FEDERAL UNIVERSITY OF SÃO CARLOS
SCHOOL OF MANAGEMENT AND TECHNOLOGY
DEPARTAMENT OF ECONOMICS

HENRIQUE RYOSUKE TATEISHI

THE INFLUENCE OF INSTITUTIONS AND INSTITUTIONAL FRAMEWORK ON GREENHOUSE GASES EMISSIONS

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Advisor: Prof. Dr. Cassiano Bragagnolo

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Thesis presented to Graduate Program in Economics in order to obtain the title of MS in Applied Economics. Universidade Federal de São Carlos. Sorocaba January 25th of 2019.

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“Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited.” (Hardin, 1968)

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RESUMO

TATEISHI, Henrique Ryosuke. The influence of institutions and institutional framework on greenhouse gases emissions. 2018. 103 f. Monografia (Mestrado em Economia) – Universidade Federal de São Carlos, *campus* Sorocaba, Sorocaba, 2018.

Este estudo investigou a eficácia do Protocolo de Quioto (KP) no que diz respeito à redução das emissões de gases com efeito de estufa (GEE) na primeira e segunda décadas de 2000. Também levou em conta os níveis institucionais, como os de democracia e direitos de propriedade e os impactos de desenvolvimento de um país. Além disso, propôs analisar o desempenho econômico em relação à produção do Produto Interno Bruto e o desempenho ambiental referente às emissões de GEE, empregando medidas de eficiência técnica e eficiência ambiental, respectivamente. Além disso, foi proposto verificar o efeito do ambiente institucional em tais eficiências. Este estudo empregou um modelo de diferenças em diferenças para medir a eficácia do KP e uma análise de fronteira estocástica para estimar os desempenhos econômico e ambiental (eficiências). Os resultados apontam para uma baixa eficácia geral do KP. Tendo em conta diferentes grupos de países com características semelhantes de desenvolvimento ou qualidade institucional, a eficácia do PK também foi baixa. Países com baixo desenvolvimento, baixa área de urbanização e alta desigualdade de renda apresentaram uma redução de suas emissões considerando a diferença de tempo. Países com altos direitos de propriedade e nível de democracia apresentaram uma tendência de aumento em relação às emissões ao longo do tempo. O efeito da ratificação do KP foi positivo (emissões reduzidas) para os países com níveis institucionais e de desenvolvimento médios. No entanto, o efeito da ratificação foi negativo nos extremos: maior qualidade institutional e maior nível de desenvoltimento. Os resultados apontam que a variável de capital apresentou maior elasticidade de produção, enquanto a elasticidade da produção econômica (PIB) apresentou uma participação maior nas emissões de GEE do que a utilização de energias não renováveis. Em geral, o desempenho econômico foi superior ao desempenho ambiental. A análise do impacto do ambiente institucional nas eficiências sugere resultados controversos.

Palavras-chave: Eficácia institucional. Efeitos institucionais. Eficiências técnica e ambiental. Política climática. Mitigação da Mudança Climática.

ABSTRACT

This study investigated the effectiveness of the Kyoto Protocol (KP) in regards to the Greenhouse Gases (GHG) emissions reduction on the first and early second decades of 2000s. It has also taken into account the institutional, such as democracy and property rights levels and development impacts of a countries. Furthermore, it has proposed to analyze the economic performance of Gross Product Value output and the environmental performance concerning the GHG emissions employing a technical efficiency and an environment efficiency measures, respectively. Moreover, it has been proposed to verify the effect of institutional framework on these efficiencies. This study employed a difference in difference model to measure the KP effectiveness and a stochastic frontier analysis to estimate the economic and environmental performances. The results point out an overall low effectiveness of KP. Taking into account different groups of countries with similar characteristics of development or institutional quality, the effectiveness of KP was also low. Countries with low development, low urbanization area covered and high inequality tended to reduce its emissions considering the time difference. Countries with high property rights and democracy level tended to increase the emissions over time. The effect of KP ratification was positive (reduced emissions) for the countries with average institutional and development levels. However, the effect of ratification was negative on the extremes: lowest and highest institutional quality and development levels. The main driver of economic output was capital input and the level of economic output presented a higher share in GHG emissions than the non-renewable energy utilization. The overall economic performance was higher than overall environmental performance. The analysis of the impact of institutional framework on efficiencies suggests mixed results.

Keywords: Institutional effectiveness. Institutional effects. Technical and Environmental efficiencies. Climate Policy. Mitigation of Climate Change.

