsidy and emissions. The updated graph is presented in Figure 2.5. The downward sloping fitted regression line indicate a slight negative relationship between fossil fuel subsidy and CO_2 emissions which challenges the intuitive expectation of a positive relationship between these two variables.

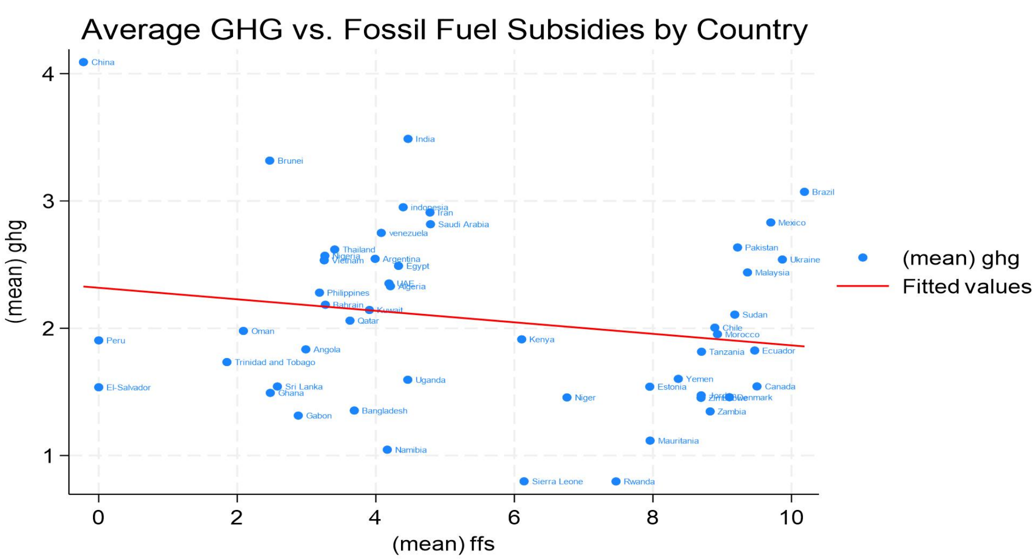
A visualization of the relationship between fossil fuel subsidies and greenhouse gas emissions is presented in Figure 2.6. The scatterplot does not appear to be significantly different from that of CO_2. However, with the GHG graph, there is a wider variation in emissions level relative to the CO_2 plot which is more compact. This is not surprising given that CO_2 is a subset of GHG. Another consideration for the wider disparity in the GHG graph is that greenhouse gases capture emissions from sources that are non-fossil based like agriculture and land use.



Source: Scatterplots based on data from the IEA (2023) and EDGAR (2023)

Figure 2.6: Average GHG vs. fossil fuel Subsidy by Country

As with the previous analysis, fitting a regression line in the GHG scatterplot show a weak inverse relationship between greenhouse gas emissions and fossil fuel subsidies. However, the slope of the GHG graph is slightly steeper.



Source: Scatterplots based on data from the IEA (2023) and EDGAR (2023)

Figure 2.7 Average GHG vs. fossil fuel Subsidy by Country with trend line

Given the focus of this study, these trend analysis provides challenging but interesting insights. Mainly, it suggests that the relationship between emissions and fossil fuel subsidies is not straightforward. Thus, unilaterally cutting subsidies may not yield reduction in emissions levels. Rather, it is imperative to consider country-specific factors like the economic structure and developmental stage of a country or even the population dynamics. Other considerations like the role of energy efficiency, investments in renewable energy are essential to emissions reduction.

In conclusion, while fossil fuel subsidy reform can contribute to emissions mitigation, its effectiveness is likely to depend on complementary factors such as energy alternatives, economic structures as well as institutional and regulatory frameworks. This suggests the need for a deeper causal analysis as a correlation analysis (like was presented in this chapter) may not capture the full impact of fossil fuel subsidy reforms. In other to fully capture and understand these effects, this study employs the Callaway and Sant'Anna Difference in Difference approach. It also accounts for heterogeneity in country responses and the potential for delayed or non-linear effects.

CHAPTER THREE

LITERATURE REVIEW

3.1 Review of Conceptual Literature

3.1.1 Fossil Fuel Subsidy

Fossil fuel subsidies are financial mechanisms such as tax breaks, direct financial transfers, and price controls that governments use to reduce the cost of fossil fuels for consumers and producers. These subsidies are often justified as a means to make energy more affordable, promote energy security, and support economic growth, particularly in energy-dependent industries (International Energy Agency, 2021). However, they are widely criticized for promoting carbon-intensive energy consumption, discouraging investment in renewable energy, and contributing significantly to environmental degradation and climate change (Coady et al., 2018).

Globally, fossil fuel subsidies were estimated at $5.9 trillion in 2020, taking into account both explicit subsidies and unpriced externalities such as air pollution and greenhouse gas emissions (Coady et al., 2018). Removing these subsidies could reduce global CO_2 emissions by as much as 28%, supporting climate goals outlined in the Paris Agreement (Jewell et al., 2018). Additionally, reforms can help redirect resources toward healthcare, education, and green energy, potentially leading to positive social and environmental outcomes (United Nations Environment Programme, 2020).

3.1.2 Fossil Fuel Subsidy Reforms

Subsidy reforms aim to gradually reduce or eliminate government support for fossil fuels, redirecting funds toward more sustainable and socially beneficial areas such as renewable energy, healthcare, and education. These reforms are widely considered essential for aligning energy policies with climate goals, as they reduce incentives for carbon-intensive energy use and support the shift toward cleaner alternatives (United Nations Environment Programme 2020). Successfully implementing subsidy reforms can lead to significant reductions in greenhouse gas emissions, improved air quality, and more equitable allocation of resources (Coady et al., 2019).

However, subsidy reforms are often politically sensitive, particularly in developing countries where fossil fuel subsidies are seen as vital for affordable energy access and economic stability. For this reason, effective reform strategies typically include phased reductions, targeted cash transfers, and investment in social programmes to mitigate the impact on low-income households (International Monetary Fund, 2020). Recent studies indicate that well-designed reforms could cut global CO_2 emissions by 10%–15%, demonstrating their critical role in sustainable development strategies (Jewell et al., 2018).

3.1.4 Emissions and Environmental Impact

Emissions refer to the release of pollutants and greenhouse gases (GHGs) into the atmosphere from human activities, contributing to air pollution, global warming, and environmental degradation. Emissions arise from various sources, including energy production, transportation, agriculture, and industrial processes. These pollutants include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, which collectively contribute to the greenhouse effect and climate change by trapping heat in the Earth's atmosphere (IPCC, 2021).

The burning of fossil fuels (coal, oil, and natural gas) for electricity, heating, and industrial processes is the largest source of CO_2 emissions. Energy production also emits other pollutants like sulphur dioxide (SO_2) and nitrogen oxides (NO_x), which contribute to smog and acid rain. Fossil fuel emissions are the primary driver of climate change, responsible for about 65% of global GHG emissions (International Environmental Agency, 2020). Transportation emissions primarily result from the combustion of fossil fuels in cars, trucks, ships, trains, and planes. Transportation is a major source of CO_2 and NO_x emissions and contributes significantly to air pollution, especially in urban areas. The rise in vehicle ownership and air travel has made transportation one of the fastest-growing sources of emissions (EPA, 2021).

Environmental impact refers to any change in the environment, whether adverse or beneficial, resulting from human activities or natural events. These impacts can be direct; such as emissions from industrial processes or indirect, resulting from subtler interactions within ecosystems, like habitat fragmentation or shifts in biodiversity due to pollution or climate change (Glasson et al., 2013). Environmental impacts are often classified into categories such as ecological, social, and economic, highlighting the interconnectedness of environmental factors with broader socio-economic systems (Morris & Therivel, 2009).

3.2 Drivers of Environmental Impact

The three main drivers of environmental impact often discussed in the literature are population growth, GDP growth (or affluence) and the technology of consumption and production.

3.2.1 Population, Urbanization, Population density and Environmental Impact

Population is a fundamental driver of environmental impact and economic development, influencing resource demand, waste generation, and overall ecosystem stress. As populations grow, the need for natural resources such as water, energy, food, and land increases, often resulting in resource depletion, habitat loss, and biodiversity decline. These pressures are particularly evident in rapidly urbanizing areas, where population growth necessitates expanded infrastructure, energy production, transportation, and housing; further intensifying environmental strain (Ehrlich & Holdren, 1971).

One critical aspect is the direct link between population growth and rising energy demand. As populations increase, especially in industrialized and urbanized regions, fossil fuel consumption rises to meet the needs of expanding cities, leading to higher emissions and greater resource extraction (York et al., 2003). This dynamic not only contributes to greenhouse gas emissions but also places stress on existing natural resources. High population densities in urban and industrial centers can exacerbate pollution, create challenges in waste management, and strain public health systems. Overcrowded areas often contend with severe air and water pollution, limited green space, and a buildup of waste, which together degrade environmental quality and hinder sustainable urban living.

Environmental concerns largely stem from the fear that Earth's limited resources may eventually be insufficient to meet the needs of a growing global population, a position that was advanced and popularized by Malthus (1967). While future technological advances could potentially prevent this outcome (see for example Boserup, 1965), the ongoing degradation of the environment threatens the ability of both current and future generations to sustain themselves. Reducing population growth rates would help mitigate many of these environmental challenges. However, the speed and scale of fertility declines and thus the eventual size of the world population would depend heavily on governmental efforts to create the economic and institutional frameworks necessary for limiting population growth. Economic theories suggest that fertility behavior is associated with the costs and benefits of having children. Becker (1960), Easterlin (1976), Ermisch, (1989) suggest that fertility decisions are influenced by economic factors, such as income, cost of raising children, division of labour within the households and opportunity costs. Higher income and education levels typically lead to lower fertility rates. Although, lower fertility rates can reduce environmental pressure by slowing population growth, higher incomes may lead to increased consumption and environmental impact. Insight is also drawn from Urbanization theories which explain the processes, causes, and consequences of the growth and development of cities and urban areas, and how these transformations affect society and the environment. As urban areas expand, they bring with them a range of environmental impacts, including resource consumption, pollution, and ecosystem disruption (Thompson, 1929; Notestein, 1945; Davis, 1965).

In many of the world's poorest regions, rapid population growth has led to shortages of essential resources such as land, water, and fuel, as well as urban health issues caused by inadequate sanitation and water supplies. In these areas, rising population density has clearly worsened the degradation of critical resources needed for survival (Todaro and Smith, 2014). Several theories have been developed to explain how population, fertility rates and urbanization interact to impact the environment. Some of them are discussed below.

The Demographic Transition Theory (Thompson, 1929; Notestein, 1945) also link population growth to fertility rates. It proposes that at the pre-industrial stage, high fertility rate combined with high levels of mortality lead to a stable population, this is because families will have many children to compensate for the high infant mortality rate. However, in stage two which coincide with early industrialization, mortality rates decline due to improvements in healthcare and living conditions. Yet fertility remains high, leading to rapid population growth. By stage three, fertility rates begin to decline as more women enter the workforce, access to contraception improves, and social norms around family size shift. The decline in fertility is partly driven by economic incentives, as families prioritize investing in fewer children's education and well-being. In the final stage of post-industrialization, fertility rates are low, and population growth stabilizes. Families typically have fewer children due to the higher costs of child-rearing, and there is greater access to education and employment for women (Dyson, 2010). With regard to environmental impact, in the early stages of the transition, population growth can strain environmental resources. However, as a society progresses, birth rates decline, potentially reducing environmental pressure.

Similar to the Demographic Transition Theory, urban transition theory (Davis, 1965) follows three distinct phases, the pre-industrial stage, the industrial phase and the post-industrial phase. In the Industrial Stage**,** rapid urbanization leads to severe environmental degradation as cities rely heavily on fossil fuels, extractive industries, and intensive resource use. Theories like the

Environmental Transition Theory and Urban Transition Theory hypothesize that the early stages of urbanization, especially in developing countries, contribute to air and water pollution, deforestation, and loss of biodiversity. However, as countries move into the Post-Industrial Stage, urban areas often begin to address their environmental challenges by investing in cleaner technologies, renewable energy, and more efficient infrastructure. This is where Modernization Theory and Environmental Kuznets Curve come into play, suggesting that as income levels rise, societies develop more sustainable practices.

3.2.2 Income growth (Affluence) and the Environment

Affluence, or the level of wealth and consumption within a society, is a significant factor influencing environmental impact. As affluence increases, so does the demand for goods, services, and energy, often leading to greater resource consumption and environmental degradation. Wealthier societies typically have higher per capita consumption levels, which drives the extraction and use of natural resources, including fossil fuels, minerals, and water. This pattern intensifies environmental impacts, such as deforestation, air and water pollution, and waste production (Dietz et al., 2007).

The relationship between income levels and environmental impact is a central theme given that as countries develop and income rises, their environmental impact changes in complex ways, often with varying effects on natural resources, pollution levels, and sustainability efforts. On the most popular theory that have been put forward as explaining this relationship is the Environmental Kuznets Curve (EKC).

3.2.4. Technology and the Environment

Technology influences environmental outcomes by determining how efficiently resources are used, the nature and extent of pollution, and the sustainability of production and consumption processes. Yet, technological advancements can have both positive and negative environmental impacts. For example, technology that increases efficiency in energy use, such as LED lighting or electric vehicles, can reduce per capita emissions and resource demands, thereby lowering the overall environmental impact. However, technology can also lead to greater resource extraction and pollution if it encourages increased production and consumption. This phenomenon, known as the *rebound effect*, occurs when efficiency gains are offset by increased consumption, as people may use resources more freely when they are cheaper or more accessible (Jevons, 1865).

Technology also enables the transition from fossil fuels to renewable energy sources like solar, wind, and hydropower, which reduce greenhouse gas emissions and dependence on non-renewable resources. These "green technologies" are critical for mitigating climate change and reducing air pollution. In this context, technology can lead to smaller environmental footprint even as population and affluence grow (Grubler et al., 2012).

3.3 Review of Theoretical Literature

3.3.1 The Demographic Transition

The Demographic Transition Theory first proposed by Warren Thompson in 1929 and later refined by Frank Notestein in the 1945, provides a framework for examining how population dynamics interact with environmental pressure over time. The theory describes a societal shift from high birth and death rates to low birth and death rates, unfolding across pre-industrial, transitional, industrial, and post-industrial stages. While traditionally applied to explain demographic and economic change, the theory also provides significant insights for understanding patterns of environmental impact.

In the early pre-industrial stage, high fertility and mortality rates keep population growth modest, but resource use is largely subsistence-based and locally contained. As societies enter the transitional phase, mortality declines rapidly due to advances in healthcare, sanitation, and nutrition, while fertility remains high. This demographic imbalance fuels rapid population growth, intensifying pressure on land, water, forests, and other natural resources. Industrialization magnifies these pressures through increased energy use, urban expansion, and higher per capita consumption. In the later industrial and post-industrial stages, fertility rates decline as economic incentives shift, women's educational and employment opportunities expand, and access to family planning improves. Slower population growth can reduce direct demographic pressure on the environment, yet rising affluence, technological change, and consumption-oriented lifestyles may generate new forms of ecological strain such as higher carbon emissions, greater waste generation, and biodiversity loss. Thus, the Demographic Transition Theory provides a framework not only for tracing demographic shifts but also for anticipating how population change intersects with environmental sustainability at different stages of development.

In the context of this study, the Demographic Transition Theory provides a typical case study of how population theory can explain the persistence of fossil fuel subsidies and the need for reforms. Consider **Stage 2** of the **Demographic Transition**, rapid population growth and industrialization drive energy demand, leading to heavy reliance on fossil fuels, often subsidized by governments. These subsidies encourage overconsumption, inefficiency, and delayed investment in renewable energy, resulting in increased greenhouse gas emissions and environmental degradation. Furthermore, in **Stage 3**, urbanization further raises energy demands, with continued fossil fuel use keeping emissions high even as population growth slows. By **Stage 4**, as countries become post-industrial, there is a shift toward renewable energy driven by greater environmental awareness and policy changes, including the removal of fossil fuel subsidies, which helps reduce emissions and supports sustainable energy transition (Stern, 2011; Davis & Gertler, 2015).

Fossil fuel subsidies play a significant role in exacerbating the environmental concerns tied to population growth and resource depletion. In many regions, especially in poorer countries with rapidly growing populations, continued use of subsidized fossil fuels can accelerate deforestation, soil degradation, and water contamination, further straining ecosystems that are already vulnerable due to population pressures. Fossil fuel subsidies make activities that lead to deforestation such as logging, agriculture, infrastructure development, and fuelwood collection economically viable on a larger scale. This drives unsustainable exploitation of forests, contributing to significant environmental degradation, including biodiversity loss and soil erosion.

The link between fossil fuel subsidies and environmental damage is clear: by promoting the unchecked use of energy-intensive practices, they lead to increased greenhouse gas emissions and climate change, which directly impact the availability of resources necessary for survival. As population density rises in these regions, the need for sustainable resource management becomes even more critical.

3.3.2 The Environmental Kuznets Curve

Developed by Grossman and Krueger (1995), the Environmental Kuznets Curve hypothesizes that the early stages of environmental growth will see deterioration in environmental quality as income increases. However, as growth progresses, the degradation will give way to greater environmental consciousness and ultimately improvements in environmental quality. Thus, the relationship between environmental degradation and economic growth follows an inverted "U", implying the existence of a critical income level at which environmental improvement is prioritized. The EKC hypothesis makes intuitive sense as it is expected that at low levels of income, individuals as well as their governments are more concerned with improving their economic fortunes than with prioritizing environmental needs but as income rises, attention will shift from core growth indices to a more holistic view of development.

The Environmental Kuznets Curve (EKC) hypothesis further supports the role of technology in reducing environmental degradation, suggesting that as societies become wealthier, they invest more in advanced, cleaner technologies, ultimately leading to a decline in pollution levels (Grossman & Krueger, 1995). However, critics of EKC argue that technology alone cannot solve environmental issues without significant policy support, lifestyle changes, and global cooperation, especially for complex challenges like climate change, where systemic and large-scale interventions are necessary.

The theoretical framework for the EKC is of the form

$$EQ = \alpha_1 + \alpha_2 Y_i + \alpha_3 {Y_i}^2 + \sum_k \alpha_k \mathrm{Z}_{ki} + \varepsilon_t$$

Where EQ is the dependent variable and denotes the environmental quality measure being considered, Y is income per capita with Y^2 denoting the squared derivation of income per capita Z_k is a set of other explanatory variables affecting the pollutant such as subsidies, population, industrialization, agriculture etc. ε is the random error term. α_i are parameters.

According to De Bruyn et al. (1998), the signs of the coefficients of income per capita, $\alpha_1$and α_2 determines the shape of the EKC. It could be a linear monotonic increasing function, which denotes that increasing income levels are associated with decreasing environmental quality. If on the other hand, a linear monotonic decreasing function is achieved, then it implies that higher income levels are characterized by a higher environmental quality. However, the relationship consistent with the EKC is one indicated by a quadratic relationship with increase in income initially accompanied by decreases in environmental quality up to a point after which a reversal is noted where increases in income is now linked with increases in the quality of the environment (see Figure 3.1).

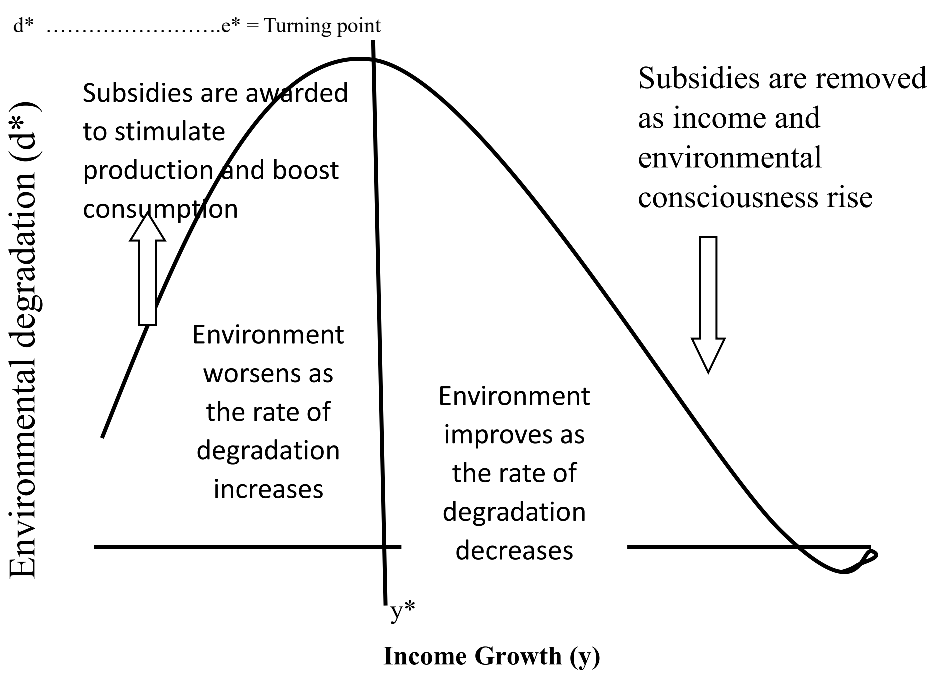


Figure 3.1: A hypothetical Environmental Kuznets Curve with subsidies.

The EKC has been criticized for not applying uniformly across all environmental indicators. For example, while local air and water pollution might decrease with income growth, global issues like **carbon emissions** often do not follow this pattern. Additionally, wealthier countries often "export" pollution to lower-income countries through outsourcing of manufacturing.

The Environmental Kuznets Curve is perhaps one of the most fundamental theories for explaining the effect fossil fuel subsidies on the environment. It has been modified to explain the persistence of fossil fuel subsidy and the resistance to reforms. At the early stage of growth, countries rely heavily on fossil fuels for energy production needed to power industrialization. Subsidies are rationalized as necessary to support domestic production and stimulate economic growth. However, as economies progress and hit a certain income threshold, concern for the environment becomes paramount and effort is shifted towards the transition to cleaner energy and more sustainable technologies. At this wealthier stage, governments will shift subsidies away from fossil fuels to the development of renewable energy.

3.3.5. Ecological Modernization Theory

Closely associated with the EKC hypothesis is the Ecological Modernization theory, this theory posits that economic development, particularly in high-income countries, can lead to improved environmental outcomes through innovation, regulation, and industrial transformation. As countries develop, they invest in **technological advancements** that allow them to decouple economic growth from environmental degradation. Clean energy, improved waste management, and more efficient industrial processes are examples of this decoupling.

Moreso, high-income countries often have more robust institutions that enforce environmental regulations and encourage industries to adopt sustainable practices. Governments and businesses work together to integrate environmental concerns into economic planning. Furthermore, with higher income comes a shift in consumer preferences, wealthier populations are more likely to demand environmentally friendly products and services. This shift can drive markets to innovate, creating products that are less resource-intensive or have a lower carbon footprint (Mol, & Sonnenfeld, 2000).

The Ecological Modernization Theory (EMT) argues that developed economies can mitigate environmental impacts through proactive policies, technological innovations, and market incentives. It challenges the idea that economic growth must always lead to environmental harm, suggesting that economies can grow sustainably through carefully planned **green growth** strategies. EMT postulates that environmental improvements can be achieved through institutional reforms, technological innovation and shifts in societal values. From this perspective, fossil fuel subsidy reform can be considered as a potential catalyst for environmental improvement, however, this potential would only be realized through a framework that promotes regulatory support and market based incentives such as environmental taxes (e.g., carbon pricing), the removal of environmentally harmful subsidies (e.g., fossil fuel subsidies), and incentives for sustainable technologies (e.g., subsidies for renewable energy). These interventions aim to internalize the environmental costs of production and consumption. Furthermore, **technological innovation** is at the heart of EMT. The theory holds that advanced technologies can mitigate or eliminate the harmful effects of industrial processes. For example, carbon capture and storage (CCS) technologies, renewable energy sources (solar, wind), and energy-efficient production systems are critical tools for reducing emissions without halting economic growth (Weale, 1992).

More critically, **policy reforms** are crucial in creating the right incentives for the private sector to innovate. Governments can influence environmental outcomes by reforming harmful subsidies, like those on fossil fuels, or by imposing environmental taxes that reflect the true cost of pollution. The introduction of carbon pricing, for instance, forces firms to innovate by reducing their reliance on carbon-intensive processes and investing in clean technologies (Mol & Spaargaren, 2000). Yet, critics argue that ecological modernization tend to overlook the environmental impacts of consumption in wealthier countries, as the per capita resource use in these countries remains high. Additionally, high-income countries may reduce their domestic environmental impacts but continue to rely on resource extraction and production in less-developed regions (Mol, & Sonnenfeld, 2000).

3.3.6. Technological Choice in Production and Consumption: Neoclassical Economic Theory and Induced Innovation Hypothesis

Neoclassical economics explains technological choice based on the principle of cost minimization and profit maximization. Firms and consumers are assumed to make rational decisions by selecting technologies that offer the highest efficiency at the lowest cost. While on the one hand, firms adopt technologies that minimize production costs, increase productivity, or maximize profits. Factors like labor costs, capital availability, and raw material prices guide the choice of technology. Consumers on the other hand choose technologies (such as electric cars or home appliances) that maximize their utility while minimizing costs, influenced by factors like price, income levels, and preferences (Varian, 1992).

The presence of subsidies particularly for energy, agriculture, or industry can significantly alter the decision-making process of producers and consumers. Given that subsidies lower the cost of certain inputs or technologies, making them more attractive to producers and consumers. For example, fossil fuel subsidies reduce energy costs, incentivizing firms to choose fossil-fuel-based production technologies over cleaner but costlier alternatives.

Developed by **Hicks (1932)** and later expanded by others, the Induced Innovation Hypothesis posits that technological innovation is often a response to changes in relative resource prices. When certain resources (such as labor or energy) become more expensive, firms are motivated to innovate or adopt new technologies that reduce the use of those costly resources. Firms in countries with high labor costs might adopt automation technologies, while firms in energy-scarce countries may adopt more energy-efficient technologies. However, while subsidies can distort this process by artificially lowering the cost of certain inputs; for example, fossil fuel subsidies encourage energy-intensive technologies that may not be sustainable in the long run. Government policies, such as carbon taxes or renewable energy incentives, can also induce firms to innovate in ways that reduce environmental impact or resource use.

3.4 The Impact = Population × Affluence × Technology (IPAT) / Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) Model

There are several factors that determine the level of environmental degradation in a society, chief among them are population, affluence and technology. These three factors were identified by Ehrlich & Holdren (1971;1972) and Commoner (1971) who together developed what became known as the IPAT model.

The Commoner/Ehrlich and Holdren debates were centered around the factors that drive anthropogenic environmental impacts (York et al. 2003). While Commoner (1971) argued that environmental impact was primarily driven by production technology, Ehrlich & Holdren (1971;1972) believed that all three factors, population, affluence and technology were crucial although human population size and growth were a more fundamental factor. To properly capture the role of population, Ehrlich &Holdren (1971) presented the following equation.

$$I = P \times F \qquad (1)$$

Where I is defined as total environmental impact, P is population size and F is the impact per capita. Both variables were assumed to be nonlinear and interdependent, hence the equation becomes;

$$I = P\,(I, F) \times F \qquad (2)$$

Equation 2 states that while F is dependent on P, P is also dependent on I and F as well. As stated by Chertow (2001), a good example is how rapid increases in population growth may limit the growth of income and consumption especially in developing countries. In this earliest model by Ehrlich and Holdren (1971), technology is not considered as a separate variable, but it is discussed in relation to F, that is as a facilitator of consumption. In other words, technological improvement can hold per capita impact constant or even decrease it even when consumption is growing (Ehrlich & Holdren, 1972). Commoner (1971) further developed a mathematical equation for each of the variables by defining them:

$$I = Population \times \frac{economic\ good}{population} \times \frac{pollutant}{economic\ good} \qquad (3)$$

$I = P \times A \times T$……………………………………………………………………………..4

Where economic good = the amount of a particular good produced or consumed over a given year. Dividing this by population gives the level of affluence in the society. Pollutant refers to the amount of a specific pollutant released. Pollutant divided by economic good becomes technology. Simplifying this mathematical identity, the equation becomes;

$I = Pollutant = productive\ technology\ utilised$ ………………………………………….

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Hence, for Commoner (1971), technology was the major culprit in environmental degradation. However, Ehrlich & Holdren (1972) in their rejoinder argue that Commoner's mathematical simplification treats the variables in the model as independent of each other and in their impact on I. They argued instead that population acts as a multiplier of consumption and the environmental damages that arise from production and consumption activities. Hence, even if the individual increases in the IPAT factors are small, it is their combined impact that result in largescale environmental damages (Chertow, 2000).

In modifying the IPAT equation, Dietz & Rosa (1994) points out that although, it starts out as a controversial ecological formulation, the model came with a lot of appealing features that can be repurposed for empirical rigour. One major advantage of the IPAT model is that it is not only a parsimonious specification of the major determinants of environmental degradation but it also clearly shows the relationship between the determinants and environmental degradation. Yet, its greatest drawback was that in its current formulation, it did not provide an adequate framework for analyzing the identified factors. This they said limited its contribution to cumulative theory and empirics. In other words, the IPAT equation supports a definitional relationship between the variables so that once three of the variables are fixed, the fourth is automatically fixed. Hence, while it can provide efficiency or intensity measures, it is inadequate for hypothesis testing (Dietz & Rosa, 1994).

Given the foregoing, Dietz & Rosa (1994) presented a reformulation of the model that transforms it from an accounting equation to a stochastic model. According to the authors, the advantage of this stochastic formulation is that it opens up the possibility of employing a variety of indicators to proxy environmental impact. It also provides the opportunity to explore the effect of population growth in various dimensions such as the size, rate of growth, its distribution and even the composition of population as they are likely to have varied effects on the environment. Furthermore, they suggest that alternative measures of affluence like gross national and gross domestic product can be utilized. They also proposed that their formulation would allow technology to be assessed directly rather than been considered as a residual of affluence and population. They suggested two approaches to conceptualizing technology, first, one could incorporate operational measures of technology such as the efficiency of energy conversion. A second approach would be to conceptualize technology to include a variety of factors that influences how human activity effects the environment such as culture, social structure and institutional arrangements (Dietz & Rosa, 1994). Finally, the reformulated model makes it possible to develop a system of equations to capture both the direct and indirect effects of the driving forces of environmental impacts. The Dietz & Rosa (1994) reformulated IPAT model, which they named STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model, is presented below.

$$I = Ap^{b}A^{c}T^{d}e \quad \ldots\ldots 6$$

Where I, P, A and T are environmental impact, population size, per capita economic activity, and impact per unit economic activity respectively, a, b, c, and d are parameters and e a residual term.

STIRPAT has evolved over time as various researchers engage with the model components to broaden the understanding of environmental impacts. York & Rosa (2012) used the model to estimate the impacts of population size on air pollution. Their research illustrates the nuanced impacts of population size; in particular, it demonstrated that the way a population is distributed across space is relevant at various levels of socio-environmental analysis. While Jorgenson & Clark (2013) for instance explored the population component by examining the varying global relationships between specific populations and carbon dioxide (CO_2) emissions. Engaging with the affluence component, Jorgenson & Clark (2013) compare the multiplicative effect of gross domestic product on CO_2 in order to observe the extent to which nations' economic development is being 'decoupled' from carbon emissions. This is accomplished by creating an interaction effect between GDP and time to observe the effect of GDP in a particular period on carbon emissions. They find that while overall carbon emissions are increasing over time in relation to affluence (GDP), this correlation differs from nation to nation. Bargaoui et al (2014) utilized the STIRPAT model to determine the impact of economic and population growth, urbanization, energy intensity and Kyoto protocol obligations on carbon dioxide emissions. They found a significant effect which was dependent on the revenue level.

Recently, researchers have used the STIRPAT model to explain the effect of fossil fuel subsidies and their reforms on environmental quality., For example, Solarin (2020) replaced the technology variable in the model with fossil fuel subsidies in a bid to understand how it combine with other components to impact environmental degradation. Gani (2021) extended the STIRPAT model to control for a range of economic, social, and institutional factors in order to test for the supply side effect of energy generation on environmental quality, while Arzaghi & Squalli (2023) augmented the STIRPAT model to include a dummy variable to capture subsidy policy across a panel of countries.

The **IPAT** and **STIRPAT** models serve as the primary theoretical lenses utilized in this study due to their established relevance in capturing the complexity of environmental impacts. The IPAT framework helps illustrate why fossil fuel use remains a significant driver of environmental degradation, especially in terms of carbon emissions and climate change. Fossil fuels, due to their high carbon content, release large amounts of greenhouse gases (GHGs) when burned. These emissions contribute directly to global warming, leading to severe impacts such as rising sea levels, extreme weather events, and biodiversity loss (IPCC, 2021). Environmental impact, particularly fossil fuels, can be meaningfully analyzed through the IPAT equation, which provides a framework to understand how population (P), affluence (A), and technology (T) collectively influence environmental impact (I). The IPAT model shows how emissions are influenced by its key variables. Emissions typically increase with population growth and rising affluence due to higher energy consumption, transportation, and industrial output. However, technology (T) plays a crucial role in either exacerbating or mitigating emissions. Advances in clean energy, energy efficiency, and sustainable practices can reduce per capita emissions, making technology a key factor in addressing climate change (York et al., 2003).

The impact of affluence is captured both in the IPAT model and the Environmental Kuznets Curve (EKC). For instance, within the IPAT model, the dual nature of affluence in environmental impact can be studied: while it drives increased consumption and emissions, it also holds the potential to foster sustainable development through better technologies and environmental awareness. Similarly, this notion aligns with the Environmental Kuznets Curve (EKC), which proposes that environmental degradation first rises with affluence but eventually declines as societies become wealthier and adopt environmentally sustainable practices (Grossman & Krueger, 1995). Nevertheless, critics argue that affluence alone is insufficient for reversing environmental damage, as it depends on how resources are utilized and the extent to which sustainable practices are embedded in policy and culture. This shows that political economy issues may be relevant in understanding the effectiveness of policies aimed at improving the environment through limiting emission.

3.6. The Political Economy of fossil fuel subsidies and Reforms

Several political economy theories give insights to how public policies are made and the constraints under which such policies are formulated and implemented. Public Choice theory, developed by Buchanan and Tullock (1962) focuses on the interaction of various agents in the society whose major motivation is self-interest. It uses the methods and tools of economy to explain government decision making (Hill and Hupe, 2002; Butler, 2012). While neo-classical economists believe that government intervention could be a way to address market failure, public choice economics argue that such interventions may not yield the expected benefits resulting in government failure. Another important element in the public choice theory is the lack of incentives for voters to monitor governments effectively. There is also the role that bureaucrats play in government which has been used to explain the issue of state and regulatory capture. The idea is that bureaucrats are influenced by vested interests who aim to influence the direction of policy and government regulations. In the light of these various elements, public choice theory has been deployed to explain the political economy of subsidies. As Victor (2009) explains that fossil fuel subsidies persist because of the self-serving interests of those who benefit from such subsidies. In other words, as suggested by public choice theory, self-interest motivates people's private commercial choices as well as their public or communal decision making (Butler, 2012).

Rent seeking theory is an extension of the public choice theory to explain the idea that transfers are transformed into social costs when individuals spend real resources and efforts to capture them. It is a way of allocating previously existing wealth to oneself by something other than voluntary trade. The concept of rent seeking was invented by Tullock (1967; 1987) to explain the fact that transfers were not costless redistributions as initially thought, rather policy interventions on monopolies and regulations for example had implications for the economy. Essentially, people seek rents when they try to obtain private benefits through public services. This could be obtained through the issuance of a subsidy to support private production or consumption, by getting a tariff on production or by obtaining a special regulation that protects the producer against competition. Although the idea of lobbying for privileges has always been part of politics, Tullock argued that the expenditure for lobbying for these privileges were fundamental and that they reduce the gains to beneficiaries resulting in inefficiency.

Several studies have shown that for most entrepreneurs, getting subsidies is a function of having a good relationship with the government (Aidis, Estrin, and Mickiewicz, 2008). In their study, Du and Mickiewicz, (2016) took the lack of transparency in subsidies' distribution as a convenient indicator of a wider range of deficiencies in the institutional framework of an economy. they present a simple formal model that explored not only the direct effects of rent seeking for a company but also externalities under a situation of policy generated uncertainty in the distribution of subsidies (Du and Mickiewicz, 2016).

Thus, public choice theory examines how self-interested behavior by voters, politicians, and bureaucrats shapes public policy, including the creation and continuation of subsidies. In the context of subsidies, this theory helps explain why subsidies often persist even when they may not be economically efficient or environmentally sustainable. It argues that interest groups or industries that benefit from subsidies often engage in rent-seeking, lobbying government officials to maintain or increase those subsidies. These groups may have concentrated benefits from the subsidies, while the costs (in the form of taxes or environmental harm) are dispersed across the broader population. Another aspect is that politicians may use subsidies as a tool to secure votes or political support from specific industries or constituencies. This can lead to the continuation of subsidies that favor sectors, such as agriculture or fossil fuels, even when the broader economic or environmental effects are negative (Buchanan and Tullock, 1962).

There has also been focus on Institutions. North (1990) sees institutions as the rules of the game in a society or more formally, as the humanly devised constraints that shape human interaction. A major way institutions work is through incentives (North, 1990). The prevalence of fossil fuel subsidies in a country is dependent on the way the economy is structured. According to Victor (2009), fossil fuels differ in their physical and political attributes so it is plausible to expect that fossil fuel subsidies will vary along those lines too. He further states that the failure to reform subsidies fully lies in the failure to appreciate the political economy of subsidy policies.

Why the economics of fossil fuel subsidies are clearcut in that they are harmful to the economy, the reason they persist and why any move to reform them are more than likely met with resistance is because such a policy direction is viewed through the political rather than economic lens. Political economy issues are either ameliorated or exacerbated by the particular institutional arrangements that prevail in a society. North (1990) proposed that a major way institutions work is through the provision of incentives. Hence, It the institutional arrangement prevalent in a society incentivize the provision of subsidies, they are likely to be perpetuated even if the cost and benefits ratio imply otherwise. Incentives in this regard provide the mechanism that enforces the prevalence and persistence of fossil fuel subsidies.

Not surprisingly, Victor (2009) argues that the interest groups that demand subsidies are usually well organized, and the provision of a subsidy usually makes those groups even more aware of their interest in sustaining the subsidy policy. Further, the entities that supply subsidies often find political advantage in providing this costly service. These political facts make it particularly difficult for policy-makers to separate the purely interest-based political purposes of subsidy and the many “legitimate” purposes of this form of government policy.

Victor (2009) further argues that why government might use a subsidy to help provide energy services to low-income communities as part of a worthy effort to redistribute income or help alleviate poverty; at times, there is a case to be made for nurturing infant industries; and some subsidies are also geared to help address externalities such as environmental degradation. Yet, once a subsidy is created, regardless of its original purpose, interest groups and investments solidify around the existence of the policy and make change difficult. This might be likened to some type of path dependency given that the past condition of policy or more generally an institution affects future conditions. This is aptly explained by North (1990) when he stated that “if the institutional matrix rewards piracy, then only piratical organizations will come into existence”.

Path Dependency theory is an analytical framework used to explain how decisions made in the past can have lasting effects on the future, often locking systems into specific trajectories. Originally developed in the fields of economics and political science, the theory suggests that once a particular path is taken; whether in technology, politics, or economics, it becomes increasingly difficult to change course due to the accumulating costs of altering the established structure, behaviors, or institutions. Path dependency begins with a critical decision or event that sets a particular trajectory into motion. This initial choice or set of circumstances creates the conditions for a self-reinforcing process. Early decisions often reflect chance, but once a path is selected, it can have long-lasting consequences.

In the case of fossil fuel subsidies, path dependency begins with the initial decision to subsidize either as a way to spur growth, or to gain political traction. Once a particular path is established, several mechanisms may reinforce it. These mechanisms make deviation from the chosen path more difficult and costly over time, creating a form of "lock-in." Some of these mechanisms include increasing returns to adoption, institutional inertia, and coordination effects. This makes alternative paths less viable due to the high costs of changing course, whether these costs are economic, social, or political. This lock-in can create inefficiencies, as systems remain on suboptimal paths even when better alternatives exist. In the energy sector for instance, countries that have invested heavily in fossil fuel infrastructure face significant lock-in, making the transition to renewable energy more difficult. The existing infrastructure, subsidies, and political interests create barriers to adopting cleaner energy sources, even as the environmental costs of fossil fuels become clearer (Arthur, 1989).

Finally, there could be unintended consequences of fuel subsidy reform arising from structural and institutional factors in societies. The "Green Paradox", first conceptualized by Sinn (2009), describes a rather counterintuitive scenario where climate policies designed to reduce carbon emissions end up increasing them at least temporarily. While Sinn (2009) focused on one specific reason for the paradox; that is the impact of climate policies have on the long-term profitability and scarcity rents of fossil fuel owners, other scholars have in recent times used the term green paradox to broadly capture the unintended consequences of climate policies (Jensen, Mohlin, Pittel and Sterner, 2015).

Given that fossil fuels are nonrenewable resources, and their prices are influenced not only by production costs but also by their scarcity. To maximize profits, owners of these resources must decide the optimal timing for extracting their reserves. Climate policies that indicate future tightening – like carbon taxes or subsidy reforms – can alter these decisions in a way that results in unintended consequences. These consequences may result in a weak green paradox where fossil fuel producers anticipate that stricter future regulations may reduce their future profits, so they choose to extract more resources now rather than later. This forward shift in extraction can result in a temporary increase in carbon emissions. In the case of a strong green paradox, fossil fuel producers believe that can still profitably extract nearly all their resources despite future regulations, the accelerated extraction might not only cause a short-term spike in emissions but could also increase cumulative carbon emissions over time, exacerbating environmental damage.

Jensen et al. (2015) illustrate that the green paradox is a practical example of the Hotelling Rule. This rule states that resource owners with secure tenure aim to maximize the net present value of their profits by timing extraction so that the resource rent increases at the discount rate. According to Hotelling (1931), if there are no external costs from fossil fuel use, the extraction rate chosen by resource owners to maximize profits would also be the socially optimal rate over time. However, because climate change represents a significant external cost of fossil fuel use, this simple Hotelling result is invalidated. Climate policy aims to internalize this external cost. Yet, if such policy fails to consider the Hotelling rule regarding supply-side behavior, it could lead to a policy-driven shift in future demand, resulting in a green paradox outcome.

Jevons Paradox (also called the Rebound effect) occurs when increases in energy efficiency lead to a rise in overall energy consumption rather than a decrease. This theory suggests that even as fossil fuel subsidy reforms and technological improvements make energy use more efficient, the resulting lower energy costs can drive up consumption, potentially offsetting environmental gains. Energy efficiency improvements reduce the cost of energy consumption, which can encourage greater use of energy services. For example, if fuel subsidies are reduced, leading to more energy-efficient vehicles, consumers might respond by driving more, thus negating some of the expected reductions in fuel consumption and emissions. The rebound effect demonstrates that policy measures aimed at improving efficiency must be carefully designed to ensure they do not inadvertently lead to increased energy use. This effect is particularly important when considering the impact of fossil fuel subsidies, as consumers may respond to lower energy costs by increasing consumption (Sorrell, 2009).

The Stranded Assets Theory suggest that fossil fuel subsidy reform may create stranded assets. The concept of stranded assets refers to fossil fuel reserves or infrastructure that lose economic value due to market shifts or policy changes aimed at addressing climate change. The theory suggests that fossil fuel subsidy reforms can trigger a rapid decline in the value of fossil fuel assets, as the transition to renewable energy accelerates and carbon-intensive industries become more viable. As governments phase out fossil fuel subsidies and implement stricter climate policies, investments in fossil fuel exploration, extraction, and infrastructure may become "stranded" because they are no longer economically viable. This can lead to significant financial losses for companies and investors, as well as economic dislocation in fossil fuel-dependent regions (Caldecott, 2017).

The theory of stranded assets encapsulates the risks associated with delaying fossil fuel subsidy reforms. The longer governments wait to implement reforms, the more abrupt and costly the transition will be for industries and workers' dependent on fossil fuels. It also highlights the need for "just transition" policies to support workers and communities affected by the shift away from fossil fuels (Caldecott, 2017).

3.6 Empirical Review of Literature

The analysis of fuel subsidies and their impacts have been extensively studied in the literature. In empirical literature, evidence suggests that there is a general agreement that fuel subsidies are becoming larger and increasingly unsustainable. However, there is no consensus on the ultimate impact of their reforms on the economy especially in the short to medium term.

Starting with the impact of fossil fuel subsidies, Overland (2010) aimed to determine the most effective way to combat GHGs emissions in China, Russia and India. The comparative case studies found that the most obvious measure to combat greenhouse gas emissions is to remove the vast subsidies that promote higher energy consumption in more than half of the countries in the world, and that this measure should take precedence over many others. In terms of contributions, the study found that democratic states may be better positioned to remove subsidies than non-democratic ones. However, the study was limited due to a lack of empirical analysis given that it was not data based. Similarly, Coady et al (2017) estimated fossil fuel subsidies and the economic and environmental benefits from reforming them in 155 countries. the study utilized the price -gap approach to estimate the size of subsidies across the various countries. They used a long-run comparative static framework (comparing outcomes in 2013 and a counterfactual without energy subsidies in the analysis. The study found that subsidies are pervasive across advanced and developing, oil-producing and non-oil-producing, economies alike. While this paper provided valuable global estimates of fossil fuel subsidies, but their reliance on normative pricing, aggregation, and limited attention to political economy and adjustment costs reduces their applicability for country-level policy analysis. Their results are more useful for global diagnosis than for designing context-specific reforms.

In addition, Solarin (2020) examined the factors driving environmental degradation, emphasizing the role of fossil fuels, in 35 emerging and developing countries using the STIRPAT model and the GMM technique. The results show that an increase in fossil fuel subsidies leads to an increase in ecological footprint. Specifically, a 10% increase in fossil fuel subsidies will increase the ecological footprint by between 0.3% and 1.5%. although, Solarin (2020) showed that fossil fuel subsidies increase ecological footprint, but the study's small sample of 35 countries limits generalizability. The estimated effect may be sensitive to model specification, data quality, and measurement of subsidies. Moreso, the study did not fully account for non-linearities or interaction effects that could influence environmental outcomes.

Abdulwakil et al. (2022) examined the impact of energy subsidies on environmental quality across 70 low- and middle-income countries using the Environmental Kuznets Curve (EKC) framework and the least squares dummy variable-corrected (LSDVC) technique. Their analysis confirms the existence of the EKC for the full panel, but disaggregated results reveal no EKC for low-income and upper middle-income countries. The study finds that energy subsidies worsen environmental quality in middle-income countries, while a negative relationship is observed in low-income countries. At the panel level, the results indicate that an optimal, country-specific subsidy level exists, and that higher population density in upper middle-income countries does not necessarily lead to greater environmental pollution. The study contributes to the literature by highlighting the importance of country-specific contexts in shaping the relationship between energy subsidies, population density, and environmental outcomes. While Abdulwakil et al. (2022) show that energy subsidies have heterogeneous effects on environmental quality across income groups, confirming an EKC at the panel level but not for low- and upper middle-income countries, their analysis assumes linear relationships within country panels, potentially overlooking non-linear or dynamic interactions, and the sources of heterogeneity in the disaggregated results are not fully explored.

In a like manner, Arzaghi and Squalli (2023) using data from 139 countries with the STIRPAT framework and the fixed and random effects technique examined the environmental impact of fossil fuel subsidies. A dummy variable was introduced to capture four categories – high subsidy, moderate subsidy, high tax and moderate tax. Urbanization was also introduced into the model to account for the effect of consumption patterns on emissions. Their result provides evidence of a positive effect of high subsidy policy on emissions of GHGs and CO_2. They found that countries pursuing high-subsidy policies emit 11.4% more GHG emissions and 14.8% more CO2 emissions than those pursuing a high-tax policy. Countries pursuing high-subsidy policies tend to vary with changes in crude oil prices. For instance, the number of countries increases from 8 to 25 when the oil price rises from $64.9 to $120 per barrel. Arzaghi and Squalli (2023) showed that high fossil fuel subsidies increase CO_2 and GHG emissions, but their use of categorical dummies may oversimplify policy variation and assumes homogeneous effects within groups. Structural factors beyond urbanization, such as energy mix and technology, were not fully accounted for, and the classification of countries may be sensitive to short-term oil price fluctuations, which may affect the robustness of the results.

Several studies have examined the fallout from fossil fuel subsidy reforms, for instance, Ellis (2010) reviewed six major studies on fossil-fuel reforms carried out in the early 1990s, their multi-country meta-analysis was undertaken to understand methodological and empirical issues in fossil fuel subsidy research. The review mainly covered the strengths and limitations of partial and general equilibrium models. Focusing on a synthesis of the results from the 6 studies it reviewed, it concluded that significant economic and environmental benefits arise from fossil fuel subsidy reforms and hence it should be a key consideration in designing an overall package for global climate change mitigation. However, Ellis (2010) were not specific about what these benefits were.

Plante (2014) acknowledges that fossil fuel subsidies are market-distorting and can reduce aggregate welfare in both net oil-importing and oil-exporting countries. He argues that replacing subsidies with lump-sum transfers of equivalent value would be a superior policy alternative, as this approach preserves household benefits while eliminating distortions in energy markets and enhancing overall welfare. While Plante (2014) provides a theoretically appealing policy prescription, the analysis is largely conceptual and simulation-based, limiting its direct empirical applicability. The study does not account for country-specific factors such as income distribution, political feasibility, or the dynamics of subsidy reform, which may influence the effectiveness and equity of lump-sum transfer policies.

Akinyemi et al (2015) examined the long run effect of the existence of fuel subsidy reform on environmental quality in Nigeria for the period of 1970-2012 using the Johansen and the Engle–Granger two step co-integration procedure techniques and the Environmental Kuznets curve as a framework. The study developed a three - case scenario with the first being a case of subsidy payment, the second is a case of effective subsidy and finally, a case of no subsidy payment. The estimation results showed that the first and the last case scenario do not significantly influence environmental quality. This implies that subsidy payment in Nigeria does not enhance access and consumption of liquid fuel. rather, the results show that the interaction of sound regulatory framework with subsidy payment (the case of effective subsidy) significantly exerts a responsive influence on environmental quality. the study succeeded in confirming the existence of the EKC for Nigeria, as well as identifying the effective level of subsidy which is the interaction of sound institutions with subsidy payment to mitigate corruption and smuggling. However, the study seems to focus more on welfare impacts as against environmental impacts. The paper was not very clear on what effect it is trying to capture. With 'effective subsidy', there is a significant and positive relationship between emissions and subsidy payment. Yet there is no discussion on how this impact the environment – the suppose focus of this paper.

In contrast, Coady et al (2019) estimated that the net economic welfare gains from eliminating post-tax subsidies. The welfare gain is calculated as the benefits from reduced environmental damage and higher revenue minus the losses from consumers facing higher energy prices. At the global level, they found that the annual welfare gain was more than $1.3 trillion, or 1.7 percent of global GDP for the year 2015. Another interesting area of research is the most optimal way government can invest the savings from subsidy reforms. Monasterolo and Raberto (2019) examined the implications of a gradual phasing out of fossil fuel subsidy using the EIRIN stock flow consistent behavioural model where revenue saved can be used by government to subsidize energy investments in green capital through fiscal policies or green bonds. Their results show that a smooth phasing out of fossil fuels subsidies will improve macroeconomic performance, decrease inequality, improve the fiscal space to enable government support renewable energy policies.

In the same vein, Chepeliev et al (2020) in a study that covered 25 countries examined the impacts of fossil -fuel subsidy reform in achieving country -specific emissions reduction targets as defined by the Nationally Determined Contributions (NDCs) under different oil price projections. Their results suggest that the elimination of the fossil -fuel consumption subsidies could be an effective mechanism for meeting NDC targets for an important subset of countries, even if only leading to global emissions reduction of between 1.8 - 3.2% in 2030 depending on the oil price scenario. One interesting aspect of their findings is the situation where heavy subsidy providers experience GHG emissions increase following subsidies removal. Such countries include Ghana, Zambia and Zimbabwe. However, in these countries, most fossil - fuel consumption subsidies are associated with the electricity sector, which accounts for only 3% -17% of national emissions. As a result, fossil -fuel subsidies elimination leads to reductions in electricity -related emissions, but growing output in other sectors (mainly, livestock, trade and transport, and other services) thus leading to sectoral GHG leakages and an overall increase in emissions at the national levels. They then suggest that in such countries subsidies elimination on its own is not an effective policy to cut the GHG emissions and additional policy instruments should be implemented.

Similarly, in a study for Saudi Arabia, Sarrakh et al (2020) used the price-gap approach to determine the size of subsidies and the input-output model to determine the impact of their removal. The result show that the elimination of energy subsidies will lead to an increase in energy prices accompanied with a reduction of carbon dioxide emissions and an improvement on energy consumption. Kuehl et al (2021) utilized the Integrated Fiscal model (GSI-IF model) to assess the magnitude of greenhouse gas (GHG) emission reductions that can be achieved with the reform of consumption FFSs for 32 countries. They found that complete removal of consumption FFSs reduces GHG emissions by an average of 6.09% across these 32 countries until 2030 compared to a BAU scenario; it reduces the emissions of certain countries by over 30%. Combined with an FFS swap to energy efficiency and renewable energy, GHG emissions are reduced by about 9%. With an additional energy tax and earmarked tax revenue to be invested in renewable energy and efficiency, the average mitigation potential is about 12%.

Gamette and Oteng (2024) carried out a meta-analysis of the effect of fossil fuel subsidy removal in Nigeria and Ghana and they found that it has a detrimental effect on poverty levels through increased transport and other living cost. However, they found that it reduced ecological impact but increased disagreements between citizens and policymakers. Similarly, De Oca Leon, Hagen and Holz (2024) studied the impact of fossil fuel subsidy removal on presidential popularity using difference-indifference approaches and a stylized theoretical model. They analyzed macro level data for two subsidy removal events in Mexico and Bolivia in the early 2010s, they found evidence of a negative impact on presidential approval.

Other papers found evidence for the green paradox. For example, Wesseh et al (2016) in a study based in Ghana looked at the environmental impacts of the removal of fossil fuel subsidies using the Global Trade Analysis Project (GTAP) model in a multi-region computable general equilibrium model. The results show that removal of subsidies on refined oil imports in Ghana would lead to increased rate of CO2 emissions; hence, demonstrating evidence of the 'green paradox'. Notwithstanding, there is an overall 1.9% improvement in environmental quality due to the subsidy removal. Also, while the study observed a welfare decline, yet no succinct explanation provided for this decline. Grafton et al. (2015) examined U.S. biofuel subsidies using time-series data from 1981 to 2011 and found evidence for both the weak and strong forms of the Green Paradox. They found that subsidies encouraged fossil fuel extraction in the short term, whereas biofuel substitution reduced emissions by less than specific thresholds (26% short run; 57% long run), yet, net CO_2 emissions increased undermining climate objectives. Similarly, Norman and Schlenker (2024) provided direct empirical evidence from the U.S. oil market, showing that expectations of stricter future climate legislation during the Waxman–Markey bill debates increased current oil consumption by 2–4%. They attributed this to resource owners accelerating extraction before policy-induced price drops took effect.

On the political economy of reform, Saddiki and Chaoti (2022) carried out a meta-analysis to identify and examine the motivators and obstacles of fossil fuel energy reforms in developing countries. They argue that the largest part of fossil fuel subsidies is embedded in mainly developing non-democratic countries with weak institutional and political systems. Their findings show that ensuring successful implementation and durability of fossil fuel reforms will require a full understanding of a country's economic, social, political, and institutional conditions and constraints. This observation aligns with broader empirical evidence. Lockwood (2015) highlights how political fragmentation and rent-seeking behaviors shape reform outcomes, with the concentration or dispersion of political authority influencing both the initiation and sustainability of reforms. Case studies, such as those from Indonesia, reveal that entrenched political interests and patronage systems can delay or reverse policy change.

Similarly, Skovgaard & van Asselt, (2019) highlight the role of vested interests (ranging from state-owned energy companies to informal transport sector coalitions) in resisting reform. These groups often mobilize effectively against perceived threats to their benefits, making inclusive stakeholder engagement and tailored compensation measures critical to overcoming opposition. Institutional weakness emerges as another persistent barrier. Coady et al., (2017) find that insufficient transparency in subsidy flows, weak administrative capacity, and low public trust frequently undermine reform. In such contexts, even well-designed policies can falter if the public doubts that savings will be redistributed equitably. Economic and political instability further complicate reform trajectories. A recent analysis in Maltinez -Alvarez et al. (2022) shows that even with strong leadership, external shocks (such as currency devaluation, fuel price volatility, or inflation) can erode the political capital needed to sustain change. Indeed, many countries that implement reform see subsidies return in some form within a few years, often through price freezes or new fiscal incentives.

3.7 Methodological Review of Literature

This section examines the methodological issues in the literature, highlighting the widely used methods in the literature, as well as the areas of strength and weaknesses of these approaches. Also, the section addresses some econometric issues observed in the literature.

3.7.2 Qualitative Techniques

There have been numerous developments in the qualitative approach to examining the impact of fossil fuel subsidies on the environment and how their reforms might serve to improve environmental quality. The methods explored so far include case studies using interviews and observations. Studies in this category are mainly theoretical reviews providing a case-by-case country analysis and at other times, cross-sectional studies aimed at examining the level of fossil fuel subsidies in such countries while others highlight the current state of affairs in fossil fuel reforms pointing out the strengths and failures of various interventions. Examples include Shah and Larsen, 1992; Victor, 2009; Overland, 2010; Fabrizio et al., 2014; Coady et al., 2018; Skovgaard and Asselt, 2019; Idrisu, 2020; Saddiki and Chaoti, 2022). Policy papers are also quite common advising governments on the best way to implement reforms. Discussions often include the arguments for reforms from an economic, social and environmental perspective. Examples are Global Subsidy Initiative, 2012; Whitley and Van der Burg 2015, Gass and Echeverria, 2017; Rentschler and Brazilian 2017; UNDP, 2021;

Laan and Main, 2022; Giacosa and Walker, 2022; Damania et al., 2023; McCulloch, 2023; Global Solution Initiative, 2025.

Although, the descriptive technique is quite popular, it is not without its limitations. Most prominent among the disadvantages is the limited scope as it is unable to determine cause and effect. There is also the likelihood of subjectivity as the researchers' own biases can influence how the data is interpreted. This opens up the possibility of introducing personal preconceptions and assumptions which would influence the validity of the final outcome. The issue of generalizability is also concerning giving that findings from this sort of research may not be applicable in other population. Descriptive analysis has also been criticized as lacking in depth and rigor.

3.7.2 Quantitative Techniques

Numerous challenges have been highlighted with the qualitative approach. As a result, studies have explored quantitative techniques to examine the effects of fossil fuel subsidy reforms. According to Ellis (2010), these studies can be classed under two categories; economic modelling approach which is deployed to examine what will happen if fossil fuel subsidies are removed, and empirical approaches that analyse countries in which fossil fuel reforms have actually taken place. With regard to the economic modelling approach, both partial and general equilibrium models have been adopted in the literature. While partial equilibrium models focus on the product market in which reform takes place in order to simulate or estimate how prices, demand and production changes in fossil fuel markets based on economic theory and their assumptions. Although, partial equilibrium models provide useful insights on the impact of subsidy reforms, it is not ideal for addressing macroeconomic issues that cuts across sectors and even countries. Hence, general equilibrium models are considered to be ideal because it can be used to simulate the markets for the various factors of production and goods using equations that specify supply and demand across a variety of markets (Ellis, 2010).

The Asian Development Bank presented an integrated report in 2016 where Social Accounting Matrix (SAM), Market Allocation Models (MARKAL), Energy- Environment-Economy Models (E3MG) and the Computable General Equilibrium Model (CGE), were utilized to understudy the results of fossil fuel reforms in India, Indonesia and Thailand (ADB, 2016). The Bank argue that the results obtained from the models were highly influenced by the assumptions of the model and methodology. For example, SAM and macroeconomic models assume that wealthier households stimulate economic demand relative to government expenditure or debt. Hence the models tend to emphasize reallocating a greater proportion of savings to households relative to government budgets given they would deliver more positive results. It also posits that macroeconomic models like CGE can be dynamic and are more grounded in reality unlike SAM which tend to be static. MARKAL model is purely an energy system model and thus does not allow for the reallocation of subsidy savings back to the economy while the E3MG is an energy augmented macroeconomic model whose projections are entirely based on historical trends.

It is not surprising that the CGE has become a popular model in the literature with numerous studies adopting it. The CGE may be static or dynamic, it could focus on a single country or it can be multi-country (see for example, Burniaux et al, 2009; Wesseh et al, 2016; Akinyemi et al., 2017; Li et al., 2017; Coxhead and Grainger, 2018; Agboje, 2022;). Other studies have also utilized the Dynamic Stochastic General Equilibrium model for their research (see for example, Akinyemi, 2017; Amin et al, 2018; Omotosho, 2019; Amin et al., 2022)

Most of the studies that have followed the empirical approach are quite valuable given that they utilize actual data and are able to explore the relationships between confounding variables. Several econometric methods such as the Johnson and Engle Ganger 2 step cointegration technique Autoregressive Distributive Lag (ARDL); Generalized Method of Moments (GMM); Vector Error Correlation Model (VECM), Fixed and Random Effects, least square dummy variable corrected (LSDVC) method, and the Feasible Generalized Least Squares (FGLS) have been used in this regard. (Lvovsky et al., 2000; Akinyemi et al., 2015; Mundaca, G. 2017; Layachi, 2019; Solarin, 2020; Abdulwakil et al., 2022; Arzaghi and Squalli, 2023). The focus of majority of these studies are on the determination of the impact of fossil fuel subsidies on environmental degradation either by looking at a single country or multiple country cases. Although, majority of these studies conclude on the need for reforms as a way to mitigate the environmental degradation, little or no study exist that actually try to measure the impact of reforms where they exist on environmental quality, a gap this current study attempts to fill.

Some other studies have developed specific models to assess the impact of subsidy reforms on the environment like the EIRIN stockflow consistent behavioural model (Monasterolo and Raberto,2019). Institutions like the IMF, GSI, the World Bank e.t.c have also created models that help to simulate how subsidy removal can provide environmental and other benefits to countries. Some of these models include GSI-IF model that was developed to analyze the effect of fossil fuel subsidy reforms on greenhouse gas emissions (Kuehl et al., 2022). There is also the IMF-WB CPAT model developed by the International Monetary Fund and the World Bank which can be used to estimate the environmental, fiscal and welfare impact of fossil fuel price reform. The Global Trade Analysis Project (GTAP) ENVISAGE model developed by the World Bank has been used to provide an assessment of the fossil -fuel subsidies elimination pathways (Van der Mensbrugghe, 2008; Aguiar et al. 2019).

3.8 Identified Gaps

3.8.1 Theoretical Gap

The theoretical literature has identified a "green paradox" which is a situation where climate policy ends up worsening global warming (Sinn, 2009; Wesseh, 2016). This can be applied to the case of fossil fuel subsidy removal if it triggers a shift to the use of biomass for energy so that we witness a rise rather than a reduction in CO2 emission after reforms. Furthermore, the theoretical literature on reforms suggests that political economy issues and reform strategies may also matter for the success of reforms (Lockwood, 2015; Rentschler and Brazillian, 2017; Skovgaard and Van Asselt, 2019; Coady et al., 2018; Abdulwakil et al., 2022). This may be even more complex in the case of fossil fuel subsidy reforms because of its very nature and its perceived benefits to the masses. Its effects on the environment may also depend on such issues as literacy, educational attainment, poverty levels and environmental awareness (Zinecker et al., 2018). This study will attempt to address this gap by examining how factors like state capacity, the structure of the economy, the enactment of a biomass protection policy and educational attainment affect the outcome of reforms.

3.8.2 Empirical Gap

Studies on the environmental impact of fossil fuel subsidies reforms are very limited. The environmental impact studies are majorly on fossil fuel subsidies rather than the effect after reforms (Akinyemi et al 2015; Abdulwakil, 2022). Azaghi and Squalli (2023) considers their study the first to examine the effects of fossil fuel subsidy reform on the environment. They argue that previous relevant research addressing the environmental impact of fuel subsidy reform has been limited to studies focusing predominantly on individual countries, such as China (Lin and Jiang, 2011), Ghana (Wesseh et al, 2016) Malaysia (Li et al., 2017), Kuwait (Gelan, 2018), and Saudi Arabia (Sarrakh et al., 2020), employing computable general equilibrium (CGE) models, and imposing restrictive assumptions. However, none of these studies provided estimates specifically addressing the environmental impact of fuel subsidy policies.

Nonetheless Azaghi and Squalli (2023) can be criticized on several counts. First, the study is mainly a simulation of various reforms scenarios (The extent and spread of the data are mainly limited by the fuel price and subsidy variables, which are compiled from the GIZ biennial reports. These reports categorize countries based on the extent of their subsidies on domestic fuel consumption as compared to international prices into four groups: High-Subsidy (defined by GIZ as when the gas price is below the crude oil price), Moderate-Subsidy (defined by GIZ as when the gas price is at least as high as the crude oil price and below the price level in the United States), Moderate-Tax (defined by GIZ as when the gas price is at least as high as the price of the United States and below the price level of Bulgaria), and High-Tax (defined by GIZ as when the gas price is at least as high as the price level in Bulgaria)). The study infers that countries in the high tax and moderate tax categories have reformed fossil fuel subsidy. However, high tax does not always indicate reforms as many countries with high taxes in the study still provided substantial subsidies in the study period, particularly for highly polluting fuels like diesel and coal.

Second, the paper does not directly identify episodes or timing of reforms in other to determine their environmental impact. Third, a static model was utilized for the study which the authors justified on the basis that environmental impacts occur contemporaneously rather than with lag or lead. Yet, changes in the measures of environmental impact used in the study, CO_2 and GHGs are not necessarily contemporaneous, rather, the full extent of their impacts may take years or decades to become fully apparent.

Furthermore, Arzaghi and Squalli (2023) concluded their paper by saying that while fossil fuel subsidy reforms can help to reduce GHG emissions and promote energy efficiency, it is far from a silver bullet and cannot be relied on absolutely to meet emissions target. This statement serves as one on the motivating factor for this study given that it highlights a gap on the need to use actual data to determine if indeed reforms make sufficient difference to warrant the global call for them. Our study assembles a panel of countries that have carried out fossil fuel subsidy reform and examine if there has been improvement in their emissions levels since the reforms were enacted.

3.8.3 Methodological Gap

This study contributes to the extant methodological literature in two key ways. First, it uses a combination of the STIRPAT model, the EKC and the Ecological modernization theory to examine the way fossil fuel subsidy and it reforms interact with the variables of the model to determine environmental quality. Given that theoretical literature argue that fossil fuel subsidies create disincentives for investment in energy efficiency and renewable energy, the study interact the technology variable with fossil fuel subsidies in other to capture how subsidies influence the adoption of certain technologies. This enabled the model to distinguish between the direct effects of subsidies and indirect effects captured through the interactive term. This enabled the study to properly demonstrate the dynamics of how subsidies affect investment in energy efficiency and renewable energy which is an important factor in environmental quality. Similarly, given that extant literature argue that subsidy result in overconsumption, the affluence variable in the STIRPAT model was interacted with fossil fuel subsidy to capture the extent to which subsidy influence GDP and by implication, consumption.

Secondly, while the literature abounds with many studies that have explored the effect of fossil fuel subsidies on the economy, welfare, and environment quality, few studies have examined the environmental impact of its removal. The studies that have attempted to assess the environmental impact of fossil fuel subsidy removal have been mainly based on simulations and projections using such methodologies as input-output tables, SAM, CGE and DSGE. Others have utilized simulation-based models such as EIRIN, GSI-IF, CPAT, and GTAP-ENVISAGE which are valuable for projecting the ex-ante impacts of fossil fuel subsidy reforms, however, they require detailed sectoral datasets and strong behavioural assumptions that are not consistently available for the multi-country panel used in this study. More importantly, these models are designed to simulate hypothetical outcomes, whereas this study aims to identify the realised effects of subsidies and reforms using historical data.

This study deployed a combination of the system and the fixed and random effects models to analyse objectives 1–3. System GMM is particularly useful as it allows the study to address potential endogeneity and unobserved heterogeneity in dynamic panel settings. For Objective 4, the CSDID estimator was selected as it is well-suited for evaluating staggered reform episodes, allows for treatment effect heterogeneity, and offers a causal inference framework grounded in actual policy implementation. While some studies have employed the staggered Difference in Difference methodology to analyze issues such as agricultural policy interventions (Dhoubhadel and Azzam, 2021) health policy interventions (Ellis, Keogh, Clark and O'Neil, 2023) and crime deterrence reforms (Bielen, 2024), the political economy of fossil fuel subsidy removal (De Oca Leon, Hagen and Holz, 2024), to the best of our understanding, this study will be the first to use the methodology in the assessment of the environmental impact of fossil fuel subsidy reforms.

CHAPTER FOUR

THEORETICAL FRAMEWORK AND METHODOLOGY

4.1 Theoretical Framework

The study presents below the theoretical framework underlying each of the questions that are the focus of the research.

4.1.1 A Simple Framework of Choice among Alternative Energy Sources

Fossil fuel could be used in household cooking (the use of kerosene), generation of electricity (fuel-powered generators), or in transportation (fuel-petrol and diesel-powered automobiles). There are also alternative sources of energy for each of these services. For example, biomass (forest products), cooking gas, and publicly-provided electricity could be used for cooking, renewable energy sources (solar, windmills) could be used to generate electricity, and automobiles can be powered by Compressed Natural Gas (CNG) or electricity. The cost and potential environmental impact of the various products differ (see figure 4.1.1). The use of biomass may come with little or no private financial cost to households, but it generates multiple environmental effects, including deforestation and land degradation (which impacts forest ecosystem and climate), and pollution through the release of greenhouse gases and harmful air pollutants associated with burning. The environmental hazard associated with the use of biomass is potentially greater than that which is associated with the use of kerosene. However, the use of kerosene comes with significant financial cost to households. Cooking gas (Liquified Natural Gas (LPG)) is also considered to be less environmentally hazardous than kerosene as it emits lower levels of carbon dioxide and other pollutants and offers a cleaner, more convenient cooking environment. Nonetheless, it requires a greater financial outlay making it less accessible to low-income households. Electric stoves are another instrument of household cooking fuel but in environments where access to electricity is low, it may not be a dependable appliance. Even in societies where there is total access, the cost may make it prohibitive for cooking.

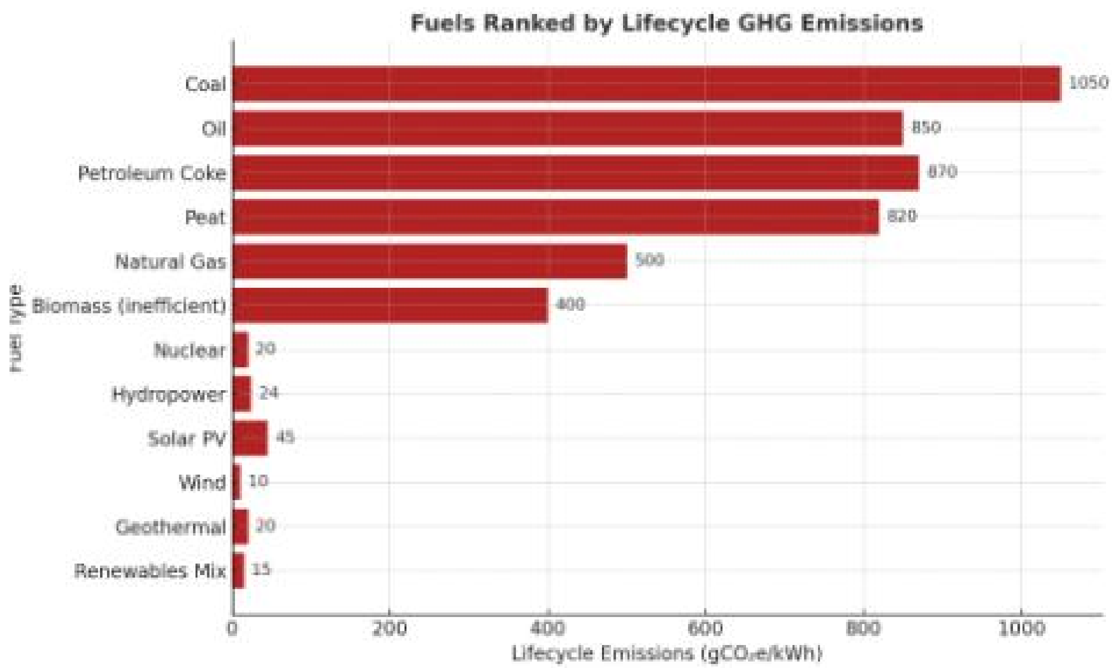

Figure 4.1.1: Fuels ranked by lifecycle GHG emissions.

With regard to electricity generation for lighting and powering household devices, grid electricity remains the most popular source in many countries. However, in many developing countries, it is often unreliable, intermittently supplied, or entirely inaccessible to a significant portion of the population. As a result, households and businesses frequently rely on fuel or diesel-powered generators as alternative sources of electricity. While these generators provide a stopgap solution, their use carries substantial environmental and economic risks. Environmentally, they emit high levels of greenhouse gases, including carbon dioxide (CO_2) and nitrogen oxides (NO_x), and contribute to noise pollution and poor urban air quality.

Economically, generators impose a heavy financial burden due to fluctuating fuel prices, high operating and maintenance costs, and long-term inefficiencies.

CNG-powered automobiles are believed to release fewer harmful emissions into the atmosphere compared to diesel and petrol-powered vehicles, making them a cleaner alternative. However, CNG vehicles are generally more expensive to purchase, and converting an existing diesel or petrol-powered automobile to run on CNG entails significant upfront costs. Meanwhile, electric vehicles (EVs), which produce zero tailpipe emissions, remain prohibitively expensive and largely inaccessible to the average citizen. Furthermore, the infrastructure and technology required to support widespread EV adoption have not yet taken root in many societies, particularly in low- and middle-income countries.

Fossil fuel subsidy alters the price purchasers pay for the fuel-based products. Like all price changes, this induces a substitution and an income effect. If fossil fuel consumption is a normal good, the income effect, like the subsection effect will be negative. However, in a situation where the use of fossil fuel is considered an inferior good, the income effect will be positive, such that subsidy may lead to a reduction in consumption via the income effect. The overall effect of subsidy on consumption will depend on the relative strength of the substitution and income effects.

4.1.2 Drivers of Environmental Impact, fossil fuel subsidies and Reform

The systematic relationship between the drivers of environmental impact, fossil fuels subsidy and reforms are explained by the schematic in Figure 4.1.2 below. The diagram visually illustrates how fossil fuel subsidies impact the environment driving increased energy consumption and emissions (the direct effect illustrated by the dark arrows), and how it interacts with the drivers of environmental impact (population, affluence, and technology illustrated by the broken lines) to influence environmental outcome (the indirect effect). It also shows how subsidy reform can influence energy consumption, promote clean energy adoption, and reduce emissions and resource depletion, ultimately mitigating the overall environmental impact.

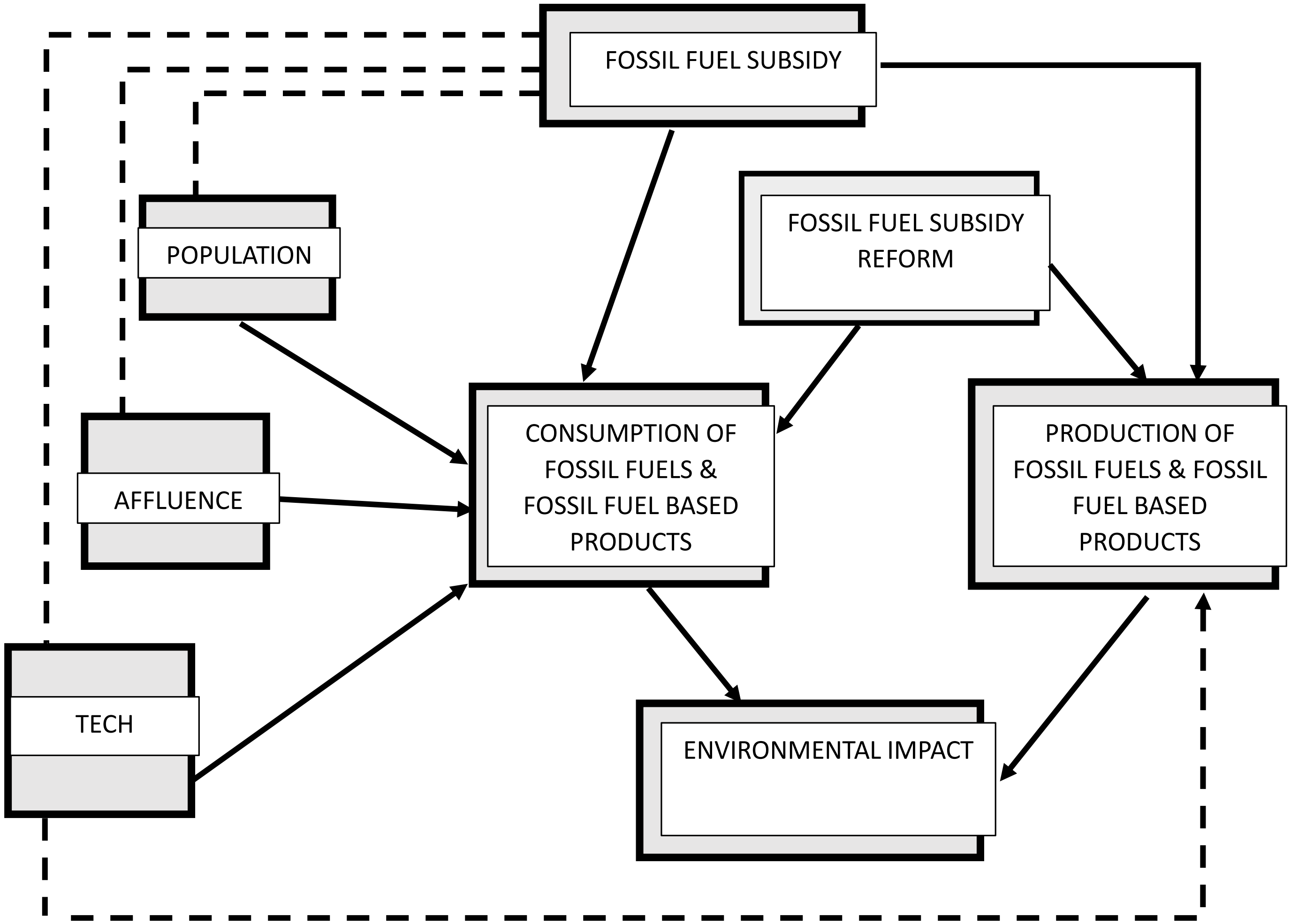

Figure 4.1.2: Conceptual Framework: STIRPAT, fossil fuel subsidies and subsidy reforms. Source: Author's own construction based on standard economic theory

While it may be expected that fossil fuel subsidies may have negative effect on the environment (due to increased use of fossil fuel) its interaction with the drivers of environmental impact, such as population, affluence, and technology choice, may produce different outcomes. Consider the interaction of subsidy with population for example, one may expect the impact on the environment to be higher at higher levels of population, population density, and/or urbanization. Subsidy itself may accentuate urbanization and raise population density in cities (cheaper fuel enhances mobility and translate to artificially low pricing of other infrastructural goods). Furthermore, fossil fuel subsidy in high density areas can magnify environmental damage through multiple channels; they may encourage increased private vehicle use over public transportation in congested urban cities, and are likely to stimulate energy intensive industrial activities in concentrated zones. How subsidy interact with affluence to determine environmental impact will depend on the share of income expended on fossil fuel related items and the relative strength of the substitution and income effects. At very low levels of affluence, people may depend more on biomass for cooking so that the presence or absence of fuel subsidy may not have significant effect on the choice of energy source for cooking. However, it may significantly influence household transportation activities, and decisions by small businesses (including traders and artisans) on private electricity generation, since this may constitute a significant portion of income or business operating cost. In other words, subsidy may induce increased use of fossil fuel through increased transportation activities and increases in the use of privately power generators.

On the other hand, at moderate levels of affluence, the presence of subsidy may make households to substitute kerosene for biomass so that subsidy fuels greater consumption of fossil fuel products through the substitution and income effects, leading to increased environmental damage. Still, at slightly higher or moderate affluence levels, household may consider the use of kerosene for cooking to be an inferior good (service). Thus, the income effect of fuel subsidy may shift demand from kerosene to cooking gas, which implies less environmental impact. Also, subsidy may encourage increased use of private automobiles for transportation rather than reliance on public transportation system and greater use of fossil fuel powered generators for electricity supply for household consumption and business use.

The situation may be dramatically altered at higher levels of affluence. For example, if the share of income spent on fueling private automobiles and powering other household appliances is insignificant, affluent households may not respond significantly to the presence of subsidy. (On the other hand, the response may be very significant where these costs constitute a substantial portion of expenditure as at moderate levels of affluence. In this case, subsidy may stimulate significant increase in the use of fossil fuel to power generators and other household appliances and enjoy the luxury of private rides). It is also possible that at high levels of affluence, households and businesses consider the use of fossil fuel powered generators for electricity supply to be an inferior good so that fossil fuel subsidy leads to investments in private renewable energy sources and a reduction in fossil fuel consumption via the income effect. If the income effect is very strong subsidy may be associated with an overall reduction in fossil fuel consumption and expectedly in environmental damage. The above postulations easily extend to production technology choices of firms (including small businesses, traders and artisans etc.).

On the supply side, subsidy may distort technological innovation by encouraging firms to continue investing in carbon-intensive technologies rather than developing or adopting cleaner, more sustainable alternatives (since demand is enhanced by subsidies). When energy or input costs are kept artificially low through subsidies, firms may lack the economic incentive to upgrade to more efficient production methods. For example, subsidies for diesel may delay the adoption of electric or hybrid delivery vehicles among logistics firms, or discourage small manufacturers from investing in energy-efficient equipment. Furthermore, in the case of fossil fuel subsidies, the expectation of continued government support can discourage long-term planning for energy transition, as firms see little need to hedge against future energy price volatility or regulatory shifts.

It is easy to see how fossil fuel subsidy reform can affect these dynamics. Reform makes fossil fuel and fossil fuel-based products more expensive and therefore has the potential to reduce demand shifting it to non-fuel based products alternatives where available and affordable and where the regulatory environment permits. On the supply side, reduction in demand may promote investments in alternative sources where demand has risen. It is important to note that producers do not benefit financially from subsidy reforms as the higher price only offsets what the government has been paying them before in the form of subsidies.

4.2 Model Specification

4.2.1 Theoretical Models

To sufficiently address objective one which examines the direct and indirect effect of fossil fuel subsidy on the environment, the study adopts the STIRPAT model developed by Dietz and Rosa (1994, 1997). The model is a reformulation and improvement on the Ehrlich and Holdren's (1971) IPAT model. Its strength is that it makes it possible to develop a system of equations to capture both the direct and indirect effects of the driving forces of environmental impacts as well as the influence of other variables, such as the presence of fossil fuel subsidy (*FSS*) (as in Liu & Xiao, 2018; Gani, 2021; and Arzaghi & Squalli, 2023 for example). The

STIRPAT model is presented below as:

$$I = \alpha P^{\beta} A^{\gamma} T^{\delta} \quad \ldots\ldots(4.1)$$

Where *I, P, A* and *T* are environmental impact, population size, per capita economic activity or gross domestic product per capita, and impact per unit economic activity or technology respectively, and α . β, γ and δ are parameters.

We carry out a log transformation of equation (1) to get the linearized form:

$$In\, I = ln\, \alpha + \beta ln\, P + \gamma ln\, A + \delta ln\, T \ldots\ldots(4.2)$$

Following Liu & Xiao (2018), Gani (2021) and Arzaghi & Squalli (2023), we introduce the subsidy variable, *FFS*, into the model to capture the direct effect of fossil fuel subsidies, as follows:

$$In\, I = ln\, \alpha + \beta ln\, POP + \gamma ln\, AFF + \delta ln\, TEC + \varphi ln\, FFS \ldots\ldots(4.3)$$

Where I = Environmental Impact; POP = Population, AFF = Affluence, TEC = Technology and FFS = fossil fuel subsidy.

We go beyond Liu & Xiao (2018), Gani (2021) and Arzaghi & Squalli (2023) to reflect in the model the indirect effect of *FSS* on *I* though its interactions with each of the drivers of *I* as follows:

$$\ln I = ln\delta_1 + \delta_2 lnpop + \delta_3 lnaff + \delta_4 lntec + \delta_5 lnffs + \delta_6 lnpop * ffs + \delta_7 lnaff * ffs + \delta_8 lntec * ffs$$

4.4

Where $POP * FFS$ represents the interaction of fossil fuel subsidy with population, $AFF * FFS$ represents the interaction between fossil fuel subsidies and affluence and $TEC * FFS$ is the interaction effect between fossil fuel subsidies and technology. Equation (4.4) is the theoretical model adopted to investigate the direct and indirect effect of fossil fuel subsidy on the environment.

Following York et al (2003), the study test for the ecological elasticity (EE) of the driving factors. Ecological elasticity refers to the responsiveness or sensitivity of environmental impacts to a change in any of the driving factors. Thus, they identified population elasticity of impact (EEIP) as the responsiveness of environmental impact to a change in population size while affluence elasticity of impact (EEIA) refers to the responsiveness of environmental impact to a change in affluence. Similarly, technology elasticity of impact (EEIT) is the responsiveness of environmental impact to change in technology. EEIP, EEIA and EEIT are captured by the parameters δ_2 , δ_3 and δ_4 respectively.

The second research objective is to examine whether the presence of fossil fuel subsidy affects the validity and shape of the Environmental Kuznets Curve. As discussed in Chapter 3, the EKC has faced significant controversies, with critics arguing that it is not universally valid across countries or pollutants, and that the turning point often occurs at very high income levels, making it potentially irrelevant for many developing economies. Nonetheless, the presence of fossil fuel subsidies could play a pivotal role in shaping the EKC. It is possible that subsidies may contribute to the emergence of an EKC where one does not yet exist, or alter the trajectory and turning point of an existing curve. At lower levels of affluence, the income effect of subsidies may be particularly strong. Since fossil fuel consumption is likely to be a normal good for lower-income households, the combined influence of the income and substitution effects could stimulate substantial increases in consumption. In contrast, at higher income levels, the income effect may weaken, and fossil fuels may even become an inferior good for wealthier households. In such cases, the presence of subsidies could be associated with moderate or even declining fuel consumption, depending on the relative strength of the income and substitution effects.

These economic effects have broader implications for the trajectory of the EKC. By artificially lowering fossil fuel prices, subsidies encourage greater reliance on polluting energy sources, which can delay the adoption of cleaner technologies essential for environmental improvement. This postponement may keep countries on the upward-sloping portion of the EKC for longer. Moreover, subsidies can distort economic incentives by diverting resources away from renewable energy investments and environmental conservation, hindering the growth of green industries and innovative solutions for sustainability. If the substitution effect is stronger, the continued attractiveness of cheap fossil fuels will delay the turning point of the EKC. If the income effect dominates, particularly at higher levels of affluence, it may signal that consumers are increasingly substituting away from fossil fuels toward cleaner alternatives, prioritising the environmental and personal benefits of reduced pollution over the perceived cost savings from subsidised fuels (Hasaini, 2016; Husaini, Lean and Ab-Rahim, 2021; Abdulwakil et al., 2022).

Given the flexibility of the STIRPAT model, several authors have further modified it to test empirically environmental theories like the EKC for instance. This is done by obtaining the quadratic term for the affluence variable. This is seen in the work Dietz and Rosa (1997) as well as York, Rosa, and Dietz (2003). The interesting aspect of this is that it allows the result of the STIRPAT model to be interpreted as ecological elasticity (EE) coefficients where impacts are multiplicative functions of population, technology, and affluence. EE coefficients are able to obtain precise relationships between A, P, and T by understanding the effect of percentage increases in the independent variables on the dependent variable. Liu and Xiao (2018) formulated an extension of the model that included the quadratic form of the affluence variable to test for the existence of the EKC. Xu et al, (2020) extended the STIRPAT model by examining how urbanization affect environmental impacts. They tested for EKC in the extended model by added the quadratic term of the urbanization variable. The results of the STIRPAT model are often interpreted as ecological elasticity (EE) coefficients where impacts are multiplicative functions of population, technology, and affluence.

Drawing from equation 4.4, we proceed to specify a model that allows us to address whether the presence of subsidy leads to an inverted-U relationship between affluence and environmental degradation or alter the trajectory and turning point of an existing relationship. The model to be estimated is of the form:

$$\ln I = ln\alpha_1 + \alpha_2 lnX + \alpha_3 lnffs + \alpha_4 lnaff + \alpha_5 lnaff^2 + \alpha_6 lnaff * ffs + \alpha_7 lnaff^2 * ffs \ldots\ldots(4.5)$$

The parameters α_4 and α_5 determines whether an EKC exist. For one to exist we must have $\alpha_4 > 0$ and $\alpha_5 < 0$ in an estimated model. The interaction terms, $Aff*FFS$ and $Aff^2 * FFS$, captures the differential effect of subsidies on the relationship between affluence and environmental impact. They assist us to investigate whether subsidy leads to the realization of the EKC hypothesis given that α_4 and α_5 do not meet the required signs, or how subsidy affect the trajectory and the turning point of the EKC, given that the signs of α_4 and α_5 met apriori expectations. $\alpha_2 lnX$ is a vector that captures the other STIRPAT variables, population and technology.

Even if the presence of fossil fuel subsidy does not create or alter the trajectory of the EKC, reform may lead to the emergence of such a relationship between affluence and environmental impact. For the purpose of this study, we define reform as a policy that significantly scales back fossil fuel subsidy, or one that significantly raises the price of fossil-fuel products, In both cases, we assume that the increase in price is not a direct result of and proportional to a current increase in the international price of crude oil.[1] The presence of a reform augmented EKC implies that reform leads to greater environmental damages at lower level of affluence and lowers damages at higher affluence level. Intuitively, reform that raises the prices of fossil-fuel products may cause low-income households to replace less environmentally damaging sources of energy for more hazardous ones (such as replacing cooking gas with kerosene, or kerosene with firewood). This is an application of the 'green paradox' earlier noted in the literature. On the transportation side, poor households and small businesses (including traders and artisans) already constrained by limited income or financial capital, often use public transportation services as a last resort (when it is not possible to use cheaper or costless means, such as trekking, using wheelbarrows or livestock-drawn carriages to transport goods, etc.) so that reform may not significantly reduce their use of fossil-fuel powered transportation. Thus, the potential for this channel to mitigate the effect derived from the use of more environmentally damaging sources for cooking following subsidy reform may disappear at lower levels of affluence. The implication of these is that reform may lead to greater environmental damages at lower levels of affluence in line with the EKC hypothesis.

[1] If domestic prices of fossil fuel products rise proportionately in response to an increase in the crude oil price, the existing level of subsidy has not changed.

On the other hand, because reform raises the relative prices of fossil-fuel products viz-a-viz products associated with cleaner energy sources, such as solar panels, inverters, and batteries etc., more affluent households may find it optimal to switch to the latter for electricity generation and running of household appliances, so that reform leads to lower environmental damages at higher affluent levels. Also, for more affluent households, reform is likely to have significant effect on the use of private automobiles for transportation. For example, medium income households may switch from private to public means of transportation following the withdrawal of subsidy (reserving the use of private automobiles for special occasions). Similarly, more affluent households may limit their vehicular movements, cutting off some leisure journeys, or switch from fossil-fuel powered automobiles to electric cars for example, or from a fuel-intensive automobile to one that uses less fossil fuel. Given that the switch from private to public means of transportation reduces congestion and vehicular pollution (through significant reduction in the number of vehicles on the roads) and substitution of fuel intensive automobiles for more fuel-efficient ones reduces emission per automobile, reform may lead to less environmental damages at higher level of affluence via the transportation channel. When this is combined with the impact of reform on choice of energy source, the beneficial effect of reform on the environmental at higher affluent levels may be even more pronounced.

Other factors may play vital roles in these dynamics. For example, the existence of an effective biomass (forest) protection policy may limit the ability of poor households to substitute fossil fuel. Government policy that encourages the use of cooking gas by subsidizing production and distribution of cylinders, for example, may limit the switch from cooking gas to kerosene, greater access to electricity may prevent the switch to biomass, other fossil-based energy, or even renewable energy sources altogether. If publicly provided electricity is based on renewable energy, this could lead to significant reduction in environmental damages but where electricity is generated from fossil-fuel powered plants, this may inadvertently lead to greater pollution. Similarly, policies that promote the use of clean energy by promoting investments in solar panels and batteries or subsidizing their production, for example, may incentivize the switch to renewable energy sources and thus lead to lower environmental damages. The same applies to policies that promote investments in electric cars, massive investment, and improvement in access to CNG powered automobiles or conversion of existing petrol/diesel powered automobiles to one running on CNG. Finally, state capacity or quality of governance will determine the ability of states to formulate and implement policies in a way that achieve results.

To test the hypothesis of the existence of a reform augmented EKC we specify the following theoretical model which is a modified form of equation (4.5):

$$\ln I = ln\beta_1 + \beta_2 lnaff + \beta_3 lnaff^2 + \beta_4 lnffs + \beta_5 lnffsr + \beta_6 lnaff * ffsr + \beta_7 lnaff^2 * ffsr + \beta_8 lnX \quad ..(4.6)$$

Where *ffsr* indicates fossil fuel subsidy reform, X is a vector of economic, governance, policy variable variables that may include educational attainment, governance, structure of the economy variables (mineral sector, service) and environmental policy variables (biomass protection policy and renewable energy). The existence of a reform augmented EKC implies that $\beta_1 > 0$ and $\beta_2 < 0$.