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LIST OF ABBREVIATIONS, ACRONYMS, INITIALS AND SYMBOLS

$GtCO_2 - eq/yr$ – Giga (10^9) tons of Carbon Dioxide equivalent per year

CDIAC - Carbon Dioxide Information Analysis Center

DD - Difference in Difference

EE – Environmental Efficiency

EIU - The Economist Intelligence Unit

EKC – Environmental Kuznets Curve

GDP - Gross Domestic Product

GHG – Greenhouse gases

GMM - Generalized Method of Moments

HDI - Human Development Indicator

IEA - International Energy Agency

IPCC - International Panel on Climate Change

km – kilometers

KP – Kyoto Protocol

kWh - kilowatts per hour

NIE – New Institutional Economics

OECD - Organisation for Economic Co-operation and Development

RA - Ratification of Kyoto Protocol in 1998

TE – Technical Efficiency

UNDP - United Nations Development Programme

UNFCCC – United Nations Framework Convention on Climate Change

WB - World Bank

WDI - World Development Indicators

SUMMARY

1 INTRODUCTION

This study focuses on the influence of institutions and the institutional framework on mitigation of climate change efforts. Plus, how economic performance underlines this relationship and works as a background to support or bind the effectiveness of climate change mitigation policies. Institutions is defined as the rules, laws, regulations, knowledge as a heritage from culture and traditions of a society. Institutions are mechanisms which bounds the understanding, action and behavior of a society, thus shaping its interactions within and between itself and with other societies (HODGSON, 2006; NORTH, 1990; SEARLE, 2005).

According to the Intergovernmental Panel on Climate Change – IPCC (2014), the concentration of carbon dioxide in the atmosphere increased to 380 parts per million (ppm) in 2010, from 280 ppm in 1850, In 2010, the yearly emissions was 49 billion of tons of carbon dioxide equivalent per year ($GtCO_2 - eq/yr$). The volume of emissions was 38 $GtCO_2 - eq/yr$ in 2000 and 27 $GtCO_2 - eq/yr$ in 1970. This unit converts the emissions of other greenhouse gases (GHG) into carbon dioxide equivalent by its contribution to the greenhouse effect and sums up the accumulated contributions per one year. Between 1970 to 2000, the average emission change was of positive 1.3% per year. From 2000 to 2010, the average change increased to 2.2% per year, despite of climate mitigation policies IPCC (2014).

The simulated scenarios from the IPCC (2014) considered the influence of human activity patterns and projected baseline scenarios for temperature variation in 2100 based on the concentration by the same year. Scenarios pointed out at least 430 ppm to 1000 ppm by 2100. The former concentration scenario would increase the global average temperature by 1.5ºC, the latter would increase by more than 4ºC.

The scenario appointed by Paris Agreement (UNFCCC, 2015) considered that the maximum average temperature increase should be 2ºC. To achieve this goal, the concentration of carbon dioxide should range from 480 ppm to 530 ppm and the accumulated carbon dioxide quantities should be at most 2900 $GtCO_2$. However, the current path of emissions would lead to a 4ºC increase in the global average temperature. The influence of economic activities, mostly from fossil fuels utilization, cement and flaring are the main drivers of carbon dioxide emissions (IPCC, 2014a).

Furthermore, the path of temperature rise might not be linear, thus at some tipping points, the consequences of GHG concentration might lead to a vertiginous increase on temperature. One objective of mitigating GHG emissions is to avoid and reduce the risks of reaching these tipping points, which can be also irreversible (IPCC, 2014a).

Before Paris Agreement, the Kyoto Protocol (UNFCCC, 1992a) was an specific effort focused on enforcing the reduction of GHG emissions and help mitigating climate change. By the year of 2012, the countries who signed the Protocol must had been reduced their emissions by 5%. Although some countries could achieve the 5% reduction, the overall world's emissions of GHG rose and the concentration of carbon dioxide increased. According to this increment of emissions, the projections have pointed out that the likelihood of the temperature rising more than the 2ºC, proposed by Paris Agreement, is very high.

Paris Agreement and Kyoto Protocol are examples of institutions, because they consist in a set of rules which were agreed by the parties at the summits and should shape society's behavior and interaction towards reducing GHG emissions. Thus, a first question that this study aims to investigate is: was the Kyoto Protocol (KP), effective as an institution?

It can be difficult for an institution "A" to thrive by itself. Other institutions (rules, laws, regulations, contracts), which has been created by society can support the effectiveness of institution A by creating or enhancing mechanisms that corroborates to achieve A's goal. On the other hand, albeit sometimes it is desired that exists an institution A to focus on, in reality every institution is an element of a set of institutions (NORTH, 1990). This set I call institutional framework.