The final research objective is to examine whether fuel subsidy reform have impact of the environment. The theoretical postulations in section 4.1 and 4.2 suggests that it may not be possible to determine the impact of fossil fuel subsidy reform on the environment apriori, as the substitution and income effects of reform on consumption decisions may play out in several ways, structural, policy environment factors and governance quality may also play critical roles. The knowledge base of society also matters. Where a large number of citizens are enlightened about environmental issues, subsidy reform is more likely to stimulate responses that lead to reduction in environmental impact. These different possibilities align with the core principles of the Ecological Modernisation Theory which forms the analytical framework for objective four.

In pursuit of the above objective, that is objective 4, a modified form of the EMT as follows:

$$lnI = ln\rho_1 + \rho_2 lnffsr + \rho_3 lntec + \rho_4 lnX \quad \ldots 4.7$$

Where I is environmental outcome, ffsr is fossil fuel reforms, tec is technology and X is a vector variable that include socio-economic and environmental factors such as governance, structure of the economy, renewable energy, and biomass protection policy.

4.2.2 Empirical Models

From the theoretical models above, we present the following empirical models to address each of the four research questions.

$$\ln I = ln\delta_1 + \delta_2 lnpop + \delta_3 lnaff + \delta_4 lntec + \delta_5 lnffs + \delta_6 lnpop * ffs + \delta_7 lnaff * ffs + \delta_8 lntec * ffs + \mu_{it} \ldots 4.8$$

$$\ln I = ln\alpha_1 + \alpha_2 lnX + \alpha_3 lnffs + \alpha_4 lnaff + \alpha_5 lnaff^2 + \alpha_6 lnaff * ffs + \alpha_7 lnaff^2 * ffs + \mu_{it} \ldots (4.9)$$

$$\ln I = ln\beta_1 + \beta_2 lnaff + \beta_3 lnaff^2 + \beta_4 lnffs + \beta_5 lnffsr + \beta_6 lnaff * ffsr + \beta_7 lnaff^2 * ffsr + \beta_8 lnX + \mu_{it} \ldots (4.10)$$

$$\ln I = \rho ln_1 + \rho_2 lnffsr + \rho_3 lntec + \rho_4 lnX + \mu_{it} \quad \text{.........4.11}$$

In estimating the above models, the study adopts two measures of environmental impact (I). the first is carbon dioxide (CO_2) emissions (CO_2). The second is Greenhouse gas emission (GHG). As discussed in the previous chapters, these two are strongly linked to fossil fuel production and consumption.

4.3 Variable Description and Data Sources

The variables to be employed in the estimations, their descriptions and the underlying data sources are presented in Table 4.3.1 below. As suggested in chapter two, we employed two variables to capture the environmental impact of fossil fuel consumption, subsidy, and reform. These are

Carbon dioxide emission (represented as CO_2), and greenhouse gas emissions (represented as GHG). Many studies in the literature have followed a similar approach (see Dietz & Rosa (1994; 1997; Stern, 2004; Shahbaz et al., 2013). This is because CO_2 emissions is considered one of the most important drivers of radiative forcing, and data on emission by countries is widely available. Greenhouse gas emissions is utilized in this study because of the wide range of pollutants it covers which contributes in varying degrees to environmental degradation.

Governance is used to capture state capacity while BPP reflects the biomass protection policy and it is captured by access to clean energy for cooking. EDU reflects educational attainment in each country. We assume that higher educational attainment will translate to a greater environmental awareness and act as a deterrent to greater emissions. MIN and SERV captures the composition of the economy with regard to the size of the mineral sector relative to the service sector. This could play a significant role in emissions as countries with high dependence on mineral resources are more likely to emit more CO_2 and GHGs, all things being equal. Again, economies that are driven mainly by services may have relatively lower emissions rate. In particular, the study seeks to investigate the impact of fossil fuel subsidies reforms on CO_2 and GHG emissions. GHGs (a broad range of pollutants including carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O) e.t.c) is usually the focus of climate discussions. While CO_2 is one of the GHGs, the study will separate it for particular investigation because it is considered the most important GHG as far as the climate crisis is concerned. The global warming potential (GWP) of other GHGs is often compared with that of CO_2. In addition, CO_2 emission is a major derivative of fossil fuel use.

Table 4.3.1: Variable Description and Data Sources

S/N	Variables	Description	Data sources
Dependent Variables			
1.	GHG	Greenhouse gas emissions: defined as inclusive of fossil fuel generated CO_2 emissions, CH_4, N_2O and F-gases.	EDGAR
2.	CO_2	Carbon dioxide emissions: includes emissions from various sectors including power industry, industrial combustion, buildings, transport, agriculture, fuel exploitation, processes and waste.	EDGAR
Independent Variables			
3.	POP	Population: all residents of a country regardless of legal status or citizenship.	WDI
4.	POPDEN	Population density: people per sq. km of land area	WDI
5.	AFF	Affluence: represented by gross domestic product per capita and is defined as the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the product, divided by mid-year population.	WDI
6.	AFF^2	Affluence squared: the quadratic form of affluence	WDI
7.	TEC	Technology: represented by Energy efficiency and it is measured as energy intensity level of primary energy. It is an indicator of how much energy is required to produce one unit of economic output.	WDI
8.	FFS	Fossil fuel consumption subsidy: measured as subsidies that are consumed directly by end users or consumed as inputs to electricity generation.	IEA
9.	FFS*POP	The interaction of fossil fuel subsidies and population	WDI, IEA
10.	FFS*POPDEN	The interaction of fossil fuel subsidies and population density	WDI, IEA
11.	FFS*AFF	The interaction of fossil fuel subsidies and affluence.	WDI, IEA
12.	FFS*TEC	The interaction of fossil fuel subsidies and technology.	WDI, IEA
13.	FFSR	Fossil fuel subsidy reform: computed as a binary variable of countries that enacted reforms between 2010 -2023	IMF, IISD-GSI
14.	FFSR*AFF	The interaction of fossil fuel subsidy reform and affluence.	IMF, IISD-GSI, WDI
15.	$FFSR*AFF^2$	The interaction of fossil fuel subsidy reform and affluence squared.	IMF, IISD-GSI, WDI
16.	GOVERNANCE	State Capacity: measured as the average of regulatory quality, control of corruption and government effectiveness.	Oyefusi and Nnadozie (2024)
17.	EDU	Educational Attainment: measured by the secondary school completion rate	WDI
18.	BPP	Biomass Protection Policy: represented by access to clean energy for cooking	WDI
19.	MIN & SERV	Structure of the Economy: measured as the size of the mineral sector relative to gross domestic product (GDP) and the ratio of the service sector to the GDP	WDI
20.	RENEG	Investment in green technology. Measured by renewable energy consumption	WDI

Note: EDGAR= Emissions Database for Global Atmospheric Research; WDI = World Development Indicators; IEA = International Energy Agency

4.4 Estimation Techniques

To estimate the models represented by equations 4.8, 4.9 and 4.10, the study employs the System Generalized Method of Moments (sys-GMM). This is because of the panel data nature of the study and the fact that the GMM technique is versatile and able to handle the likelihood of endogeneity, and heterogeneity among regressors. Furthermore, the GMM is able to produce efficient estimators especially with the addition of moments conditions which will provide robust and precise estimates over other instrumental variable techniques (Arellano and Bond, 1991; Blundell and Bond, 1998). In addition, the GMM technique is applicable in the case of unobserved models when the explanatory variables are not strictly exogenous even after controlling for unobserved effects (Wooldridge, 2001). Given that the STIRPAT model have both time invariant and time varying characteristics, the sys-GMM is particularly ideal.[2] Also, the fact that the selected countries differ in their geographic location and in the structure of their economies is a potential source of heterogeneity. Fortunately, the GMM controls for this.

The general dynamic panel model estimated is specified as follows;

$$\Delta Iny_{it} = \delta_0 + \delta_1 Iny_{it-1} + \sum_{j=1}^{k} \alpha_j \Delta X_{j,\,it-1} + \tau_t + \mu_{it} \qquad (4.12)$$

Where

y_{it} = dependent variable

$\Delta =$ denotes the first-difference operator

$X_{j,\,it-1} =$ represents the one-period lag of the j-th regressor or interaction term

$\tau_t =$ captures time fixed effects

$\mu_{it} =$ is the idiosyncratic error term

This dynamic model is estimated using the system GMM estimator (Arellano-Bover, 1995; Blundell-Bond,1998) which combines moments conditions in levels and first differences to address potential endogeneity and omitted variable bias (Roodman, 2009).

The system GMM estimator relies on two sets of moment conditions based on the assumptions that there is no serial correlation in the idiosyncratic error terms or in the

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[2] Population for example is relatively time invariant in the short to medium time because while the size may increase over time, its composition like gender distribution, age distribution and urbanization level are largely time invariant. Affluence on the other hand is mostly time varying changing with economic conditions in a country over time.

endogenous and predetermined regressors. Specifically, for endogenous regressors or predetermined regressors X_{it} and the lagged dependent variable y_{it-1}, the valid instruments are their levels dated t – s, for s ≥ 2:

$E\left[y_{i,t-s.}.\,\Delta\mu_{it}\right] = 0$ for s ≥ 2, …………………………………………………………(4.13a)

$E\left[X_{i,t-s.}.\,\Delta\mu_{it}\right] = 0$ for s ≥ 2, …………………………………………………………(4.13b)

To increase efficiency and address weak instrument issues in persistent series, system GMM also imposes moment conditions on the levels equations using lagged differences as instruments. This conditions are specified below.

$E\left[\Delta y_{i,t-1.}.\,v_{it}\right] = 0$ ……….. ……………………………………………………………(4.13c)

$E\left[\Delta X_{i,t-1.}.\,v_{it}\right] = 0$ ……….. ……………………………………………………………(4.13d)

All other variables are as previously defined while v_{it} represent error term in levels equation including fixed effects.

To estimate the fourth model represented by equation 4.11 which involve determining the environmental impact of fossil fuel subsidy reforms, the SDiD estimation technique was deployed. The sDiD methodology was chosen because it allows the distinct isolation of the causal effects in an observational study. It enables the comparison of the changes in outcomes between a treatment group and the control group over time. However, given that the variation in the timing of reforms across the countries in the study may introduce bias into the estimation, the Callaway and Sant'Anna Difference in Difference estimation technique (Callaway and Sant'Anna 2021) is used.

The general form of the SDiD model is presented as follows;

$Y_{it} = \beta_0 + \beta_1 treatment_i + \beta_2 post_i + \beta_3(treatment_i * post_i) + \in_{it}$ .4.14

Where Y_{it} is the outcome for unit i at time t. $treatment_i$ represents units that undergo the treatment. $post_i$ represent the post treatment period.

Specifically, this study utilized the Callaway and Sant'Anna Difference in Difference methodology to evaluate the environmental effects of fossil fuel subsidy reforms across a panel of countries. The CSDiD approach is particularly suitable for staggered treatment adoption settings and allows for the estimation of group-time average treatment effects (ATTs). This methodology addresses the limitations of the traditional two-way fixed effects (TWFE) approach, which may produce biased estimates when treatment effects are heterogeneous or when treatment timing varies across units.

The CSDiD estimator builds on the potential outcomes framework, relying on the assumption of parallel trends between treated and not-yet-treated units. The treatment variable in this context is fossil fuel subsidy reform which is a binary indicator equal to 1 if a country implemented reform in a given year, and 0 otherwise. The estimator compares the post-reform outcomes of treated countries to the outcomes of countries that have not yet implemented reforms by that time. The main estimable equation in this study is of the form;

$ln\mathrm{I}_{it} = \beta_0 + \mathrm{ATT}\ (g, t) + lnV_{it} + \gamma_t + c_i + \epsilon_{it}$ ……………………….....…………………..4.15

Where lnI represent the natural log of environmental impact. ATT (g, t) is the average treatment effect for group (treatment cohort) in time capturing the effect of reform. lnV_{it} is a vector of time-varying control variables including state capacity (SC), structure of the economy (SE), educational attainment (EA), and biomass protection policy (BPP), γ_t represents time fixed effects to control for shocks common to all units, c_i captures unit (country) fixed effects. ϵ_{it} is the idiosyncratic error term.

The model specified in equation 4.15 allows for a flexible estimation of the dynamic and heterogeneous impact of fossil fuel subsidy reforms on environmental outcomes over time. The use of enables the study to capture the treatment effects specific to each reforming group at each time point, accounting for both timing and heterogeneity. By aggregating the group-time ATTs, the overall average treatment effect of the reform across all treated units is obtained, providing robust inference under staggered adoption of reforms.

Robustness Tests

To confirm the robustness of the specified models and estimation techniques utilized for analyzing objectives 1 to 3, the fixed and random effects was deployed. These techniques are popular in panel data analysis because it accounts for unobserved heterogeneity across individual units in a longitudinal dataset. FE and RE are commonly applied as it controls for the effects of unobserved factors that may be correlated with the independent variables. While the fixed effects capture time -invariant characteristics specific to each individual unit in the panel, the random effects methodology accounts for both time – invariant and time varying unobserved heterogeneity by assuming that the individual specific effects are random variables.

4.5 Data and Data Source

The study covers a panel of 68 countries over the period 2005–2023. Of these, 51 countries implemented documented fossil fuel subsidy reforms between 2010 and 2023 and are classified as treated units. These countries include Algeria, Angola, Argentina, Bahrain, Bangladesh, Brazil, Brunei, Canada, Chile, China, Denmark, the Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, France, Gabon, Ghana, Indonesia, India, Iran, Jordan, Kenya, Kuwait, Namibia, Nigeria, Niger, Mauritania, Malaysia, Mexico, Morocco, Oman, Pakistan, Peru, the Philippines, Qatar, Rwanda, Saudi Arabia, Sierra Leone, Sri Lanka, Sudan, Thailand, Trinidad and Tobago, Tanzania, Uganda, Ukraine, the United Arab Emirates, Venezuela, Vietnam, Yemen, Zambia, and Zimbabwe. Despite differences in geography and socio-economic structures, all these countries share a common experience of implementing fossil fuel subsidy reforms during the study period.

To facilitate rigorous causal inference using the staggered Difference-in-Differences (CSDID) framework, an additional 17 countries were included as pure controls. The control group comprises Albania, Cameroon, Comoros, Croatia, Kiribati, Libya, Madagascar, Mali, Mauritius, Panama, Puerto Rico, São Tomé and Príncipe, Tajikistan, Timor-Leste, Turkmenistan, Tunisia, and Lebanon. The 17 countries included as pure controls were selected to provide an appropriate counterfactual for reform-implementing countries within the staggered Difference-in-Differences (CSDID) framework. Selection was guided by two core criteria: continued provision of fossil fuel subsidies without major reforms during the study period, and broad comparability to treated countries in terms of geographic distribution and energy subsidy practices.

First, these countries maintained relatively stable fossil fuel subsidy regimes between 2005 and 2023, with no documented large-scale subsidy removals or structural reforms. This stability is essential for identifying treatment effects in a staggered DiD setting, as it ensures that control units remain untreated throughout the observation window and provide a credible baseline against which post-reform outcomes in treated countries can be evaluated. Second, the control countries were chosen to be broadly representative of the treated sample in terms of geographic spread and development context, rather than to mirror individual countries one-to-one. The control group spans Africa, Europe, Asia, the Middle East, Latin America, and Small Island Developing States, reflecting the regional diversity of the reform-implementing countries. This helps mitigate concerns that estimated treatment effects are driven by region-specific shocks, climate patterns, or institutional dynamics unrelated to subsidy reforms. Third, the selected control countries share common structural features relevant to fossil fuel subsidy policy, including continued government involvement in energy pricing, exposure to international energy price volatility, and the use of subsidies as tools for social protection or macroeconomic stabilization. These similarities strengthen the plausibility of the parallel trends assumption in the pre-reform period, which is empirically assessed within the CSDID framework.

Importantly, the control countries were not required to be identical to treated countries in all socio-economic dimensions. The CSDID methodology explicitly allows for heterogeneity across units and over time, relying instead on untreated potential outcomes and sufficiently long pre-treatment periods for identification. By extending the sample back to 2005, the study ensures adequate pre-reform observations to establish baseline trends and validate the appropriateness of the control group.

Country selection was based on publicly available information compiled by the IMF, the International Institute for Sustainable Development's Global Subsidies Initiative (IISD-GSI), and documented evidence from peer-reviewed journal articles. Data were sourced from multiple reputable databases including the IMF, IISD-GSI, EDGAR, World Development

Indicators (WDI), and the Worldwide Governance Indicators (WGI). The selected countries differ in their geographic location and in the structure of their economies. In addition, existing post-reform subsidy levels differ among the countries. While for some countries, the post reform subsidy is almost zero (implying full reform), for a larger number, there still exist significant subsidies. A number of plausible factors explains this, first is the case of reform reversals which is mostly due to political pressures and social discontent that follows the implementation of the policy. Second, the volatility in international oil prices have led some countries to reintroduce subsidies to protect the domestic economy. Finally, the coronavirus pandemic and the Russian-Ukraine war led even countries that have completely eliminated fossil fuel subsidies to reintroduce them. Unsurprisingly, there was a huge spike in subsidy receipts between 2020 and 2022.

Nonetheless, we do not consider this a challenge since the focus of this study is on the environmental impact of reform and not on the fiscal sustainability problem associated with fossil fuel subsidy. It is expected that increases in the prices of fossil fuel-based products (such as gasoline, kerosene natural gas, coal and electricity) would reduce consumption level and generate significant environmental benefit even when subsidy has not been completely phased out.

CHAPTER FIVE

PRESENTATION OF RESULTS AND ANALYSIS

This chapter presents and discusses the empirical results of the study. Several procedures were employed in the assessment of the environmental impact of fossil fuel subsidies and subsidy reforms across a wide variety of reform enacting countries. The chapter begins with a brief presentation of the descriptive statistics and other pre-estimation tests and ends with policy findings based on the estimated results.

5.1 Preliminary Analysis

The pre-estimation tests of the variables employed in achieving the objectives one to three of this study are presented and discussed below. The section presents and provide brief discussions on summary statistics, correlation analysis and multicollinearity tests.

Summary Statistics

Table 5.1 presents the mean, standard deviation, minimum and maximum values of the variables utilized in the study. The dataset is a balanced panel of 68 countries observed over 18 years (2005–2023) with 1292 observations across all variables. Fossil fuel subsidy reform (FFSR) is a binary indicator equal to one in reform years. All continuous variables are logged and mean-centered where applicable.

Table 5.1: Descriptive Statistics of the key variables

Variable	Mean (Overall)	SD (Overall)	Between SD	Within SD	Min	Max
CO_2 emissions (CO_2)	1.437	0.970	0.971	0.111	-1.253	4.123
GHG emissions (GHG)	1.792	0.908	0.886	0.227	-1.086	4.203
Fossil fuel subsidies (FFS)	5.837	3.276	3.109	1.097	-1.523	10.664
Fossil fuel subsidy reform (FFSR)	0.420	0.494	0.281	0.407	0	1
GDP per capita (GDP)	10.775	0.877	0.869	0.153	8.051	13.252
Affluence (AFF)	4.849	1.132	1.137	0.079	2.552	8.270
Education (EDU)	1.955	0.323	0.304	0.113	0	2.195
Biomass Protection Policy (BPP)	1.457	0.751	0.736	0.174	-1	2
Governance quality (GOV)	-0.290	0.774	0.762	0.161	-2.012	2.236
Technology (TEC)	0.649	0.259	0.254	0.058	-0.745	1.344
Mineral sector (MIN)	-0.481	1.069	0.975	0.452	-4.949	1.451
Services sector (SERV)	1.692	0.109	0.090	0.062	0.809	1.974
Population (POP)	7.137	0.800	0.802	0.083	4.991	9.155
Renewable energy (RENEG)	1.157	1.069	1.071	0.110	-1	6.141
Population density (POPDEN)	1.855	0.603	0.603	0.072	0.378	3.286

Source: Table prepared by author based on Stata output.
Note that all variables have been log-transformed apart governance (values range between -2.5 to +2.5).

For the environmental variables, the pre-estimation diagnostics show that CO_2 and GHG emissions exhibit very high between-country variation (0.971 and 0.886) but low within-country variation (0.111 and 0.227). This implies that there are persistent differences in emissions levels across countries. Fossil fuel subsidy has moderate between-country variation (0.281) but higher within country variation (0.407) indicating that subsidy levels change more within countries than between them. This may be due to frequent policy adjustments in response to fiscal pressures, energy price volatility, and macroeconomic shocks. In contrast, renewable energy exhibits high between-country variation but low within-country variation (0.110). With regard to the economic variables, GDP shows almost all variation is between countries (0.869) with minimal within-country changes (0.153). Services sector has low variation both between and within countries, while in contrast, the mining sector shows both high between-country (0.975) and substantial within-country (0.452) variation. Education, population density, governance and technology all show high between country variation.

Correlation Analysis

The correlation matrix in Table 5.2 demonstrates the relationships between CO2 emissions, greenhouse gas emissions, fossil fuel subsidies and other explanatory variables.

Table 5.2: Correlation Matrix of key Variables

Variable	CO2	GHG	FFSR	FFS	AFF	EDU	BPP	GOV	TEC	MIN	SERV	POP	RENEG	POPDEN
CO2	1.000	0.865*	0.292*	-0.002	0.201*	-0.034	0.540*	0.194*	0.105*	-0.102*	0.003	0.720*	-0.426*	-0.019
GHG		1.000	0.320*	-0.039	0.193*	0.006	0.430*	0.089*	0.194*	-0.086*	-0.172*	0.687*	-0.351*	-0.047
FFSR			1.000	-0.089*	0.142*	0.121*	0.226*	0.123*	0.020	-0.070*	0.076*	0.298*	-0.038	0.020
FFS				1.000	0.016	-0.197*	0.008	-0.055*	0.101*	-0.013	0.064*	0.071*	0.009	-0.250*
AFF					1.000	-0.083*	-0.097*	0.109*	0.049	-0.129*	0.023	0.259*	-0.051	0.140*
EDU						1.000	0.114*	0.156*	-0.069*	-0.083*	-0.023	0.071*	0.205*	-0.035
BPP							1.000	0.324*	0.059*	-0.092*	0.104*	0.119*	-0.352*	-0.113*
GOV								1.000	-0.145*	-0.114*	0.266*	-0.186*	-0.238*	0.111*
TEC									1.000	-0.014	-0.214*	0.031	-0.209*	-0.177*
MIN										1.000	-0.086*	-0.082*	-0.002	-0.063*
SERV											1.000	-0.099*	0.126*	0.186*
POP												1.000	0.057*	0.014
RENEG													1.000	0.028
POPDEN														1.000

Source: Table prepared by author based on Stata output.

As expected, both CO_2 emissions and greenhouse gas emissions are strongly correlated with GDP and affluence. Population, GDP and affluence are also positively correlated with emissions indicating that both economic and demographic growth contribute to environmental degradation. Interestingly, fossil fuel subsidies show a negative but insignificant correlation with emissions, this is not surprising as the trend analysis carried out in chapter two of this study produced similar findings. Another interesting finding is that technology and affluence have weak effects but these effects become stronger when combined with fossil fuel subsidies. Thus, technology and affluence has a mediating effect on fossil fuel subsidies to produce a negative relationship with emissions.

Test for Multicollinearity: Variance Inflation Factor

The Variance Inflation Factor was computed to test for potential multicollinearity. VIF values measure the extent to which the variance of a regression coefficient is inflated due to the presence of multicollinearity. The results are presented in Table 5.3.

Table 5.3: Variance Inflation Factor

Variable	VIF	1/VIF
ghg	3.83	0.2613
pop	3.21	0.3119
bpp	2.84	0.3524
reneg	2.76	0.3621
governance	1.62	0.6154
popden	1.56	0.6416
serv	1.47	0.6820
tec	1.38	0.7266
edu	1.30	0.7694
aff	1.25	0.8011
ffs	1.24	0.8045
ffsr	1.23	0.8146
min	1.09	0.9162
Mean VIF	**1.91**	

Source: Table prepared by author based on Stata output.

A VIF value of 1 indicates no correlation between a given predictor and the other predictors in the model. Values between 1 and 5 suggest moderate multicollinearity, while values greater than 5 indicate high multicollinearity, potentially warranting corrective measures. From the table, none of the explanatory variables exhibited a VIF exceeding the critical threshold of 5. The mean VIF was 1.91, indicating that multicollinearity is not a serious concern in the estimated models.

5.2 Model Estimation Results

This section presents an overview of the model estimation results. It highlights the key findings and their implications for the objectives of the study. The analysis for objectives one through to three were carried out using the Blundell and Bond two-step System GMM (1998) which is a suitable methodology for the panel data estimation explored in this study. This methodology is preferred over the fixed and random effects model (used for robustness analysis in this study) for the main estimation due to the fact that the GMM effectively addresses endogeneity, unobserved country-specific heterogeneity, and potential dynamic persistence in the dependent variables.

5.2.1 Direct and Indirect Effect of Fossil Fuel Subsides on the Environment

The first objective of this research work was to ascertain the direct and indirect effects of fossil fuel subsidies on the environment. In estimating this model (equation 4.8), we employ population density instead of population. The reason as shown in chapter 3 and 4 is because urbanization and population density may cause a strain on environmental resources, and will result in more resource use, yet it also concentrates people in spaces where sustainable infrastructure can be more easily implemented. There are three models that are estimated, model 1 contains the basic determinants of environmental impact as captured in the IPAT equation (popden, aff and tec) plus fossil fuel subsidy (ffs) and an interaction term to reflect a possible effect of fossil fuel subsidy on the environment through population density. In model 2, the interaction is between fossil fuel subsidy and affluence (ffs_aff) while in model 3, fossil fuel subsidy is interacted with tec (ffs_tec). As demonstrated in chapter four, the interaction of fossil fuel subsidy with each of these variables captures its indirect effect on the environment through those drivers of environmental impact. Table 5.4 presents the parameter estimates of the impact of fossil fuel subsidy on CO_2 emissions using the GMM methodology.

Table 5.4: Parameter estimates of GMM on impact of fossil fuel subsidy and other factors on CO_2 emissions

Variable	Model 1	Model 2	Model 3
Dependent Variable: CO2 Emissions			
L.co2	0.968***	0.959***	0.961***
	(0.017)	(0.016)	(0.012)
popden	0.007	-0.0002	-0.001
	(0.010)	(0.006)	(0.006)
aff	0.009**	0.023**	0.009***
	(0.004)	(0.010)	(0.003)
tec	0.005	0.007	0.009
	(0.011)	(0.013)	(0.018)
ffs	0.005	0.013*	-0.001
	(0.003)	(0.008)	(0.002)
Ffs_popden	-0.002	-	-
	(0.002)		
Ffs_aff	-	-0.003*	-
		(0.001)	
Ffs_tec	-	-	0.001
			(0.003)
Constant	-0.005	-0.044	0.021
	(0.022)	(0.035)	(0.017)
Model Statistics			
Observations	884	884	884
Groups	68	68	68
Instruments	13	13	13
F-statistic	68,933.10***	46,353.86***	50,082.87***
Diagnostic Tests			
AR(1) p-value	0.000	0.000	0.000
AR(2) p-value	0.637	0.622	0.618
Hansen J p-value	0.004	0.000	0.017
Sargan p-value	0.000	0.000	0.000

Source: Table prepared by author based on Stata output. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

From the result presented in Table 5.4, the system GMM estimation results for CO_2 emissions reveal important patterns regarding the dynamic relationships between fossil fuel subsidies, population density, technology, and carbon emissions across 68 countries from 2010-2023. All three models demonstrate high persistence in CO_2 emissions, with lagged dependent variable coefficients ranging from 0.959 to 0.968, indicating that current emissions are strongly influenced by previous year's levels. The AR diagnostic tests validate the dynamic specification across all models, with significant AR(1) and non-significant AR(2) tests confirming proper treatment of serial correlation. While the Hansen J-tests indicate potential instrument validity concerns, the consistent AR test results and economically plausible coefficient patterns support the reliability of the substantive findings.

The results provide strong evidence for the affluence-emissions relationship, with affluence showing consistently significant positive effects across all specifications. Model 2 reveals the strongest affluence effect (0.023, $p<0.05$), while Models 1 and 3 show more modest but significant impacts (0.009, $p<0.05$ and 0.009, $p<0.01$ respectively). Fossil fuel subsidies demonstrate a positive relationship with CO_2 emissions in Model 2 (0.013, $p<0.10$), providing direct evidence that subsidizing fossil fuel consumption contributes to increased carbon emissions. This agrees with the findings of Solarin (2020), Abdulwakil et at (2022) and Azaghi and Squalli (2023). While the technology variable shows positive but generally insignificant coefficients, population density is positive but insignificant in model one but negative and insignificant in models 2 and 3.

The interaction effects reveal some interesting policy insights. While the population density-fossil fuel subsidy and technology-fossil fuel subsidy interactions in Models 1 and 3 respectively show negative but insignificant effects, indicating that these moderating relationships may be weaker, in Model 2 the affluence-fossil fuel subsidy interaction (ffs_aff) shows a significant negative coefficient (-0.003, $p<0.10$). This finding suggests that the emission-increasing effect of fossil fuel subsidies diminishes as countries become more affluent. In other words, fossil fuel subsidies in societies with higher income level per capita may actually have beneficial effects on the environment in terms of reducing CO_2 emissions. This seemingly counterintuitive finding could be due to improved efficiency in energy use, a greater capacity for environmental regulation as income rises as well as more transparent reporting of emissions level. Or it may be rationalized (as we posited in the theoretical framework) by the fact that at higher levels of income, the consumption of fossil fuel based products may be an inferior good to citizens because of the value they place on environmental quality such that subsidies enable them to invest the income gains from the price reduction in cleaner energy sources. If the income effect is very strong, then subsidy might actually lead to a reduction in the consumption of fossil fuel and fossil fuel based products. In contrast, at low levels of income, subsidy may drive greater consumption of fossil fuel products through both the income and substitution effect. These postulations suggest that if we find support for an EKC type relationship emerging from the presence of fossil fuel subsidy, this would provide a further validation of these assertions.

Table 5.5: Parameter estimates of GMM on impact of fossil fuel subsidy and other factors on GHG emissions

Variable	Model 1	Model 2	Model 3
Dependent Variable: GHG			
L.ghg	0.931***	0.992***	0.935***
	(0.033)	(0.015)	(0.030)
popden	0.006	0.001	-0.007
	(0.014)	(0.003)	(0.015)
aff	0.014*	0.006	0.015*
	(0.008)	(0.006)	(0.008)
tec	0.058*	0.013	0.037
	(0.033)	(0.010)	(0.031)
ffs	0.005**	0.003	-0.001
	(0.002)	(0.004)	(0.003)
popdenffs	-0.002	-	-
	(0.002)		
affffs	-	-0.001	-
		(0.001)	
tecffs	-	-	0.003
			(0.005)
Constant	0.006	-0.018	0.033
	(0.047)	(0.013)	(0.052)
Model Statistics			
Observations	884	884	884
Groups	68	68	68
Instruments	13	13	13
F-statistic	10,381.55***	238,962.19***	10,192.57***
Diagnostic Tests			
AR(1) p-value	0.014	0.016	0.014
AR(2) p-value	0.303	0.394	0.312
Hansen J p-value	**0.216**	**0.001**	**0.189**
Sargan p-value	0.000	0.000	0.000

Source: Table prepared by author based on Stata output. t-statistics in parentheses. *** $p<0.01$, ** $p<0.05$, *$p<0.10$

As with the CO_2 estimates, the system GMM estimation results displayed in Table 5.5, reveal important insights about the dynamic relationship between greenhouse gas emissions, fossil fuel subsidies, population, affluence and technology. All three models demonstrate strong persistence in GHG emissions, with the lagged dependent variable coefficients ranging from 0.931 to 0.992, indicating that current emissions are heavily influenced by previous year's emissions. The AR tests confirm the validity of the dynamic specification, with significant AR(1) tests and non-significant AR(2) tests across all models, indicating proper treatment of serial correlation.

From a methodological perspective, Models 1 and 3 demonstrate superior instrument validity compared to Model 2. The Hansen J-test, which is the primary diagnostic for instrument validity in the presence of robust standard errors, shows acceptable p-values for Model 1 (0.216) and Model 3 (0.189) but fails for Model 2 (0.001). This suggests that the instruments used in the affluence-fossil fuel subsidy interaction specification may be invalid, potentially due to correlation with the error term. The consistent failure of the Sargan test across all models ($p=0.000$) is expected and less concerning, as this test is not robust to heteroskedasticity and is known to over-reject when using robust standard errors with many instruments.

In Model 1, fossil fuel subsidies show a significant positive effect (0.005, $p<0.05$) on GHG emissions, confirming that subsidizing fossil fuels directly contributes to higher emissions. Again, this direct positive impact of subsidy on GHG emissions agrees with findings by Solarin (2020), Abdulwakil et at (2022) and Azaghi and Squalli (2023). The affluence variable demonstrates a marginally significant positive coefficient (0.014, $p<0.10$) in Models 1 and 3. Technology (which was proxied with energy intensity with the assumption that higher energy intensity implies lower energy efficiency) shows positive but weakly significant effects in Model 1. In the case of population density, the study finds that it is insignificant in all 3 models. The lack of significance of the interaction term across all three model specification denote that fossil fuel subsidies have no indirect effect through population, affluence or technology to impact GHG emissions.

Robustness Checks of the Impact of fossil fuel subsidies on the environment

To ensure robustness of the findings of the main estimation technique employed for objective one – the generalized method of moments, the fixed and random effects models are estimated.

Table 5.6 present the results of fixed effects and random effects model that examine the moderating impact of fossil fuel on the drivers of CO_2 emissions.

Table 5.6: Fixed Effects and Random Effects Model -Impact of fossil fuel subsidy on CO_2

Variable	Model 1		Model 2		Model 3	
	Fixed Effects	**Random Effects**	**Fixed Effects**	**Random Effects**	**Fixed Effects**	**Random Effects**
L.co2	0.764***	0.992***	0.759***	0.992***	0.763***	0.993***
	(0.018)	(0.002)	(0.018)	(0.002)	(0.018)	(0.002)
popden	0.030	0.007	0.032	-0.000	0.035	0.000
	(0.031)	(0.006)	(0.029)	(0.003)	(0.030)	(0.003)
aff	0.291***	0.003	0.305***	0.005	0.298***	0.003
	(0.030)	(0.002)	(0.031)	(0.004)	(0.031)	(0.002)
tec	0.156***	0.006	0.154***	0.006	0.122***	-0.006
	(0.029)	(0.008)	(0.029)	(0.008)	(0.035)	(0.011)
ffs	0.000	0.002	0.017**	0.002	-0.004	-0.002
	(0.003)	(0.002)	(0.008)	(0.003)	(0.003)	(0.001)
popdenffs	-0.000	-0.001	-	-	-	-
	(0.001)	(0.001)	-	-	-	-
affffs	-	-	-0.0031**	-0.000	-	-
	-	-	(0.0015)	(0.001)	-	-
tecffs	-	-	-	-	0.007*	0.003
	-	-	-	-	(0.004)	(0.002)
Constant	-1.220***	-0.010	-1.291***	-0.006	-1.242***	0.010
	(0.157)	(0.015)	(0.159)	(0.018)	(0.156)	(0.012)
R-squared Within	0.821	0.799	0.822	0.799	0.821	0.799
R-squared Between	0.859	0.999	0.861	0.999	0.853	0.999
R-squared Overall	0.859	0.999	0.861	0.998	0.853	0.998
F-statistic	F(6,810)=617.49	-	F(6,810)=621.32	-	F(6,810)=620.04	-
Wald chi2	-	$\chi^2(6)$=267,269.32	-	$\chi^2(6)$=260,539.00	-	$\chi^2(6)$=262,413.92
Prob > F/chi2	0.000	0.000	0.000	0.000	0.000	0.000
F-test (all u_i=0)	F(67,810)=5.16***		F(67,810)=5.30***		F(67,810)=5.24***	
Sargan-Hansen Test	$\chi^2(6)$=204.443***		$\chi^2(6)$=210.414***		$\chi^2(6)$=207.102***	
	p-value=0.000		p-value=0.000		p-value=0.000	

Source: Table prepared by author based on Stata output.

Given that the Sargan-Hansen test consistently rejects the null hypothesis ($p < 0.001$) implying that the fixed effects model is preferred over the random effects model. Moreover, FE model estimates are traditionally preferred over random effects given its ability for addressing unobserved heterogeneity. Thus, only the results of the fixed effect models were discussed.

As with the system GMM, across all FE models, lagged CO_2 emissions are strongly significant ($p < 0.001$), with coefficients ranging from 0.759 to 0.764, indicating substantial path dependence in emissions trends. Affluence emerges as the dominant factor with large, highly significant coefficients ($\beta \approx 0.291–0.305$, $p < 0.001$), indicating that wealthier countries generate substantially higher emissions after controlling for country-specific effects. Technology also shows robust positive effects ($\beta \approx 0.122–0.156$, $p < 0.001$) in the fixed effects model but it was insignificant in the system GMM. Population density on the other hand is insignificant in both methods.

The interaction effects between fossil fuel subsidies and the main drivers reveal important methodological differences. In the FE models, the affluence-FFS interaction is negative and significant in Model 2 ($\beta = -0.0031$, $p < 0.05$), while the technology-FFS interaction is positive and marginally significant in Model 3 ($\beta = 0.007$, $p < 0.10$). These findings suggest that subsidies may reduce the emissions impact of affluence while potentially exacerbating the environmental effects of energy-intensive technologies. However, the System GMM results show weaker and largely insignificant interaction terms, with only the affluence-FFS interaction maintaining marginal significance in Model 2 ($\beta = -0.003$, $p < 0.10$). This divergence likely stems from GMM's correction for endogeneity and dynamic panel bias, which may absorb some of the interaction effects detected by FE estimation.

Table 5.7: Fixed Effects and Random Effects Model -Impact of fossil fuel subsidy on GHG

Variable	Model 1		Model 2			Model 3	
	Fixed Effects	**Random Effects**	**Fixed Effects**		**Random Effects**	**Fixed Effects**	**Random Effects**
L.ghg	0.733***	0.998***	0.731***		0.998***	0.730***	0.998***
	(0.020)	(0.001)	(0.020)		(0.001)	(0.020)	(0.001)
popden	0.060***	0.002	0.060***		0.000	0.065***	0.000
	(0.022)	(0.004)	(0.021)		(0.002)	(0.021)	(0.002)
aff	0.206***	0.002	0.210***		0.003	0.214***	0.002
	(0.020)	(0.001)	(0.021)		(0.002)	(0.021)	(0.001)
tec	0.102***	0.009*	0.102***		0.009*	0.072***	0.010
	(0.020)	(0.005)	(0.020)		(0.005)	(0.025)	(0.007)
ffs	0.001	0.000	0.006		0.001	-0.004*	-0.000
	(0.002)	(0.001)	(0.006)		(0.002)	(0.002)	(0.001)
popdenffs	-0.000	-0.000	-		-	-	-
	(0.001)	(0.001)	-		-	-	-
affffs	-	-	-0.001		-0.000	-	-
	-	-	(0.001)		(0.000)	-	-
tecffs	-	-	-		-	0.006**	-0.000
	-	-	-		-	(0.003)	(0.001)
Constant	-0.694***	-0.005	-0.711***		-0.009	-0.716***	-0.002
	(0.101)	(0.010)	(0.102)		(0.012)	(0.100)	(0.008)
R^2 Within	0.773	0.742	0.773		0.742	0.775	0.742
R^2 Between	0.900	0.999	0.901		0.999	0.893	0.999
R^2 Overall	0.900	0.999	0.901		0.999	0.893	0.999
F-statistic	460.11***	-	460.71***		-	463.64***	-
Wald chi2	-						
		584,783.82***	-		597,140.22***	-	583,602.10***
Sargan-Hansen	$\chi^2(6)$=213.250***		$\chi^2(6)$=215.263***			$\chi^2(6)$=219.914***	
	p-value=0.000		p-value=0.000			p-value=0.000	

Source: Table prepared by author based on Stata output. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

The findings from the Fixed Effect model shows some alignment with the results from the System GMM model thus reinforcing the credibility and robustness of the empirical estimations. Both methodological techniques identified lagged greenhouse gas emissions as a dominant and persistent driver of current emissions. Also both models recognized affluence and technology as significant predictors of emissions. The agreement between the two estimators, especially on the signs and significance of key explanatory variables, bolsters the internal consistency of the analysis

Specifically, in the fixed effect model, the affluence variable demonstrates remarkably consistent positive and significant effects across both estimation strategies, with fixed effects showing larger coefficient magnitudes (0.206-0.214) compared to system GMM (0.014-0.015). Technology effects also show consistency, with both methods revealing positive and significant relationships, though fixed effects estimates are substantially larger (0.072-0.102 vs. 0.037-0.058 in GMM). Population density effects present an interesting contrast: while GMM estimates were generally small and insignificant, fixed effects consistently show positive and significant coefficients (0.060-0.065), suggesting that controlling for unobserved country heterogeneity reveals a stronger urbanization-emissions relationship.

The interaction effects reveal the most striking differences between estimation methods. The technology-fossil fuel subsidy interaction (tecffs) shows a significant positive effect in fixed effects (0.006, $p<0.01$) but was insignificant in GMM. Fossil fuel subsidies themselves show mixed results: insignificant in most fixed effects specifications but positive and significant in several GMM models. These differences likely reflect the fixed effects method's inability to adequately address the endogeneity of policy variables like fossil fuel subsidies, which may be simultaneously determined with emission outcomes. The convergence on affluence and technology main effects, combined with the divergence on potentially endogenous policy interactions, supports the system GMM approach as the preferred specification for policy analysis while confirming the robustness of key socio-economic relationships identified in the dynamic panel framework.

Ecological Elasticities of the Impact of fossil fuel subsidies on the Environment

The ecological elasticities are presented in Table 5.8. They are derived from the already presented estimates of the system GMM and the fixed effect models discussed in the preceding section. Given that all the variables estimated in this study are already log transformed where appropriate, their estimated coefficients represent their elasticities.

Table 5.8: Ecological Elasticities of Emissions

Ecological Elasticity	Definition	Model 1	Model 2	Model 3
	Panel A: CO_2 Emissions (System GMM Model)			
Population Elasticity of Impact (EEIP)	Responsiveness of environmental impact to change in population size	0.007 (0.010)	-0.0002 (0.006)	-0.001 (0.006)
Affluence Elasticity of Impact (EEIA)	Responsiveness of environmental impact to change in affluence	0.009** (0.004)	0.023** (0.010)	0.009*** (0.003)
Technology Elasticity of Impact (EEIT)	Responsiveness of environmental impact to change in technology	0.005 (0.011)	0.007 (0.013)	0.009 (0.018)
	Panel B: CO_2 Emissions (Fixed Effects Model)			
Population Elasticity of Impact (EEIP)	Responsiveness of environmental impact to change in population size	0.030 (0.031)	0.032 (0.029)	0.035 (0.030)
Affluence Elasticity of Impact (EEIA)	Responsiveness of environmental impact to change in affluence	0.291*** (0.030)	0.305*** (0.031)	0.298*** (0.031)
Technology Elasticity of Impact (EEIT)	Responsiveness of environmental impact to change in technology	0.156*** (0.029)	0.154*** (0.029)	0.122*** (0.035)
	Panel C: GHG Emissions (System GMM Model)			
Population Elasticity of Impact (EEIP)	Responsiveness of environmental impact to change in population size	0.006 (0.014)	0.001 (0.003)	-0.007 (0.015)
Affluence Elasticity of Impact (EEIA)	Responsiveness of environmental impact to change in affluence	0.014* (0.008)	0.006 (0.006)	0.015* (0.008)
Technology Elasticity of Impact (EEIT)	Responsiveness of environmental impact to change in technology	0.058* (0.033)	0.013 (0.010)	0.037 (0.031)
	Panel D: GHG Emissions (Fixed Effects Model)			
Population Elasticity of Impact (EEIP)	Responsiveness of environmental impact to change in population size	0.060*** (0.022)	0.060*** (0.021)	0.065*** (0.021)
Affluence Elasticity of Impact (EEIA)	Responsiveness of environmental impact to change in affluence	0.206*** (0.020)	0.210*** (0.021)	0.214*** (0.021)
Technology Elasticity of Impact (EEIT)	Responsiveness of environmental impact to change in technology	0.102*** 0.020	0.102*** 0.020	0.072*** 0.025

Source: Table prepared by author based on Stata output.

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Following York et al. (2003), the study examined population elasticity of impact (EEIP), affluence elasticity of impact (EEIA), and technology elasticity of impact (EEIT) across different estimation approaches and environmental indicators. The most pronounced finding is the dramatic reduction in elasticity magnitudes when moving from fixed effects to GMM estimation. For CO2 emissions, affluence elasticity drops from 0.291-0.305 under fixed effects to just 0.009-0.023 under GMM; a reduction of approximately 90%. Similarly, technology elasticity falls from 0.122-0.156 to 0.005-0.009, representing a 95% reduction. This pattern is consistent across GHG emissions, where affluence elasticity decreases from 0.206-0.214 under fixed effects to 0.006-0.015 under GMM. These findings suggest that static models suffer from severe endogeneity bias, systematically overestimating the responsiveness of environmental impacts to economic drivers.

Under fixed effects estimation, CO2 emissions consistently exhibit higher ecological elasticities than total GHG emissions, with affluence effects approximately 40% larger and technology effects 30-50% larger for CO2. However, this differential largely disappears under GMM estimation, where both indicators show similarly modest elasticities. This convergence suggests that the apparent differences between CO2 and total GHG responsiveness may be artifacts of methodological choices rather than genuine differences in underlying environmental processes. Population elasticity presents a particularly interesting case, showing statistical significance for GHG emissions under fixed effects (0.060-0.065) but becoming insignificant under GMM estimation.

The policy implications of these methodological differences are profound. Traditional fixed effects estimates suggest that a 1% increase in affluence leads to a 0.29% increase in CO2 emissions, implying substantial environmental costs of economic growth. However, the more methodologically robust GMM estimates suggest this response is closer to 0.01%, indicating that short-term environmental impacts of economic changes may be far more modest than previously believed. This does not diminish the importance of environmental policy, but rather suggests that policies targeting economic drivers may require longer time horizons to achieve meaningful environmental improvements. The consistently small but significant affluence elasticities across GMM specifications reinforce that income remains a key driver of environmental impact, but the magnitude of this relationship is much smaller than static models suggest.

5.2.2 Empirical Analysis of Fossil Fuel Subsidies and the Environmental Kuznets Curve

In the section, the second objective of this study which is to ascertain the effect of fossil fuel subsidies on the trajectory or turning point of the Environmental Kuznets Curve is empirically investigated using the system GMM estimation technique. The fixed and random effects model estimates are also presented to serve as robustness checks.

In order to sufficiently address this objective, the study estimates a STIRPAT modified EKC model with fossil fuel subsidies. Here, the study sticks to the variables traditionally employed in testing the EKC that is population, affluence, and technology. The results are presented and discussed below.

Table 5.9: Effect of fossil fuel subsidies on the determination of the turning point of the EKC – CO_2 Emissions

Variable	Coefficient	Std. Error	t-statistic	P-value	95% Confidence Interval
L.co2	0.961***	0.041	23.63	0.000	[0.880, 1.043]
pop	-0.039	0.099	-0.39	0.699	[-0.237, 0.160]
aff	0.352	0.411	0.86	0.395	[-0.468, 1.171]
aff^{2}	-0.037	0.041	-0.91	0.366	[-0.118, 0.044]
tec	0.195**	0.088	2.21	0.030	[0.019, 0.370]
ffs	-0.166	0.169	-0.98	0.328	[-0.503, 0.171]
Ffs_aff	0.057	0.060	0.94	0.350	[-0.064, 0.177]
Ffs_aff^{2}	-0.005	0.005	-0.89	0.377	[-0.015, 0.006]
Constant	-0.526	0.966	-0.54	0.588	[-2.455, 1.403]
F-statistic	1164.29***				
Prob > F	0.000				
AR(1) test p-value	0.000				
AR(2) test p-value	0.542				
Hansen J test p-value	0.719				
Sargan test p-value	0.358				

Source: Table prepared by author based on Stata output. p-values in parentheses. *p<0.10, **p<0.05, ***p<0.01*

The system GMM results in Table 5.9 indicate a strong and highly significant persistence in CO_2 emissions, as reflected by the positive coefficient of the lagged dependent variable (0.961, $p<0.01$), suggesting that past emissions strongly influence current levels. Population and affluence have no statistically significant impact on emissions, and the squared affluence term is also insignificant. Thus, the finding here provides no evidence for the traditional Environmental Kuznets Curve pattern. Technology shows a positive and significant effect (0.195, $p<0.05$), implying that technology is associated with higher emissions which further confirms the result in objective one. Fossil fuel subsidy and its interactions with affluence are statistically insignificant, indicating that the role of fossil fuel subsidy in moderating the affluence–emissions relationship is unclear. Diagnostic tests support the validity of the model, the Hansen and Sargan tests suggest instrument validity (p-values > 0.35), and there is no evidence of second-order serial correlation (AR (2) p=0.542), although AR (1) is significant as expected in dynamic models.

While the insignificant of the affluence and affluence related variables seem to indicate that neither income nor fossil fuel subsidies meaningfully alter the income-emissions relationship, their coefficients exhibit the theoretically expected signs for an EKC relationship; positive effects at low income declining to negative effects at high income. Thus, the need to calculate marginal effects as it may provide valuable insights. To do this, we proceed as follows;

the basic EKC relationship is defined as $\text{Environmental Outcome} = \beta_1(aff) + \beta_2(aff^2)$

From the system GMM results in Table 5.2.2a, the estimated EKC relationship for the CO_2 emissions becomes;

$$CO_2 = \beta_3(0.352) + \beta_4(-0.037)$$

The turning point becomes; $aff^* = \frac{-\beta_3}{2\beta_4} = \frac{-0.352}{2*(-0.037)} = 4.76$

ii. To test the fossil fuel subsidy effect, the EKC relationship was modified by introducing fossil fuel subsidy directly into the model and by further interacting it with affluence. Thus the estimated full model is;

$$CO_2 = \beta_0 + \beta_1(lCO_2) + \beta_2(pop) + \beta_3(aff) + \beta_4(aff^2) + \beta_5(tec) + \beta_6(ffs) + \beta_7(aff * ffs) + \beta_8(aff^2 * ffs)$$

The marginal effect of affluence becomes

$$\frac{\partial co_2}{\partial aff} = \beta_3 + 2\beta_4(aff) + \beta_7(ffs) + 2\beta_8(aff * ffs)$$

$$\frac{\partial co_2}{\partial aff} = 0.352 + 2(-0.037)(aff) + 0.057(ffs) + 2(-0.005)(aff * ffs)$$

$$\frac{\partial co_2}{\partial aff} = 0.352 - 0.074(aff) + 0.057(ffs) - 0.010(aff * ffs)$$

iii. The study then proceeds to calculate the total effect of subsidies, that is the direct and quadratic effects;

$$\frac{\partial co_2}{\partial ffs} = -0.166 + 0.057(aff) + (-0.005)(aff^2)$$

$$\frac{\partial co_2}{\partial ffs} = -0.166 + 0.057(aff) - 0.005)(aff^2)$$

Based on the above calculations, the study presents a scenario based analysis of the marginal effects of affluence on CO_2 emissions at different income levels[3] in Table 5.10 and the marginal subsidy effects at different levels of affluence in Table 5.11.

Table 5.10: Marginal Effects at different affluence levels – CO_2 Emissions

Affluence Level	No Subsidies (ffs=0)	Low Subsidies (ffs=5)	High Subsidies (ffs=15)
aff = 1	0.352 - 0.074(1) = **0.278**	0.278 + 0.057(5) - 0.010(1×5) = **0.563**	0.278 + 0.057(15) - 0.010(1×15) = **1.083**
aff = 3	0.352 - 0.074(3) = **0.130**	0.130 + 0.057(5) - 0.010(3×5) = **0.265**	0.130 + 0.057(15) - 0.010(3×15) = **0.535**
aff = 5	0.352 - 0.074(5) = **-0.018**	-0.018 + 0.057(5) - 0.010(5×5) = **-0.033**	-0.018 + 0.057(15) - 0.010(5×15) = **-0.013**
aff = 7	0.352 - 0.074(7) = **-0.166**	-0.166 + 0.057(5) - 0.010(7×5) = **-0.331**	-0.166 + 0.057(15) - 0.010(7×15) = **-0.561**
aff = 10	0.352 - 0.074(10) = **-0.388**	-0.388 + 0.057(5) - 0.010(10×5) = **-0.803**	-0.388 + 0.057(15) - 0.010(10×15) = **-1.633**

Source: Table prepared by author based on Stata output

Table 5.11: Marginal Subsidy effects at different affluence levels – CO_2 Emissions

Affluence Level	Direct Effect (β_3)	Linear Interaction (β_4×aff)	Quadratic Interaction (β_5×aff²)	Total Subsidy Effect
aff = 1	-0.166	0.057(1) = 0.057	-0.005(1) = -0.005	**-0.114**
aff = 3	-0.166	0.057(3) = 0.171	-0.005(9) = -0.045	**-0.040**
aff = 5	-0.166	0.057(5) = 0.285	-0.005(25) = -0.125	**-0.006**
aff = 7	-0.166	0.057(7) = 0.399	-0.005(49) = -0.245	**-0.012**
aff = 10	-0.166	0.057(10) = 0.570	-0.005(100) = -0.500	**-0.096**

Source: Table prepared by author based on Stata output

From the results in Table 5.10 and Table 5.11, fossil fuel subsidy shows larger and more varied effects across the different affluence scenarios. The analysis reveals counterintuitive

[3] The log affluence used in this study range between 2 and 12. For each of computation and discussion, marginal effects are calculated for affluence levels at 1, 3, 5 ,7 and 10.

dynamics with a direct negative effect (-0.166) that varies significantly across income levels and through the different interaction terms. At low affluence levels, subsidies show emission-reducing effects (total effect at aff=1: -0.114), potentially supporting less carbon-intensive activities in developing countries, but this effect approaches zero at middle-income levels (aff=5: -0.006) before becoming negative again at higher development stages (aff=7: -0.012; aff=10: -0.096). Thus, the marginal effects demonstrate that subsidies significantly amplify the affluence-emission relationship, with high subsidy levels (ffs=15) creating marginal effects of 1.083 at low income levels compared to 0.278 without subsidies.

In general, the marginal effects analysis demonstrates that subsidies have the capacity to alter how affluence affects CO_2 emissions: while the base relationship shows declining marginal effects of income (from 0.278 at low income to -0.388 at high income), subsidies consistently increase these marginal effects across all income levels. At low and medium affluence levels, fossil fuel subsidies significantly amplify the environmental impact of income growth transforming small positive effects into much larger increases in emissions (e.g., from 0.278 to 1.083 with high subsidies). This indicates that subsidies exacerbate pollution precisely where economies are most sensitive to energy use and carbon intensity, resulting in the greatest marginal environmental harm per unit of growth. At high affluence levels, where the Environmental Kuznets Curve (EKC) predicts a decline in emissions as economies transition toward cleaner technologies and stronger regulations, subsidies interfere with this dynamic by reducing the magnitude of negative income effects. In essence, subsidies both intensify pollution in poorer countries and delay environmental improvements in wealthier ones.

Table 5.12: Impact of Fossil Fuel Subsidies on the Environmental Kuznets Curve Dynamics– GHG Emissions

Variable	Coefficient	Std. Error	t-statistic	P-value	95% Confidence Interval
L.ghg	0.953***	0.060	16.01	0.000	[0.834, 1.072]
pop	-0.001	0.052	-0.01	0.991	[-0.105, 0.104]
aff	0.019	0.353	0.05	0.958	[-0.686, 0.723]
aff^2	-0.005	0.032	-0.16	0.877	[-0.069, 0.059]
tec	0.094*	0.051	1.85	0.069	[-0.007, 0.194]
ffs	-0.090	0.118	-0.77	0.447	[-0.325, 0.145]
Ffs_aff	0.029	0.044	0.66	0.509	[-0.059, 0.118]
Ffs_aff^2	-0.002	0.004	-0.54	0.588	[-0.011, 0.006]
Constant	0.089	0.868	0.10	0.919	[-1.644, 1.822]
F-statistic	6334.43***				
Prob > F	0.000				
AR(1) test p-value	0.012				
AR(2) test p-value	0.255				
Hansen J test p-value	0.674				
Sargan test p-value	0.092				

Source: Table prepared by author based on Stata output. *p<0.10, **p<0.05, ***p<0.01*

From the results presented in Table 5.12, both the linear and quadratic affluence terms are statistically insignificant. The interaction terms (ffs_aff) and (ffs_aff) are small and statistically insignificant. As with the CO2 emissions analysis, the theoretically expected signs with the mainly insignificant variables caused us to examine the marginal effects for further insights.

To do this, we proceed as follows;

From the system GMM results, the estimated EKC relationship becomes;

$(\text{GHG}) = \beta_3(0.019) + \beta_4(-0.005)$

The turning point becomes; $aff^* = \frac{-\beta_3}{2\beta_4} = \frac{-0.019}{2*(-0.005)} = 1.90$

As before, the estimated full model is;

$$GHG = \beta_0 + \beta_1(lghg) + \beta_2(pop) + \beta_3(aff) + \beta_4(aff^2) + \beta_5(tec) + \beta_6(ffs) + \beta_7(aff * ffs) + \beta_8(aff^2 * ffs)$$

The marginal effect of affluence becomes

$$\frac{\partial GHG}{\partial aff} = \beta_3 + 2\beta_4(aff) + \beta_7(ffs) + 2\beta_8(aff * ffs)$$

$$\frac{\partial GHG}{\partial aff} = 0.019 + 2(-0.005)(aff) + 0.029(ffs) + 2(-0.002)(aff * ffs)$$

$$\frac{\partial GHG}{\partial aff} = 0.019 - 0.010(aff) + 0.029(ffs) - 0.005(aff * ffs)$$

The study then proceeds to calculate the total effect of subsidies, that is the direct and quadratic effects;

$$\frac{\partial GHG}{\partial ffs} = \beta_6 + \beta_7(aff) + \beta_8(aff^2)$$

$$\frac{\partial GHG}{\partial ffs} = -0.090 + 0.029(aff) + (-0.002)(aff^2)$$

$$\frac{\partial GHG}{\partial ffs} = -0.090 + 0.029(aff) - 0.002)(aff^2)$$

Based on the above calculations, the study presents a scenario based analysis of the marginal effects of affluence on GHG emissions at different income levels in Table 5.13 and the marginal subsidy effects at different levels of affluence in Table 5.14.

Table 5.13: Marginal Effects at different affluence levels – GHG Emissions

Affluence Level	No Subsidies (ffs=0)	Low Subsidies (ffs=5)	High Subsidies (ffs=15)
aff = 1	0.019 - 0.010(1) = **0.009**	0.009 + 0.029(5) - 0.005(1×5) = **0.139**	0.009 + 0.029(15) - 0.005(1×15) = **0.369**
aff = 3	0.019 - 0.010(3) = **-0.011**	-0.011 + 0.029(5) - 0.005(3×5) = **0.064**	-0.011 + 0.029(15) - 0.005(3×15) = **0.184**
aff = 5	0.019 - 0.010(5) = **-0.031**	-0.031 + 0.029(5) - 0.005(5×5) = **-0.006**	-0.031 + 0.029(15) - 0.005(5×15) = **-0.016**
aff = 7	0.019 - 0.010(7) = **-0.051**	-0.051 + 0.029(5) - 0.005(7×5) = **-0.076**	-0.051 + 0.029(15) - 0.005(7×15) = **-0.216**
aff = 10	0.019 - 0.010(10) = **-0.081**	-0.081 + 0.029(5) - 0.005(10×5) = **-0.186**	-0.081 + 0.029(15) - 0.005(10×15) = **-0.516**

Source: Table prepared by author based on Stata output

Table 5.14: Marginal Subsidy effects at different affluence levels – GHG Emissions

Affluence Level	Direct Effect (β_6)	Linear Interaction (β_7×aff)	Quadratic Interaction (β_8×aff²)	Total Subsidy Effect
aff = 1	-0.090	0.029(1) = 0.029	-0.002(1) = -0.002	**-0.063**
aff = 3	-0.090	0.029(3) = 0.087	-0.002(9) = -0.018	**-0.021**
aff = 5	-0.090	0.029(5) = 0.145	-0.002(25) = -0.050	**+0.005**
aff = 7	-0.090	0.029(7) = 0.203	-0.002(49) = -0.098	**+0.015**
aff = 10	-0.090	0.029(10) = 0.290	-0.002(100) = -0.200	**0.000**

Source: Table prepared by author based on Stata output

The direct effect of subsidy is negative (-0.090) in this model against apriori expectations suggesting that subsidies reduce emissions on average. However, this finding is not surprising as it is similar to the result of the trend analysis established in chapter 2 of this study. The linear interaction model (ffs_ aff) is positive (0.029) indicating that relatively, subsidies have larger effects at higher income levels. The quadratic interaction (ffs_aff^2) is negative (-0.002) which suggests diminishing subsidy effects that at high income levels. The total subsidy effect follows an inverted-U pattern: negative at low income (-0.063 at aff=1), becoming slightly positive at medium income (+0.015 at aff=7), then returning to zero at high income (0.000 at aff=10).

Similar to the CO_2 analysis, the marginal effects analysis demonstrates that subsidies fundamentally alter how affluence affects GHG emissions although not by as much impact as it does CO_2 emissions.

The findings from objective 2 show that the relationship between emissions and income growth appears to conform to what is suggested by the Environmental Kuznets Curve hypothesis, however, because the coefficients are not statistically significant, it cannot be said that the relationship is driven by income growth itself. This implies that some other factor may explain the EKC hypothesis. In this results, the technology of production and consumption appears to play a significant role in this dynamics. Nonetheless, a better picture may appear from the estimation of model 3.

Robustness Tests on the effect of fossil fuel subsidies on the Environmental Kuznets Curve

For robustness sake, the findings from system GMM are compared with results from the fixed and random effects model presented below.

Table 5.15: Effect of fossil fuel subsidies on the determination of the turning point of the EKC – CO2 Emissions

Variable	Fixed Effects			Random Effects		
	Coefficient	**Std. Error**	**P-value**	**Coefficient**	**Std. Error**	**P-value**
L.co2	0.725***	0.064	0.000	0.985***	0.002	0.000
pop	0.138	0.088	0.119	0.013***	0.003	0.000
aff	0.107	0.246	0.663	-0.004	0.021	0.863
aff^2	0.023	0.024	0.347	0.001	0.002	0.753
tec	0.178	0.114	0.123	0.009	0.008	0.241
ffs	-0.001	0.065	0.992	-0.003	0.009	0.754
Ffs_aff	0.003	0.023	0.894	0.001	0.004	0.764
Ffs_aff^2	-0.001	0.002	0.794	-0.0001	0.0004	0.719
Constant	-1.788*	1.058	0.096	-0.063	0.054	0.242
R^2 Within	0.825	0.799		0.799		
R^2 Between	0.829	0.999		0.999		
R^2 Overall	0.829	0.999		0.999		
F-statistic/Wald χ^2	251.54***			867,172.70***		
Prob > F/χ^2	0.000			0.000		
Hausman Test (Sargan Hansen Statistics	61.268					
Chi-sq (8) P-Value	0.000***					

Source: Table prepared by author based on Stata output. *Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

The comparison between fixed effects and system GMM results for CO2 emissions demonstrates both the consistency of key findings and the methodological superiority of the GMM approach in addressing dynamic panel estimation challenges. The technology coefficient exhibits directional consistency across both methods (FE: 0.178, p=0.123; GMM: 0.195, p=0.030), with the GMM approach achieving statistical significance that the fixed effects model narrowly misses. The lagged dependent variable shows the expected pattern of upward bias correction, moving from 0.725 in fixed effects to 0.961 in system GMM, with the latter providing a more realistic estimate of emission persistence that accounts for the downward bias inherent in fixed effects estimation of dynamic panels. Most notably, the fossil fuel subsidy effects that disappear entirely in the fixed effects model (all coefficients near zero and insignificant) are recovered and properly estimated in the GMM framework, where the direct subsidy effect (-0.166) and interaction terms become meaningful though statistically insignificant.

Table 5.16: Effect of fossil fuel subsidies on the determination of the turning point of the EKC – GHG Emissions

Variable	Fixed Effects			Random Effects		
	Coefficient	**Std. Error**	**P-value**	**Coefficient**	**Std. Error**	**P-value**
L.ghg	0.678***	0.090	0.000	0.997***	0.002	0.000
pop	0.167*	0.087	0.059	0.002	0.002	0.330
aff	0.014	0.184	0.938	0.007	0.013	0.617
aff^2	0.022	0.014	0.141	-0.0004	0.001	0.757
tec	0.123**	0.052	0.022	0.010**	0.004	0.024
ffs	-0.030	0.045	0.516	0.002	0.006	0.676
Ffs_aff	0.012	0.016	0.472	-0.001	0.002	0.673
Ffs_aff^2	-0.001	0.001	0.435	0.0001	0.0002	0.738
Constant	-1.286	0.980	0.194	-0.028	0.034	0.415
R^2 Within	0.782			0.742		
R^2 Between	0.860			0.999		
R^2 Overall	0.860			0.999		
F-statistic/Wald χ^2	237.61***			1.63×10^6***		
Prob > F/χ^2	0.000			0.000		
Hausman Test (Sargan –Hansen statistic	52.605					
Chi-sq(8)	0.000****					

Source: Table prepared by author based on Stata output. *Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.*

The robustness tests using the fixed effects and random effects methodology reveal substantial differences in coefficient estimates and model specifications, with the Sargan-Hansen test strongly rejecting the random effects model (χ^2=51.605, p<0.001) in favor of the fixed effects specification. Based on this, the study focus on the Fixed Effects estimations and compared it with the results derived from the system GMM.

Population is marginally significant in the FE model but becomes negligible in the GMM model. The technology variable is positively associated with emissions in both estimations. The results from both the Fixed Effects and System GMM estimations reveal limited support for the Environmental Kuznets Curve hypothesis in the context of greenhouse gas emissions. While the quadratic terms for affluence are statistically insignificant across both models, the signs of their coefficients vary, the FE model suggests a U-shaped relationship, while the GMM model leans toward the theoretically expected inverted U-shape. However, in neither case is the turning point statistically robust. Additionally, the interaction terms between affluence and fossil fuel subsidies do not significantly influence emissions, suggesting that fossil fuel subsidies do not meaningfully moderate the shape or trajectory of the EKC. This implies that, at least in the studied context, affluence and subsidy structures may not be strong enough determinants to shift environmental outcomes along the Kuznets pathway. However, as we have already established in the preceding section, calculating the marginal effects and using a scenario based analysis allowed the study to establish that indeed, fossil fuel subsidies can alter the trajectory of the EKC. The implication here is that economic growth alone especially in the face of fossil fuel subsidies cannot be relied upon as automatic solutions for CO2 emission reductions, necessitating more direct environmental policy interventions. This is an option the study turns to in the next set of estimations where it proceeds to see whether policy interventions like fossil fuel subsidy reforms can make a difference in environment outcomes and if that is the case, could an augmented- Environmental Kuznets Curve become a possibility?

5.2.3 Empirical analysis of the existence of a reform-augmented Environmental Kuznets Curve

The third objective of this study is to empirically determine the existence of a reform – augmented Environmental Kuznets Curve. The study utilizes the system GMM as the primary estimation technique. The fixed and random effects models are deployed to ensure robustness. The results of the system GMM estimations are presented below.

Table 5.17: Determining the Existence of a reform-augmented EKC- CO2 Emissions

Variable	Model 1 – Economic Structure		Model 2: Environmental Policy	
	Coefficient	t-stat	Coefficient	t-stat
L.CO_2	0.989***	5.16	0.943***	4.53
Affluence (aff)	3.331***	3.14	2.140**	2.04
Fossil Fuel Subsidy(ffs)	-0.00157	-1.15	-0.00103	-0.82
Affluence²(aff2)	-0.297***	-2.71	-0.171	-1.53
Fossil Fuel Subsidy Reform (ffsr)	-0.4509	-0.31	-0.8756	-0.53
Ffsr_Aff	0.1724	0.29	0.3480	0.52
Ffsr_Aff²	-0.0159	-0.28	-0.0333	-0.52
Governance	0.0246	1.13	0.0180	0.94
Education	-0.00038	-0.02	-0.00048	-0.04
Mineral Sector	0.0213**	2.47	–	–
Services Sector	0.0295	0.41	–	–
Biomass Protection Policy	–	–	-0.0157*	-1.98
Renewable Energy	–	–	-0.171***	-2.72
Constant	-8.784***	-3.40	-5.813**	-2.28
Observations	884		884	
Groups	68		68	
Instruments	15		15	
F-Statistics	95.93***		148.92***	
AR(1) p-value	0.004		0.004	
AR(2) p-value	0.792		0.821	
Hansen p-value	0.937		0.979	

Source: Table prepared by author based on Stata output. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

The reform-augmented Environmental Kuznets Curve results for CO2 emissions in Table 517 provide strong evidence for the EKC hypothesis while revealing important insights about the role of fossil fuel subsidies and reforms in shaping the income-emissions relationship. While Model 1 (Economic Structure) demonstrate strong support for the traditional EKC pattern, with highly significant positive linear affluence coefficients (3.33, $p<0.01$) and negative quadratic affluence term being highly significant ($t = -2.71$, $p<0.01$), Model 2 shows only a significant linear affluence term. This baseline EKC pattern aligns with the expectation provided in the theoretical framework that environmental damages initially increase with economic growth but eventually decline.

Notably, fossil fuel subsidy is statistically insignificant in both models, which suggests that fossil fuel subsidy has minimal direct impact on CO2 emissions. However, the fossil fuel subsidy reform variables and its interaction with affluence and the quadratic form also prove insignificant across both specifications although, they bear the expected signs. Again, this indicates that subsidy reforms do not meaningfully alter the income-emissions trajectory for CO2. Thus, the central question of whether fossil fuel subsidy reform creates or alters the EKC trajectory receives some support that aligns with the green paradox hypothesis. While the individual ffsr coefficients lack statistical significance, the pattern of interaction effects tells a compelling story. The positive coefficient on the ffsr_affluence interaction (ffsr_aff = 0.1724 in Model 1, 0.3480 in Model 2) combined with the negative coefficient on the quadratic interaction (ffsr_aff2= -0.0159 in Model 1, -0.0333 in Model 2) suggests that fossil fuel subsidy reform indeed has differential effects across income levels, even if not reaching conventional significance thresholds. This pattern indicates that at low levels of affluence, ffsr may exacerbate CO_2 emissions as poor households substitute to dirtier energy sources (the green paradox - switching from cooking gas to kerosene or firewood when fossil fuel prices rise). However, at higher affluence levels, the negative quadratic interaction suggests that ffsr becomes beneficial, enabling affluent households to switch to cleaner alternatives like solar panels, electric vehicles, or more efficient transportation modes. This non-linear relationship across income levels provides empirical support for the theoretical framework where reform effects vary systematically with economic growth and the attendant increases in income.

However, the significant effects of complementary policies provide important insights into how the reform-augmented EKC can be optimized through policy design. In model 2, the renewable energy variable shows a strong negative and significant association with CO2 emissions -0.171, t = -2.72, p<0.01), while biomass protection policies also contribute negatively (coefficient = -0.0157, t = -1.98, p<0.10). This supports the argument that policies promoting clean energy investments can mitigate the potential negative effects of ffsr at lower income levels while amplifying the benefits at higher income levels. This finding validates the theoretical proposition put forward in this study that effectively providing cleaner alternatives that can prevent the green paradox substitution to dirtier fuels. Overall, these results suggest that while the basic EKC relationship holds for CO2 emissions, the pathway to environmental improvement is more strongly influenced by an active renewable energy programme and environmental protection policies rather than fossil fuel subsidy reforms.

As with objective two, the study proceeds to calculate the marginal effects of affluence and the total effects of fossil fuel subsidy reforms for models one and two. The results are presented below.

From the system GMM results for model 1, the estimated EKC relationship becomes;

$$CO2 = \beta_2(3.331) + \beta_4(-0.297)$$

The turning point becomes;

$$aff^* = \frac{-\beta_2}{2\beta_4} = \frac{-3.331}{2*(-0.297)} = 5.61$$

As before, to test the fossil fuel subsidy reform effect, the EKC relationship was modified by introducing fossil fuel subsidy reform directly into the model and by further interacting it with affluence. Thus the estimated full model is;

$$CO2 = \beta_0 + \beta_1(lco2) + \beta_2(aff) + \beta_3(ffs) + \beta_4(aff^2) + \beta_5(ffsr) + \beta_6(affffsr) + \beta_7(aff^2ffsr) + \beta_7(governance) + \beta_8(edu) + \beta_8(min) + \beta_9(serv)$$

The marginal effect of affluence becomes

$$\frac{\partial CO2}{\partial aff} = \beta_2 + 2\beta_4(aff) + \beta_6(ffsr) + 2\beta_7(aff * ffsr)$$

$$\frac{\partial CO2}{\partial aff} = 3.331 + 2(-0.297)(aff) + 0.1724(ffsr) + 2(-0.0159)(aff * ffsr)$$

$$\frac{\partial CO2}{\partial aff} = 3.331 - 0.594(aff) + 0.1724(ffsr) - 0.0318(aff * ffsr)$$

The study then proceeds to calculate the total effect of fossil fuel subsidy reforms, that is the direct and quadratic effects;

$$\frac{\partial CO2}{\partial ffsr} = \beta_5 + \beta_6(aff) + \beta_7(aff^2)$$

$$\frac{\partial CO2}{\partial ffsr} = -0.4509 + 0.1724(aff) + (-0.0159)(aff^2)$$

$$\frac{\partial CO2}{\partial ffsr} = -0.457 + 0.182(aff) - 0.017)(aff^2)$$

Next, we calculate the marginal of affluence and total effects of fossil fuel subsidy reforms for model 2.

From the system GMM results for model 2, the estimated EKC relationship becomes;

$$CO2 = \beta_2(2.140) + \beta_4(-0.171)$$

The turning point becomes;

$$aff^* = \frac{-\beta_2}{2\beta_4} = \frac{-2.140}{2 * (-0.171)} = 6.25$$

As before, to test the fossil fuel subsidy reform effect, the EKC relationship was modified by introducing fossil fuel subsidy reform directly into the model and by further interacting it with affluence. Thus the estimated full model is;

$$\text{CO2} = \beta_0 + \beta_1(lco2) + \beta_2(aff) + \beta_3(ffs) + \beta_4(aff^2) + \beta_5(ffsr) + \beta_6(affffsr) + \beta_7(aff^2ffsr) + \beta_7(governance) + \beta_8(edu) + \beta_8(bpp) + \beta_9(reneg)$$

The marginal effect of affluence becomes

$$\frac{\partial \text{CO2}}{\partial aff} = \beta_2 + 2\beta_4(aff) + \beta_6(ffsr) + 2\beta_7(aff * ffsr)$$

$$\frac{\partial \text{CO2}}{\partial aff} = 2.140 + 2(-0.342)(aff) + 0.3480(ffsr) + 2(-0.0333)(aff * ffsr)$$

$$\frac{\partial \text{CO2}}{\partial aff} = 2.140 - 0.342(aff) + 0.3480(ffsr) - 0.0666(aff * ffsr)$$

The study then proceeds to calculate the total effect of fossil fuel subsidy reforms, that is the direct and quadratic effects;

$$\frac{\partial \text{CO2}}{\partial ffsr} = \beta_5 + \beta_6(aff) + \beta_7(aff^2)$$

$$\frac{\partial CO2}{\partial ffsr} = -0.8756 + 0.3480(aff) + (-0.0333)(aff^2)$$

$$\frac{\partial CO2}{\partial ffsr} = -0.8756 + 0.3480(aff) - 0.0333)(aff^2)$$

Based on the above calculations, the study presents a scenario based analysis of the marginal effects of affluence on CO_2 emissions at different income levels in Table 5.18 and the marginal subsidy effects at different levels of affluence in Table 5.19

Table 5.18: Marginal Effects at different affluence levels – CO2 Emissions

Affluence Level	No Reform (ffsr=0)	Moderate Reform (ffsr=5)	High Reform (ffsr=15)
	Model 1		
aff = 1	3.331 - 0.594(1) = **2.737**	2.737 + 0.1724(5) - 0.0318(1×5) = **3.589**	2.737 + 0.1724(15) - 0.0318(1×15) = **4.792**
aff = 3	3.331 - 0.594(3) = **1.549**	1.549 + 0.1724(5) - 0.0318(3×5) = **2.346**	1.549 + 0.1724(15) - 0.0318(3×15) = **2.638**
aff = 5	3.331 - 0.594(5) = **0.361**	0.361 + 0.1724(5) - 0.0318(5×5) = **0.266**	0.361 + 0.1724(15) - 0.0318(5×15) = **-0.484**
aff = 7	3.331 - 0.594(7) = **-0.827**	-0.827 + 0.1724(5) - 0.0318(7×5) = **-1.702**	-0.827 + 0.1724(15) - 0.0318(7×15) = **-3.606**
aff = 10	3.331 - 0.594(10) = **-2.609**	-2.609 + 0.1724(5) - 0.0318(10×5) = **-4.359**	-2.609 + 0.1724(15) - 0.0318(10×15) = **-8.029**
	Model 2		
aff = 1	2.140 - 0.342(1) = **1.798**	1.798 + 0.3480(5) - 0.0666(1×5) = **3.265**	1.798 + 0.3480(15) - 0.0666(1×15) = **5.219**
aff = 3	2.140 - 0.342(3) = **1.114**	1.114 + 0.3480(5) - 0.0666(3×5) = **2.115**	1.114 + 0.3480(15) - 0.0666(3×15) = **3.117**
aff = 5	2.140 - 0.342(5) = **0.430**	0.430 + 0.3480(5) - 0.0666(5×5) = **0.965**	0.430 + 0.3480(15) - 0.0666(5×15) = **1.015**
aff = 7	2.140 - 0.342(7) = **-0.254**	-0.254 + 0.3480(5) - 0.0666(7×5) = **0.815**	-0.254 + 0.3480(15) - 0.0666(7×15) = **-1.087**
aff = 10	2.140 - 0.342(10) = **-1.280**	-1.280 + 0.3480(5) - 0.0666(10×5) = **-1.610**	-1.280 + 0.3480(15) - 0.0666(10×15) = **-3.289**

Source: Table prepared by author based on Stata output.

Table 5.18 provides strong evidence for the green paradox given the dramatic amplification of the marginal effects under reform conditions. In Model 1, reform increases the marginal impact of affluence from 2.737 to 4.792 at low income levels (aff=1) under high reform scenarios, an increase of approximately 75%. This effect becomes even more pronounced in Model 2, where marginal effects increase from 1.798 to 5.219 which is a staggering 190% increase. This suggests that CO2 emissions are particularly sensitive to the substitution mechanisms that drive poor households toward high-carbon alternatives when fossil fuel prices rise. That is, reform induced fuel price rise is likely to cause poor households to choose cheaper fuels with high carbon content like coal, charcoal, or wood.

Table 5.19: Marginal subsidy reform effects at different affluence levels – CO2 Emissions

Affluence Level	Direct Effect	Linear Interaction	Quadratic Interaction	Total FFSR Effect
	Model 1			
aff = 1	-0.4509	0.1724(1) = 0.1724	-0.0159(1) = -0.0159	**-0.294**
aff = 3	-0.4509	0.1724(3) = 0.5172	-0.0159(9) = -0.1431	**-0.077**
aff = 5	-0.4509	0.1724(5) = 0.8620	-0.0159(25) = -0.3975	**+0.013**
aff = 7	-0.4509	0.1724(7) = 1.2068	-0.0159(49) = -0.7791	**-0.023**
aff = 10	-0.4509	0.1724(10) = 1.7240	-0.0159(100) = -1.5900	**-0.317**
	Model 2			
aff = 1	-0.8756	0.3480(1) = 0.3480	-0.0333(1) = -0.0333	**-0.561**
aff = 3	-0.8756	0.3480(3) = 1.0440	-0.0333(9) = -0.2997	**-0.131**
aff = 5	-0.8756	0.3480(5) = 1.7400	-0.0333(25) = -0.8325	**+0.032**
aff = 7	-0.8756	0.3480(7) = 2.4360	-0.0333(49) = -1.6317	**-0.071**
aff = 10	-0.8756	0.3480(10) = 3.4800	-0.0333(100) = -3.3300	**-0.726**

Source: Table prepared by author based on Stata output.

The marginal subsidy effects presented in Table 5.19 show the marginal subsidy effects at different income levels. In Model 1, ffsr shows modest negative effects at low income levels (-0.294 at aff=1), transitions to slightly positive effects at middle income levels (+0.013 at aff=5), then becomes negative again at higher income levels, supporting an inverted U relationship where reform benefits are concentrated around middle-income households. However, Model 2 reveals much more pronounced effects, with substantially larger negative impacts at low income levels (-0.561 at aff=1) and dramatically larger negative effects at high income levels (-0.726 at aff=10), while maintaining similar modest positive effects at middle income levels (+0.032 at aff=5). This pattern suggests that when environmental policies are controlled for, ffsr becomes costlier for both the poor and the wealthy, with the poor facing greater hardships from substitution to dirtier alternatives and the wealthy potentially experiencing diminishing returns or adverse effects from excessive reform intensity. The convergence of positive effects around aff=5 across both models indicates a critical income threshold where households possess sufficient resources to benefit from price signals while still being responsive to incentives for cleaner energy adoption.

Table 5.20: Determining the Existence of a reform-augmented EKC- GHG Emissions

Variable	Model 1: Economic Structure		Model 2: Environmental Policy	
	Coefficient	Standard error	Coefficient	Standard Error
L.ghg	1.0073***	0.2283	0.9611***	0.2322
aff	2.887**	1.3444	2.432	1.5164
ffs	-0.00061	0.00122	-0.00003	0.00115
aff2	-0.2561*	0.1333	-0.2069	0.1467
ffsr	-0.1200	1.1898	-0.4531	1.5097
affffsr	0.0405	0.4758	0.1743	0.6048
aff2ffsr	-0.00304	0.0456	-0.01599	0.0580
governance	0.00781	0.0186	0.00920	0.0164
edu	-0.0121	0.0354	-0.0129	0.0311
min	0.01484*	0.00770	—	—
serv	-0.0580	0.0679	—	—
bpp	—	—	0.00396	0.00725
reneg	—	—	-0.0842**	0.0392
_cons	-7.522**	3.3943	-6.469	3.9364
F-statistic	200.41***		132.28***	
AR(1) p-value	0.037		0.051	
AR(2) p-value	0.228		0.391	
Hansen p-val	0.913		0.782	
Sargan p-val	0.000		0.000	
Instruments	15		15	
Obs	884		884	
Groups	68		68	

Source: Table prepared by author based on Stata output. *** p<0.01, ** p<0.05, * p<0.10

The results for the GHG emissions presented in Table 5.20 further provides some confirmation for the Environmental Kuznets Curve hypothesis in the context of reforms given the positive significance of linear affluence and the quadratic form of affluence in model 1. However, these variables lose their significance in model 2. This finding implies that direct environmental interventions can decouple emissions from economic growth patterns. This stark difference in the estimates from both models confirms that whether a reform-augmented EKC exists depend critically on the type and channel of policy intervention.

Fossil fuel subsidy reform is negative as expected but insignificant in both models. The interaction of fossil fuel subsidy reforms with affluence and the quadratic form of affluence yielded the expected signs, but the coefficients were not significant in either model. The economic structure model (model 1) yields only one significant variable, mineral sector is positive and significant although weakly. All other variables apart from governance are correctly signed but insignificant. The environmental policy model is particularly weak for GHG emissions yielding only renewable energy policy as the most important policy channel in the emissions-affluence relationship. The findings here imply that there is neither a direct or indirect channel through which affluence, fossil fuel subsidies and its reforms affect the GHG emissions pathway. Thus, countries looking to mitigate emissions levels are better served by focusing on building an efficient and reliable renewable energy infrastructure before considering a reform strategy.

Given that affluence, reforms and their interactions are correctly signed but insignificant, the study proceeds to calculate the marginal effects of affluence and the total effects of fossil fuel subsidy reforms for models one and two. The results are presented below.

From the system GMM results for model 1, the estimated EKC relationship becomes;

$GHG = \beta_2(2.887) + \beta_4(-0.2561)$

The turning point becomes;

$$aff^* = \frac{-\beta_2}{2\beta_4} = \frac{-2.887}{2 * (-0.2561)} = 5.64$$

As before, to test the fossil fuel subsidy reform effect, the EKC relationship was modified by introducing fossil fuel subsidy reform directly into the model and by further interacting it with affluence. Thus the estimated full model is;

$$\text{GHG} = \beta_0 + \beta_1(lghg) + \beta_2(aff) + \beta_3(ffs) + \beta_4(aff^2) + \beta_5(ffsr) + \beta_6(affffsr) + \beta_7(aff^2ffsr) + \beta_7(governance) + \beta_8(edu) + \beta_8(min) + \beta_9(serv)$$

The marginal effect of affluence becomes;

$$\frac{\partial \text{GHG}}{\partial aff} = \beta_2 + 2\beta_4(aff) + \beta_6(ffsr) + 2\beta_7(aff * ffsr)$$

$$\frac{\partial \text{GHG}}{\partial aff} = 2.887 + 2(-0.2561)(aff) + 0.405(ffsr) + 2(-0.00304)(aff * ffsr)$$

$$\frac{\partial \text{GHG}}{\partial aff} = 2.887 - 0.5122(aff) + 0.405(ffsr) - 0.00608(aff * ffsr)$$

The study then proceeds to calculate the total effect of fossil fuel subsidy reforms, that is the direct and quadratic effects;

$$\frac{\partial \text{GHG}}{\partial ffsr} = \beta_5 + \beta_6(aff) + \beta_7(aff^2)$$

$$\frac{\partial \text{GHG}}{\partial ffsr} = -0.1200 + 0.0405(aff) + (-0.00304)(aff^2)$$

$$\frac{\partial \text{GHG}}{\partial ffsr} = -0.1200 + 0.0405(aff) - 0.00304)(aff^2)$$

Next, we calculate the marginal of affluence and total effects of fossil fuel subsidy reforms for model 2.

From the system GMM results for model 2, the estimated EKC relationship becomes;

$$GHG = \beta_2(2.432) + \beta_4(-0.2069)$$

The turning point becomes;

$$aff^* = \frac{-\beta_2}{2\beta_4} = \frac{-2.432}{2*(-0.2069)} = 5.88$$

As before, to test the fossil fuel subsidy reform effect, the EKC relationship was modified by introducing fossil fuel subsidy reform directly into the model and by further interacting it with affluence. Thus the estimated full model is;

$$\text{GHG} = \beta_0 + \beta_1(lghg) + \beta_2(aff) + \beta_3(ffs) + \beta_4(aff^2) + \beta_5(ffsr) + \beta_6(affffsr) + \beta_7(aff^2ffsr) + \beta_7(governance) + \beta_8(edu) + \beta_8(bpp) + \beta_9(reneg)$$

The marginal effect of affluence becomes;

$$\frac{\partial \text{GHG}}{\partial aff} = \beta_2 + 2\beta_4(aff) + \beta_6(ffsr) + 2\beta_7(aff * ffsr)$$

$$\frac{\partial \text{GHG}}{\partial aff} = 2.432 + 2(-0.2069)(aff) + 0.1743(ffsr) + 2(-0.01599)(aff * ffsr)$$

$$\frac{\partial \text{GHG}}{\partial aff} = 2.432 - 0.4138(aff) + 0.1743(ffsr) - 0.03198(aff * ffsr)$$

The study then proceeds to calculate the total effect of fossil fuel subsidy reforms, that is the direct and quadratic effects;

$$\frac{\partial \text{GHG}}{\partial ffsr} = \beta_5 + \beta_6(aff) + \beta_7(aff^2)$$

$$\frac{\partial \text{GHG}}{\partial ffsr} = -0.4531 + 0.1743(aff) + (-0.01599)(aff^2)$$

$$\frac{\partial \text{GHG}}{\partial ffsr} = -0.4531 + 0.1743(aff) - 0.01599)(aff^2)$$

Based on the above calculations, the study presents a scenario based analysis of the marginal effects of affluence on GHG emissions at different income levels in Table 5.21 and the marginal subsidy effects at different levels of affluence in Table 5.22

Table 5.21: Marginal Effects at different affluence levels – GHG Emissions

Affluence Level	No Reform (ffsr=0)	Moderate Reform (ffsr=5)	High Reform (ffsr=15)
		Model 1	
aff = 1	2.887 - 0.5122(1) = **2.375**	2.375 + 0.0405(5) - 0.00608(1×5) = **2.345**	2.375 + 0.0405(15) - 0.00608(1×15) = **2.283**
aff = 3	2.887 - 0.5122(3) = **1.351**	1.351 + 0.0405(5) - 0.00608(3×5) = **1.260**	1.351 + 0.0405(15) - 0.00608(3×15) = **0.804**
aff = 5	2.887 - 0.5122(5) = **0.326**	0.326 + 0.0405(5) - 0.00608(5×5) = **0.175**	0.326 + 0.0405(15) - 0.00608(5×15) = **-0.675**
aff = 7	2.887 - 0.5122(7) = **-0.698**	-0.698 + 0.0405(5) - 0.00608(7×5) = **-0.911**	-0.698 + 0.0405(15) - 0.00608(7×15) = **-2.154**
aff = 10	2.887 - 0.5122(10) = **-2.235**	-2.235 + 0.0405(5) - 0.00608(10×5) = **-2.539**	-2.235 + 0.0405(15) - 0.00608(10×15) = **-4.152**
		Model 2	
aff = 1	2.432 - 0.4138(1) = **2.018**	2.018 + 0.1743(5) - 0.03198(1×5) = **2.728**	2.018 + 0.1743(15) - 0.03198(1×15) = **4.129**
aff = 3	2.432 - 0.4138(3) = **1.191**	1.191 + 0.1743(5) - 0.03198(3×5) = **1.422**	1.191 + 0.1743(15) - 0.03198(3×15) = **1.372**
aff = 5	2.432 - 0.4138(5) = **0.363**	0.363 + 0.1743(5) - 0.03198(5×5) = **0.435**	0.363 + 0.1743(15) - 0.03198(5×15) = **-0.935**
aff = 7	2.432 - 0.4138(7) = **-0.465**	-0.465 + 0.1743(5) - 0.03198(7×5) = **-0.442**	-0.465 + 0.1743(15) - 0.03198(7×15) = **-3.242**
aff = 10	2.432 - 0.4138(10) = **-1.706**	-1.706 + 0.1743(5) - 0.03198(10×5) = **-2.435**	-1.706 + 0.1743(15) - 0.03198(10×15) = **-7.107**

Source: Table prepared by author based on Stata output.

From Table 5.21, in Model 1 (economic structure), fossil fuel subsidy reform shows limited impact on the marginal effects of affluence, with effects ranging from 2.375 at baseline to 2.283 under high reform at low income levels (aff=1). However, Model 2 (environmental policy framework) demonstrates stronger green paradox characteristics, with marginal effects increasing from 2.018 to 4.129 - a significant 105% increase. This suggests that GHG emissions encompass broader environmental impacts that may be more responsive to policy alternatives when environmental frameworks are in place.

Table 5.22: Marginal Subsidy effects at different affluence levels – GHG Emissions

Affluence Level	Direct Effect	Linear Interaction	Quadratic Interaction	Total FFSR Effect
			Model 1	
aff = 1	-0.1200	0.0405(1) = 0.0405	-0.00304(1) = -0.00304	**-0.083**
aff = 3	-0.1200	0.0405(3) = 0.1215	-0.00304(9) = -0.02736	**-0.026**
aff = 5	-0.1200	0.0405(5) = 0.2025	-0.00304(25) = -0.0760	**+0.007**
aff = 7	-0.1200	0.0405(7) = 0.2835	-0.00304(49) = -0.14896	**+0.015**
aff = 10	-0.1200	0.0405(10) = 0.4050	-0.00304(100) = -0.3040	**-0.019**
			Model 2	
aff = 1	-0.4531	0.1743(1) = 0.1743	-0.01599(1) = -0.01599	**-0.295**
aff = 3	-0.4531	0.1743(3) = 0.5229	-0.01599(9) = -0.14391	**-0.073**
aff = 5	-0.4531	0.1743(5) = 0.8715	-0.01599(25) = -0.39975	**+0.019**
aff = 7	-0.4531	0.1743(7) = 1.2201	-0.01599(49) = -0.78351	**-0.016**
aff = 10	-0.4531	0.1743(10) = 1.7430	-0.01599(100) = -1.59900	**-0.309**

Source: Table prepared by author based on Stata output.

From Table 5.22, both models identify critical income thresholds around aff=5-6 where EKC turning points emerge, but the reform impacts differ substantially. Model 1 shows minimal policy sensitivity, with total ffsr effects remaining small across all income levels (ranging from -0.083 to 0.015). Model 2 reveals more pronounced policy responsiveness, particularly at middle-income levels where reform effects turn positive (0.019 at aff=5), though the window of beneficial impacts remains narrow. The analysis suggests that comprehensive environmental policy frameworks are essential for maximizing the effectiveness of fossil fuel subsidy reforms in reducing GHG emissions, particularly for middle-income populations where infrastructure transitions are most feasible. The convergence of positive effects around aff=5 across both the CO_2 and GHG models indicates a critical income threshold where households possess sufficient resources to benefit from price signals while still being responsive to incentives for cleaner energy adoption.

Overall, for both the greenhouse gas and co2 emissions analysis, the pattern uncovered here is unequivocal. The results indicate that for the EKC to emerge, prices of fossil fuel products must be competitive (through the removal of fossil fuel subsidies). This must be accompanied with structural transformation that leads to a reduction in the dependence on the mineral sector. Other policies such as biomass protection and renewable energy promotion are vital in this transformation but it appears an EKC relationship can only be guaranteed by coupling subsidy reforms with a structural transformation of the economy that leads to a lower dependence on minerals. In other words, environmental policies are crucial complements that determine if reforms will be effective especially with regard to addressing climate concerns. When renewable energy and biomass protection policies are present, they provide clean alternatives that makes reforms viable. Without these environmental policies, fossil fuel reforms create more severe distributional and environmental consequences. In essence, without environmental policies, the green paradox becomes more acute especially for the poor, they will substitute for dirtier fuels worsening the income- emissions relationship. Ultimately, the implication is that fossil fuel subsidy reform alone is not just ineffective, it is potentially counterproductive without complementary infrastructure. Without these environmental policy infrastructure, fossil fuel subsidy reforms are more likely to harm rather than help the environment.