The culture and traditions may also influence the effectiveness of an institution A due to the legitimacy and acceptance that people entrust to it. A society that believes in environmental protection, inherited from its ancestors might corroborate to the enforcement of environmental goals' institutions (HODGSON, 2006; SEARLE, 2005). Thereby, the second question I will investigate is: does the institutional framework influence the mitigating GHG institutions (KP)?

Beyond the effectiveness of GHG mitigation, the IPCC (2014) and UNFCCC (1992) considers that mitigation efforts should consider the economic performance and distributional and social impacts. The former intends to achieve mitigation goals with cost-effectiveness, thus reducing at most, when feasible, the costs involved on the mitigation efforts. In other words, minimizing the costs and preferring the less costly strategy when dealing with mitigation goals. The latter regards the burden/benefit-sharing and equity principles. Equity means that the responsibility of how much a society can burden mitigation efforts must be taken into account when sharing the burden; on the other hand, the benefits must also be shared proportionally.

Besides, economic performance and equity are key factors to create and support a feasible institutional framework for mitigating efforts. The IPCC (2014) points out that the acceptance of international mitigation policies are subject to the feasibility of domestic policy, which also depends of the domestic institutional framework. An environment of inclusive institutions, which civil society participation is broad in government decision-making, property rights are well defined and contracts are very likely to be enforced, migh increase the potential of better economic performance, which also minds equity principle (ACEMOGLU; ROBINSON, 2012). The last two questions I will investigate are: the economic performance of an economy corresponds to its environmental performance? By environmental performance it is considered as achieving cost-efficiency in concern of mitigatng GHG emissions policies. Do the economic and environmental performances relate to the institutional framework and institutions?

The objectives of this study are to answer the four questions by analyzing the results from different econometric models according to the proposed theoretical framework on Chapters 2 and 3. I will employ a difference in difference model to address the effectiveness of KP and the influence of institutional framework. I employed some models to consider the relationship between economic and environmental performance and institutional framework and institutions. Chapter 2 mainly answers the first two questions and Chapter 3 focuses on the analysis of the other two last questions.

Chapter 2 aims to contribute with one possibility of measuring effectiveness of climate policies and decomposing it on time effect and KP ratification effect. The latter represents if a country confirmed the signature to contribute to KP emission reduction until 2012. It was done by using an econometric approach model called the Difference in Difference estimator, mainly used on public health, psychology and social sciences to evaluate policies (ABADIE, 2005). By stratifying groups considering economic, social and institutional issues, Chapter 2 also tries to contribute to discussion of equity and justice of mitigation of climate change.

Chapter 3 focus the AR5 Chapter 13's principle of aggregate economic performance by measuring the efficiency in using carbon dioxide emissions as a detrimental input. The AR5 chapter 13 shows assessing means to achieve international cooperation in order to tackle GHG emissions. One mean is to achieve aggregate economic performance, where the costs of the policy to the society are minimized and the benefits are maximized. Instead of evaluating benefits and costs of the policies, I will analyze the economic performance by using inputs on a technical efficient and on an environmental efficient way to economic growth. Also, Chapter 3 model measures the impact of income inequality and institutional framework on efficiencies.

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2 GLOBAL GOVERNANCE AND CLIMATE CHANGE MITIGATION POLICIES: EVIDENCE FROM KYOTO PROTOCOL

Resumo: O presente estudo analisou o a efetividade do Protocolo de Quioto (KP), considerando este último como uma instituição formal, sob o efeito do nível de atividade econômica e qualidade institucional de um país. Para a qualidade institucional utilizou como *proxies* o nível de democracia, o cumprimento de contratos e o nível dos direitos de propriedade. Este estudo utilizou um modelo de Diferenças em Diferenças para isolar o efeito do KP e decompô-lo no efeito do tempo e no efeito da ratificação do protocolo. A metodologia empregada considerou a endogeneidade entre as variáveis. A heterogeneidade entre os países foi controlada utilizando uma estratificação que considerou variáveis *proxies* para o nível de desenvolvimento, qualidade institucional e características estruturais. O KP apresentou uma baixa efetividade, no geral. Os resultados considerando a heterogeneidade sugerem que os países com baixo nível de desenvolvimento reduziram as emissões ao longo do tempo. Países com alto nível de democracia e altos direitos de propriedade apresentaram um aumento nas emissões ao longo do tempo. Os resultados sugerem que a ratificação do KP aumentou as emissões nos extremos: grupos com menores e maiores níveis de desenvolvimento; maior e menor qualidade institucional. Enquanto isso, os países que apresentaram níveis médios das variáveis apresentaram um decaimento das emissões em relação à ratificação do protocolo.