Subsidies, subsidy reforms and the Environmental Kuznets Curve

The findings and discussions in sections 5.2.2 and 5.2.3 so far has produced several interesting insights into how an EKC type relationship might emerge. First, in the analysis of whether fossil fuel subsidy has the capacity to validate or shape the EKC, the study found no evidence of the EKC given the insignificance of affluence and affluence squared as well as the interaction of fossil fuel subsidies with these variables. However, in objective three where the study sort to examine if a reform augmented EKC exists, some evidence of the EKC was found in Models 1 of both the CO2 and GHG relationships and they help to illustrate how subsidy reforms modify the income-emissions trajectory. Visual plots of these EKC relationships with and without subsidy reforms based on the estimated coefficients are presented and discussed below.

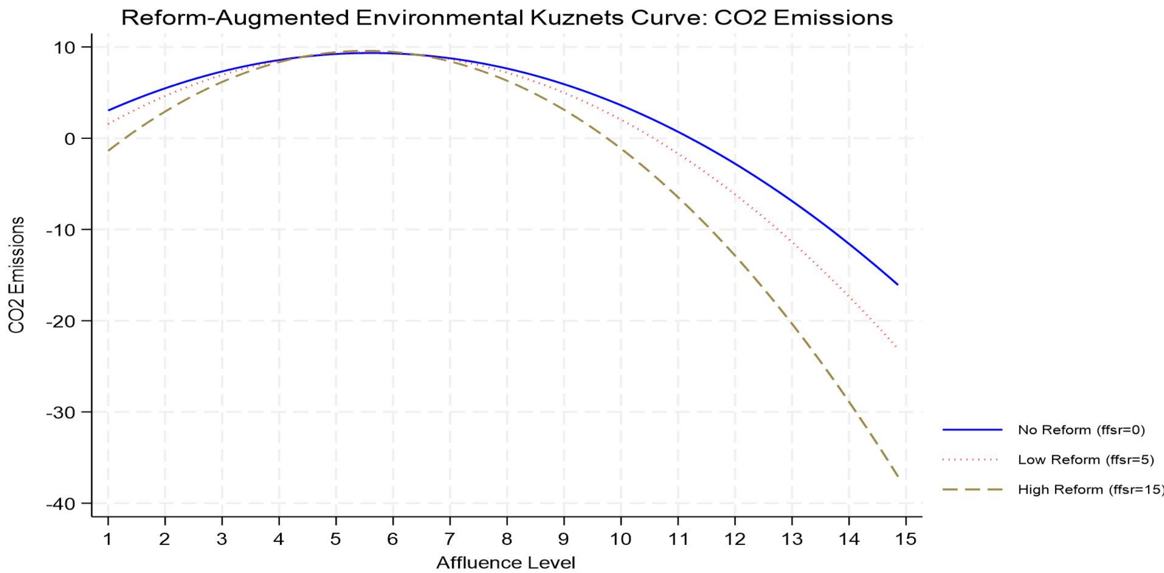

Figure 5.1: Reform-Augmented Environmental Kuznets Curve with CO_2 Emissions.
Source: Figure prepared by author based on Stata output

The reform-augmented Environmental Kuznets Curve presented above was derived from the system GMM regression results reported in Table 5.17(Model 1). The chart plots the predicted CO_2 emission levels across different affluence levels under three fossil fuel subsidy reform scenarios. Using the estimated coefficients from the full model specification;

The environmental component of the relationship was isolated by focusing on the affluence and reform terms. The three curves represent: (1) No subsidies scenario where ffs=0, yielding the relationship $CO2 = 3.331aff - 0.297aff^2$ with a turning point of 5.61; (2) Low subsidies scenario where ffs=5, producing $CO2 = 4.193aff - 0.3765aff^2 - 2.2545$ with a turning point of 5.57; and (3) High subsidies scenario where ffs=15, resulting in $CO2= 5.917aff - 0.5355aff^2 - 6.7635$ with a turning point of 5.52.

Across most of the affluence range, the reform scenarios predict lower CO_2 emissions than the no-reform scenario, as reflected in their curves lying below the baseline, however, the reductions in CO_2 emissions are not uniform. At lower affluence levels, the gap between the curves is small, indicating limited short-term emission savings from reform. The largest differences appear in the middle-income range, around and before the turning points, where reforms most effectively dampen emissions. After the turning points, all three curves slope downward, and while reforms still yield lower emissions, the margin of improvement narrows. This pattern again confirms that subsidy reforms have their greatest environmental impact during the middle income phase with comparatively smaller gains at very low and very high affluence levels.

As with the CO2 emissions, the study then presents a diagrammatic representation of the reform-augmented EKC curve for greenhouse gas emissions below.

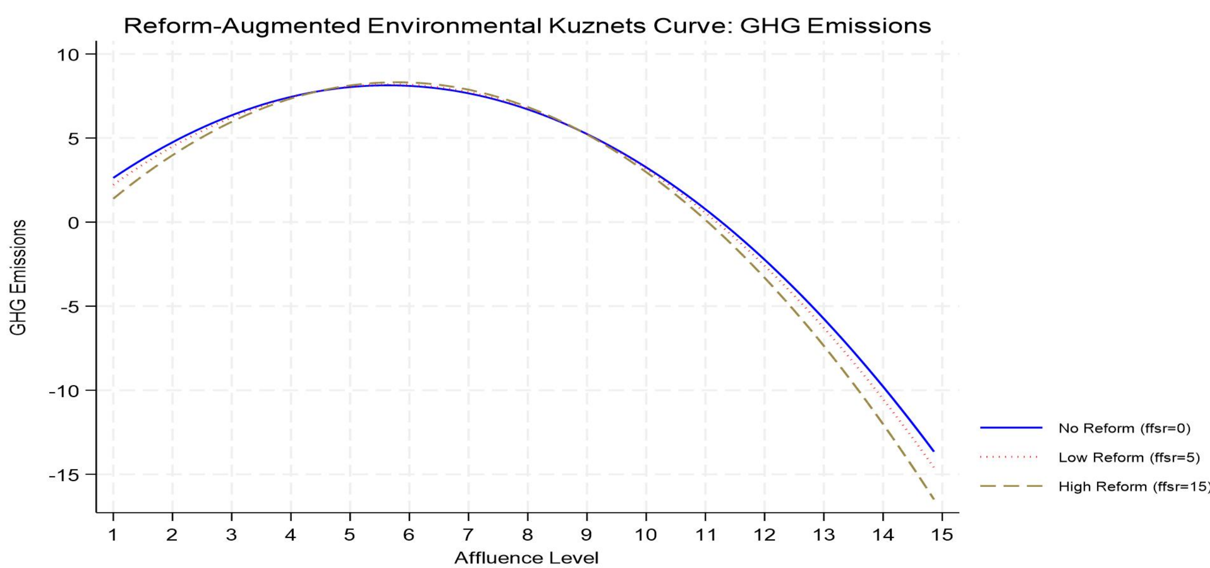

Figure 5.2: Reform-Augmented Environmental Kuznets Curve with Greenhouse Gas Emissions
Source: Figure prepared by author based on Stata output

The GHG Environmental Kuznets Curve chart based on Model 1 results reveals a non-uniform relationship between fossil fuel subsidy reforms and greenhouse gas emissions across the affluence spectrum. While the reform scenario generally lies below the no-reform curve at middle-income levels suggesting that reforms can reduce emissions when economies are transitioning towards cleaner energy structures, `there are notable affluence ranges where the reform curve converges with or even slightly exceeds the no-reform curve. This indicates that in some stages of economic development, particularly in lower- and upper-income brackets, reforms may not immediately deliver environmental gains and can, in certain contexts, coincide with higher emissions. Such divergence could stem from transitional effects, including increased fossil fuel use before full reform benefits materialize, or from the Green Paradox mechanism.

Robustness Tests based on the Fixed and Random Effects Model

To confirm the robustness of the findings here, the estimations from system GMM are compared with results from the fixed and random effects model presented below.

Table 5.23: Determining the Existence of a reform-augmented EKC – CO2 Emissions

	Model 1				**Model 2**			
Variable	**Fixed effects**		**Random effects**		**Fixed effects**		**Random effects**	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
L.co2	0.7871***	0.000	0.9950***	0.000	0.7534***	0.000	0.9971***	0.000
aff	0.1389	0.422	-0.0025	0.868	0.0779	0.589	-0.0036	0.850
ffs	0.0005	0.619	-0.0003	0.560	0.0001	0.937	-0.0003	0.489
aff^2	0.0115	0.457	0.0004	0.765	0.0180	0.173	0.0004	0.827
ffsr	-0.0073	0.933	-0.0554	0.181	-0.0250	0.762	-0.0213	0.678
aff×ffsr	0.0034	0.916	0.0166	0.311	0.0139	0.646	0.0029	0.887
aff^2×ffsr	-0.0006	0.830	-0.0013	0.403	-0.0019	0.485	0.0000	0.998
governance	0.0035	0.819	0.0009	0.742	-0.0005	0.974	0.0012	0.700
edu	-0.0100**	0.039	0.0075***	0.001	-0.0130***	0.006	0.0077	0.162
min	0.0042	0.177	0.0032***	0.029	–	–	–	–
serv	-0.0439	0.202	-0.0401*	0.091	–	–	–	–
bpp	–	–	–	–	-0.0001	0.995	-0.0064	0.117
reneg	–	–	–	–	-0.0730***	0.020	0.0002	0.912
Constant	-0.5440	0.225	0.0788	0.149	-0.3446	0.405	0.0217	0.632
R-squared (within)	0.8180	–	0.8017	–	0.8232	–	0.7998	–
R-squared (between)	0.8918	–	0.9998	–	0.8841	–	0.9998	–
R-squared (overall)	0.8914	–	0.9985	–	0.8837	–	0.9985	–
F-statistic	237.80***	–	561999.71***	–	267.43***	–	569460.08***	–
Sargan-Hansen Test p-value	–	–	–	0.0000	–	–	–	0.0000

Source: Table prepared by author based on Stata output *** $p<0.01$, ** $p<0.05$, * $p<0.10$

The results presents in Table 5.23 above confirm the consistency and superiority of the main estimation technique, the system GMM. To start with, the Sargan-Hansen test confirms that the fixed effects model is preferred over the random effects model, thus, the discussion here focus on comparing the FE estimates with those from system GMM.

First, the FE and System GMM estimations generally exhibit consistency in the signs of key explanatory variables, supporting the robustness of the findings. In both estimation methods, the signs and magnitudes of most coefficients broadly consistent, though notable differences arise. Affluence retains its positive sign in both approaches, with GMM producing substantially larger coefficients (3.331 in Model 1; 2.140 in Model 2) compared to fixed effects (0.1389 in Model 1; 0.0779 in Model 2), suggesting that GMM captures a stronger scale effect of income on emissions. The squared affluence term is negative in both methods. This supports the inverted-U shape of the EKC found in the system GMM analysis where larger magnitudes were also reported (–0.297 and –0.171 than fixed effects –0.0115 and –0.0180). In Model 2, education and renewable energy are both significant in the fixed effects estimation, with negative coefficients, consistent with the expectation that higher education levels and greater renewable energy adoption reduce emissions. GMM yields the same negative signs but without statistical significance for education. Biomass protection policy is negative in both approaches, but only significant in GMM.

Table 5.24: Determining the Existence of a reform-augmented EKC – GHG Emissions

	Model 1				Model 2			
Variable	**Fixed effects**		**Random effects**		**Fixed effects**		**Random effects**	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
L.ghg	0.7607	0.000	0.9988	0.000	0.7345	0.000	0.9999	0.000
aff	0.1297	0.461	0.0046	0.620	0.0758	0.614	-0.0004	0.973
ffs	0.0005	0.321	-0.0002	0.470	0.0003	0.583	-0.0003	0.362
aff²	0.0080	0.563	-0.0003	0.715	0.0125	0.294	0.0001	0.936
ffsr	0.0278	0.507	-0.0186	0.459	0.0263	0.594	-0.0080	0.811
aff×ffsr	-0.0068	0.681	0.0044	0.659	-0.0045	0.808	-0.0001	0.994
aff²×ffsr	0.0003	0.830	-0.0003	0.783	-0.0001	0.962	0.0002	0.891
governance	-0.0139	0.290	0.0015	0.380	-0.0145	0.258	0.0001	0.965
edu	-0.0092	0.020	0.0015	0.410	-0.0125	0.020	0.0030	0.265
min	0.0038	0.119	0.0022	0.039	–	–	–	–
serv	-0.0570	0.184	-0.0467	0.061	–	–	–	–
bpp	–	–	–	–	0.0069	0.263	-0.0019	0.400
reneg	–	–	–	–	-0.0356	0.031	-0.0014	0.184
Constant	-0.2809	0.509	0.0762	0.105	-0.1443	0.725	0.0095	0.728
R-squared (within)	0.7750	–	0.7474	–	0.7732	–	0.7415	–
R-squared (between)	0.9084	–	0.9999	–	0.9109	–	0.9999	–
R-squared (overall)	0.9080	–	0.9992	–	0.9105	–	0.9992	–
F-statistic	169.21***	–	1.44×10^{6}***	–	154.76***	–	1.78×10^{6}***	–
Hausman Test p-value	–	–	–	0.0000	–	–	–	0.0000

Source: Table prepared by author based on Stata output *** p<0.01, ** p<0.05, * p<0.10

For GHG emissions, both the System GMM and fixed effects estimates confirm the high persistence of emissions over time. Under System GMM, the lagged GHG coefficient is slightly above unity in Model 1 (1.0073) and just below unity in Model 2 (0.9611), suggesting a very slow rate of adjustment and strong path dependence. Whereas, the fixed effects models, produce smaller coefficients for the lagged term (0.832 in Model 1; 0.781 in Model 2). Affluence is positive in both estimators, but its magnitude is larger in GMM (2.887 in Model 1; 2.432 in Model 2) than in fixed effects (0.147 in Model 1; 0.086 in Model 2), while the squared affluence term is negative in all cases, a further confirming of the evidence for an inverted-U EKC pattern. In Model 2, renewable energy adoption is negative and significant in both estimators, reinforcing its role in mitigating GHG emissions. Education remains negative in both approaches but is not statistically significant. The mineral sector is positive and significant in Model 1 for both estimators, while biomass protection policy has a small negative but insignificant effect in both frameworks.

Overall, the alignment in coefficient signs across GMM and fixed effects for both the CO2 and GHG models suggests the reform-augmented EKC relationship holds robustly for GHG emissions, although GMM captures larger magnitudes due to its correction for endogeneity and dynamic bias.

In summary, what these results suggests is that the EKC relationship may be fundamentally tied to economic structural transformation rather than policy interventions per se. From a theoretical point of view, this finding supports the traditional EKC hypothesis that environmental improvements stem from structural transitions, that is the shift from resource-intensive primary sector to manufacturing and then to services. These shifts are inadvertently linked to changes in energy intensity as economies adopt cleaner technologies, improve energy efficiency and develop better environmental management capabilities. While these environmental policies maybe implicit or explicit, the findings here show that these policies act as mediating or even accelerating factors rather than independent drivers. Thus, one may say policies are potentially endogenous responses to underlying structural changes rather than independent causal factors. In other words, policies might not create environmental improvements out of thin air, but they could significantly speed up the structural changes that naturally accompany development. However, they are likely to be ineffective without the fundamental mechanism of structural transformation. To conclude, as we already established in section 5.2.3, reforms are likely to be ineffective without environmental policies but policies themselves will not yield any substantial rewards without structural transformation.

5.2.4 Empirical Analysis of the Environmental Impact of Fossil Fuel Subsidy Reforms

The section is concerned with the determination of the effect of fuel subsidy reforms on CO2 and GHG emissions in 51 reform enacting countries of the world using the Staggered Difference in Difference methodology as proposed by Callaway and Sant'anna (CSDiD). The application of the CSDiD requires several key steps, the first being to ensure that the parallel trend assumption is satisfied. Thus, this section begins by presenting the pre-trend visualization, followed by the dynamic treatment overtime using the event study and finally, the CSDiD. This approach follows a logical progression of the findings of the study from assumption testing to dynamic treatment effects to robust causal estimation.

Validation of Parallel Trend

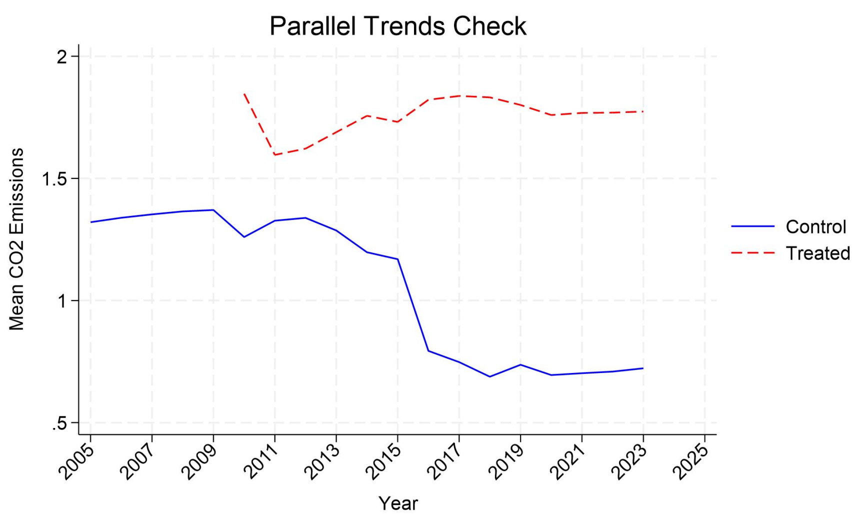

Figure 5.3 Parallel Trend for CO_2 Emissions
Source: Figure prepared by author based on Stata output

While the visual approach to verifying parallel trend may be subjective, it can be useful for checking if the treated and control groups were comparable before reform. The graph in Figure 5.3 suggests that in the pre-treatment period (2005 – 2010), the slope of the control and treatment group were not drastically different. Although, the slope of the treated group appears to be slightly steeper than the control group in the early years. As expected, in the post-treatment period, there is a divergence between the control and treated groups as treatment effect take place.

Figure 5.4 Parallel Trend for GHG emissions

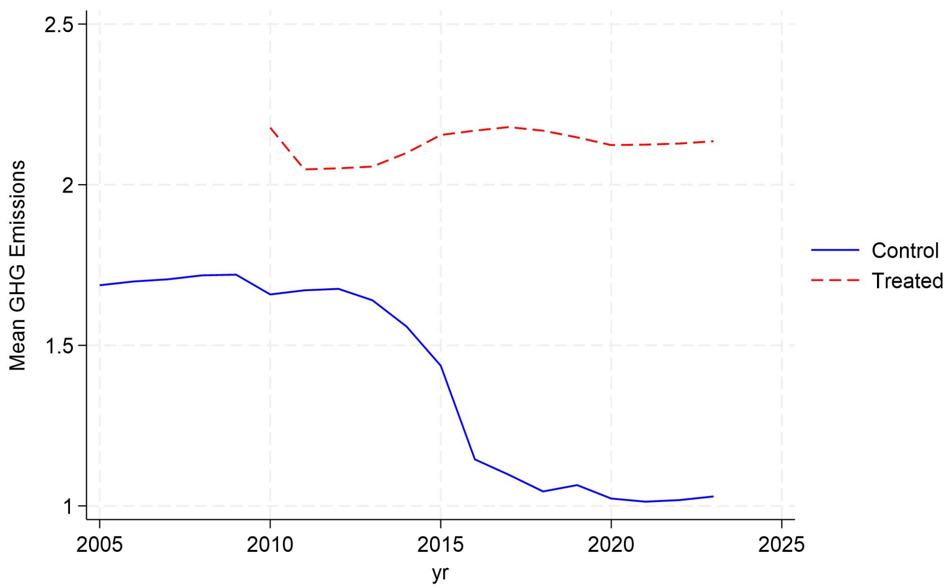

Figure 5.4 Parallel Trend for Greenhouse Gas Emissions
Source: Figure prepared by author based on Stata output

A cursory look at Figure 5.4 show that the control and treated groups have different pre-treatment trend. The control group show a relatively stable trend but slightly increasing before 2010 while the treated group show a slightly downward trend pre 2010. Post reform, the control group experience a sharp decline in GHG emissions especially around 2015 while the treated group remained relatively stable suggesting that reforms did not have much impact in the emissions level. Given that the visual approach does not show a clear support for the parallel trend assumption, it is important to carry out further tests.

Dynamic Treatment Effects

One way to formally test the parallel trend assumption is the use of the event study method. The Event Study approach helps to visualize the effect of treatment before and after its occurrence. By showing the dynamic treatment effects over time, it allows the parallel trend assumption to be validated. The results from the event study is presented in Table 5.25 below.

Table 5.25: Event Study estimates of the impact of fossil fuel subsidy reforms on CO_2 emissions

Average Treatment Effect on the Treated - ATT by Event Time)

Event Time	*Coefficient*	*Std. Error*	*z-Statistic*	*p-Value*	*95% Confidence Interval*
Pre_avg	0.0025	0.0026	0.97	0.331	-0.0025, 0.0075
Post_avg	-0.0905	0.0373	-2.42	0.015	-0.1637, -0.0174
Tm14	-0.0198	2.35e-18	-8.4e+15	0.000	-0.0198, -0.0198
Tm13	0.0768	0.0310	2.47	0.013	0.0159, 0.1376
Tm12	-0.0483	0.0226	-2.14	0.033	-0.0927, -0.0040
Tm11	0.0080	0.0161	0.50	0.620	-0.0236, 0.0395
Tm10	0.0182	0.0185	0.99	0.324	-0.0180, 0.0544
Tm9	0.0308	0.0138	2.23	0.026	0.0037, 0.0578
Tm8	-0.0054	0.0118	-0.45	0.650	-0.0285, 0.0178
Tm7	0.0021	0.0092	0.23	0.819	-0.0159, 0.0200
Tm6	-0.0064	0.0066	-0.97	0.330	-0.0193, 0.0065
Tm5	-0.0202	0.0072	-2.80	0.005	-0.0343, -0.0060
Tm4	-0.0082	0.0068	-1.21	0.226	-0.0215, 0.0051
Tm3	0.0013	0.0056	0.23	0.822	-0.0097, 0.0122
Tm2	0.0025	0.0060	0.43	0.670	-0.0091, 0.0142
Tm1	0.0034	0.0066	0.52	0.601	-0.0095, 0.0163
Tp0	-0.0060	0.0068	-0.87	0.382	-0.0194, 0.0074
Tp1	-0.0034	0.0115	-0.29	0.771	-0.0259, 0.0192
Tp2	-0.0139	0.0202	-0.69	0.491	-0.0536, 0.0257
Tp3	-0.0100	0.0270	-0.37	0.711	-0.0629, 0.0429
Tp4	-0.0343	0.0291	-1.18	0.238	-0.0914, 0.0227
Tp5	-0.0245	0.0402	-0.61	0.543	-0.1033, 0.0543
Tp6	-0.0641	0.0551	-1.16	0.245	-0.1721, 0.0440
Tp7	-0.0982	0.0631	-1.56	0.120	-0.2219, 0.0254
Tp8	-0.1496	0.0878	-1.70	0.088	-0.3217, 0.0224
Tp9	-0.1884	0.0836	-2.25	0.024	-0.3522, -0.0246
Tp10	-0.4037	0.0543	-7.44	0.000	-0.5101, -0.2973

Source: Table prepared by author based on Stata output

The Event Study examines the impact of fossil fuel subsidy reforms on CO_2 emissions overtime with negative coefficients indicating a reduction in emissions level following treatment. The pre-trend analysis which covers the periods before reform is denoted as Tm14 to Tm1, while the post treatment period runs from Tp1 to Tp10. It should be noted that the ideal choice of pretreatment and post treatment window is automatically selected by Stata taking account of data availability.

From Table 5.25 the pre-treatment average is given as 0.0025 with a p-value of 0.331. This coefficient represents the average effect of the reform before implementation across all pre-treatment periods. Given that the coefficient is statistically insignificant, it can be inferred that there is no significant difference in CO_2 emissions between treated and untreated units before reform. This finding further support the parallel trend assumption which is critical for the methodology adopted for this study implying that the treated and untreated groups were on a similar trajectory before the reform. The post-treatment coefficient of -0.0905 with a p-value of 0.015 is the average impact of fossil fuel subsidy reform on CO_2 emissions after implementation across all post-treatment periods. Since the post treatment average is negative and statistically significant, it suggests that reforms led to significant reductions in CO_2 emissions

By way of specifics, the periods before the reform (Tm 14 – Tm1) saw the coefficients mostly fluctuating around zero, more so, these coefficients were mainly insignificant (p-values>0.05) further confirming that there was no strong pre-existing trend in emissions levels before the reform. The immediate impact of the reform captured at Tp0 with coefficient of -0-0060 and p-value equals to 0.382 shows that the impact of reforms is not instantaneous and is more likely to appear with some lags. The coefficients for the short term post – reform effects (Tp1 – Tp5) are negative but statistically insignificant again signifying that initial reductions in emissions after the reform are weak or delayed. However, in the middle to long term, the post reform effects (Tp6 - Tp10) becomes stronger. By Tp8, the coefficient is -0.1496 with p-value of 0.088 which is negative and statistically significant at 10%. By periods Tp9 (-0.1884, 9 =

0.024) and Tp10 (-0.4037, p = 0.000), post-reform effects are both statistically significant and negative suggesting that CO_2 emissions significantly declined in the long run due to fossil fuel subsidy reforms. Interestingly, the impact of the reform seems to become stronger overtime with emissions reduction peaking at Tp10 where reforms caused emissions to fall by 40.4%.

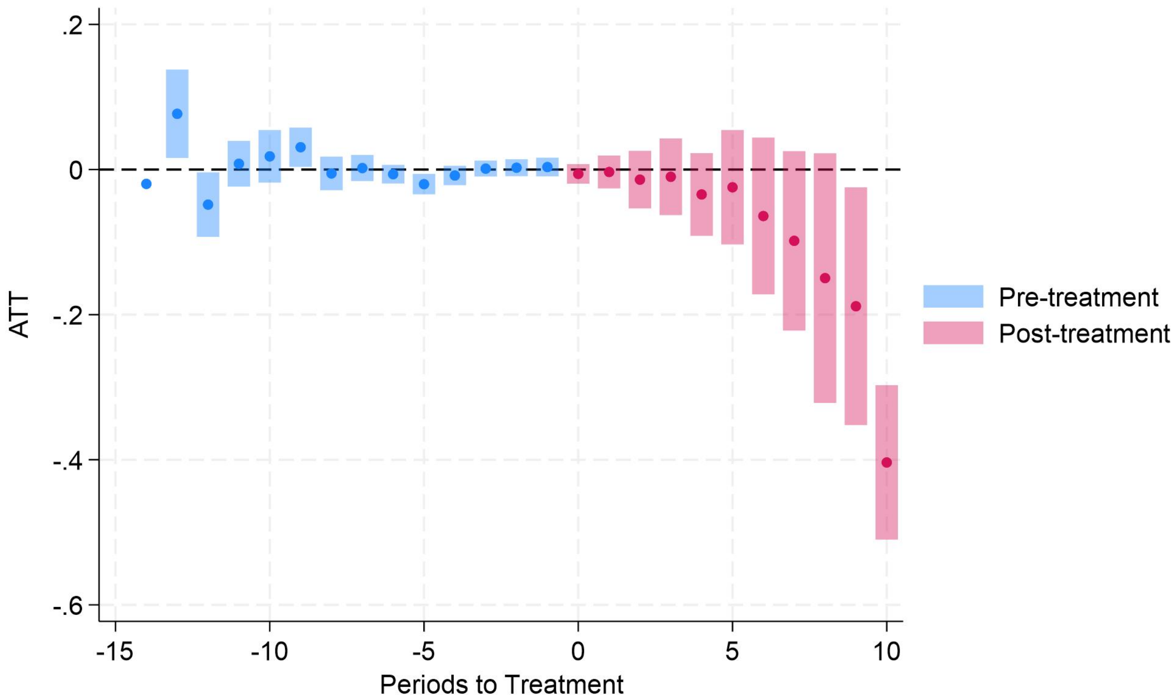

Figure 5.5 Event Study Plot visualizing the impact of reform on CO_2 emissions.
Source: Figure prepared by author based on Stata output

The event study plot presents the impact of fossil fuel subsidy reform on CO_2 emissions visually. The blue dots and bars that range between -15 and zero show the average treatment effect on the treated (ATT) before the intervention while the post-treatment period signified with red dots and bars and ranging from zero to +10 show the ATT after reforms. The vertical bars represent confidence intervals with wider bars indicating greater uncertainty. For instance, before treatment, the intervals are relatively small with stable estimates. After treatment, they widen initially to reflect uncertainty of the effect of the reform, but as the effect gets stronger, the intervals become more precise.

The event study plot graphically illustrates the results from the event study presented in Table 5.25. It confirms the lack of pre-treatment effects validity the parallel trend assumption. It suggests the gradual impact of reforms as emissions decline overtime rather than immediately and finally, it illustrates that treatment effect is stronger overtime becoming more pronounced after six to ten years.

Table 5.26: Event Study estimates of the impact of fossil fuel subsidy reforms on GHG emissions

Average Treatment Effect on the Treated - ATT by Event Time)

Event Time	Coefficient	Std. Error	z-Statistic	p-Value	95% Confidence Interval
PRE_AVG	0.0027	0.0047	0.57	0.569	-0.0065, 0.0118
POST_AVG	-0.0194	0.0376	-0.52	0.605	-0.0931, 0.0542
TM14	-0.0260	—	—	—	—
TM13	0.0340	0.0115	2.96	0.003	0.0115, 0.0565
TM12	-0.0321	0.0144	-2.22	0.026	-0.0604, -0.0038
TM11	0.0103	0.0146	0.71	0.480	-0.0183, 0.0388
TM10	0.0111	0.0113	0.98	0.328	-0.0111, 0.0333
TM9	0.0206	0.0111	1.86	0.063	-0.0011, 0.0423
TM8	-0.0071	0.0076	-0.94	0.348	-0.0221, 0.0078
TM7	0.0014	0.0064	0.22	0.829	-0.0112, 0.0139
TM6	-0.0675	0.0611	-1.11	0.269	-0.1872, 0.0522
TM5	0.1169	0.0925	1.26	0.206	-0.0643, 0.2981
TM4	-0.0125	0.0211	-0.59	0.554	-0.0539, 0.0289
TM3	-0.0286	0.0320	-0.89	0.372	-0.0913, 0.0341
TM2	0.0033	0.0074	0.44	0.660	-0.0113, 0.0178
TM1	0.0136	0.0191	0.71	0.477	-0.0239, 0.0511
TP0	-0.0067	0.0382	-0.17	0.861	-0.0815, 0.0682
TP1	-0.0031	0.0439	-0.07	0.943	-0.0892, 0.0829
TP2	-0.0101	0.0479	-0.21	0.833	-0.1038, 0.0837
TP3	-0.0257	0.0579	-0.44	0.658	-0.1392, 0.0878
TP4	-0.0435	0.0718	-0.61	0.545	-0.1843, 0.0973
TP5	0.0590	0.0625	0.94	0.345	-0.0634, 0.1814
TP6	0.0014	0.0339	0.04	0.966	-0.0649, 0.0678
TP7	-0.0090	0.0356	-0.25	0.800	-0.0788, 0.0608
TP8	-0.0378	0.0445	-0.85	0.395	-0.1250, 0.0493
TP9	-0.0298	0.0524	-0.57	0.570	-0.1326, 0.0730
TP10	-0.1082	0.0570	-1.90	0.058	-0.2199, 0.0035

Source: Table prepared by author based on Stata output

The event study in Table 5.26 evaluates the impact of fossil fuel subsidy reform on Greenhouse gas emissions. This involves estimating the average treatment effect on the treated by comparing treated and control units across different time periods. From the table, most pre-treatment coefficients are statistically insignificant which implies that there was no significant difference between treatment and control groups before reform. However, there are two significant pre-treatment coefficient (tm12 and tm13) even though the overall pre-treatment average is not statistically significant. This validates the parallel trend assumption to a significant extent.

As for the post-treatment effects, neither the post-average coefficient none the individual post-treatment coefficients are statistically significant. The negative coefficient suggests that post treatment emissions declined but not significantly suggesting a long term impact of reform. This is confirmed by the larger and larger negative coefficient that became significant in period 10.

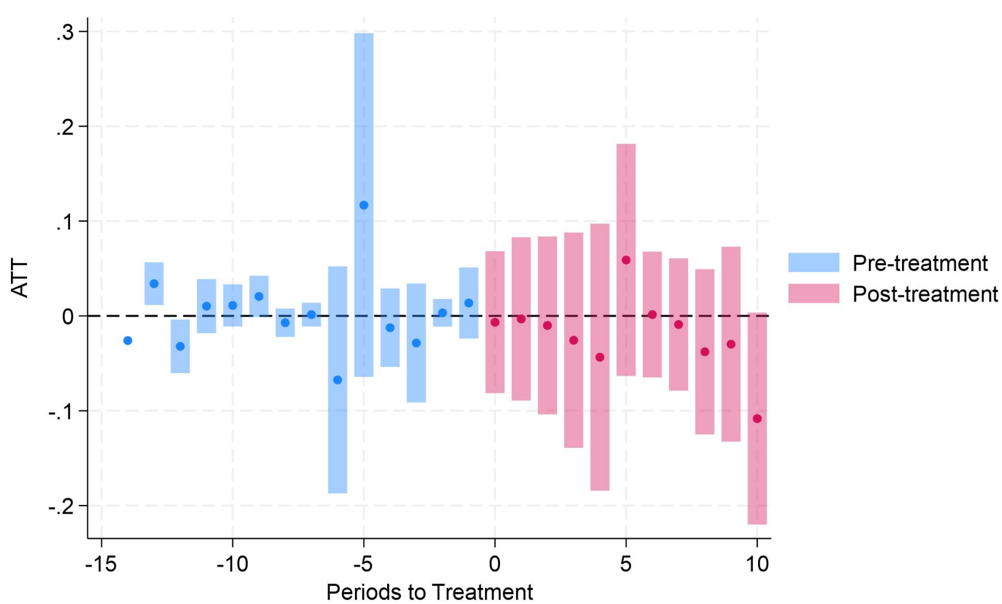

Figure 5.6 Event Study Plot visualizing the impact of reform on Greenhouse Gas Emissions.
Source: Figure prepared by author based on Stata output

Figure 5.6 provides a visual representation of the event study analysis. The pre-treatment coefficients show a wider variability around zero relative to the event plot for CO_2. There is a general downward trend in the coefficient after period 5 with the largest negative effect appearing in period 10. Overall, the plot suggests that there is no clear statistically significant effect on overall GHG emissions, yet the negative trend of later coefficients is worth noting as it implies that reform effects gets stronger with time.

An interesting point of consideration is the contrast between the event plots for CO_2 and GHG emissions. The visual mapping strongly indicates that fossil fuel subsidy reforms has a more direct and measurable impact on CO_2 emissions relative to GHG emissions. This is no surprising coming from the estimates obtained from objectives one to three. It is evident that the impact of the various covariates on greenhouse gas emissions is weaker and more disperse than the effect on CO_2 emissions validating the assumptions that subsidies and their reforms have a more direct impact on CO_2 emissions.

Callaway and Sant'Anna Difference in Difference (CSDiD) Estimation Results

Unlike the traditional two- way fixed effects (TWFE) models, CSDiD models are more robust for staggered treatment settings as they correct for heterogeneous treatment timing and provides dynamic effects for treated and untreated groups overtime. Another advantage of the CSDiD is that it ensures that later treated groups do not contaminate the results as they enter into the model. Like the Event Study, CSDiD provides aggregated average treatment effects on the treated.

This sub-section begins with a presentation of the results of the baseline model which involves estimating the causal effect of the timing of fossil fuel subsidy reforms on CO_2

emissions. While in the CSDiD framework, two possible control groups exist, “never-treated or pure controls and “not yet treated units”, this study utilize the former not only because the ‘never-treated” group provides a more stable comparison group as they are not affected by anticipatory or actual policy change that can bias the estimates but also because “never treated” units are robust to treatment heterogeneity. Thus, for the purpose of this study, 17 countries (which is approximately 30% of the treated countries) were included in the dataset to serve as valid counterfactuals for the analysis bringing the total number of units to 68 countries. Another important consideration here is that the CSDiD framework requires sufficient pre-treatment data in order to confirm pre and post treatment effects and to verify parallel trend. Thus, the data used for this analysis runs from the year 2005 to 2023 even though the first reform intervention happened in 2010.

Impact of fossil fuel subsidy reforms on CO_2 emissions

a. CSDiD estimates of the impact of fossil fuel subsidy reforms on CO_2 emissions

For the purpose of conciseness and clarity, only significant estimates are provided in this section. The full results of the CSDiD model is presented in the appendix. Table 5.2.4g thus, presents an abridged version of the CSDiD estimates derived for the model.

Table 5.27: **CSDiD estimates of the impact of fossil fuel subsidy reforms on CO_2 emissions**

Cohort	*Time Period*	*Coefficient*	*Std. Error*	*z-stat*	*p-value*	*95% Confidence Interval*
g2010	t2009_2017	-0.1242175	0.0711141	-1.75	0.081	-0.2635985, 0.0151636
	t2009_2018	-0.190803	0.0899397	-2.12	0.034	-0.3670817, -0.0145244
	t2009_2019	-0.1964279	0.1079818	-1.82	0.069	-0.4080684, 0.0152125
	t2009_2020	-0.4036937	0.0542855	-7.44	0.000	-0.5100912, -0.2972961
g2011	t2010_2020	-0.1626594	0.0599829	-2.71	0.007	-0.2802238, -0.0450951
g2012	t2005_2006	-0.0495185	0.019619	-2.52	0.012	-.087971, -0.011066
	t2011_2013	0.0225046	0.0121146	-1.86	0.063	-0.0012396, 0.0462487
	t2011_2014	0.035492	0.018477	1.92	0.055	-0.0007223, 0.0717063
	t2011_2020	-0.3177389	0.0204071	-15.57	0.000	-0.3577361, -0.2777417
g2013	t2006_2007	0.02075 .	0.0080387	2.58	0.010	0.0049945, 0.0365055
	t2010_2011	-0.0245605	0.0125138	-1.96	0.050	-0.0490872 -0.0000339
	t2012_2020	-0.129781	0.0199643	-6.50	0.000	-0.1689103, -0.0906516
g2014	t2013_2020	-0.1936018	0.0247998	-7.81	0.000	-0.2422084 -.1449952
g2015	t2005_2006	0.0566573	0.028405	1.99	0.046	0.0009846, 0.1123301
	t2010_2011	-0.0242581	0.0145461	-1.67	0.095	-0.052768, 0.0042518
	t2014_2020	-0.100211	0.0320655	-3.13	0.002	-0.1630583, -0.0373637
g2016	t2006_2007	0.0239374	0.0117805	2.03	0.042	0.0008481 0.0470268
	t2007_2008	0.0404559	0.0190932	2.12	0.034	0.003034, 0.0778778
	t2010_2011	-0.0519724	.0259926	-2.00	0.046	-0.102917 -0.0010279
	t2015_2020	-0.1940247	.024558	-7.90	0.000	-0.2421574 -0.145892
g2017	t2006_2007	0.0207962	0.0111921	1.86	0.063	-0.00114 0.0427324
	t2008_2009	-0.0929076	.0122255	-7.60	0.000	-0.1168692 -0.068946
	t2010_2011	-0.0571528	.0285678	-2.00	0.045	-0.1131446 -0.0011609
	t2013_2014	-0.1017175	0.0124093	-8.20	0.000	-0.1260393 -0.0773957
	t2014_2015	-0.0744038	0.0182628	-4.07	0.000	-0.1101983, -0.0386093
	t2016_2017	-0.0504158	0.0181097	-2.78	0.005	-0.0859102 -0.0149213
	t2016_2018	-0.0728264	0.0373628	-1.95	0.051	-0.146056 0.0004033
	t2016_2019	-0.078318	0.0307082	-2.55	0.011	-0.138505 -0.018131
g2018	t2006_2007	0.0444338	.0107316	4.14	0.000	0.0234004 0.0654673
	t2009_2010	-0.0324138	0.0174383	-1.86	0.063	-0.0665923 0.0017648
	t2010_2011	-0.074963	.0427063	-1.76	0.079	-0.1586657, 0.0087397
	t2017_2018	-0.0443266	0.0233175	-1.90	0.057	-0.090028, 0.0013748
	t2017_2020	-0.059116	0.0080858	-7.31	0.000	-0.0749639, -0.0432682
g2019	t2005_2006	0.1229437	0.0069881	17.59	0.000	0.1092472, 0.1366401
	t2009_2010	-0.0353372	0.0213947	-1.65	0.099	-0.0772699, 0.0065956
	t2012_2013	0.0507375	0.0081229	6.25	0.000	0.0348169, 0.0666581
	t2014_2015	-0.0911886	0.0081123	-11.24	0.000	-0.1070883, -0.0752888
	t2017_2018	-0.0628165	0.0027821	-22.58	0.000	-0.0682693 -0.0573636
	t2018_2019	0.0413755	0.0065588	6.31	0.000	0.0285206 0.0542305

Source: Table prepared by author based on Stata output

The notation utilized in this analysis (e.g. **t2009_2017)** represents relative time periods with t2009 denoting pretreatment year and t2017 showing the year of observation of the treated group post treatment. This notation helps to track the effect of treatment overtime. In general, the full CSDiD estimates (presented in Appendix 1A) show no significant changes in CO2 emissions before reforms for the period under review verifying the parallel trend assumption. Post- reform effect in the short term were mixed and mostly statistically insignificant. Notably, the effect of reforms became evident from around 6 years post reform with the effect going stronger overtime. This suggests that subsidy reforms result in delayed but substantial reductions in emissions.

With regard to specifics, for the first cohort denoted as g2010, we find significant reductions in CO_2 emissions from 2018 onwards with the effect getting progressively larger so that by 2020, fossil fuel subsidy reforms had resulted in a 40% reduction in emissions. This same trajectory is observed for the 2011, 2012, 2013, 2014, 2015, 2016 and 2018 cohorts with reforms resulting in 16%, 32%, 13%, 19%, 10%, 19%, 5% reductions in emissions respectively. Furthermore, the estimates in Table 5.2.3g also suggests that there are significant variations across the cohorts with earlier reform groups experiencing larger and more significant emissions reduction in the long term. For instance, g2010, g2011, g2012 experienced large reductions in emissions relative to g2015 and g2018.

b. Overall Average Treatment Effects

The average treatment effect on the treated (ATT) estimates provides the overall policy impact of fossil fuel subsidy reforms over all post-treatment period. Thus, it shows at a glance if the intervention had the desired effect. The result of the aggregated ATT is presented in Table 5.2.4h below.

Table 5.28: Average Treatment Effect on Treated

	Coefficient	*Std. Error*	*z-stat*	*p-value*	*95% Confidence Interval*
ATT	-.0574809	.0318478	-1.80	0.071	-.1199015 .0049397

Source: Table prepared by author based on Stata output

The result suggests that on average, fossil fuel subsidy reform is associated with a 5.74% reduction in CO_2 emissions. However, this result is only significant at the 10% level. This moderate but significant results indicates that while on average, subsidy reforms cause emissions levels to fall, the effect are likely to vary across time and cohorts.

c. Average Treatment Effect by Group

Table 5.29 presents the impact of reforms across different treatment groups. The results describe how different treatment cohorts experience different effects. From the table, *Gaverage* which denotes the overall treatment average across all groups show that fossil fuel subsidy reform result in a 5.3% fall in CO_2 emissions across all cohorts. Again, this effect is only significant at the 10% level.

Table 5.29: Average Treatment Effect on Treated by Group

Group	*Coefficient*	*Std. Error*	*z-Statistic*	*P-Value*	*95% Confidence Interval*
GAverage	-0.0531	0.0285	-1.87	0.062	[-0.1089, 0.0027]
g2010	-0.1017	0.0382	-2.66	0.008	[-0.1765, -0.0269]
g2011	0.0080	0.0467	0.17	0.864	[-0.0835, 0.0994]
g2012	-0.0273	0.0505	-0.54	0.589	[-0.1264, 0.0717]
g2013	0.0099	0.0330	0.30	0.763	[-0.0547, 0.0746]
g2014	-0.0343	0.0370	-0.93	0.355	[-0.1068, 0.0383]
g2015	-0.0197	0.0364	-0.54	0.589	[-0.0911, 0.0517]
g2016	-0.0723	0.0329	-2.19	0.028	[-0.1369, -0.0077]
g2017	-0.0925	0.0199	-4.65	0.000	[-0.1315, -0.0535]
g2018	-0.0342	0.0073	-4.67	0.000	[-0.0486, -0.0199]
g2019	0.0414	0.0033	12.62	0.000	[0.0350, 0.0478]

Source: Table prepared by author based on Stata output

Looking at the cohort specific effects, the study finds significant reductions in some cohorts relative to others. For instance, ATT for the g2010, g2016, g2017 and g2018 cohorts suggests high to moderate significant reductions. This is in contrast to the insignificant effects produced by g2011, g2012, g2013, g2014 and g2015 cohorts. More concerning is the estimate for g2019 which imply a strong but positive significance between fossil fuel reforms and CO_2 emissions. Apriori, a positive relationship between subsidy reforms and emissions could result from policy reversals, economic shocks or compensatory emissions behavior (Sinn, 2009). This is not surprising because most of the earliest reform efforts were riddled with implementation and structural bottlenecks. Thus, an explanation for the estimates of the g2019 cohort could be that due to the COVID 19 pandemic, many countries relaxed their reform efforts or completely roll-backed to mitigate the effect of the crisis.

d. Average Treatment Effect by Calendar Year

This sub-section summarizes how treatment effects vary by year across all cohorts. That is, it presents the impact of fossil fuel reforms on CO2 emissions over time by looking at the specific effect year on year.

Table 5.30: Average Treatment Effect on Treated by Calendar Year

Calendar Year	Coefficient	Std. Error	z-Statistic	P-value	95% Confidence Interval
CAverage	-0.0434	0.0263	-1.65	0.099	[-0.0950, 0.0082]
T2010	0.0045	0.0141	0.32	0.751	[-0.0232, 0.0322]
T2011	-0.0101	0.0166	-0.61	0.543	[-0.0425, 0.0224]
T2012	-0.0087	0.0192	-0.45	0.651	[-0.0464, 0.0290]
T2013	-0.0040	0.0175	-0.23	0.819	[-0.0383, 0.0303]
T2014	-0.0050	0.0193	-0.26	0.793	[-0.0428, 0.0327]
T2015	-0.0058	0.0269	-0.22	0.829	[-0.0585, 0.0468]
T2016	-0.0116	0.0455	-0.26	0.798	[-0.1009, 0.0776]
T2017	-0.0484	0.0512	-0.94	0.345	[-0.1488, 0.0521]
T2018	-0.0845	0.0735	-1.15	0.250	[-0.2286, 0.0595]
T2019	-0.0670	0.0879	-0.76	0.446	[-0.2393, 0.1053]
T2020	**-0.2368**	**0.0263**	**-9.01**	**0.000**	**[-0.2883, -0.1853]**

Source: Table prepared by author based on Stata output

From the Table, the overall impact captured by the CAverage is -0.0434 but this is only significant at the 10% level. In terms of specifics, the finding show that why insignificant, reform always had a negative impact on emissions level with the effect becoming stronger across the years till 2020 where the results show fossil fuel subsidy reforms result in a 23% reduction in CO_2 emissions.

Impact of fossil fuel subsidy reforms on GHG emissions

a. CSDiD estimates of the impact of fossil fuel subsidy reforms on GHG emissions

Table 5.31: CSDiD estimates of the impact of fossil fuel subsidy reforms on GHG emissions

Treatment Group	*Time Period*	*Coefficient*	*Std. Error*	*z-statistic*	*p-value*	*95% CI*
g2012	t_2007_2008	-0.0145	0.0060	-2.43	0.015	[-0.0261, -0.0028]
	t_2011_2020	-0.1317	0.0126	-10.42	0.000	[-0.1564, -0.1069]
g2013	t_2006_2007	0.0154	0.0068	2.26	0.024	[0.0020, 0.0288]
	t_2011_2012	-0.0162	0.0060	-2.70	0.007	[-0.0279, -0.0044]
g2014	t_2013_2020	-0.0538	0.0177	-3.04	0.002	[-0.0884, -0.0191]
g2015	t_2007_2008	0.0458	0.0110	4.15	0.000	[0.0242, 0.0675]
g2016	t_2015_2018	-0.0496	0.0220	-2.25	0.024	[-0.0928, -0.0064]
	t_2015_2020	-0.0776	0.0156	-4.96	0.000	[-0.1083, -0.0470]
g2017	t_2006_2007	0.0271	0.0108	2.50	0.012	[0.0059, 0.0483]
	t_2008_2009	-0.0882	0.0100	-8.83	0.000	[-0.1078, -0.0687]
	t_2013_2014	-0.0611	0.0080	-7.63	0.000	[-0.0768, -0.0454]
	t_2014_2015	-0.0766	0.0137	-5.59	0.000	[-0.1035, -0.0498]
	t_2016_2017	-0.0328	0.0088	-3.74	0.000	[-0.0500, -0.0156]
	t_2016_2018	-0.0599	0.0081	-7.38	0.000	[-0.0758, -0.0440]
	t_2016_2019	-0.0516	0.0159	-3.25	0.001	[-0.0827, -0.0205]
g2018	t_2016_2017	-0.0276	0.0119	-2.32	0.020	[-0.0510, -0.0043]
	t_2017_2018	-0.0278	0.0079	-3.53	0.000	[-0.0432, -0.0124]
g2019	t_2005_2006	0.0525	0.0092	5.72	0.000	[0.0345, 0.0705]
	t_2006_2007	-0.0525	0.0055	-9.59	0.000	[-0.0633, -0.0418]
	t_2007_2008	0.0380	0.0177	2.15	0.032	[0.0034, 0.0727]
	t_2014_2015	-0.0471	0.0049	-9.67	0.000	[-0.0566, -0.0375]
	t_2015_2016	0.0285	0.0133	2.15	0.032	[0.0025, 0.0546]
	t_2017_2018	0.0278	0.0031	8.98	0.000	[0.0217, 0.0338]
	t_2018_2019	-0.0542	0.0057	-9.58	0.000	[-0.0653, -0.0431]

Source: Table prepared by author based on Stata output

The results of the CSDiD estimates of the effect of fossil fuel subsidy reform on greenhouse gas emissions. The analysis compares how emissions levels evolve overtime between treated and control units. While most coefficients are not significant, there are some coefficients that are statistically significant, however, these significant effects are mixed in direction with some showing positive effects and others negative effects. Another interesting finding is that later cohorts (g2017 – g2019) show more statistically significant effects than earlier cohorts suggesting that either more recent reforms are more effective possibly due to a better policy design and implementation or that the effect of reforms become more evident over time.

b. Overall Average Treatment Effects

Table 5.32: Average Treatment Effect on Treated

	ESTIMATE	STD. ERROR	Z-STATISTIC	P-VALUE	95% CONFIDENCE INTERVAL
ATT	-0.0135	0.0396	-0.34	0.733	[-0.0912, 0.0641]

Source: Table prepared by author based on Stata output

The output of the overall average treatment effect is presented in Table 5.32. The result show that the overall ATT estimate is -0.0135 which indicates a small negative treatment effect of approximately 1.35%. however, this effect is not statistically different from zero at conventional significance levels. This results imply that on average, across the various cohorts and time periods, there is no strong evidence that fossil fuel subsidy reforms had a meaningful impact on greenhouse gas emissions.

c. Average Treatment Effect by Group

Table 5.33: Average Treatment Effect on Treated by Group

COHORT	COEFFICIENT	STD. ERROR	Z-STATISTIC	P-VALUE	95% CONFIDENCE INTERVAL
GAVERAGE	-0.0143	0.0297	-0.48	0.631	[-0.0726, 0.0440]
G2010	-0.0235	0.0854	-0.28	0.783	[-0.1910, 0.1439]
G2011	-0.0105	0.0383	-0.27	0.784	[-0.0855, 0.0646]
G2012	0.0005	0.0316	0.02	0.988	[-0.0614, 0.0623]
G2013	0.0128	0.0170	0.75	0.451	[-0.0205, 0.0462]
G2014	0.0027	0.0188	0.14	0.886	[-0.0341, 0.0395]
G2015	0.0164	0.0164	1.00	0.318	[-0.0158, 0.0485]
G2016	-0.0301	0.0153	-1.97	0.049	[-0.0601, -0.0001]
G2017	-0.0601	0.0072	-8.31	0.000	[-0.0743, -0.0459]
G2018	-0.0180	0.0082	-2.20	0.028	[-0.0341, -0.0020]
G2019	-0.0581	0.0028	-20.51	0.000	[-0.0636, -0.0525]

Source: Table prepared by author based on Stata output

Table 5.33 presents the impact of reforms across different treatment groups. The coefficient of the average treatment effect across all cohorts denoted by Gaverage is -0.0143. this result implies that fossil fuel subsidy reform result in a decrease of 1.43% in GHG emissions. However, the value is not significant indicating that on average, reforms has no clear overall impact on greenhouse gas emissions. Nonetheless, looking at the findings for the various cohorts, while there are no significant effects in the early cohorts (2010 -2015), the later cohorts all show negative effects that become progressively more significant with the largest effect being observed in g2017 where reform caused greenhouse gas emissions to reduce by 6.01%.

d. Average Treatment Effect by Calendar Year

This sub-section discusses how the effect of reform on GHG emissions vary year by year across all cohorts.

Table 5.34: Average Treatment Effect on Treated by Calendar Year

YEAR	COEFFICIENT	STD. ERROR	Z-STATISTIC	P-VALUE	95% CONFIDENCE INTERVAL
CAVERAGE	-0.0131	0.0526	-0.25	0.803	[-0.1163, 0.0899]
T2010	-0.0063	0.1181	-0.05	0.958	[-0.2378, 0.2253]
T2011	-0.0042	0.1025	-0.04	0.967	[-0.2052, 0.1968]
T2012	-0.0136	0.1001	-0.14	0.892	[-0.2097, 0.1826]
T2013	-0.0465	0.0932	-0.50	0.618	[-0.2293, 0.1362]
T2014	-0.0507	0.0995	-0.51	0.610	[-0.2457, 0.1443]
T2015	0.0521	0.0622	0.84	0.402	[-0.0698, 0.1739]
T2016	0.0169	0.0296	0.57	0.566	[-0.0410, 0.0749]
T2017	0.0040	0.0247	0.16	0.871	[-0.0444, 0.0524]
T2018	-0.0278	0.0280	-0.99	0.321	[-0.0826, 0.0271]
T2019	0.0006	0.0416	0.02	0.988	[-0.0809, 0.0821]
T2020	-0.0691	0.0205	-3.37	0.001	[-0.1092, -0.0290]

Source: Table prepared by author based on Stata output

Unlike the cohort effects analysis which showed significant effects for later cohorts, the output in Table 5.34 indicate non-significant effects across all the years except for 2020. It is imperative to consider that the dramatic reduction in emissions since in 2020 across CO2 and GHG likely reflects the impact of the COVID 19 pandemic rather that reforms itself.

To conclude this section, the overall finding from the study imply that fossil fuel subsidy reform appears to be more effective at reducing CO2 emissions rather than the broader GHG emissions. This indicates that reforms are more efficient in tackling fossil fuel combustion rather than other sources of GHG like methane and nitrous oxide. Another key finding is that the outcome of reforms is not immediate, rather, it exhibits delayed impact. The study also find that the cumulative effects of reforms can be quite substantial and tend to build up overtime.

Robustness Checks and Model Extensions

To ensure the reliability of the specified baseline model results, this section explores alternative specifications by incorporating covariates into the model. The selected covariates are in two broad categories; socioeconomic variables and environmental variables. The socioeconomic variables explored include education, governance, population and service value added. In the case of environmental factors, the variables considered include biomass protection policy (access to clean energy for cooking), technology, renewable energy consumption, and mineral rent.

A stepwise approach was adopted to sequentially add the variables to the baseline model in other to determine how their inclusion affects the estimated treatment effects. The results showed that the covariates had minimal impact on the estimated treatment effects. The study also tried an alternative estimation technique (the regression based estimation as opposed to the doubly robust inverse probability weighting employed for the baseline model), but the result remained largely unchanged. This suggests that the treatment effect is not sensitive to the choice of weighting or the estimation technique.

The robustness of the findings across different model specifications supports the reliability of the baseline results. Since the inclusion of covariates and alternative estimation methods did not materially change the estimates, this study present the baseline specification in the main analysis and provide alternative model results in the appendix for completeness.

5.3 Policy Implications of Findings

The various empirical investigations carried out in this study has important implications for policy making. This section outlines these lessons starting with policy implications garnered from objective one and ending with those that arose from objective four.

1. The results from objective one reveal that CO_2 and GHG emissions are highly persistent over time, indicating that past emissions exert a strong influence on current levels. This aligns with theory and signals the need for consistent, long-term climate policies rather than short-lived measures. Affluence is found to be a significant driver of emissions, reinforcing the importance of income-sensitive environmental strategies. In lower-affluence contexts, fossil fuel subsidies are clearly associated with increased emissions, reflecting their role in locking economies into carbon-intensive energy pathways and stimulating demand for fossil fuels.

   The significant negative interaction between affluence and fossil fuel subsidies implies that as countries become more affluent, the emissions-boosting effect of subsidies weakens and may even reverse. Thus, at higher income levels, subsidies could indirectly support cleaner energy use, possibly because of greater energy efficiency, stronger environmental regulation, or shifts in consumer preferences that make fossil fuel–based energy less desirable. This suggests that the environmental impact of subsidies is not uniform but varies depending on the stage of economic development. This finding suggests that subsidy strategies should be calibrated to the income level of each country. In low-income economies, subsidies tend to exacerbate emissions and should be carefully managed or redirected toward cleaner energy options.

2. Several policy implications can be derived from the empirical analysis of objective two. First, the various estimations carried out across several models and methods dominantly demonstrated that fossil fuel subsidies elevate emissions across all stages of economic growth. This high persistence of emissions supports the need for early and sustained mitigation efforts, as delays will lock countries into higher-emission trajectories for prolonged periods. Second, the lack of a statistically significant EKC pattern in the baseline results suggests that income growth alone is unlikely to deliver automatic environmental improvements; deliberate policy interventions are necessary to decouple growth from emissions. Third, the positive and significant role of technology in driving emissions points to the risk that without targeted support for clean technologies, technological progress may reinforce rather than reduce carbon intensity. The marginal effects analysis of fossil fuel subsidies further emphasizes these findings and provides particularly sharp policy guidance. Subsidies not only amplify the emissions impact of income growth in low- and middle-income countries where energy demand is likely to be expanding rapidly but also weaken the natural decline in emissions expected at higher income levels. This implies that subsidy reform is critical for aligning economic development with climate objectives. Specifically, phasing out subsidies in developing economies would prevent the disproportionate rise in emissions during early

industrialization, while removing them in high-income economies would accelerate the transition to cleaner energy sources.

3. Empirical evidence from objective three provides critical insights into the dynamics of fossil fuel subsidy reforms, especially when examined through both the Environmental Kuznets Curve plots and the marginal effects analysis. While the EKC plots capture the overall long-run shape of the income–emissions relationship and help identify the turning point that validates the EKC hypothesis, they smooth over short-term fluctuations and transitional anomalies. In contrast, the marginal effects analysis evaluates the instantaneous change in emissions with respect to income at specific levels of affluence, accounting for interactions such as the presence or absence of fossil fuel subsidy reform. Thus, it is able to reveal short-run dynamics; in this case temporary "green paradox" effects where emissions rise in the early stages of reform that are not visually apparent in the EKC plot. The combined perspective shows that fossil fuel subsidy reform, when implemented in isolation, may unintentionally increase greenhouse gas emissions among low-income populations. Rather than triggering a cleaner development trajectory, reform intensifies the emissions impact of income growth for the poor by as much as 75% in the CO_2 model and a staggering 105% in the GHG model. This likely occurs because reform raises energy prices without expanding access to affordable clean alternatives, thereby forcing low-income households deeper into energy poverty. The conventional reform strategy of "price signals plus compensation" is therefore environmentally counterproductive in countries where large segments of the population fall below a critical affluence threshold. In such contexts, reforms push these households toward greater reliance on dirtier fuels, effectively penalizing their economic progress (even when cash

transfers are provided) with heightened environmental harm. The true path to a sustainable and just energy transition thus lies not in immediate market correction, but in deliberate public investment that expands the choice set of the poor. Only then can fossil fuel subsidy reform function as a meaningful climate strategy rather than a regressive policy trap.

4. Objective four of this study was to empirically determine the environmental impact of fossil fuel subsidy reforms. This was achieved by using the Callaway and Sant'Anna Difference in Difference methodology with staggered treatment. The findings demonstrate that while the impact of fossil fuel subsidy reforms may not be immediately felt, there are substantial reductions in emissions in the longer term for most cohorts. The countries that underwent subsidy reforms in 2010 had achieved a 40% reduction in emissions a decade later. This delayed impacts suggests that there are no quick fixes, policymakers must design reforms with the knowledge that their impact will become measurable only in the long term. Furthermore, the need to understand and control for country specific factors can also be deduced from the findings. Difference cohorts show varying magnitudes and effects, more so some cohorts show initial positive coefficients in the period immediately following reform implementation. This suggests the possibility that such increases in emissions are likely due to adjustment speed and policy adaptation and transition challenges. It must be noted that the strong negative coefficients in 2020 across multiple cohorts may partially reflect the COVID-19 pandemic effect coinciding with reform impacts. Another interesting policy implication is that timely implementation matter. This is evidenced by the fact that earlier cohorts (2010 -2012) eventually show large reductions suggesting that early adopters are likely to achieve greater cumulative emissions

reductions relative to late adopters. Furthermore, the growing magnitude of effects over time indicate that maintaining reforms (rather than it being seen as a one of event or a temporary measure) is crucial for a positive environmental outcome. This is a critical point for policy makers especially in the face of reform reversals and failures that have plagued some countries implementation efforts. Reforms are a continuous process and must be designed as such.

CHAPTER SIX

SUMMARY OF FINDINGS, POLICY RECOMMENDATIONS, AND CONCLUSION

This chapter provides the summary of major findings from the study, it proffers some policy recommendations derived from the policy implications and concludes. Additionally, to provide guidance for future research, it highlights the limitations of this current study and suggests possible focus for future studies.

6.1 Summary of Findings

The broad objective of this study is to assess the impact of fossil fuel subsidies and fossil fuel subsidy reforms on environmental outcomes in 68 selected countries for the periods 2010 to 2023. While all countries selected for the study offer fossil fuel subsidies, 51 of them were chosen primarily on the basis that they had enacted fossil fuel subsidies reform policies at some point in the period between 2010 and 2023. Given this distinguishing characteristics, it is not surprising that the panel of countries are geographically disperse with representation from Africa, Asia, the Americas, Europe and the Middle East. To take care of possible heterogeneity bias, the study carried out several robustness and sensitivity tests that included different methodologies and specifications. The study findings were found to be robust across methodologies and specifications.

The theoretical underpinning of this study is predicted on the Stochastic Impacts by Regression on Population, Affluence, and Technology model. This model is modified to incorporate the Environmental Kuznets Curve in order to successfully address some of the objectives of the study. Estimation techniques deployed include the system Generalized Method of Moments, the Fixed Effects and Random Effects Models and the Callaway and

Sant'Anna Difference in Difference method with staggered effects. The results from the empirical investigations suggests the following;

The evidence consistently shows that fossil fuel subsidies and their reforms have complex and context-dependent effects on emissions. The persistence of CO_2 emissions shows the need for sustained, long-term climate policies. Affluence remains a significant driver of emissions, but the impact of subsidies varies by income level; exacerbating emissions in low-income economies while potentially supporting cleaner energy use in high-income settings through efficiency gains and shifting preferences. This calls for subsidy strategies calibrated to a country's stage of development. The absence of an automatic income-driven environmental improvement (EKC) highlights the necessity of deliberate interventions. Phasing out subsidies particularly in developing countries, would help avoid locking in high-emission trajectories during early industrialization, while removal in richer nations would accelerate clean energy transitions.

The results show that examining only the long-run EKC trajectory risks overlooking short-term dynamics. Marginal effects analysis uncovers temporary "green paradox" effects where reforms can increase emissions among low-income populations by raising energy costs without expanding access to affordable clean alternatives. Such outcomes make isolated reforms environmentally counterproductive in poorer contexts. The results point to the need for complementary investments in clean energy access and the enactment of environmental policies like biomass protection before or alongside subsidy removal. In addition, the environmental benefits of subsidy reforms are often delayed but substantial in the long term, with early adopters achieving the largest cumulative reductions. Variation in outcomes across reform cohorts supports the importance of accounting for country-specific conditions, maintaining reforms over time, and avoiding policy reversals. Effective reform must therefore be one that is sustained, contextual, and paired with supportive measures to ensure a just and lasting low-carbon transition.

6.2 Conclusion

The issue of fossil fuel subsidies and their potential reforms has garnered significant attention from governments at local and national levels, as well as from multilateral organizations globally. This focus has intensified as policymakers grapple with the seemingly contradictory objectives of economic sustainability and meaningful climate action. Fossil fuel subsidies have increasingly been identified as counterproductive instruments that simultaneously undermine both economic and environmental outcomes. Conversely, fossil fuel subsidy reforms are widely advocated as mechanisms that not only alleviate the fiscal burden on economies but also generate the ancillary benefit of improved environmental outcomes.

This study set out to examine the environmental impact of fossil fuel subsidies and their reforms within the broader framework of the STIRPAT model and the Environmental Kuznets Curve, using a rich panel dataset of 68 countries and robust econometric techniques, including the Callaway and Sant'Anna Difference-in-Differences methodology for staggered treatment effects. Across multiple empirical specifications, the results challenge the validity of the traditional EKC hypothesis for CO_2 and greenhouse gas emissions in the study sample. In contrast, strong support emerged for a reform-augmented EKC, indicating that the turning point in the income–emissions relationship is contingent upon the presence and nature of fossil fuel subsidy reforms. The evidence shows that the presence of subsidies amplifies the emissions impact of income growth in low- and middle-income settings, suggesting that subsidies not only distort energy markets but also reinforce the environmental costs of economic progress. In essence, income growth alone does not lead to emissions reduction beyond a certain threshold unless it is accompanied by structural policy changes that alter the energy mix and consumption patterns.

When examining reforms, the results caution against an overly simplistic "price-signal-driven" approach. The empirical evidence reveals that subsidy reform, if implemented in isolation, can be environmentally regressive for low-income populations. By raising energy prices without simultaneously expanding access to affordable clean alternatives, reform may increase energy poverty and push households towards dirtier fuels, thereby intensifying emissions in the short term. The marginal effects analysis confirm that these dynamics are particularly acute below certain affluence thresholds. These findings highlight that an effective reform strategy must go beyond fiscal correction and market efficiency to address the structural inequities in renewable energy access that underpin the emissions–income relationship.

6.3 Policy Recommendations

Several policy recommendations can be drawn from the empirical investigations carried out in this study, some of which are discussed below;

1. There is no doubt that environmentally harmful fossil fuel subsidies need to be phased out, a fact supported by the findings in objective one were we see a positive relationship between fossil fuel subsidies and environmental outcome. Yet, phasing out subsidies should be done in a carefully sequenced manner that considers their interaction with key drivers of emissions such as affluence, technology, and population growth. Policy design

should ensure that subsidy removal is complemented by measures that enhance clean energy access and technological efficiency to prevent unintended increases in greenhouse gas emissions. In this regard, the study recommends two strategies. First, policymakers are advised to implement a phased subsidy reform program where subsidies are gradually redirected from fossil fuels to renewable energy initiatives. The phased subsidy reform program should have clear timelines and should be designed based on country specific contexts. Second, the reform policy should also be designed with inbuilt compensatory mechanisms to protect vulnerable citizens during the transition. The savings from reforms should be channeled towards funding clean energy research and development.

2. The lack of validation of the Environmental Kuznets Curve found by this study suggests that economic growth alone cannot be relied on to solve environmental problems; rather, structural, institutional, and other country-specific factors are more critical. While global coalitions like the Kyoto Protocol and the Paris Agreement have provided important platforms for countries to commit to reducing emissions, they have not met much success because of the perception that some countries are not contributing equitably to global emissions reduction efforts. This perceived imbalance, combined with uneven enforcement and delivery on commitments, has undermined the credibility and effectiveness of international climate frameworks and may help explain the lack of statistically significant effects observed in the analysis. To address this, the study recommends strengthening the existing system of Nationally Determined Contributions (NDCs), which are already designed around the principle of common but differentiated responsibilities and respective capabilities. Specifically, this can be achieved by making emissions reduction targets more dynamically indexed to national income levels and

periodically recalibrated to reflect changes in economic capacity. This would ensure that wealthier nations shoulder a greater portion of the emissions burden, while lower-income countries commit to progressively stricter targets as their economies grow. Such a strengthened, income-linked approach would provide a fair, progressive, and realistic pathway for global climate action, better aligning commitments with current realities and future development trajectories.

3. The study found evidence of the existence of a reform – augmented EKC which propose that reforms can help countries achieve the turning point of the EKC faster than income alone can achieve. The findings implied that the level of income matter for reform success. Thus, in countries with significant low-income populations, fossil fuel subsidy reforms must go beyond simple price adjustments and targeted cash transfers. Without affordable and accessible clean energy alternatives, reforms risk deepening energy poverty and increasing reliance on dirtier fuels. Governments should therefore prioritize large-scale public investment in renewable energy infrastructure, clean cooking technologies, and energy efficiency programmes before or alongside reform implementation.

   Based on this findings, this study recommends as an approach to conceptualize and implement the integrated emissions reduction–income linked framework at the national level, a tiered fossil fuel subsidy reforms program that accelerates as the country reaches a higher income threshold. In line with the Green Climate Fund, financial support mechanisms from wealthy countries will help low income countries manage the transition from subsidies to reforms.

   In addition, enhanced environmental education and awareness programs can help government communicate effectively the need for and the benefits from reforms. Thus, this study recommends expanding environmental education at all levels of formal school systems. Countries should also develop public awareness campaigns that clearly connects individual behaviors to environmental outcomes. Government should also support community-based initiatives that promote green energy alternatives for home and industrial use.

The finding that improvements in governance does not translate to better environmental outcomes were quite concerning. To mitigate this, this study recommends that specialized environmental governance frameworks must be developed with metrics that are distinct from general governance criteria. If possible, dedicated regulatory bodies should be created that focus solely on emissions control and general natural resource management.

4. A major focus of this study was to determine if the fossil fuels subsidy reforms carried out across several countries in the last two decades have yielded any substantial environmental benefits. The study found delayed but substantial long term emissions reductions. Based on this findings, the study recommends a long term commitment to reform implementation. This is crucial because the empirical evidence suggest that the most significant emissions reduction occur six to ten years post reforms. To take advantage of this, policymakers should design reform policies with explicit long term horizons of at least ten years. Institutional mechanisms should be built in to ensure policy continuity regardless of government change. Given the findings that early reform groups experience larger and more significant emissions reductions relative to later cohorts, international support mechanisms can be designed to encourage and reward early reformers such as financial incentives and assess to knowledge sharing platforms and other resources.

6.4 Contribution to Knowledge

This study contributes to the advancement in knowledge in theory, empirics and methodology. First, the study introduces and provide evidence for a novel "reform-augmented EKC". The reform-augmented EKC is an improvement on the standard EKC and it demonstrates that fossil fuel subsidy reforms can accelerate a country's progress towards the turning point of the EKC allowing it to achieve emissions reductions faster than through economic growth alone. Second, the study demonstrates the temporal dynamics of fossil fuel subsidy reforms. By providing evidence of a time gap in environmental returns, the study provides policy makers with the confidence to implement reforms even when benefits will be delayed.

The study also produced several significant empirical contributions. Unlike previous simulations based studies, this research provides empirical evidence using actual reform episodes and was able to prove that reforms can deliver meaningful emissions reductions. The study also revealed that early adopters of fossil fuel subsidy reforms experience greater environmental benefits than later reform cohorts thus contributing new insights into the link between reform timing and environmental outcomes. The research also challenged conventional wisdom by demonstrating that improvements in general governance indicators do not necessarily translate to better environmental outcomes, thus demonstrating the need for specialized environmental governance frameworks.

With regard to methodology, the study utilized a comprehensive analytical framework that combines the STIRPAT model with the Environmental Kuznets Curve and the Ecological Modernization theory to examine the complex relationship between fossil fuel subsidies, reforms and environmental outcomes. Significantly, the study pioneered the use of the

Callaway and Sant'Anna Difference in Difference methodology with staggered treatments to analyse environmental outcomes following fossil fuel subsidy reforms.

6.5 Study Limitations and Suggestions for Further Studies

A significant limitation of this study is the potential bias introduced by the COVID-19 pandemic particularly in the Callaway and Sant'Anna Difference in Difference analysis. The unprecedented global lockdowns and economic slowdowns during 2020 resulted in dramatic reductions in greenhouse gas emissions that were unrelated to policy interventions. This external shock may have artificially inflated the apparent effectiveness of fossil fuel subsidy reforms implemented before 2020, as their post-reform periods would include this anomalous emissions reduction. This effect is quite apparent in the dramatic reductions in emissions by approximately 40% in 2020. However, given that emissions were already trending down before 2020, the COVID 19 effect does not negate the findings of this study.

Another potential bias came from the inability to comprehensively capture reform episodes. The binary treatment approach may over simplify the complex and context specific nature of reforms in terms of variations in reform magnitude, scope and implementation quality across countries.

Data limitations was also another cause for concern with regard to the availability and quality of data. For example, different methodologies used for calculating subsidies across countries and time periods may introduce measurement errors that can affect the reliability of the findings.

Future research should aim to develop methodological approaches that capture the intensity, scope, and quality of fossil fuel subsidy reforms**,** rather than treating them as binary policy events. Recognizing that reforms differ in magnitude and implementation effectiveness across countries, such an approach would provide a more accurate assessment of their environmental impacts. In addition, efforts to improve the harmonization and consistency of subsidy data across countries and over time are necessary to minimize measurement errors and strengthen comparability. Advancements in these areas would enhance the robustness of cross-country analyses and contribute to more reliable policy guidance.

Finally, given the middle- to long-term reform impacts observed in this study, it would be valuable for future research to revisit these findings with an extended dataset that covers additional years beyond 2020. Such work would help to validate the conclusions presented here and further clarify the long-run environmental effects of fossil fuel subsidy reforms.

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APPENDIX

APPENDIX I

A. Fossil fuel subsidy reforms in selected countries.

i. Angola

Angola is the second largest oil producer in Africa producing about 1.37 million barrels of oil daily with an estimated 17.904.5 million cubic feet of natural gas. Although Angola is an oil producer, it imports a large part of refined petroleum for domestic consumption. The country heavily subsidizes local consumption of fossil fuels. Moreso, fuel products are tax exempt hence fuel prices in the country were among the lowest in the world. By 2014, Angola was spending more to subsidize fossil fuels than it spent for health and Education combined thereby crowding out growth opportunities. The International Monetary Fund carried out an assessment on the effect of these subsidies on the Angolan economy. Their report showed that the subsidies were creating room for overconsumption and smuggling with 77% of the fuel subsidies benefiting the richest 40% households with only 10% accruing to the poorest 40%. Ironically, although poor households benefit less from subsidies, they spend a greater proportion of their income on fossil fuels relative to richer households (Fabrizio et al, 2014).

Given the foregoing, the IMF proposed a gradual fossil fuel reforms that should see a 133% increase in prices between 2015 to 2020. The IMF postulated that since most consumer goods in Angola were imported, reforms would have limited impact on the economy. They also suggested strengthening existing social protection plans and including cash transfers to the poorest and most vulnerable. In their report, they argued that reforms would help generate fiscal space, and reduce fiscal pressure, while increasing social spending and public investments (Fabrizio et al, 2014). In line with the advice from the IMF, the Angolan government approved a 60% cut in fossil fuel subsidy payments (Whitley and Van der Burg, 2015).

Angola was unable to stay within the timeline proposed by the IMF and by 2022, with the spike in the international price of oil due to the Ukraine-Russian war, the country was again paying approximately $3.1 billion in subsidies. By December 2022, market gasoline and diesel prices were 202 percent and 279 percent higher than subsidized prices in Angola. Fuel subsidies in 2022 accounted for about 92 percent of the country's health and education expenses in the same year (Xinhua, 2023).

The government proposed an 87% cut in petrol and diesel subsidy payout by the 2nd quarter of 2023 and a complete removal by 2025 with the aim of promoting economic diversification, strengthening social inclusion and building climate resilience. To support this goal, the World Bank committed to providing a $500 million Diversification Development Policy Loan (DPL) to mitigate the social impacts of the reform. The reforms immediately resulted in sharp price hikes for petroleum products especially petrol which went from 165 kwanza (€0.25) to 300 kwanza (€0.48) per liter on May 3, 2023. This led to violent protests and violent crackdowns by security agencies (World Bank, 2023).

ii. Argentina

Argentina is considered one of the largest producers of natural gas and petroleum in Latin America and the Caribbean. In terms of energy consumption, 52% comes gas and 34% from oil. The government provides both consumption and production subsidies for fossil fuels. This includes natural gas tariffs, export taxes and subsidized imported crude to refineries. Argentina has justified providing subsidies as a way to protect citizens from the rise in energy prices, yet this has led to greater energy demand, causing supply shortages pushing the country from a net exporter or a net importer.

Argentina started reforming the energy sector in the late 1980s to the early 1990s in other to make electricity generation more competitive and efficient. The reforms saw the unbundling and privatization of the generation of electricity while transmission and distribution were still highly regulated and thus less competitive. The reforms also the establishment of an independent regulator. Due to the economic downturn in 2002, the government froze the prices of electricity, oil and gas and renationalized electricity distribution companies, thus, effectively rolling back the reforms. This, unsurprisingly led to a fall in investments in the sector and placed a huge burden on the government as it had to pay the difference between the frozen rates and the true cost of production.

In 2008, the Argentinian government increased electricity tariff by 10 -30% but had to suspend it in the winter of 2009 as a response to the global financial crisis and citizen protests. By 2011, the government was determined to reform subsidies for electricity and natural gas by raising prices while providing compensation for the impact of subsidy reforms. This involved replacing the subsidy with a direct cash transfer to low-income pensioners and retain subsidy for electricity supplied to rural areas. Hence, by 2012, subsidies amounted to 2% of GDP. Direct and indirect fossil fuel subsidies were 3.9% of GDP and 14% of tax revenue between 2011 and 2013. Hence, in 2013, the government committed to phasing out electricity and gas subsidies by 20%, saving the country $1.6 billion. The saving was used to cover utility costs and boost social expenditure.

iii. Canada

Canada has the world's third-largest proven oil reserves, of which oil sands, one of the fastest growing sources of global GHGs, account for the biggest share. It is also the world's fifth-largest energy producer, behind China, the USA, Russia and Saudi Arabia, and a net exporter of oil, natural gas, coal and uranium. Canada's energy consumption needs are primarily met by petroleum, followed by natural gas and hydropower, with the latter providing most of the country's electricity needs. In Canada, production and consumption have historically been provide at both the federal and provincial level. According to the OECD inventory, fossil fuel subsidies was worth $3.1 billion in 2014. Subsidies were provided mainly to aid the exploration and production of fossil fuels. It has been estimated that between 2010 and 2014, Canada spent $27.4 million on average annually for fossil fuel exploration projects both locally and abroad.

When Canada reformed various subsidies for the oil, gas and mining sectors in 1990, she was not motivated by climate or budgetary considerations, rather the reforms were principally undertaken because the subsidies were no longer regarded as necessary because the goal of growing a robust oil, gas and mining sector had been achieved.

Between 1990 and 2007, Canada carried out reforms in the oil and gas sector by removing previous tax exemptions saving the country $904 million annually. Canada also made commitments in 2009 at the G20 meetings to phase-out subsidy. This commitment saved the country a further $150 million. Yet, two primary subsidy measures were retained – the Canadian Development Expense (CDE) and the Canadian Exploration Expense (CEE), which provided accelerated deduction rates for pre-production development and exploration expenses at a combined value of US$732 million in 2008, and thereby incentivized increased production. Exploration expenditure increased rapidly between 2008 and 2013, with Shell's exploration spending rising by more than 7.5 times. However, in 2014, due to rising production costs and falling oil prices, the government eliminated tariffs on mobile offshore drilling units used in oil and gas exploration and development, and additional tax breaks for natural gas projects were eliminated in 2015.

iv. Egypt

Natural gas and oil account for 94% of Egypt's primary energy consumption. Even though Egypt is Africa largest non-OPEC oil producer, oil demand has outpaced production since 2010. In 2013, subsidies to fossil fuel consumption amounted to 12% of Egypt's GDP valued at $32 billion. Subsidy payouts exceeded expenditure on health, education and infrastructure combined which made Egypt the world's eighth largest spender on fossil fuel subsidies. The country subsidizes petrol and LPG for general consumption while natural gas and fuel subsidies are provided for energy-intensive industries to aid their competitiveness. It was estimated by the world bank in 2005 that a 50% cut in fossil fuel subsidies and a uniform distribution of the savings to Egyptians could cause the poverty rate to fall by as much as 33%.

According to the Egyptian Ministry of Petroleum, in 2013, 92% of petrol subsidies and 66% of natural gas subsidies benefited the richest 20% of consumers. Moreso, these subsidies were a significant factor in the country's budget deficit. The state owned Egyptian General Petroleum was also heavily indebted. The subsidies were also considered to have significantly contributed to over-consumption, black markets and air-pollution. Air pollution was estimated to contribute to 15,000 deaths annually. The triple effect of negative economic, social and environmental impact led the Egyptian government enact a subsidy reform policy with support from the World Bank and the International Monetary Fund. In line with the reforms, the price of electricity and diesel rose between 2005 and 2009, however, this was met with a lot of resistance, this combined with the 2008 financial crisis caused the reforms to be temporarily put on hold. In 2012, government removed subsidy from high octane petrol but motorists just switched to low-octane petrol which was still subsidized. By July of 2014, the government announced significant cuts to subsidies on petrol, diesel, natural gas and electricity as part of measures to reduce the budget deficit. Several social intervention schemes were earmarked on to cushion the effect of the reforms on poor households, minimum wage was increased, pensions were increased and certain foods were subsidized. The government's long-term aim was for energy and cost efficiency with the reforms expected to save the country $7 billion. About half of this saving was to be invested in health and education.

v. El Salvador

LPG is perhaps the most common cooking fuel in El Salvador with about 70% of households using it in the country. The price of LPG has been subsidized since 1974 and other than a minor change in 2008, the price of $5.10 per 25lb cannister has been fixed since 1996. However, by 2011, a 25 lb cannister cost $13.60 with the government having to pay the difference of $8.50. As at 2010, this cost the government around $154 million annually. Another issue was that the LPG subsidy did not get to almost half of El-Salvadoreans in the bottom 40% of the income bracket as they did not use LPG at all. Unsurprisingly, in April 2011, the government raised the price of LPG to reflect the full international market price. To compensate citizens, all households with electricity consumption under 200 kWh per month would receive $8.50 as cash transfer monthly. Households without electricity were put on a scheme to receive the same amount monthly. By all, intent, this was a progressive reform and so after the initial skepticism, and with vigorous information campaign, citizens embraced the reforms.

vi. Ethiopia

Prior to fossil fuel subsidy reforms in Ethiopia, subsidy expenditure was more than $600 million annually. This sum was equivalent to 50% of the country's total earnings from export. Furthermore, the subsidy expenditure led to a huge and lingering trade deficit, diverting resources away from key sectors like education, health and agriculture. Another aspect of the subsidy payment was that it benefited higher income households especially in urban areas over poor households in rural areas (IISD-GSI, 2016).

By 2008, Ethiopia was facing a severe food crisis and required additional funds to tackle it. This necessitated the removal all fossil fuel subsidies. The immediate effect of the reforms was an increase in diesel and kerosene prices by 40% and 50% respectively (Carlisle, 2008; Kojima, 2009). Gasoline prices also increased. Despite the price hikes, the reforms came with a lot of benefits for Ethiopia. Fossil fuel energy consumption decreased, as government invested in cleaner fuels both for domestic cooking and transport. Electricity demand increased significantly with majority of the demand met with renewable energy.

vii. Germany

Germany has been heavily focused on renewable energy yet it is still the second largest producer of coal and the third largest producer of natural gas in Europe. The country provides both consumption and production subsidies. Consumption subsidies include energy tax breaks for agriculture and manufacturing, tax exemption for energy intensive processes, for aviation fuels e.t.c. While production subsidies were mainly to the coal industry. In 2003, the eco-tax on fuel products and electricity were reformed in response to pressure from various environmental advocacy groups including the German Green Party and the European Commission. Yet, by 2006, new tax exemptions were introduced to promote competitiveness of German businesses. Also, the Hard Coal Financing Act was adopted in 2007. This Act stipulates that subsidies for hard coal production have to be phased out by the end of 2018. This long-term reform plan demonstrated the importance of transparency especially with carrying the public along for it to be successful.

The OECD inventory report of 2014 estimated that fossil fuel subsidies in Germany had a combined value of US$6.3 billion in 2014. Despite these efforts to phase out subsidies for the domestic production of fossil fuels, Germany continues to provide significant support to fossil fuel projects abroad but has been some progress in limiting this funding of fossil fuel projects abroad. In December 2014, the federal government agreed to limit development finance for new coal power stations overseas. As Germany holds the G7 presidency in 2015, it has an opportunity to take the lead in turning commitments to reform subsidies for fossil fuels (reiterated in the Brussels G7 Summit Declaration) into firm action.

viii. Ghana

Ghana first attempted to reform fossil fuel subsidies in 2001 following the losses incurred due to the low oil price set by the government relative to the international price of oil. To mitigate this, President Kufuor introduced a fuel price adjustment formula but had to abandon it due to the escalating costs of oil. By 2004, subsidy payments for gasoline had risen to 2.2% of GDP. This amount exceeded the total budget of the Ministry of Health and about 1% of GDP was required to support the operations of Tema Oil Refinery alone. Furthermore, the country faced severe shortages due to over-consumption.

The National Petroleum Authority (NPA) was created in 2005 with the mandate to stabilize prices, minimize subsidies and depoliticize the setting of prices. Compared with the prior subsidy reforms, the 2005 intervention was considered successful given that it did not result in riots as did the 2003 adjustments. It also was preceded with an impact assessment program called the Poverty and Social Impact Assessment (PSIA) carried out by the government in conjunction with the IMF. The PSIA found that previous subsidies were poorly targeted and benefited the rich more than the poor. Alongside the creation of the NPA, several social protection programmes were introduced, the government made communication a priority as well. The people were told that savings from the reforms will go to fund free education at the primary and secondary school levels, subsidize public transportation, fund healthcare access for the poor and to raise the minimum wage. The government also used the savings from the savings from the reform of petrol to cross subsidize kerosene and LPG that are mostly used by the poor. Although the automatic price adjustment that benchmark the international price of oil is an important policy instrument in subsidy reforms, it is highly political especially in the wake of elections. This was the case in the run-off of the 2004 presidential elections even before the creation of the NPA but continued afterwards as seen prior to the 2008 elections and again in the 2012 elections.

By 2013, fuel subsidies were costing Ghana $1.2 Billion which was equivalent to 3.2% of her GDP. To reduce cost, the government raised the price of fossil fuels. The price of kerosene went up by 15%, LPG by 50% and the tariff for electricity also went up. Yet, by 2014, Ghana was neck deep in debt, this combined with the increases in oil prices meant that the country had to ask the IMF for help. The complete deregulation of fuel prices was a key aspect of the IMF supported recovery programme. This was alongside a comprehensive engagement with stakeholders. The programme also revamped the 2008 Livelihood Empowerment Against Poverty programme (LEAP) to mitigate the impact of the reform. LEAP was used as a mechanism for conditional cash transfer that covered around 100,000 to 150,000 households. This was complemented by a 17% rise in the minimum wage. Studies have shown that LEAP had a lot of positive benefits, it reduced inequality, it was less costly than fossil fuel subsidies and it gave rise to a fiscal surplus. It was also anticipated that the reforms would limit overconsumption, air pollution, road use and ultimately, carbon emissions. However, some unintended effects have also been noticed, it has pushed the very poor to use more wood fuel and charcoal which is devastating for the environment as a result of air pollution and deforestation.

ix. Indonesia

Indonesia has attempted to reform fossil fuel subsidies many times over the last few decades. There were reform attempts in 2005, in 2008 and in 2013. Yet the most well-known attempt was that of President Joko Widodo. In his presidential campaign in 2014, Joko Widodo made subsidy removal the main talking point, sensitizing Indonesians on the harmful effect of subsidies on the economy especially its disproportionate share of benefits to the poor relative to the rich. He promised to channel the savings on subsidy removal to free education and free health. When he became president, Joko Widodo enacted subsidy reforms. In November 2014, he raised the prices of gasoline and diesel and he reallocated the savings to health, education and infrastructure. By the end of that year, president Widodo abolished gasoline subsidies completely with prices sent to adjust regularly in line with the international market. He also introduced a fixed subsidy per litre of diesel sold to regulate volatility with international prices. It is estimated that reforms saved the government of Indonesia about $15.6 billion (McCulloch, 2023).

Another important factor in the success of the Widodo reforms the widespread welfare payments using the social protection database. The abolishment of subsidies was sustained easily for a number of years especially with the crash of oil prices between 2014 to 2016. However, as oil prices started to rise, it became more and more politically difficult to raise prices especially as elections approached in 2019, hence subsidy re-emerged.

x. Iran

When Ayatollah Khomeini arrived back in the country following the revolution of 1979, he promised Iranians that he will bring the oil wealth to people's tables. This translated as access to cheap gasoline, diesel and electricity to everyday Iranians. However, this policy was very costly for the country so that various attempts were made to reform the sector in the 1980s and 1990s.

In 2008, president Ahmadinejad tried to carry out subsidy reforms but was widely opposed by parliament. However, by 2009 subsidies were consuming a major share of the budget, hence reforms were attempted again. This time, the government utilized the instrument of cash transfers in a unique manner. Every household was asked to open a special bank account into which the government deposited about $45 for every individual every month. This was at a time were about 10% of the population was earning less than $2 a day. For such households, this represented a 75% increase in income. For the average household with earnings of around $4.50 daily, this initiative was a 25% increment. However, while citizens could see these funds on their accounts, they could not withdraw it, so many thought it was a gimmick, hence many people refused to open the bank accounts. It is estimated that 4 million families did not even fill the forms. Unfortunately for them, on the 18th of December 2010, President Ahmadinejad announced that from midnight that day, people could withdraw the government transfers. Furthermore, he explained that the price of gasoline was to go up fourfold, the price of natural gas, eightfold and the price of diesel, ninefold. Iranians were stunned by this pronouncement, for the poor who used very little fuel, this was a massive boost to their income but for the rich and middleclass, their income was eroded temporarily reducing inequality.

By the time people realized that the payments were genuine and continuous, even non-Iranians signed up. Given the lack of quality control, the payment became unsustainable. Another factor responsible for the failure was the size of the payout, according to McCulloch (2023), subsidy reforms should pay for itself with savings made from the reform greater than the compensation. Hence, rather than reducing the budget deficit, the reforms worsened it. The extra cash in people's pockets raise the inflation rate worsening the economic condition of the poor. Yet, removing the handouts have been impossible, although it has been adjusted so that only a certain income bracket is eligible. Till date, it still pays about 60 million of Iran's 85 million people. A combination of economic mismanagement and US sanctions have resulted in a highly devalued Iranian rial. Yet the price of petrol in Iran is the second lowest in the world even though the cost of supplying it is on the rise implying that subsidies are back in place. It is in fact estimated that subsidy payments amounted to approximately $80 billion in 2019 was equivalent to close to 20% of the country's GDP.

xi. Morocco

In 2013, Morocco embarked on fossil fuel subsidy reforms with special focus on gasoline and diesel due to the regressive nature of the subsidy on those products. To mitigate the social impact of the reforms, the government expanded the national conditional cash transfer system and introduced a health insurance scheme for the poor. The government also committed to increased funding for renewable energy particularly solar energy (GSI, 2016).

The fossil fuel reforms reduced fuel subsidy spending from 5.3 per cent of GDP in late 2011 to 1.1 per cent of GDP in early 2015. By 2015, subsidies on gasoline, diesel and fuel oil were completely eliminated, resulting in annual fiscal savings of about USD 3 billion relative to 2011. Subsidy removal has led to increased domestic energy prices; between 2011 and early 2015, gasoline and diesel increased by 25 per cent and 35 percent (GSI, 2016).

Studies have shown that the reforms in Morocco were decidedly 'pro-poor' given that regressive subsidies, that is those that benefit the poor the least were successfully eliminated. Subsidies were however retained on products that make up a larger share of household expenditure for the poor than for the rich: LPG, basic food items and electricity. Furthermore, whilst subsidies on industrial fuel oil used in electricity generation were included in the 2014 subsidy reforms, an agreement between the government and the state-owned electricity generator allows for gradual increases to retail electricity prices between 2014 and 2017. The one exception to this was for the lowest consumption bracket (monthly use of less than 100 kilowatt-hours), which were to remain exempt from tariff increases (GSI, 2016).