Palavras-chave: Instituições; Qualidade institucional; Desenvolvimento sustentável; Mitigação das mudanças climáticas; Política climática

Abstract: This study analyzed the effectiveness of Kyoto Protocol (KP) formal institution under the effect of a country’s economic activity and institutional quality, such as democracy level, legal rights and property rights enforcement. The study employed a Difference in Difference model to isolate the KP effect and decompose the time effect and the ratification of KP effect. It also considered the endogeneity of variables. The heterogeneity among countries was controlled using a stratified sample according to variables that proxies the development level, the institutional quality and structural characteristics. The KP presented a low effectiveness in overall. The stratified sample suggested that the time effect impact on GHG emissions were higher than the ratification of KP effect. Countries with low development level presented a decrease in emissions

over time. Countries with high democracy level and high property rights increased their emissions in the time trend. The ratification of KP seemed to increase emissions on the extremes: highest and lowest development and equality levels; highest and lowest institutional quality. Countries which ratified the KP with medium development levels and institutional quality presented an overall decrease in emissions according to the results.

Keywords: Institutions; Institutional quality; Sustainable development; Climate change mitigation; Climate policy

2.1 INTRODUCTION

This study regards the evaluation of the effectiveness of the Kyoto Protocol (KP) and its influence on greenhouse gas (GHG) mitigation. In this study we treat the KP as an economic institution. The goal of the KP as an economic institution was to shape or influence the behavior of society (civil society, government, and businesses) to reduce a country's emissions by 5% if the country ratified the KP by 1998. Our period of analysis is from 1971 to 2012.

Carbon dioxide emissions increased from 38 to 49 billion of tons of carbon dioxide equivalent per year ($GtCO_2\ eq/yr$) between 1990 and 2010, a 29% increase in GHG emissions (IPCC, 2014). Data from the World Bank indicates that average country emissions rose by 40% in 2012 compared to 1990 (World Bank, 2017). However, the KP called for a 5% reduction in GHG emissions from 1990 to 2012 (UNFCCC, 1992).

According to the Intergovernmental Panel on Climate Change (IPCC, 2014), despite the efforts of the international community toward climate change mitigation (the KP, the Copenhagen Accord/Cancun Summit, and climate change mitigation policies), total world GHG emissions increased more in the 2000-2010 period than in the four decades prior. Stern (2016) highlights that action towards climate change mitigation was either too weak or too little and too slow.

In 2004, Pacala and Socolow (2004) argued that the stabilization of carbon dioxide emissions could be achieved by increasing the implementation of already established technologies and production processes on a larger scale, and referred to such technology and processes as *stabilization wedges*. Following this study, Davis *et al.* (2013) claimed that the delay in employing stabilization wedges consequently demanded disruptive innovations to support the same stabilization level suggested in 2004, as the technologies current in 2013 would not suffice.

The concentration of carbon dioxide in the atmosphere increased from roughly 355 parts per million (ppm) to 380 ppm from 2000 to 2010. In 2015, the carbon dioxide concentration was roughly 400 ppm (Dlugokencky and Tans, 2018). By the same year, the global average temperature exceeded the 1ºC of preindustrial[1] levels for the first time (Hawkins *et al.*, 2017). The concentration of carbon dioxide in the atmosphere affects the temperature of the planet by the greenhouse effect. Without the greenhouse effect, the world's temperature would be 33ºC colder. This effect is responsible for allowing and maintaining life on the planet. Carbon dioxide concentration increases with the rise in emissions caused by the intensification of anthropogenic activities. Over the past 400,000 years through 1950, the carbon dioxide concentration in the atmosphere remained consistently around 280 ppm.

Natural and human systems are susceptible to large-scale changes, which can be irreversible and abrupt due to rising temperatures. The incremental risk associated with these events is not linear. Due to this non-linearity, certain tipping points in temperature change exist where the risk of certain large-scale events is more likely (IPCC, 2014a). The Paris Agreement aims to keep the average global temperature below 2ºC compared to preindustrial temperatures (UNFCCC, 2015). To achieve this goal, the concentration of carbon dioxide in the atmosphere must remain between 430 and 530 ppm (IPCC, 2014a).