The case of Morocco show that a well-structured reform strategy will yield enormous benefits. the reduction in subsidies to fossil fuels were combined with a commitment to increasing targeted support to the poorest, as well embracing the role of renewable energy.

xii. Nigeria

Nigeria, a member of OPEC is the largest oil producer in Africa. She also has the ninth-largest natural gas reserves globally. The country's economy is heavily dependent on the oil and gas sector which accounts for about 25% of its GDP, 75% of government revenue and over 95% of total exports (WDI, 2023). This dependence of the economy on the oil and gas sector has made Nigeria highly vulnerable to international oil price volatility.

Due to institutional and infrastructural limitations, Nigeria relies on imports to meet her domestic petroleum consumption. Data from the World Bank also indicate that only about 50% of the Nigerian population has access to electricity (WDI, 2023). Given the electricity supply shortages and the frequency of blackouts, Nigerians resort to fossil fuels to power their generators. The use of biomass is also quite common, in fact, biomass and waste account for 80% of the country's primary energy consumption, while oil and natural gas accounts for 13% and 6% respectively (WDI, 2023).

Fossil fuel subsidies existed alongside subsidies on different types of goods and services such as fertilizers, manufactured goods and even air travel since the 1970s. However, the middle eastern crisis of 1973 resulted in the first major oil price shock leading the government to peg the price of crude oil supplied to the local refinery at 35.7% less than the international price of crude oil. The idea behind this policy was the need to control inflation, promote industrialization, and enhance growth. Given that the subsidy implementation depended on supplying crude oil to local refineries at prices lower that the world price, it met that the amount paid for subsidy rose or fell with the international price level. The austerity measures that were introduced as part of the structural adjustment programme of 1985 saw the stoppage of all subsidies except those on petroleum products. To better control the price of petroleum products, government became a major player in the downstream sector effectively controlling production, supply, and pricing. Keeping subsidies in place in the early years was easy because oil revenues were high, crude oil output was high with low demand for petroleum products with significant refining capacity from four functioning refineries. However, with time, the demand for petroleum products grew above refinery output resulting in a supply gap. The government stranglehold on the downstream sector and the price control meant that little private investment flowed into the sector creating serious market distortions (NEITI, 2023).

By 1978, the country was experiencing severe fuel shortages leading to the first attempt to reduce fuel subsidy payments. The new government policy involved reducing the subsidy gap from the initial 35.7% to only 2%. This saw a jump of 74% in petrol prices. Subsidy has increased to 65% in 1980 to make up for the rise in crude oil price from $14 to $40 per barrel. These continuous upheavals severely affected Nigeria's earnings and worsening her balance of payment problems. Hence, the removal of fossil fuel subsidies became a strategic reform agenda. In 2005, the government deregulated the petroleum sector and set up the Petroleum Support Fund (PSF) Scheme to take care of the subsidy payments.

Although, fossil fuel subsidies may be justified primarily as supporting social welfare, studies show that their benefits accrue mainly to richer households that consume more energy. Kerosene (which low-income households tend to use more) subsidies are also often captured by intermediaries in the parallel market, who sell it at far above the price set by the PPPRA. Moreso, even though electricity subsidies include lifeline tariffs that are supposed to be progressive, the poorest households often lack access to electricity and hence do not benefit from these subsidies. Finally, as with other countries, fossil fuels subsidies in Nigeria creates a disincentive for investments in efficiency such as for upgrading and maintaining energy infrastructure, which can in turn be linked to frequent blackouts and oil spills in the country, and to over-consumption and inefficient use of fossil fuels, all of which aggravate fuel shortages (Whitley and Van der Burg, 2015).

To mitigate these issues, the government in 2005 adopted a 15-year plan to achieve cost reflective energy pricing across the various energy sources. Electricity reforms were carried out in 2005 with the unbundling of the Nigeria Electric Power Authority. Petrol reforms was scheduled for 2011. Towards the end of 2011, President Jonathan released public statements on the cost of subsidies and how the savings on their removal would be channeled to infrastructural development as well as health and education. The government created a safety net programme: the Subsidy Reinvestment and Empowerment (SURE) Programme. In January 2012, only six weeks after the SURE Programme was presented to the public, the government raised the price of petrol to full cost-recovery level, leading to a 117% price increase. The relatively short notice and a low level of trust in the government resulted in a nationwide protest and strikes. In response, the government reduced the price increase from 117% to 49% by mid-January 2012, meaning that the country's petrol subsidies were reduced significantly but not eliminated.

Over the next decade, subsidy payments became a huge fiscal burden for the country. NEITI (2023) reports that in the periods between 2005 and 2021, Nigeria spent N13.7 trillion to finance fuel subsidy. Yet crude oil output which is primarily used to finance subsidy spending has been on the decline (NEITI, 2023). Hence, subsequent governments continued to advocate for the complete removal of fossil fuel subsidies. Not surprisingly, on May 29th, 2023, the newly sworn in president, Bola Tinubu announced the complete removal of petroleum subsidy. This latest policy move has generated a lot of controversy in the country. However, the government adopted several social intervention programmes to cushion the effect of the price hikes, chief of which was a minimum wage review to take effect in January of 2024 with a N35,000 salary increment to bridge the gap in the immediate for the 6 months before 2024. N25,000 cash transfer was also approved for poor households in the same period. Approval was also given for the purchase of gas run buses for mass transportation.

xiii. Peru

Since the early 2000s, Peru relied on its fuel price stabilization fund and tax exemptions on fossil fuel purchases to control the price of fossil fuels. However, following the rapid rise in international oil prices between 2006 and 2008, the stabilization fund was converted into a subsidy regime. The total amount the government paid for subsidies peaked at $1.7 billion in 2008 representing an average transfer of $55 per person. The period between 2004 and 2008 also saw reductions in fuel excise tax which cost an additional 0.5% of GDP annually (IISD-GSI, 2016).

The cost and volatility of the subsidies system led to reforms resulting in price increment of approximately 75% for gasoline, 50% for diesel and 5% for LPG (IISD-GSI, 2016). To mitigate the effect of fossil fuel price increases, the existing conditional cash transfer programme was expanded and the government introduced a cook stove distribution programme for LPG and improved biomass in 2009 and a targeted LPG voucher scheme in 2012. By the end of 2014, around 1 million low-income families had been provided with an LPG or improved biomass cook stove, 900,000 families were receiving monthly LPG vouchers and 800,000 families were benefiting from regular cash transfers (IISD-GSI, 2016). Interestingly, this various government strategy resulted in subsidy per person falling to around $17 from the initial $55. Peru's reforms have been adjudged to be successful given that properly targeted its social interventions to benefit poor households the most (IISD-GSI, 2016).

xiv. The Philippines

The Philippines adopted a gradual phaseout of fossil fuel subsidies between 1996 and 2001. In other to cushion the effect of fuel price hikes, it invested heavily in safety nets and renewable energy. With the successful implementation of the reforms, the Philippines introduced fuel taxes to further achieve its green energy policy. These various reforms strategy have yielded results such as a decline in the consumption of fossil fuels, an increase in energy efficiency as well as a stabilized emission per kilowatt-hour generated (GSI, 2016).

The successful implementation of fossil fuel reforms in the Philippines provides important lessons for countries contemplating reforms. The country's reforms strategies were wide ranging and involved deregulating the downstream oil and electricity sectors. The oil price stabilization fund was cancelled and the National Power Corporation was privatized. As an importer of energy, the Philippines mitigated the effect of rising oil price by implementing targeted cash transfers to low -income households and specific sectors. A range of other measures include a transition period where prices were adjusted monthly, a special rate for the elderly, the vulnerable and low-income electricity users as well as a one-off cash transfer to electricity consumers with monthly consumption of 100 kilowatts hour or less. This was funded from the value added tax on oil. Moreso, a Public Transport Assistance Programme disbursed through debit and smart cards was targeted at jeepney and motorised tricycle operators whose fares are regulated and hence were unable to review their fares to reflect the change in fuel price. The Philippines has managed to turn energy from a drain on the government budget to a gain, by removing heavy fossil fuel subsidy expenditure and turning it into tax revenue.

Similarly, reforms in the electricity sector followed the same trajectory. The sector was privatized in 2001, with the major aim of reducing the fiscal burden of energy subsidies, introducing competition, increasing private sector participation and ensuring efficient and reliable energy supply. To finance the expansion of electricity networks and investments in renewable energy, VAT was raised to 12 per cent on gasoline; with an addition of excise tax while VAT was set at 0 per cent for renewables.

APPENDIX II

OBJECTIVE 1

i. System GMM Output

```
. xtabond2 co2 L.co2 popden aff tec ffs popdenffs, gmm(L.co2, lag(2 2) collapse) iv(popden aff tec ffs popdenff
> s, equation(diff)) iv(popden aff tec ffs popdenffs, equation(level)) twostep robust small
Favoring space over speed. To switch, type or click on mata: mata set matafavor speed, perm.

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 13                      Obs per group: min =        13
F(6, 67)      =  68933.10                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         co2 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .9681307   .0167076    57.95   0.000     .9347823    1.001479
             |
      popden |   .0072657   .0100877     0.72   0.474    -.0128695    .0274008
         aff |   .0087299   .0036274     2.41   0.019     .0014896    .0159703
         tec |   .0048774   .0108506     0.45   0.655    -.0167805    .0265352
         ffs |   .0047012   .0033672     1.40   0.167    -.0020198    .0114222
   popdenffs |  -.0023944   .0016468    -1.45   0.151    -.0056814    .0008926
       _cons |  -.0050991    .022489    -0.23   0.821    -.0499874    .0397892
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(popden aff tec ffs popdenffs)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.L.co2 collapsed
```



```
Instruments for levels equation
  Standard
    popden aff tec ffs popdenffs
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    DL.L.co2 collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -4.79  Pr > z =  0.000
Arellano-Bond test for AR(2) in first differences: z =  -0.47  Pr > z =  0.637
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(6)    = 138.32  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(6)    =  18.81  Prob > chi2 =  0.004
  (Robust, but weakened by many instruments.)

Difference-in-Hansen tests of exogeneity of instrument subsets:
  GMM instruments for levels
    Hansen test excluding group:     chi2(5)    =  16.88  Prob > chi2 =  0.005
    Difference (null H = exogenous): chi2(1)    =   1.93  Prob > chi2 =  0.165
  gmm(L.co2, collapse lag(2 2))
    Hansen test excluding group:     chi2(4)    =  14.60  Prob > chi2 =  0.006
    Difference (null H = exogenous): chi2(2)    =   4.21  Prob > chi2 =  0.122
  iv(popden aff tec ffs popdenffs, eq(diff))
    Hansen test excluding group:     chi2(1)    =   2.65  Prob > chi2 =  0.103
    Difference (null H = exogenous): chi2(5)    =  16.16  Prob > chi2 =  0.006
  iv(popden aff tec ffs popdenffs, eq(level))
    Hansen test excluding group:     chi2(1)    =   4.97  Prob > chi2 =  0.026
    Difference (null H = exogenous): chi2(5)    =  13.84  Prob > chi2 =  0.017
```

```
. xtabond2 ghg L.ghg popden aff tec ffs popdenffs, gmm(L.ghg, lag(2 2) collapse) iv(p
Favoring space over speed. To switch, type or click on mata: mata set matafavor speed

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 13                      Obs per group: min =        13
F(6, 67)      =  10381.55                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         ghg | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   .9309714   .0331597    28.08   0.000     .8647843    .9971584
             |
      popden |   .0060342   .0138674     0.44   0.665    -.0216452    .0337136
         aff |   .0141352   .0076472     1.85   0.069    -.0011285     .029399
         tec |   .0576125   .0332678     1.73   0.088    -.0087902    .1240153
         ffs |   .0049025   .0023567     2.08   0.041     .0001985    .0096065
   popdenffs |  -.0022461   .0015993    -1.40   0.165    -.0054384    .0009462
       _cons |   .0059182   .0472035     0.13   0.901    -.0883003    .1001368
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(popden aff tec ffs popdenffs)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.L.ghg collapsed
Instruments for levels equation
  Standard
    popden aff tec ffs popdenffs

  _cons
 GMM-type (missing=0, separate instruments for each period unless collapsed)
   DL.L.ghg collapsed
------------------------------------------------------------------------------
rellano-Bond test for AR(1) in first differences: z =  -2.45  Pr > z =  0.014
rellano-Bond test for AR(2) in first differences: z =  -1.03  Pr > z =  0.303
------------------------------------------------------------------------------
argan test of overid. restrictions: chi2(6)    = 224.59  Prob > chi2 =  0.000
 (Not robust, but not weakened by many instruments.)
ansen test of overid. restrictions: chi2(6)    =   8.31  Prob > chi2 =  0.216
 (Robust, but weakened by many instruments.)

ifference-in-Hansen tests of exogeneity of instrument subsets:
 GMM instruments for levels
   Hansen test excluding group:     chi2(5)    =   8.31  Prob > chi2 =  0.140
   Difference (null H = exogenous): chi2(1)    =   0.01  Prob > chi2 =  0.925
 gmm(L.ghg, collapse lag(2 2))
   Hansen test excluding group:     chi2(4)    =   7.40  Prob > chi2 =  0.116
   Difference (null H = exogenous): chi2(2)    =   0.92  Prob > chi2 =  0.633
 iv(popden aff tec ffs popdenffs, eq(diff))
   Hansen test excluding group:     chi2(1)    =   0.86  Prob > chi2 =  0.354
   Difference (null H = exogenous): chi2(5)    =   7.45  Prob > chi2 =  0.189
 iv(popden aff tec ffs popdenffs, eq(level))
   Hansen test excluding group:     chi2(1)    =   3.57  Prob > chi2 =  0.059
   Difference (null H = exogenous): chi2(5)    =   4.75  Prob > chi2 =  0.447
```

```
. xtabond2 ghg L.ghg popden aff tec ffs tecffs, gmm(L.ghg, lag(2 2) collapse) iv(popden aff tec ffs tecffs, equ
> ation(diff)) iv(popden aff tec ffs tecffs, equation(level)) twostep robust small
Favoring space over speed. To switch, type or click on mata: mata set matafavor speed, perm.

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 13                      Obs per group: min =        13
F(6, 67)      =  10192.57                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         ghg | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   .9351369   .0303354    30.83   0.000     .8745872    .9956865
             |
      popden |   -.007459   .0146115    -0.51   0.611    -.0366235    .0217056
         aff |   .0145312    .007546     1.93   0.058    -.0005307     .029593
         tec |   .0365485   .0312175     1.17   0.246    -.0257618    .0988589
         ffs |  -.0007717   .0033117    -0.23   0.816    -.0073819    .0058385
      tecffs |   .0027002   .0054818     0.49   0.624    -.0082416     .013642
       _cons |   .0330615   .0516194     0.64   0.524    -.0699712    .1360941
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(popden aff tec ffs tecffs)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.L.ghg collapsed
Instruments for levels equation
  Standard
    popden aff tec ffs tecffs
```



```
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    DL.L.ghg collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -2.45  Pr > z =  0.014
Arellano-Bond test for AR(2) in first differences: z =  -1.01  Pr > z =  0.312
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(6)    = 228.12  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(6)    =   8.74  Prob > chi2 =  0.189
  (Robust, but weakened by many instruments.)

Difference-in-Hansen tests of exogeneity of instrument subsets:
  GMM instruments for levels
    Hansen test excluding group:     chi2(5)    =   8.73  Prob > chi2 =  0.120
    Difference (null H = exogenous): chi2(1)    =   0.01  Prob > chi2 =  0.931
  gmm(L.ghg, collapse lag(2 2))
    Hansen test excluding group:     chi2(4)    =   7.73  Prob > chi2 =  0.102
    Difference (null H = exogenous): chi2(2)    =   1.01  Prob > chi2 =  0.604
  iv(popden aff tec ffs tecffs, eq(diff))
    Hansen test excluding group:     chi2(1)    =   0.84  Prob > chi2 =  0.358
    Difference (null H = exogenous): chi2(5)    =   7.89  Prob > chi2 =  0.162
  iv(popden aff tec ffs tecffs, eq(level))
    Hansen test excluding group:     chi2(1)    =   3.63  Prob > chi2 =  0.057
    Difference (null H = exogenous): chi2(5)    =   5.11  Prob > chi2 =  0.402
```

```
. xtabond2 ghg L.ghg popden aff tec ffs affffs, gmm(L.ghg, lag(2 2) collapse) iv(popden aff tec ffs affffs, equ
> ation(diff)) iv(popden aff tec ffs affffs, equation(level)) twostep robust small
Favoring space over speed. To switch, type or click on mata: mata set matafavor speed, perm.

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 13                      Obs per group: min =        13
F(6, 67)      = 238962.19                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         ghg | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   .9920311   .0147978    67.04   0.000     .9624946    1.021568
             |
      popden |   .0009067   .0027984     0.32   0.747    -.0046788    .0064923
         aff |   .0060313    .006324     0.95   0.344    -.0065915    .0186541
         tec |   .0129621   .0096343     1.35   0.183    -.0062681    .0321923
         ffs |   .0030621   .0036784     0.83   0.408    -.0042801    .0104043
      affffs |  -.0006604   .0007644    -0.86   0.391     -.002186    .0008653
       _cons |  -.0177274   .0128137    -1.38   0.171    -.0433036    .0078489
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(popden aff tec ffs affffs)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.L.ghg collapsed
Instruments for levels equation
  Standard
```



```
  Standard
    popden aff tec ffs affffs
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    DL.L.ghg collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -2.41  Pr > z =  0.016
Arellano-Bond test for AR(2) in first differences: z =  -0.85  Pr > z =  0.394
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(6)    = 214.10  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(6)    =  22.75  Prob > chi2 =  0.001
  (Robust, but weakened by many instruments.)

Difference-in-Hansen tests of exogeneity of instrument subsets:
  GMM instruments for levels
    Hansen test excluding group:     chi2(5)    =  22.60  Prob > chi2 =  0.000
    Difference (null H = exogenous): chi2(1)    =   0.15  Prob > chi2 =  0.698
  gmm(L.ghg, collapse lag(2 2))
    Hansen test excluding group:     chi2(4)    =  21.47  Prob > chi2 =  0.000
    Difference (null H = exogenous): chi2(2)    =   1.29  Prob > chi2 =  0.525
  iv(popden aff tec ffs affffs, eq(diff))
    Hansen test excluding group:     chi2(1)    =   2.88  Prob > chi2 =  0.090
    Difference (null H = exogenous): chi2(5)    =  19.87  Prob > chi2 =  0.001
  iv(popden aff tec ffs affffs, eq(level))
    Hansen test excluding group:     chi2(1)    =   3.35  Prob > chi2 =  0.067
    Difference (null H = exogenous): chi2(5)    =  19.40  Prob > chi2 =  0.002
```

ii. Fixed and Random Effects Output

```
. ****CO2 emissions*******
.
. xtreg co2 L.co2 popden aff tec ffs popdenffs, fe

Fixed-effects (within) regression               Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.8206                                         min =         13
     Between = 0.8587                                         avg =       13.0
     Overall = 0.8585                                         max =         13

                                                F(6, 810)         =     617.49
corr(u_i, Xb) = 0.0424                          Prob > F          =     0.0000

------------------------------------------------------------------------------
         co2 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .7636497   .0176542    43.26   0.000     .7289963    .7983032
             |
      popden |   .0297609   .0314494     0.95   0.344    -.0319709    .0914927
         aff |   .2913122   .0303431     9.60   0.000     .2317518    .3508727
         tec |   .1556693   .0290156     5.37   0.000     .0987147    .2126239
         ffs |   .0004161   .0028665     0.15   0.885    -.0052105    .0060427
   popdenffs |  -.0000589   .0013825    -0.04   0.966    -.0027725    .0026547
       _cons |  -1.219706   .1566592    -7.79   0.000    -1.527212   -.9122002
-------------+----------------------------------------------------------------
     sigma_u |   .3633479
     sigma_e |  .03308802
         rho |   .9917755   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(67, 810) = 5.16                     Prob > F = 0.0000
```

```
. xtreg co2 L.co2 popden aff tec ffs popdenffs, re

Random-effects GLS regression                   Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.7991                                         min =         13
     Between = 0.9998                                         avg =       13.0
     Overall = 0.9985                                         max =         13

                                                Wald chi2(6)      =  267269.32
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000

------------------------------------------------------------------------------
         co2 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .9924348   .0019915   498.35   0.000     .9885316    .9963379
             |
      popden |   .0068248   .0058025     1.18   0.240    -.0045478    .0181974
         aff |   .0033694   .0017257     1.95   0.051    -.0000128    .0067516
         tec |   .0056331   .0075847     0.74   0.458    -.0092328    .0204989
         ffs |   .0020907   .0017279     1.21   0.226    -.0012958    .0054773
   popdenffs |  -.0013614   .0008812    -1.54   0.122    -.0030886    .0003657
       _cons |  -.0102853   .0153652    -0.67   0.503    -.0404005    .0198298
-------------+----------------------------------------------------------------
     sigma_u |  .01041556
     sigma_e |  .03308802
         rho |  .09015516   (fraction of variance due to u_i)
------------------------------------------------------------------------------

. estimates store re_model

. estimates store fe_model

. xtoverid

Test of overidentifying restrictions: fixed vs random effects
Cross-section time-series model: xtreg re
Sargan-Hansen statistic 204.443  Chi-sq(6)    P-value = 0.0000
```



```
. xtreg co2 L.co2 popden aff tec ffs affffs, fe

Fixed-effects (within) regression               Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.8215                                         min =         13
     Between = 0.8610                                         avg =       13.0
     Overall = 0.8607                                         max =         13

                                                F(6, 810)         =     621.32
corr(u_i, Xb) = 0.0580                          Prob > F          =     0.0000

------------------------------------------------------------------------------
         co2 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .7591523   .0177476    42.77   0.000     .7243156     .793989
             |
      popden |   .0321985   .0293223     1.10   0.272    -.0253581    .0897552
         aff |   .3047208    .030972     9.84   0.000     .2439259    .3655158
         tec |   .1537552   .0289441     5.31   0.000     .0969409    .2105696
         ffs |   .0168406   .0082121     2.05   0.041     .0007212      .03296
      affffs |  -.0030804   .0015165    -2.03   0.043     -.006057   -.0001038
       _cons |  -1.290719   .1590391    -8.12   0.000    -1.602897   -.9785421
-------------+----------------------------------------------------------------
     sigma_u |   .3607448
     sigma_e |   .0330041
         rho |  .99169928   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(67, 810) = 5.30                     Prob > F = 0.0000
```

```
. xtreg co2 L.co2 popden aff tec ffs affffs, re

Random-effects GLS regression                   Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.7993                                         min =         13
     Between = 0.9998                                         avg =       13.0
     Overall = 0.9984                                         max =         13

                                                Wald chi2(6)      =  260539.00
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000

------------------------------------------------------------------------------
         co2 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .9923651   .0020519   483.63   0.000     .9883435    .9963868
             |
      popden |   -.000337   .0033366    -0.10   0.920    -.0068766    .0062025
         aff |   .0054442   .0035505     1.53   0.125    -.0015147    .0124031
         tec |   .0059633   .0076907     0.78   0.438    -.0091102    .0210368
         ffs |   .0016404   .0026343     0.62   0.533    -.0035227    .0068035
      affffs |  -.0004378   .0005427    -0.81   0.420    -.0015016    .0006259
       _cons |  -.0062818   .0184788    -0.34   0.734    -.0424995     .029936
-------------+----------------------------------------------------------------
     sigma_u |  .01062306
     sigma_e |   .0330041
         rho |  .09387532   (fraction of variance due to u_i)
------------------------------------------------------------------------------

. estimates store re_model

. estimates store fe_model

. xtoverid

Test of overidentifying restrictions: fixed vs random effects
Cross-section time-series model: xtreg re
Sargan-Hansen statistic 210.414  Chi-sq(6)    P-value = 0.0000
```

```
. xtreg co2 L.co2 popden aff tec ffs tecffs, fe

Fixed-effects (within) regression               Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.8212                                         min =         13
     Between = 0.8533                                         avg =       13.0
     Overall = 0.8531                                         max =         13

                                                F(6, 810)         =     620.04
corr(u_i, Xb) = 0.0236                          Prob > F          =     0.0000

------------------------------------------------------------------------------
         co2 | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .7633884   .0176249    43.31   0.000     .7287926    .7979842
             |
      popden |   .0348101   .0295016     1.18   0.238    -.0230985    .0927187
         aff |   .2984007   .0305877     9.76   0.000     .2383603    .3584411
         tec |    .121804   .0354605     3.43   0.001     .0521988    .1914093
         ffs |  -.0041733   .0029095    -1.43   0.152    -.0098843    .0015377
      tecffs |   .0069138   .0041752     1.66   0.098    -.0012816    .0151092
       _cons |  -1.241703   .1557998    -7.97   0.000    -1.547522   -.9358841
-------------+----------------------------------------------------------------
     sigma_u |  .36998527
     sigma_e |   .0330322
         rho |  .99209216   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(67, 810) = 5.24                     Prob > F = 0.0000
```

```
. xtreg co2 L.co2 popden aff tec ffs tecffs, re

Random-effects GLS regression                   Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.7993                                         min =         13
     Between = 0.9998                                         avg =       13.0
     Overall = 0.9984                                         max =         13

                                                Wald chi2(6)      =  262413.92
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000

------------------------------------------------------------------------------
         co2 | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .9928137   .0019973   497.07   0.000      .988899    .9967284
             |
      popden |    .000122   .0033444     0.04   0.971     -.006433     .006677
         aff |    .003118   .0017213     1.81   0.070    -.0002556    .0064917
         tec |  -.0055216   .0112064    -0.49   0.622    -.0274857    .0164425
         ffs |  -.0022104   .0013267    -1.67   0.096    -.0048107    .0003899
      tecffs |   .0029085   .0019807     1.47   0.142    -.0009736    .0067905
       _cons |   .0098699    .012165     0.81   0.417     -.013973    .0337128
-------------+----------------------------------------------------------------
     sigma_u |  .01057781
     sigma_e |   .0330322
         rho |   .0930079   (fraction of variance due to u_i)
------------------------------------------------------------------------------

. estimates store re_model

. estimates store fe_model

. xtoverid

Test of overidentifying restrictions: fixed vs random effects
Cross-section time-series model: xtreg re
Sargan-Hansen statistic 207.102  Chi-sq(6)    P-value = 0.0000
```

Objective two

```
. xtabond2 co2 L.co2 pop aff aff2 tec ffs affffs aff2ffs, gmm(L.co2 pop tec aff ffs, lag(2 2)
collapse) iv(pop tec affffs aff2ffs, equation(diff)) twostep robust small
Favoring speed over space. To switch, type or click on mata: mata set matafavor space, perm.
Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 15                      Obs per group: min =        13
F(8, 67)      =   1164.29                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         co2 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |    .961454   .0406936    23.63   0.000     .8802292    1.042679
             |
         pop |   -.038642   .0994358    -0.39   0.699    -.2371166    .1598326
         aff |   .3516022   .4107172     0.86   0.395    -.4681927    1.171397
        aff2 |  -.0368299   .0405061    -0.91   0.366    -.1176805    .0440207
         tec |   .1947508    .087943     2.21   0.030     .0192159    .3702858
         ffs |  -.1660193   .1686579    -0.98   0.328     -.502662    .1706233
      affffs |   .0567979   .0603064     0.94   0.350    -.0635742    .1771701
```

```
     aff2ffs |  -.0047585   .0053521    -0.89   0.377    -.0154414    .0059244
       _cons |  -.5260397   .9663238    -0.54   0.588     -2.45483    1.402751
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(pop tec affffs aff2ffs)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.(L.co2 pop tec aff ffs) collapsed
Instruments for levels equation
  Standard
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    DL.(L.co2 pop tec aff ffs) collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -4.69  Pr > z =  0.000
Arellano-Bond test for AR(2) in first differences: z =  -0.61  Pr > z =  0.542
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(6)    =   6.62  Prob > chi2 =  0.358
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(6)    =   3.69  Prob > chi2 =  0.719
  (Robust, but weakened by many instruments.)

Difference-in-Hansen tests of exogeneity of instrument subsets:
  GMM instruments for levels
    Hansen test excluding group:     chi2(1)    =   1.28  Prob > chi2 =  0.258
    Difference (null H = exogenous): chi2(5)    =   2.41  Prob > chi2 =  0.790
  iv(pop tec affffs aff2ffs, eq(diff))
    Hansen test excluding group:     chi2(2)    =   0.28  Prob > chi2 =  0.870
    Difference (null H = exogenous): chi2(4)    =   3.41  Prob > chi2 =  0.492
```

```
. *****CO2 emissions*******
. xtreg co2 L.co2 pop aff aff2 tec ffs affffs aff2ffs, fe robust

Fixed-effects (within) regression               Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.8246                                         min =         13
     Between = 0.8293                                         avg =       13.0
     Overall = 0.8293                                         max =         13

                                                F(8, 67)          =     251.54
corr(u_i, Xb) = -0.1840                         Prob > F          =     0.0000

                                   (Std. err. adjusted for 68 clusters in cid)
------------------------------------------------------------------------------
             |               Robust
         co2 | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .7247558   .0636217    11.39   0.000     .5977663    .8517452
             |
         pop |   .1381466   .0875041     1.58   0.119    -.0365122    .3128055
         aff |   .1074132   .2456541     0.44   0.663    -.3829144    .5977407
        aff2 |   .0227549   .0240122     0.95   0.347    -.0251736    .0706835
         tec |   .1780561   .1140668     1.56   0.123    -.0496221    .4057343
         ffs |  -.0006358   .0654234    -0.01   0.992    -.1312214    .1299498
      affffs |   .0031104   .0232915     0.13   0.894    -.0433797    .0496004
     aff2ffs |  -.0005367   .0020499    -0.26   0.794    -.0046284     .003555
       _cons |  -1.788018   1.057852    -1.69   0.096      -3.8995    .3234634
-------------+----------------------------------------------------------------
     sigma_u |  .40593058
     sigma_e |  .03275934
         rho |  .99352936   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

```
Random-effects GLS regression                   Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.7992                                         min =         13
     Between = 0.9998                                         avg =       13.0
     Overall = 0.9985                                         max =         13

                                                Wald chi2(8)      =  867172.70
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000

                                    (Std. err. adjusted for 68 clusters in cid)
------------------------------------------------------------------------------
             |               Robust
         co2 | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         co2 |
         L1. |   .9853592   .0022846   431.30   0.000     .9808814     .989837
             |
         pop |   .0131208   .0029093     4.51   0.000     .0074187    .0188229
         aff |  -.0036712   .0212154    -0.17   0.863    -.0452526    .0379103
        aff2 |   .0006504   .0020645     0.32   0.753     -.003396    .0046968
         tec |   .0088131    .007521     1.17   0.241    -.0059278    .0235541
         ffs |  -.0028008   .0089347    -0.31   0.754    -.0203125    .0147109
       affffs |    .001101   .0036601     0.30   0.764    -.0060726    .0082747
      aff2ffs |  -.0001311   .0003651    -0.36   0.719    -.0008467    .0005845
       _cons |  -.0629584   .0538085    -1.17   0.242    -.1684211    .0425042
-------------+----------------------------------------------------------------
     sigma_u |  .00911135
     sigma_e |  .03275934
         rho |  .07180191   (fraction of variance due to u_i)
------------------------------------------------------------------------------

.
. estimates store re_model

. estimates store fe_model

. xtoverid

Test of overidentifying restrictions: fixed vs random effects
Cross-section time-series model: xtreg re  robust cluster(cid)
Sargan-Hansen statistic  61.268  Chi-sq(8)    P-value = 0.0000
```



```
 *****Robustness test******
.
. ****Greenhouse gas*****
. xtreg ghg L.ghg pop aff aff2 tec ffs affffs aff2ffs, fe robust

Fixed-effects (within) regression               Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.7818                                         min =         13
     Between = 0.8600                                         avg =       13.0
     Overall = 0.8598                                         max =         13

                                                F(8, 67)          =     237.61
corr(u_i, Xb) = 0.0774                          Prob > F          =     0.0000

                                    (Std. err. adjusted for 68 clusters in cid)
------------------------------------------------------------------------------
             |               Robust
         ghg | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   .6780892    .089607     7.57   0.000      .499233    .8569455
             |
         pop |   .1667459   .0866813     1.92   0.059    -.0062706    .3397624
         aff |   .0143985   .1839498     0.08   0.938    -.3527668    .3815639
        aff2 |   .0215683   .0144891     1.49   0.141    -.0073521    .0504886
         tec |   .1231892   .0524328     2.35   0.022     .0185329    .2278456
         ffs |  -.0295784   .0453396    -0.65   0.516    -.1200766    .0609198
       affffs |   .0116634   .0161359     0.72   0.472     -.020544    .0438709
      aff2ffs |  -.0011106   .0014154    -0.78   0.435    -.0039357    .0017146
       _cons |  -1.285888   .9801083    -1.31   0.194    -3.242193    .6704163
-------------+----------------------------------------------------------------
     sigma_u |  .34489345
     sigma_e |  .02276805
         rho |  .99566096   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

```
Random-effects GLS regression                   Number of obs     =        884
Group variable: cid                             Number of groups  =         68

R-squared:                                      Obs per group:
     Within  = 0.7423                                         min =         13
     Between = 0.9999                                         avg =       13.0
     Overall = 0.9992                                         max =         13

                                                Wald chi2(8)      =   1.63e+06
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000

                                     (Std. err. adjusted for 68 clusters in cid)
------------------------------------------------------------------------------
             |               Robust
         ghg | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   .9969249    .001662   599.82   0.000     .9936674    1.000182
             |
         pop |   .0019785    .002033     0.97   0.330    -.0020061     .005963
         aff |   .0065245   .0130391     0.50   0.617    -.0190317    .0320807
        aff2 |  -.0003934   .0012694    -0.31   0.757    -.0028815    .0020946
         tec |   .0100305   .0044304     2.26   0.024      .001347     .018714
         ffs |   .0023618   .0056596     0.42   0.676    -.0087308    .0134545
      affffs |   -.000976    .002309    -0.42   0.673    -.0055016    .0035495
     aff2ffs |   .0000768   .0002297     0.33   0.738    -.0003733     .000527
       _cons |  -.0275441      .0338    -0.81   0.415    -.0937908    .0387026
-------------+----------------------------------------------------------------
     sigma_u |  .00616197
     sigma_e |  .02276805
         rho |  .06824762   (fraction of variance due to u_i)
------------------------------------------------------------------------------

.
. estimates store re_model

. estimates store fe_model

. xtoverid

Test of overidentifying restrictions: fixed vs random effects
Cross-section time-series model: xtreg re  robust cluster(cid)
Sargan-Hansen statistic  51.605  Chi-sq(8)    P-value = 0.0000
```


.

Objective 3

```
. *******GHG emissions********
. xtabond2 ghg L.ghg aff aff2 ffsr  affffsr aff2ffsr governance min serv, gmm(L.ghg ffsr governance, la
g(2 2) c
> ollapse) iv(aff affffsr aff2ffsr governance min serv, equation(diff)) twostep robust small
Favoring speed over space. To switch, type or click on mata: mata set matafavor space, perm.

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 13                      Obs per group: min =        13
F(9, 67)      =    228.13                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         ghg | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   1.011006   .2288853     4.42   0.000     .5541491    1.467863
             |
         aff |   2.863089   1.346951     2.13   0.037     .1745639    5.551614
        aff2 |  -.2537499   .1334615    -1.90   0.062    -.5201401    .0126404
        ffsr |  -.1570272   1.165673    -0.13   0.893    -2.483721    2.169666
     affffsr |   .0553176   .4656173     0.12   0.906    -.8740585    .9846937
    aff2ffsr |  -.0044648   .0445868    -0.10   0.921    -.0934603    .0845308
  governance |   .0073134    .019374     0.38   0.707    -.0313574    .0459841
         min |   .0146778   .0075589     1.94   0.056    -.0004098    .0297654
        serv |  -.0590525   .0687659    -0.86   0.394    -.1963099    .0782049
       _cons |  -7.496638    3.41281    -2.20   0.032    -14.30863   -.6846413
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(aff affffsr aff2ffsr governance min serv)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.(L.ghg ffsr governance) collapsed
Instruments for levels equation
  Standard
     cons
```

```
. xtabond2 ghg L.ghg aff aff2 ffsr affffsr aff2ffsr bpp reneg governance, gmm(L.ghg ffsr governance, la
g(2 2) c
> ollapse) iv(aff affffsr aff2ffsr governance bpp reneg, equation(diff)) twostep robust small
Favoring speed over space. To switch, type or click on mata: mata set matafavor space, perm.

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: cid                             Number of obs      =       884
Time variable : yr                              Number of groups   =        68
Number of instruments = 13                      Obs per group: min =        13
F(9, 67)      =    153.56                                      avg =     13.00
Prob > F      =     0.000                                      max =        13
------------------------------------------------------------------------------
             |              Corrected
         ghg | Coefficient  std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
         ghg |
         L1. |   .9610404   .2337913     4.11   0.000     .4943909     1.42769
             |
         aff |    2.40342    1.52382     1.58   0.119    -.6381385    5.444978
        aff2 |  -.2041585   .1471932    -1.39   0.170    -.4979574    .0896405
        ffsr |  -.5031849   1.486418    -0.34   0.736    -3.470087    2.463717
     affffsr |   .1943281   .5948702     0.33   0.745    -.9930378    1.381694
    aff2ffsr |  -.0179085   .0569826    -0.31   0.754    -.1316462    .0958292
         bpp |   .0039702   .0072942     0.54   0.588     -.010589    .0185294
       reneg |   -.084916   .0401849    -2.11   0.038    -.1651254   -.0047066
  governance |   .0089597   .0170219     0.53   0.600    -.0250161    .0429355
       _cons |  -6.421068   3.977375    -1.61   0.111    -14.35994    1.517806
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(aff affffsr aff2ffsr governance bpp reneg)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L2.(L.ghg ffsr governance) collapsed
Instruments for levels equation
  Standard
    _cons
     DL.(L.ghg ffsr governance) collapsed
 ------------------------------------------------------------------------------
 Arellano-Bond test for AR(1) in first differences: z =  -1.94  Pr > z =  0.053
 Arellano-Bond test for AR(2) in first differences: z =  -0.84  Pr > z =  0.403
 ------------------------------------------------------------------------------
 Sargan test of overid. restrictions: chi2(3)    = 21.17  Prob > chi2 =  0.000
   (Not robust, but not weakened by many instruments.)
 Hansen test of overid. restrictions: chi2(3)    =  1.15  Prob > chi2 =  0.765
   (Robust, but weakened by many instruments.)

 Difference-in-Hansen tests of exogeneity of instrument subsets:
   GMM instruments for levels
     Hansen test excluding group:     chi2(0)    =  0.00  Prob > chi2 =      .
     Difference (null H = exogenous): chi2(3)    =  1.15  Prob > chi2 =  0.765
```



```
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    DL.(L.ghg ffsr governance) collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -2.08  Pr > z =  0.038
Arellano-Bond test for AR(2) in first differences: z =  -1.20  Pr > z =  0.231
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(3)    = 30.23  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(3)    =  0.57  Prob > chi2 =  0.904
  (Robust, but weakened by many instruments.)

Difference-in-Hansen tests of exogeneity of instrument subsets:
  GMM instruments for levels
    Hansen test excluding group:     chi2(0)    =  0.00  Prob > chi2 =      .
    Difference (null H = exogenous): chi2(3)    =  0.57  Prob > chi2 =  0.904
```

APPENDIX III

Objective four

```
xtset cid yr

Panel variable: cid (strongly balanced)
 Time variable: yr, 2005 to 2023
         Delta: 1 unit

. csdid co2, ivar(cid) time(yr) gvar(treatmenttime) method(dripw)
No never treated observations found. Using Not yet treated data
...............xxx..............xxx.............
.xxx..............xxx..............xxx..........
.....xxx..............xxx..............xxx......
.........xxx..............xxx..............xxxxx
xxxxxxxxxxxxxxxx


Difference-in-difference with Multiple Time Periods

                                                   Number of obs = 816
Outcome model  : least squares
Treatment model: inverse probability
------------------------------------------------------------------------------
             | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
g2010        |
 t_2005_2006 |  -.0055531   .0102166    -0.54   0.587    -.0255774    .0144711
 t_2006_2007 |   .0122269   .0087764     1.39   0.164    -.0049745    .0294283
 t_2007_2008 |    .007853   .0085133     0.92   0.356    -.0088327    .0245387
 t_2008_2009 |   .0039957   .0102852     0.39   0.698     -.016163    .0241543
 t_2009_2010 |   .0044878   .0141391     0.32   0.751    -.0232243    .0321999
 t_2009_2011 |  -.0119159    .020115    -0.59   0.554    -.0513406    .0275087
 t_2009_2012 |  -.0228554    .023128    -0.99   0.323    -.0681855    .0224747
 t_2009_2013 |  -.0185636   .0238331    -0.78   0.436    -.0652757    .0281485
 t_2009_2014 |  -.0251427   .0287044    -0.88   0.381    -.0814024    .0311169
 t_2009_2015 |  -.0492128   .0429597    -1.15   0.252    -.1334121    .0349866
 t_2009_2016 |  -.0800167   .0707566    -1.13   0.258     -.218697    .0586636
 t_2009_2017 |  -.1242175   .0711141    -1.75   0.081    -.2635985    .0151634
 t_2009_2018 |   -.190803   .0899397    -2.12   0.034    -.3670817   -.0145244
 t_2009_2019 |  -.1964279   .1079818    -1.82   0.069    -.4080684    .0152125
 t_2009_2020 |  -.4036937   .0542855    -7.44   0.000    -.5100912   -.2972961
 t_2009_2021 |          0  (omitted)
 t_2009_2022 |          0  (omitted)
 t_2009_2023 |          0  (omitted)
-------------+----------------------------------------------------------------
g2011        |
 t_2005_2006 |  -.0129604   .0095443    -1.36   0.174    -.0316669     .005746
 t_2006_2007 |  -.0043378   .0158653    -0.27   0.785    -.0354333    .0267576
 t_2007_2008 |  -.0060006   .0134929    -0.44   0.657    -.0324463    .0204451
 t_2008_2009 |   .0250613   .0194269     1.29   0.197    -.0130147    .0631373
 t_2009_2010 |   .0193735   .0189688     1.02   0.307    -.0178045    .0565516
 t_2010_2011 |  -.0042184   .0150476    -0.28   0.779    -.0337111    .0252743
 t_2010_2012 |   .0287929   .0315645     0.91   0.362    -.0330724    .0906582
 t_2010_2013 |   .0277522    .037107     0.75   0.455    -.0449761    .1004805
 t_2010_2014 |   .0266867   .0368012     0.73   0.468    -.0454423    .0988158
 t_2010_2015 |   .0622992    .043117     1.44   0.148    -.0222086     .146807
 t_2010_2016 |   .0659425   .0697594     0.95   0.345    -.0707834    .2026684
 t_2010_2017 |   .0021531   .0763452     0.03   0.978    -.1474806    .1517869
 t_2010_2018 |  -.0163301    .100649    -0.16   0.871    -.2135985    .1809383
 t_2010_2019 |   .0493656   .1274747     0.39   0.699    -.2004802    .2992114
 t_2010_2020 |  -.1626594   .0599829    -2.71   0.007    -.2802238   -.0450951
 t_2010_2021 |          0  (omitted)
 t_2010_2022 |          0  (omitted)
```

t_2010_2023	0	(omitted)				
g2012						
t_2005_2006	-.0495185	.019619	-2.52	0.012	-.087971	-.011066
t_2006_2007	-.0255263	.0207201	-1.23	0.218	-.0661369	.0150844
t_2007_2008	-.0013478	.0201425	-0.07	0.947	-.0408263	.0381308
t_2008_2009	-.0232904	.0238535	-0.98	0.329	-.0700424	.0234616
t_2009_2010	-.000849	.0274213	-0.03	0.975	-.0545938	.0528957
t_2010_2011	-.0049816	.0140777	-0.35	0.723	-.0325734	.0226101
t_2011_2012	.0108095	.0271377	0.40	0.690	-.0423795	.0639985
t_2011_2013	.0225046	.0121146	1.86	0.063	-.0012396	.0462487
t_2011_2014	.035492	.018477	1.92	0.055	-.0007223	.0717063
t_2011_2015	.0237951	.0287699	0.83	0.408	-.032593	.0801832
t_2011_2016	.0351826	.0623846	0.56	0.573	-.087089	.1574542
t_2011_2017	-.0041908	.076543	-0.05	0.956	-.1542124	.1458307
t_2011_2018	-.0359446	.1195984	-0.30	0.764	-.2703533	.198464
t_2011_2019	-.0159639	.1710062	-0.09	0.926	-.3511298	.3192021
t_2011_2020	-.3177389	.0204071	-15.57	0.000	-.3577361	-.2777417
t_2011_2021	0	(omitted)				
t_2011_2022	0	(omitted)				
t_2011_2023	0	(omitted)				
g2013						
t_2005_2006	.0075447	.0158238	0.48	0.634	-.0234693	.0385587
t_2006_2007	.02075	.0080387	2.58	0.010	.0049945	.0365055
t_2007_2008	.0145565	.011717	1.24	0.214	-.0084083	.0375213
t_2008_2009	.0003597	.0123509	0.03	0.977	-.0238476	.0245671
t_2009_2010	-.0064044	.0098821	-0.65	0.517	-.025773	.0129643
t_2010_2011	-.0245605	.0125138	-1.96	0.050	-.0490872	-.0000339
t_2011_2012	-.0022406	.0101807	-0.22	0.826	-.0221945	.0177132
t_2012_2013	.0001752	.0079552	0.02	0.982	-.0154167	.0157671
t_2012_2014	.0055109	.0123419	0.45	0.655	-.0186788	.0297007
t_2012_2015	.0338696	.0207931	1.63	0.103	-.0068842	.0746234
t_2012_2016	.0704611	.0446226	1.58	0.114	-.0169976	.1579199
t_2012_2017	.0420915	.0502236	0.84	0.402	-.056345	.140528
t_2012_2018	.0181387	.0765304	0.24	0.813	-.1318581	.1681354
t_2012_2019	.039054	.0957361	0.41	0.683	-.1485853	.2266933
t_2012_2020	-.129781	.0199643	-6.50	0.000	-.1689103	-.0906516
t_2012_2021	0	(omitted)				
t_2012_2022	0	(omitted)				
t_2012_2023	0	(omitted)				
g2014						
t_2005_2006	-.0069525	.0246871	-0.28	0.778	-.0553384	.0414334
t_2006_2007	.0002927	.0135076	0.02	0.983	-.0261817	.026767
t_2007_2008	-.0060405	.0108872	-0.55	0.579	-.027379	.015298
t_2008_2009	.0063541	.0102644	0.62	0.536	-.0137637	.026472
t_2009_2010	-.003187	.0085526	-0.37	0.709	-.0199497	.0135757
t_2010_2011	-.0134581	.0168	-0.80	0.423	-.0463856	.0194693
t_2011_2012	.0049341	.0134412	0.37	0.714	-.0214101	.0312784
t_2012_2013	-.0102148	.0107499	-0.95	0.342	-.0312842	.0108547
t_2013_2014	.0007609	.0088883	0.09	0.932	-.0166599	.0181817
t_2013_2015	.0099392	.0174127	0.57	0.568	-.024189	.0440674
t_2013_2016	.01862	.0460959	0.40	0.686	-.0717263	.1089663
t_2013_2017	-.0221164	.0557523	-0.40	0.692	-.1313888	.087156
t_2013_2018	-.0276214	.0802003	-0.34	0.731	-.1848111	.1295684
t_2013_2019	-.0257771	.0900295	-0.29	0.775	-.2022317	.1506775
t_2013_2020	-.1936018	.0247998	-7.81	0.000	-.2422084	-.1449952
t_2013_2021	0	(omitted)				
t_2013_2022	0	(omitted)				
t_2013_2023	0	(omitted)				
g2015						
t_2005_2006	.0566573	.028405	1.99	0.046	.0009846	.1123301
t_2006_2007	.000645	.012299	0.05	0.958	-.0234606	.0247507
t_2007_2008	.0271259	.0206178	1.32	0.188	-.0132842	.067536

t_2008_2009	.0042854	.020815	0.21	0.837	-.0365112	.0450819
t_2009_2010	-.024483	.0163821	-1.49	0.135	-.0565913	.0076253
t_2010_2011	-.0242581	.0145461	-1.67	0.095	-.052768	.0042518
t_2011_2012	.0095242	.0215164	0.44	0.658	-.0326472	.0516955
t_2012_2013	.0096829	.0097952	0.99	0.323	-.0095152	.0288811
t_2013_2014	-.009171	.011011	-0.83	0.405	-.0307522	.0124102
t_2014_2015	-.0014786	.0157108	-0.09	0.925	-.0322712	.0293141
t_2014_2016	.016642	.0303296	0.55	0.583	-.042803	.076087
t_2014_2017	-.0029614	.0447117	-0.07	0.947	-.0905947	.0846719
t_2014_2018	-.0191348	.0738606	-0.26	0.796	-.1638989	.1256292
t_2014_2019	-.011111	.0764667	-0.15	0.884	-.1609829	.1387609
t_2014_2020	-.100211	.0320655	-3.13	0.002	-.1630583	-.0373637
t_2014_2021	0	(omitted)				
t_2014_2022	0	(omitted)				
t_2014_2023	0	(omitted)				
g2016						
t_2005_2006	.0153026	.0201317	0.76	0.447	-.0241549	.05476
t_2006_2007	.0239374	.0117805	2.03	0.042	.0008481	.0470268
t_2007_2008	.0404559	.0190932	2.12	0.034	.003034	.0778778
t_2008_2009	.0071554	.0194601	0.37	0.713	-.0309857	.0452964
t_2009_2010	-.0160188	.0117862	-1.36	0.174	-.0391193	.0070817
t_2010_2011	-.0519724	.0259926	-2.00	0.046	-.102917	-.0010279
t_2011_2012	-.0061199	.0287811	-0.21	0.832	-.0625298	.05029
t_2012_2013	.0159197	.0196127	0.81	0.417	-.0225205	.0543598
t_2013_2014	-.0023222	.0196763	-0.12	0.906	-.0408871	.0362426
t_2014_2015	.0277618	.0194086	1.43	0.153	-.0102784	.065802
t_2015_2016	-.0194118	.0170948	-1.14	0.256	-.0529169	.0140933
t_2015_2017	-.034584	.0338103	-1.02	0.306	-.1008511	.031683
t_2015_2018	-.0707987	.0529152	-1.34	0.181	-.1745105	.0329131
t_2015_2019	-.0425912	.0637549	-0.67	0.504	-.1675486	.0823662
t_2015_2020	-.1940247	.024558	-7.90	0.000	-.2421574	-.145892
t_2015_2021	0	(omitted)				
t_2015_2022	0	(omitted)				
t_2015_2023	0	(omitted)				
g2017						
t_2005_2006	-.0108217	.0230844	-0.47	0.639	-.0560663	.0344229
t_2006_2007	.0207962	.0111921	1.86	0.063	-.00114	.0427324
t_2007_2008	.0008532	.0209669	0.04	0.968	-.0402411	.0419475
t_2008_2009	-.0929076	.0122255	-7.60	0.000	-.1168692	-.068946
t_2009_2010	-.0139623	.0125807	-1.11	0.267	-.03862	.0106954
t_2010_2011	-.0571528	.0285678	-2.00	0.045	-.1131446	-.0011609
t_2011_2012	-.0374504	.032002	-1.17	0.242	-.1001731	.0252723
t_2012_2013	-.0187401	.0213993	-0.88	0.381	-.0606819	.0232017
t_2013_2014	-.1017175	.0124093	-8.20	0.000	-.1260393	-.0773957
t_2014_2015	-.0744038	.0182628	-4.07	0.000	-.1101983	-.0386093
t_2015_2016	-.0104933	.0194738	-0.54	0.590	-.0486612	.0276746
t_2016_2017	-.0504158	.0181097	-2.78	0.005	-.0859102	-.0149213
t_2016_2018	-.0728264	.0373628	-1.95	0.051	-.146056	.0004033
t_2016_2019	-.078318	.0307082	-2.55	0.011	-.138505	-.018131
t_2016_2020	-.168367	.	.	.	.	.
t_2016_2021	0	(omitted)				
t_2016_2022	0	(omitted)				
t_2016_2023	0	(omitted)				
g2018						
t_2005_2006	-.0241801	.041575	-0.58	0.561	-.1056655	.0573054
t_2006_2007	.0444338	.0107316	4.14	0.000	.0234004	.0654673
t_2007_2008	.023381	.0355078	0.66	0.510	-.0462129	.092975
t_2008_2009	-.0032049	.02485	-0.13	0.897	-.05191	.0455001
t_2009_2010	-.0324138	.0174383	-1.86	0.063	-.0665923	.0017648
t_2010_2011	-.074963	.0427063	-1.76	0.079	-.1586657	.0087397
t_2011_2012	.0003076	.0548828	0.01	0.996	-.1072608	.107876
t_2012_2013	-.0548	.0410624	-1.33	0.182	-.1352809	.0256809
t_2013_2014	.031179	.0230683	1.35	0.177	-.0140341	.0763921

t_2014_2015	.0354936	.0300021	1.18	0.237	-.0233095	.0942967
t_2015_2016	.0310364	.0385015	0.81	0.420	-.0444251	.1064979
t_2016_2017	-.0235347	.0290944	-0.81	0.419	-.0805587	.0334893
t_2017_2018	-.0443266	.0233175	-1.90	0.057	-.090028	.0013748
t_2017_2019	.0007901	.0093493	0.08	0.933	-.0175342	.0191143
t_2017_2020	-.059116	.0080858	-7.31	0.000	-.0749639	-.0432682
t_2017_2021	0	(omitted)				
t_2017_2022	0	(omitted)				
t_2017_2023	0	(omitted)				
g2019						
t_2005_2006	.1229437	.0069881	17.59	0.000	.1092472	.1366401
t_2006_2007	-.0105644	.0108241	-0.98	0.329	-.0317793	.0106504
t_2007_2008	.0270476	.0475293	0.57	0.569	-.0661082	.1202033
t_2008_2009	-.0140147	.0230574	-0.61	0.543	-.0592063	.0311769
t_2009_2010	-.0353372	.0213947	-1.65	0.099	-.0772699	.0065956
t_2010_2011	-.035115	.0515601	-0.68	0.496	-.136171	.0659409
t_2011_2012	.038335	.0765153	0.50	0.616	-.1116323	.1883023
t_2012_2013	.0507375	.0081229	6.25	0.000	.0348169	.0666581
t_2013_2014	.009888	.0152735	0.65	0.517	-.0200475	.0398236
t_2014_2015	-.0911886	.0081123	-11.24	0.000	-.1070883	-.0752888
t_2015_2016	.02174	.0316091	0.69	0.492	-.0402127	.0836927
t_2016_2017	-.039715	.0400491	-0.99	0.321	-.1182098	.0387797
t_2017_2018	-.0628165	.0027821	-22.58	0.000	-.0682693	-.0573636
t_2018_2019	.0413755	.0065588	6.31	0.000	.0285206	.0542305
t_2018_2020	.04138	.	.	.	.	.
t_2018_2021	0	(omitted)				
t_2018_2022	0	(omitted)				
t_2018_2023	0	(omitted)				
g2020						
t_2005_2006	-.0197654	.	.	.	.	.
t_2006_2007	.0306151	.	.	.	.	.
t_2007_2008	-.1344332	.	.	.	.	.
t_2008_2009	-.0652161	.	.	.	.	.
t_2009_2010	.0605132	.	.	.	.	.
t_2010_2011	.145834	.	.	.	.	.
t_2011_2012	-.216418	.	.	.	.	.
t_2012_2013	-.022975	.	.	.	.	.
t_2013_2014	-.0432	.	.	.	.	.
t_2014_2015	-.0229449	.	.	.	.	.
t_2015_2016	-.089404	.	.	.	.	.
t_2016_2017	-.1132759	.	.	.	.	.
t_2017_2018	.007869	.	.	.	.	.
t_2018_2019	.018551	.	.	.	.	.
t_2019_2020	-.117302	.	.	.	.	.
t_2019_2021	0	(omitted)				
t_2019_2022	0	(omitted)				
t_2019_2023	0	(omitted)				
g2021						
t_2005_2006	0	(omitted)				
t_2006_2007	0	(omitted)				
t_2007_2008	0	(omitted)				
t_2008_2009	0	(omitted)				
t_2009_2010	0	(omitted)				
t_2010_2011	0	(omitted)				
t_2011_2012	0	(omitted)				
t_2012_2013	0	(omitted)				
t_2013_2014	0	(omitted)				
t_2014_2015	0	(omitted)				
t_2015_2016	0	(omitted)				
t_2016_2017	0	(omitted)				
t_2017_2018	0	(omitted)				
t_2018_2019	0	(omitted)				
t_2019_2020	0	(omitted)				

```
 t_2020_2021 |          0  (omitted)
 t_2020_2022 |          0  (omitted)
 t_2020_2023 |          0  (omitted)
------------------------------------------------------------------------------
Control: Not yet Treated

See Callaway and Sant'Anna (2021) for details


ATT by Periods Before and After treatment
Event Study:Dynamic effects
------------------------------------------------------------------------------
             | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
     Pre_avg |   .0024881   .0025568     0.97   0.331    -.0025232    .0074994
    Post_avg |  -.0905489   .0373455    -2.42   0.015    -.1637447   -.0173531
        Tm14 |  -.0197654   2.35e-18 -8.4e+15   0.000    -.0197654   -.0197654
        Tm13 |   .0767794   .0310439     2.47   0.013     .0159345    .1376243
        Tm12 |  -.0483394   .0226202    -2.14   0.033    -.0926742   -.0040047
        Tm11 |   .0079755   .0160866     0.50   0.620    -.0235536    .0395046
        Tm10 |   .0181906   .0184564     0.99   0.324    -.0179834    .0543645
         Tm9 |   .0307688   .0137938     2.23   0.026     .0037335    .0578041
         Tm8 |  -.0053547   .0118025    -0.45   0.650    -.0284872    .0177778
         Tm7 |   .0020891    .009153     0.23   0.819    -.0158504    .0200286
         Tm6 |  -.0063965   .0065687    -0.97   0.330    -.0192709    .0064779
         Tm5 |  -.0201506   .0072093    -2.80   0.005    -.0342806   -.0060206
         Tm4 |  -.0082067   .0067782    -1.21   0.226    -.0214918    .0050783
         Tm3 |   .0012584   .0055926     0.23   0.822    -.0097028    .0122197
         Tm2 |    .002542   .0059642     0.43   0.670    -.0091475    .0142315
         Tm1 |   .0034428   .0065804     0.52   0.601    -.0094545    .0163401
         Tp0 |  -.0059838   .0068456    -0.87   0.382    -.0194009    .0074332
         Tp1 |  -.0033551   .0115265    -0.29   0.771    -.0259467    .0192365
         Tp2 |  -.0139225   .0202222    -0.69   0.491    -.0535572    .0257123
         Tp3 |   -.009998   .0269887    -0.37   0.711    -.0628948    .0428989
         Tp4 |   -.034327   .0290984    -1.18   0.238    -.0913589    .0227049
         Tp5 |  -.0244624   .0402098    -0.61   0.543    -.1032721    .0543473
         Tp6 |  -.0640645   .0551116    -1.16   0.245    -.1720814    .0439523
         Tp7 |   -.098213   .0630897    -1.56   0.120    -.2218665    .0254405
         Tp8 |  -.1496304   .0877934    -1.70   0.088    -.3217023    .0224415
         Tp9 |  -.1883878   .0835612    -2.25   0.024    -.3521647   -.0246109
        Tp10 |  -.4036937   .0542855    -7.44   0.000    -.5100912   -.2972961


. estat pretrend
Pretrend Test. H0 All Pre-treatment are equal to 0
chi2(99) =   866.1731
p-value  =     0.0000

. csdid co2, ivar(cid) time(yr) gvar(treatmenttime) method(reg)
No never treated observations found. Using Not yet treated data
...............xxx..............xxx.............
.xxx..............xxx..............xxx..........
.....xxx..............xxx..............xxx......
.........xxx..............xxx..............xxxxx
xxxxxxxxxxxxxxxx
Difference-in-difference with Multiple Time Periods

                                                         Number of obs = 816
Outcome model  : regression adjustment
Treatment model: none
------------------------------------------------------------------------------
             | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
g2010        |
```

t_2005_2006	-.0055531	.0102166	-0.54	0.587	-.0255774	.0144711
t_2006_2007	.0122269	.0087764	1.39	0.164	-.0049745	.0294283
t_2007_2008	.007853	.0085133	0.92	0.356	-.0088327	.0245387
t_2008_2009	.0039957	.0102852	0.39	0.698	-.016163	.0241543
t_2009_2010	.0044878	.0141391	0.32	0.751	-.0232243	.0321999
t_2009_2011	-.0119159	.020115	-0.59	0.554	-.0513406	.0275087
t_2009_2012	-.0228554	.023128	-0.99	0.323	-.0681855	.0224747
t_2009_2013	-.0185636	.0238331	-0.78	0.436	-.0652757	.0281485
t_2009_2014	-.0251427	.0287044	-0.88	0.381	-.0814024	.0311169
t_2009_2015	-.0492128	.0429597	-1.15	0.252	-.1334121	.0349866
t_2009_2016	-.0800167	.0707566	-1.13	0.258	-.218697	.0586636
t_2009_2017	-.1242175	.0711141	-1.75	0.081	-.2635985	.0151634
t_2009_2018	-.190803	.0899397	-2.12	0.034	-.3670817	-.0145244
t_2009_2019	-.1964279	.1079818	-1.82	0.069	-.4080684	.0152125
t_2009_2020	-.4036937	.0542855	-7.44	0.000	-.5100912	-.2972961
t_2009_2021	0	(omitted)				
t_2009_2022	0	(omitted)				
t_2009_2023	0	(omitted)				
g2011						
t_2005_2006	-.0129604	.0095443	-1.36	0.174	-.0316669	.005746
t_2006_2007	-.0043378	.0158653	-0.27	0.785	-.0354333	.0267576
t_2007_2008	-.0060006	.0134929	-0.44	0.657	-.0324463	.0204451
t_2008_2009	.0250613	.0194269	1.29	0.197	-.0130147	.0631373
t_2009_2010	.0193735	.0189688	1.02	0.307	-.0178045	.0565516
t_2010_2011	-.0042184	.0150476	-0.28	0.779	-.0337111	.0252743
t_2010_2012	.0287929	.0315645	0.91	0.362	-.0330724	.0906582
t_2010_2013	.0277522	.037107	0.75	0.455	-.0449761	.1004805
t_2010_2014	.0266867	.0368012	0.73	0.468	-.0454423	.0988158
t_2010_2015	.0622992	.043117	1.44	0.148	-.0222086	.146807
t_2010_2016	.0659425	.0697594	0.95	0.345	-.0707834	.2026684
t_2010_2017	.0021531	.0763452	0.03	0.978	-.1474806	.1517869
t_2010_2018	-.0163301	.100649	-0.16	0.871	-.2135985	.1809383
t_2010_2019	.0493656	.1274747	0.39	0.699	-.2004802	.2992114
t_2010_2020	-.1626594	.0599829	-2.71	0.007	-.2802238	-.0450951
t_2010_2021	0	(omitted)				
t_2010_2022	0	(omitted)				
t_2010_2023	0	(omitted)				
g2012						
t_2005_2006	-.0495185	.019619	-2.52	0.012	-.087971	-.011066
t_2006_2007	-.0255263	.0207201	-1.23	0.218	-.0661369	.0150844
t_2007_2008	-.0013478	.0201425	-0.07	0.947	-.0408263	.0381308
t_2008_2009	-.0232904	.0238535	-0.98	0.329	-.0700424	.0234616
t_2009_2010	-.000849	.0274213	-0.03	0.975	-.0545938	.0528957
t_2010_2011	-.0049816	.0140777	-0.35	0.723	-.0325734	.0226101
t_2011_2012	.0108095	.0271377	0.40	0.690	-.0423795	.0639985
t_2011_2013	.0225046	.0121146	1.86	0.063	-.0012396	.0462487
t_2011_2014	.035492	.018477	1.92	0.055	-.0007223	.0717063
t_2011_2015	.0237951	.0287699	0.83	0.408	-.032593	.0801832
t_2011_2016	.0351826	.0623846	0.56	0.573	-.087089	.1574542
t_2011_2017	-.0041908	.076543	-0.05	0.956	-.1542124	.1458307
t_2011_2018	-.0359446	.1195984	-0.30	0.764	-.2703533	.198464
t_2011_2019	-.0159639	.1710062	-0.09	0.926	-.3511298	.3192021
t_2011_2020	-.3177389	.0204071	-15.57	0.000	-.3577361	-.2777417
t_2011_2021	0	(omitted)				
t_2011_2022	0	(omitted)				
t_2011_2023	0	(omitted)				
g2013						
t_2005_2006	.0075447	.0158238	0.48	0.634	-.0234693	.0385587
t_2006_2007	.02075	.0080387	2.58	0.010	.0049945	.0365055
t_2007_2008	.0145565	.011717	1.24	0.214	-.0084083	.0375213
t_2008_2009	.0003597	.0123509	0.03	0.977	-.0238476	.0245671
t_2009_2010	-.0064044	.0098821	-0.65	0.517	-.025773	.0129643
t_2010_2011	-.0245605	.0125138	-1.96	0.050	-.0490872	-.0000339

t_2011_2012	-.0022406	.0101807	-0.22	0.826	-.0221945	.0177132
t_2012_2013	.0001752	.0079552	0.02	0.982	-.0154167	.0157671
t_2012_2014	.0055109	.0123419	0.45	0.655	-.0186788	.0297007
t_2012_2015	.0338696	.0207931	1.63	0.103	-.0068842	.0746234
t_2012_2016	.0704611	.0446226	1.58	0.114	-.0169976	.1579199
t_2012_2017	.0420915	.0502236	0.84	0.402	-.056345	.140528
t_2012_2018	.0181387	.0765304	0.24	0.813	-.1318581	.1681354
t_2012_2019	.039054	.0957361	0.41	0.683	-.1485853	.2266933
t_2012_2020	-.129781	.0199643	-6.50	0.000	-.1689103	-.0906516
t_2012_2021	0	(omitted)				
t_2012_2022	0	(omitted)				
t_2012_2023	0	(omitted)				
g2014						
t_2005_2006	-.0069525	.0246871	-0.28	0.778	-.0553384	.0414334
t_2006_2007	.0002927	.0135076	0.02	0.983	-.0261817	.026767
t_2007_2008	-.0060405	.0108872	-0.55	0.579	-.027379	.015298
t_2008_2009	.0063541	.0102644	0.62	0.536	-.0137637	.026472
t_2009_2010	-.003187	.0085526	-0.37	0.709	-.0199497	.0135757
t_2010_2011	-.0134581	.0168	-0.80	0.423	-.0463856	.0194693
t_2011_2012	.0049341	.0134412	0.37	0.714	-.0214101	.0312784
t_2012_2013	-.0102148	.0107499	-0.95	0.342	-.0312842	.0108547
t_2013_2014	.0007609	.0088883	0.09	0.932	-.0166599	.0181817
t_2013_2015	.0099392	.0174127	0.57	0.568	-.024189	.0440674
t_2013_2016	.01862	.0460959	0.40	0.686	-.0717263	.1089663
t_2013_2017	-.0221164	.0557523	-0.40	0.692	-.1313888	.087156
t_2013_2018	-.0276214	.0802003	-0.34	0.731	-.1848111	.1295684
t_2013_2019	-.0257771	.0900295	-0.29	0.775	-.2022317	.1506775
t_2013_2020	-.1936018	.0247998	-7.81	0.000	-.2422084	-.1449952
t_2013_2021	0	(omitted)				
t_2013_2022	0	(omitted)				
t_2013_2023	0	(omitted)				
g2015						
t_2005_2006	.0566573	.028405	1.99	0.046	.0009846	.1123301
t_2006_2007	.000645	.012299	0.05	0.958	-.0234606	.0247507
t_2007_2008	.0271259	.0206178	1.32	0.188	-.0132842	.067536
t_2008_2009	.0042854	.020815	0.21	0.837	-.0365112	.0450819
t_2009_2010	-.024483	.0163821	-1.49	0.135	-.0565913	.0076253
t_2010_2011	-.0242581	.0145461	-1.67	0.095	-.052768	.0042518
t_2011_2012	.0095242	.0215164	0.44	0.658	-.0326472	.0516955
t_2012_2013	.0096829	.0097952	0.99	0.323	-.0095152	.0288811
t_2013_2014	-.009171	.011011	-0.83	0.405	-.0307522	.0124102
t_2014_2015	-.0014786	.0157108	-0.09	0.925	-.0322712	.0293141
t_2014_2016	.016642	.0303296	0.55	0.583	-.042803	.076087
t_2014_2017	-.0029614	.0447117	-0.07	0.947	-.0905947	.0846719
t_2014_2018	-.0191348	.0738606	-0.26	0.796	-.1638989	.1256292
t_2014_2019	-.011111	.0764667	-0.15	0.884	-.1609829	.1387609
t_2014_2020	-.100211	.0320655	-3.13	0.002	-.1630583	-.0373637
t_2014_2021	0	(omitted)				
t_2014_2022	0	(omitted)				
t_2014_2023	0	(omitted)				
g2016						
t_2005_2006	.0153026	.0201317	0.76	0.447	-.0241549	.05476
t_2006_2007	.0239374	.0117805	2.03	0.042	.0008481	.0470268
t_2007_2008	.0404559	.0190932	2.12	0.034	.003034	.0778778
t_2008_2009	.0071554	.0194601	0.37	0.713	-.0309857	.0452964
t_2009_2010	-.0160188	.0117862	-1.36	0.174	-.0391193	.0070817
t_2010_2011	-.0519724	.0259926	-2.00	0.046	-.102917	-.0010279
t_2011_2012	-.0061199	.0287811	-0.21	0.832	-.0625298	.05029
t_2012_2013	.0159197	.0196127	0.81	0.417	-.0225205	.0543598
t_2013_2014	-.0023222	.0196763	-0.12	0.906	-.0408871	.0362426
t_2014_2015	.0277618	.0194086	1.43	0.153	-.0102784	.065802
t_2015_2016	-.0194118	.0170948	-1.14	0.256	-.0529169	.0140933
t_2015_2017	-.034584	.0338103	-1.02	0.306	-.1008511	.031683

t_2015_2018	-.0707987	.0529152	-1.34	0.181	-.1745105	.0329131
t_2015_2019	-.0425912	.0637549	-0.67	0.504	-.1675486	.0823662
t_2015_2020	-.1940247	.024558	-7.90	0.000	-.2421574	-.145892
t_2015_2021	0	(omitted)				
t_2015_2022	0	(omitted)				
t_2015_2023	0	(omitted)				
g2017						
t_2005_2006	-.0108217	.0230844	-0.47	0.639	-.0560663	.0344229
t_2006_2007	.0207962	.0111921	1.86	0.063	-.00114	.0427324
t_2007_2008	.0008532	.0209669	0.04	0.968	-.0402411	.0419475
t_2008_2009	-.0929076	.0122255	-7.60	0.000	-.1168692	-.068946
t_2009_2010	-.0139623	.0125807	-1.11	0.267	-.03862	.0106954
t_2010_2011	-.0571528	.0285678	-2.00	0.045	-.1131446	-.0011609
t_2011_2012	-.0374504	.032002	-1.17	0.242	-.1001731	.0252723
t_2012_2013	-.0187401	.0213993	-0.88	0.381	-.0606819	.0232017
t_2013_2014	-.1017175	.0124093	-8.20	0.000	-.1260393	-.0773957
t_2014_2015	-.0744038	.0182628	-4.07	0.000	-.1101983	-.0386093
t_2015_2016	-.0104933	.0194738	-0.54	0.590	-.0486612	.0276746
t_2016_2017	-.0504158	.0181097	-2.78	0.005	-.0859102	-.0149213
t_2016_2018	-.0728264	.0373628	-1.95	0.051	-.146056	.0004033
t_2016_2019	-.078318	.0307082	-2.55	0.011	-.138505	-.018131
t_2016_2020	-.168367	.	.	.	.	.
t_2016_2021	0	(omitted)				
t_2016_2022	0	(omitted)				
t_2016_2023	0	(omitted)				
g2018						
t_2005_2006	-.0241801	.041575	-0.58	0.561	-.1056655	.0573054
t_2006_2007	.0444338	.0107316	4.14	0.000	.0234004	.0654673
t_2007_2008	.023381	.0355078	0.66	0.510	-.0462129	.092975
t_2008_2009	-.0032049	.02485	-0.13	0.897	-.05191	.0455001
t_2009_2010	-.0324138	.0174383	-1.86	0.063	-.0665923	.0017648
t_2010_2011	-.074963	.0427063	-1.76	0.079	-.1586657	.0087397
t_2011_2012	.0003076	.0548828	0.01	0.996	-.1072608	.107876
t_2012_2013	-.0548	.0410624	-1.33	0.182	-.1352809	.0256809
t_2013_2014	.031179	.0230683	1.35	0.177	-.0140341	.0763921
t_2014_2015	.0354936	.0300021	1.18	0.237	-.0233095	.0942967
t_2015_2016	.0310364	.0385015	0.81	0.420	-.0444251	.1064979
t_2016_2017	-.0235347	.0290944	-0.81	0.419	-.0805587	.0334893
t_2017_2018	-.0443266	.0233175	-1.90	0.057	-.090028	.0013748
t_2017_2019	.0007901	.0093493	0.08	0.933	-.0175342	.0191143
t_2017_2020	-.059116	.0080858	-7.31	0.000	-.0749639	-.0432682
t_2017_2021	0	(omitted)				
t_2017_2022	0	(omitted)				
t_2017_2023	0	(omitted)				
g2019						
t_2005_2006	.1229437	.0069881	17.59	0.000	.1092472	.1366401
t_2006_2007	-.0105644	.0108241	-0.98	0.329	-.0317793	.0106504
t_2007_2008	.0270476	.0475293	0.57	0.569	-.0661082	.1202033
t_2008_2009	-.0140147	.0230574	-0.61	0.543	-.0592063	.0311769
t_2009_2010	-.0353372	.0213947	-1.65	0.099	-.0772699	.0065956
t_2010_2011	-.035115	.0515601	-0.68	0.496	-.136171	.0659409
t_2011_2012	.038335	.0765153	0.50	0.616	-.1116323	.1883023
t_2012_2013	.0507375	.0081229	6.25	0.000	.0348169	.0666581
t_2013_2014	.009888	.0152735	0.65	0.517	-.0200475	.0398236
t_2014_2015	-.0911886	.0081123	-11.24	0.000	-.1070883	-.0752888
t_2015_2016	.02174	.0316091	0.69	0.492	-.0402127	.0836927
t_2016_2017	-.039715	.0400491	-0.99	0.321	-.1182098	.0387797
t_2017_2018	-.0628165	.0027821	-22.58	0.000	-.0682693	-.0573636
t_2018_2019	.0413755	.0065588	6.31	0.000	.0285206	.0542305
t_2018_2020	.04138	.	.	.	.	.
t_2018_2021	0	(omitted)				
t_2018_2022	0	(omitted)				
t_2018_2023	0	(omitted)				

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-------------+----------------------------------------------------------------
g2020        |
 t_2005_2006 |  -.0197654          .          .       .            .           .
 t_2006_2007 |   .0306151          .          .       .            .           .
 t_2007_2008 |  -.1344332          .          .       .            .           .
 t_2008_2009 |  -.0652161          .          .       .            .           .
 t_2009_2010 |   .0605132          .          .       .            .           .
 t_2010_2011 |    .145834          .          .       .            .           .
 t_2011_2012 |   -.216418          .          .       .            .           .
 t_2012_2013 |   -.022975          .          .       .            .           .
 t_2013_2014 |     -.0432          .          .       .            .           .
 t_2014_2015 |  -.0229449          .          .       .            .           .
 t_2015_2016 |   -.089404          .          .       .            .           .
 t_2016_2017 |  -.1132759          .          .       .            .           .
 t_2017_2018 |    .007869          .          .       .            .           .
 t_2018_2019 |    .018551          .          .       .            .           .
 t_2019_2020 |   -.117302          .          .       .            .           .
 t_2019_2021 |          0  (omitted)
 t_2019_2022 |          0  (omitted)
 t_2019_2023 |          0  (omitted)
-------------+----------------------------------------------------------------
g2021        |
 t_2005_2006 |          0  (omitted)
 t_2006_2007 |          0  (omitted)
 t_2007_2008 |          0  (omitted)
 t_2008_2009 |          0  (omitted)
 t_2009_2010 |          0  (omitted)
 t_2010_2011 |          0  (omitted)
 t_2011_2012 |          0  (omitted)
 t_2012_2013 |          0  (omitted)
 t_2013_2014 |          0  (omitted)
 t_2014_2015 |          0  (omitted)
 t_2015_2016 |          0  (omitted)
 t_2016_2017 |          0  (omitted)
 t_2017_2018 |          0  (omitted)
 t_2018_2019 |          0  (omitted)
 t_2019_2020 |          0  (omitted)
 t_2020_2021 |          0  (omitted)
 t_2020_2022 |          0  (omitted)
 t_2020_2023 |          0  (omitted)
------------------------------------------------------------------------------
Control: Not yet Treated

See Callaway and Sant'Anna (2021) for details


estat group

ATT by group
------------------------------------------------------------------------------
             | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
    GAverage |  -.0531402   .0284712    -1.87   0.062    -.1089429    .0026624
       G2010 |  -.1016692   .0381547    -2.66   0.008    -.1764511   -.0268873
       G2011 |   .0079784   .0466568     0.17   0.864    -.0834671     .099424
       G2012 |  -.0273394   .0505404    -0.54   0.589    -.1263967    .0717179
       G2013 |     .00994   .0329738     0.30   0.763    -.0546875    .0745675
       G2014 |  -.0342566   .0370274    -0.93   0.355     -.106829    .0383157
       G2015 |  -.0197091   .0364489    -0.54   0.589    -.0911476    .0517294
       G2016 |  -.0722821   .0329449    -2.19   0.028     -.136853   -.0077112
       G2017 |  -.0924818   .0198976    -4.65   0.000    -.1314804   -.0534832
       G2018 |  -.0342175   .0073224    -4.67   0.000    -.0485691   -.0198659
       G2019 |   .0413778   .0032794    12.62   0.000     .0349503    .0478052
       G2020 |   -.117302          .        .       .            .
```

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. csdid ghg, ivar(cid) time(yr) gvar(treatmenttime) method(dripw) notyet
..............xxx..............xxx.............
.xxx..............xxx..............xxx..........
.....xxx..............xxx..............xxx......
.........xxx..............xxx..............xxxxx
xxxxxxxxxxxxxxxx
Difference-in-difference with Multiple Time Periods

                                                     Number of obs = 816
Outcome model  : least squares
Treatment model: inverse probability
------------------------------------------------------------------------------
             | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
g2010        |
 t_2005_2006 |  -.0070041   .0088273    -0.79   0.428    -.0243051     .010297
 t_2006_2007 |   .0169633   .0099537     1.70   0.088    -.0025455    .0364721
 t_2007_2008 |   .0034509   .0088765     0.39   0.697    -.0139467    .0208484
 t_2008_2009 |   .0039661   .0071282     0.56   0.578    -.0100049     .017937
 t_2009_2010 |  -.0062876   .1181399    -0.05   0.958    -.2378375    .2252622
 t_2009_2011 |   .0001551   .1342865     0.00   0.999    -.2630416    .2633518
 t_2009_2012 |  -.0123033   .1431911    -0.09   0.932    -.2929526     .268346
 t_2009_2013 |  -.0755638   .1611985    -0.47   0.639    -.3915071    .2403795
 t_2009_2014 |  -.1010247   .2024756    -0.50   0.618    -.4978695    .2958201
 t_2009_2015 |   .1153478   .1380987     0.84   0.404    -.1553208    .3860163
 t_2009_2016 |   .0080116   .0581077     0.14   0.890    -.1058774    .1219006
 t_2009_2017 |  -.0083342    .052069    -0.16   0.873    -.1103875     .093719
 t_2009_2018 |  -.0459704   .0519014    -0.89   0.376    -.1476954    .0557545
 t_2009_2019 |  -.0247833   .0657979    -0.38   0.706    -.1537448    .1041782
 t_2009_2020 |  -.1082409   .0569913    -1.90   0.058    -.2199418      .00346
 t_2009_2021 |          0  (omitted)
 t_2009_2022 |          0  (omitted)
 t_2009_2023 |          0  (omitted)
-------------+----------------------------------------------------------------
g2011        |
 t_2005_2006 |   .0020346   .0067001     0.30   0.761    -.0110973    .0151665
 t_2006_2007 |    .007895   .0058557     1.35   0.178     -.003582     .019372
 t_2007_2008 |  -.0048542   .0093583    -0.52   0.604    -.0231962    .0134877
 t_2008_2009 |   .0129478   .0077389     1.67   0.094    -.0022201    .0281157
 t_2009_2010 |   .1221954   .1786297     0.68   0.494    -.2279124    .4723032
 t_2010_2011 |  -.0182558   .0117381    -1.56   0.120     -.041262    .0047504
 t_2010_2012 |  -.0291202   .0216377    -1.35   0.178    -.0715292    .0132889
 t_2010_2013 |  -.0230887   .0238706    -0.97   0.333    -.0698742    .0236968
 t_2010_2014 |  -.0271084   .0321758    -0.84   0.400    -.0901718    .0359551
 t_2010_2015 |  -.0077722   .0405847    -0.19   0.848    -.0873168    .0717724
 t_2010_2016 |    .028258   .0480898     0.59   0.557    -.0659962    .1225123
 t_2010_2017 |   .0072044   .0473595     0.15   0.879    -.0856185    .1000274
 t_2010_2018 |  -.0149488   .0552258    -0.27   0.787    -.1231893    .0932918
 t_2010_2019 |   .0258336   .0757568     0.34   0.733    -.1226469    .1743142
 t_2010_2020 |  -.0458568   .0640217    -0.72   0.474     -.171337    .0796233
 t_2010_2021 |          0  (omitted)
 t_2010_2022 |          0  (omitted)
 t_2010_2023 |          0  (omitted)
-------------+----------------------------------------------------------------
g2012        |
 t_2005_2006 |  -.0289258   .0148031    -1.95   0.051    -.0579394    .0000877
 t_2006_2007 |  -.0094263   .0169698    -0.56   0.579    -.0426866     .023834
 t_2007_2008 |  -.0144663   .0059574    -2.43   0.015    -.0261427     -.00279
 t_2008_2009 |  -.0058372   .0120097    -0.49   0.627    -.0293759    .0177015
 t_2009_2010 |  -.0254586   .1353692    -0.19   0.851    -.2907774    .2398602
 t_2010_2011 |  -.0010259    .006647    -0.15   0.877    -.0140537     .012002
 t_2011_2012 |   .0153267   .0188394     0.81   0.416    -.0215979    .0522513
 t_2011_2013 |   .0053207    .016272     0.33   0.744    -.0265718    .0372133
 t_2011_2014 |   .0176753    .023925     0.74   0.460    -.0292169    .0645675
 t_2011_2015 |   .0125619   .0296694     0.42   0.672    -.0455891    .0707129
 t_2011_2016 |   .0408131   .0447645     0.91   0.362    -.0469237    .1285499
```

t_2011_2017	.0290894	.045466	0.64	0.522	-.0600223	.1182011
t_2011_2018	-.0067339	.0575798	-0.12	0.907	-.1195883	.1061204
t_2011_2019	.0219101	.0839173	0.26	0.794	-.1425647	.1863849
t_2011_2020	-.1316649	.0126395	-10.42	0.000	-.156438	-.1068919
t_2011_2021	0	(omitted)				
t_2011_2022	0	(omitted)				
t_2011_2023	0	(omitted)				
g2013						
t_2005_2006	-.0017851	.0086273	-0.21	0.836	-.0186943	.0151241
t_2006_2007	.0154264	.0068284	2.26	0.024	.0020431	.0288098
t_2007_2008	.0009526	.0066536	0.14	0.886	-.0120882	.0139934
t_2008_2009	.001537	.0089958	0.17	0.864	-.0160944	.0191684
t_2009_2010	-.349202	.2772833	-1.26	0.208	-.8926673	.1942634
t_2010_2011	-.0111754	.0085642	-1.30	0.192	-.0279609	.0056101
t_2011_2012	-.0161552	.0059739	-2.70	0.007	-.0278638	-.0044466
t_2012_2013	.0022979	.0063301	0.36	0.717	-.0101089	.0147046
t_2012_2014	.0065392	.0105796	0.62	0.537	-.0141964	.0272749
t_2012_2015	.0055832	.0183471	0.30	0.761	-.0303765	.0415429
t_2012_2016	.0420405	.0284975	1.48	0.140	-.0138136	.0978945
t_2012_2017	.0260334	.0229216	1.14	0.256	-.0188921	.0709588
t_2012_2018	.0047923	.0298222	0.16	0.872	-.0536582	.0632427
t_2012_2019	.033042	.0473423	0.70	0.485	-.0597472	.1258312
t_2012_2020	-.017566	.0134076	-1.31	0.190	-.0438444	.0087124
t_2012_2021	0	(omitted)				
t_2012_2022	0	(omitted)				
t_2012_2023	0	(omitted)				
g2014						
t_2005_2006	-.0144464	.0190473	-0.76	0.448	-.0517785	.0228857
t_2006_2007	-.0029432	.0151553	-0.19	0.846	-.032647	.0267606
t_2007_2008	-.0087171	.0086259	-1.01	0.312	-.0256235	.0081893
t_2008_2009	.0091135	.008672	1.05	0.293	-.0078833	.0261103
t_2009_2010	-.1085107	.1953062	-0.56	0.578	-.4913039	.2742824
t_2010_2011	-.001852	.0123203	-0.15	0.881	-.0259994	.0222954
t_2011_2012	-.000873	.0085202	-0.10	0.918	-.0175722	.0158262
t_2012_2013	-.0105367	.0074999	-1.40	0.160	-.0252362	.0041629
t_2013_2014	.0022079	.0071543	0.31	0.758	-.0118143	.0162302
t_2013_2015	.0076603	.0142554	0.54	0.591	-.0202798	.0356003
t_2013_2016	.0323294	.0278433	1.16	0.246	-.0222425	.0869013
t_2013_2017	.0156972	.0234261	0.67	0.503	-.030217	.0616115
t_2013_2018	-.008292	.0328631	-0.25	0.801	-.0727024	.0561185
t_2013_2019	.023064	.0449711	0.51	0.608	-.0650776	.1112057
t_2013_2020	-.053758	.017673	-3.04	0.002	-.0883965	-.0191194
t_2013_2021	0	(omitted)				
t_2013_2022	0	(omitted)				
t_2013_2023	0	(omitted)				
g2015						
t_2005_2006	.0469399	.0270889	1.73	0.083	-.0061534	.1000331
t_2006_2007	.0061276	.0105905	0.58	0.563	-.0146295	.0268846
t_2007_2008	.0458303	.0110463	4.15	0.000	.02418	.0674806
t_2008_2009	-.0084624	.0188479	-0.45	0.653	-.0454037	.0284789
t_2009_2010	1.018847	.6282996	1.62	0.105	-.2125979	2.250291
t_2010_2011	.0071016	.0110325	0.64	0.520	-.0145217	.0287249
t_2011_2012	.0028472	.0093189	0.31	0.760	-.0154176	.0211119
t_2012_2013	.0105375	.0068178	1.55	0.122	-.0028252	.0239002
t_2013_2014	.001067	.0064958	0.16	0.870	-.0116644	.0137985
t_2014_2015	.0073226	.0093547	0.78	0.434	-.0110123	.0256575
t_2014_2016	.0219297	.0195816	1.12	0.263	-.0164495	.0603089
t_2014_2017	.0279555	.0192334	1.45	0.146	-.0097414	.0656523
t_2014_2018	.0048838	.0224926	0.22	0.828	-.039201	.0489686
t_2014_2019	.0367125	.031965	1.15	0.251	-.0259376	.0993627
t_2014_2020	-.0006349	.0259591	-0.02	0.980	-.0515138	.0502439
t_2014_2021	0	(omitted)				
t_2014_2022	0	(omitted)				

t_2014_2023	0	(omitted)				
g2016						
t_2005_2006	.0062314	.0132028	0.47	0.637	-.0196456	.0321084
t_2006_2007	.0182588	.0119358	1.53	0.126	-.0051349	.0416524
t_2007_2008	.0142508	.0108625	1.31	0.190	-.0070392	.0355409
t_2008_2009	-.0095914	.0166941	-0.57	0.566	-.0423112	.0231284
t_2009_2010	-.2300733	.2119825	-1.09	0.278	-.6455513	.1854047
t_2010_2011	-.0161604	.0143178	-1.13	0.259	-.0442228	.011902
t_2011_2012	.0077137	.0147112	0.52	0.600	-.0211196	.0365471
t_2012_2013	.0112002	.0099952	1.12	0.262	-.0083901	.0307905
t_2013_2014	.0215792	.0121881	1.77	0.077	-.002309	.0454675
t_2014_2015	.0219279	.0165	1.33	0.184	-.0104115	.0542673
t_2015_2016	-.005998	.0078755	-0.76	0.446	-.0214338	.0094378
t_2015_2017	-.0079921	.013509	-0.59	0.554	-.0344692	.0184851
t_2015_2018	-.0496227	.0220374	-2.25	0.024	-.0928153	-.0064301
t_2015_2019	-.0091562	.0311055	-0.29	0.768	-.0701219	.0518094
t_2015_2020	-.0776174	.0156382	-4.96	0.000	-.1082677	-.0469671
t_2015_2021	0	(omitted)				
t_2015_2022	0	(omitted)				
t_2015_2023	0	(omitted)				
g2017						
t_2005_2006	-.0096172	.0109488	-0.88	0.380	-.0310765	.011842
t_2006_2007	.0270947	.0108215	2.50	0.012	.0058848	.0483045
t_2007_2008	-.0159222	.0105685	-1.51	0.132	-.0366362	.0047917
t_2008_2009	-.0882366	.0099901	-8.83	0.000	-.1078168	-.0686564
t_2009_2010	-.0058857	.0052701	-1.12	0.264	-.016215	.0044436
t_2010_2011	.0018837	.0151396	0.12	0.901	-.0277894	.0315567
t_2011_2012	-.027783	.0162505	-1.71	0.087	-.0596335	.0040674
t_2012_2013	-.0128578	.0077099	-1.67	0.095	-.0279689	.0022533
t_2013_2014	-.0611304	.0080081	-7.63	0.000	-.0768261	-.0454348
t_2014_2015	-.0766137	.0136973	-5.59	0.000	-.10346	-.0497675
t_2015_2016	.0045384	.008791	0.52	0.606	-.0126916	.0217684
t_2016_2017	-.032809	.0087816	-3.74	0.000	-.0500207	-.0155974
t_2016_2018	-.0598632	.0081108	-7.38	0.000	-.07576	-.0439663
t_2016_2019	-.0516	.0158887	-3.25	0.001	-.0827412	-.0204587
t_2016_2020	-.0962099	.	.	.	.	.
t_2016_2021	0	(omitted)				
t_2016_2022	0	(omitted)				
t_2016_2023	0	(omitted)				
g2018						
t_2005_2006	-.0128663	.019942	-0.65	0.519	-.0519519	.0262193
t_2006_2007	.0282965	.0148133	1.91	0.056	-.0007371	.0573302
t_2007_2008	.0207288	.0161613	1.28	0.200	-.0109468	.0524045
t_2008_2009	-.023272	.019535	-1.19	0.234	-.0615598	.0150158
t_2009_2010	-.0053693	.0086652	-0.62	0.535	-.0223528	.0116143
t_2010_2011	-.021969	.0250178	-0.88	0.380	-.0710029	.0270649
t_2011_2012	-.0089883	.0275722	-0.33	0.744	-.0630288	.0450521
t_2012_2013	-.0138797	.0174006	-0.80	0.425	-.0479842	.0202249
t_2013_2014	.0098577	.0128523	0.77	0.443	-.0153324	.0350478
t_2014_2015	.0299689	.0261701	1.15	0.252	-.0213235	.0812613
t_2015_2016	.0095307	.0167926	0.57	0.570	-.0233822	.0424435
t_2016_2017	-.0276319	.0119114	-2.32	0.020	-.0509778	-.0042861
t_2017_2018	-.0277864	.0078751	-3.53	0.000	-.0432213	-.0123514
t_2017_2019	.00301	.0063975	0.47	0.638	-.0095288	.0155488
t_2017_2020	-.0293549	.0167267	-1.75	0.079	-.0621386	.0034287
t_2017_2021	0	(omitted)				
t_2017_2022	0	(omitted)				
t_2017_2023	0	(omitted)				
g2019						
t_2005_2006	.0524881	.0091771	5.72	0.000	.0345013	.070475
t_2006_2007	-.0525388	.0054798	-9.59	0.000	-.0632789	-.0417986
t_2007_2008	.0380439	.0176964	2.15	0.032	.0033596	.0727282

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 t_2008_2009 |  -.0037892   .0118751    -0.32   0.750     -.027064    .0194855
 t_2009_2010 |  -.0180059   .0103781    -1.73   0.083    -.0383466    .0023347
 t_2010_2011 |   -.014298   .0340189    -0.42   0.674    -.0809738    .0523777
 t_2011_2012 |   .0166299   .0388944     0.43   0.669    -.0596016    .0928615
 t_2012_2013 |   .0016791   .0043841     0.38   0.702    -.0069136    .0102717
 t_2013_2014 |    .027892   .0155564     1.79   0.073    -.0025979    .0583819
 t_2014_2015 |   -.047067   .0048684    -9.67   0.000     -.056609   -.0375251
 t_2015_2016 |    .028543   .0133042     2.15   0.032     .0024672    .0546187
 t_2016_2017 |   -.011619   .0133184    -0.87   0.383    -.0377225    .0144845
 t_2017_2018 |    .027769   .0030936     8.98   0.000     .0217056    .0338324
 t_2018_2019 |   -.054239   .0056639    -9.58   0.000    -.0653402   -.0431379
 t_2018_2020 |   -.061955          .        .       .            .           .
 t_2018_2021 |          0  (omitted)
 t_2018_2022 |          0  (omitted)
 t_2018_2023 |          0  (omitted)
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