If the trend in carbon dioxide emissions from past decade continues, the concentration of carbon dioxide in the atmosphere is expected to rise to more than 750 ppm and the global average temperature, to more than 3.5ºC. GHG emissions were mostly caused by growth in economic activity, population, and energy consumption. While population growth remained stable from 2000 to 2010, economic growth and energy consumption have increased their share in the responsibility for emissions (IPCC, 2014a).

From 1998 to 2012, GHG emissions from anthropogenic sources increased by 29%, from 38 to 49 $GtCO_2\ eq/yr$. During the same period, average emissions in all countries increased by 40%. The emissions share of the top five greenhouse-gas-emitting countries accounts for 72% of all world emissions. Using the same data source, while

[1] The IPCC Assessment Report Five (AR5) considers the period of 1850 to 1900, but Hawkins et al. (2017) argue that this period is not a formal definition. They instead suggest that the period of 1720 to 1800 is more suitable, given that the natural radiative forcings from 1720 to 1800 are closer to those of the present levels.

some countries reduced their emissions by more than 5% during the KP enforcement period, others increased their emissions by more than 50% (World Bank 2017).

Veiga (2013) highlighted that the demands of the Kyoto Protocol were distributed unequally among countries. Specifically, the author claimed that developed countries would benefit more from the protocol while less developed countries and China would shoulder more of the emissions reduction burden, despite most emissions being produced by developed countries. In addition, the withdraw of the U.S. caused diplomatic negotiations regarding the protocol to come to a halt.

The enforcement of the KP is an example of global governance of a formal institution, creating agreements to shape human interaction. The KP proposed that countries that ratified the protocol by 1998 (RA countries)—either individually or jointly—reduce their emissions by 5% from 1990 levels. According to Adger (2001), the likelihood of free-riding may have increased under KP due to differences in country infrastructure and ability to enforce emissions mitigation policies, unless market signalization indicated benefits that outweighed the costs of ratifying the protocol (Adger, 2001).

GHG emissions have a defined source and impact the entire planet through the greenhouse effect. GHG emissions are considered a source of global pollution, implying that certain regions shoulder the costs of emissions reduction, while all regions receive the benefit. As such, mitigating climate change is referred to as a public good. However, the information of the cost and benefit of reducing GHG emissions (mitigation) are unknown and vary according to the society, region, or party involved. Therefore, decisions for emission mitigation efforts imply bearing costs without knowing the benefits (Sandler and Arce, 2003; Nordhaus, 2015; Paavola and Adger, 2005).

Mitigating emissions is likely to involve many parties, which implies complex negotiations and many transaction costs. Thus, economic agents would try to minimize these costs. One possibility is free-riding behavior, which implies that one agent pays more for pollution abatement than another agent, yet both benefit from better environmental quality. Therefore, free-riding mitigation benefits can be treated as an institutional problem (Cole, Rayner, and Bates, 1997; Young, 2003; Stern, 2006; Nordhaus, 2015).

Tackling free-riding, reducing transaction costs, and managing information asymmetry can be possible by establishing institutions. Institutions serve to provide ‘rules to the game’, which give authority or power to an organization, a person, or a society, or grant power to one party to enforce the rules on another party. In the last case, this second party must accept and recognize the power of the first party. The result of this institutional behavior is to shape human interaction (Searle, 2005; North, 1990). If an institution is ineffective, it cannot empower one party to enforce the behavior of another party, which implies that free-riding is likely to occur and information asymmetry may lead to increased transaction costs. To be effective, the institution must complete its objective (Young and Underdal, 1997).

The main objective of this study is to analyze the effectiveness of the KP—defined as a formal institution according to North (1990)—in mitigating climate change. In addition, this study aims to observe if the influence of the KP varies across countries due to differing domestic institutions, levels of development, and physical attributes.

The Assessment Report 5 from IPCC suggested certain potential criteria to accompany each country's contribution towards its mitigation policy goal. Environmental effectiveness is the country's action to reduce anthropogenic sources of emissions within a certain period of time. Distributional and social impacts regard the principle of fairness and equity of benefit sharing for a country's population, across generations. Institutional feasibility of enforcement of a mitigation policy in a given country is supported by society, and by the acceptance and participation of the population.

The contribution of this study is its assessment of the effectiveness of the KP in reducing GHG emissions by employing a difference-in-difference quantitative method. One difference measures the impact of time on the emissions trend, before and after the existence of the protocol. A second difference is the change in the emissions trend of RA countries compared to the change in the emissions trend of countries that did not ratify the KP in 1998 (NR countries). By subtracting the second difference from the first difference, the result is the impact of the KP.

With respect to the equity and fairness principle of IPCC, a second contribution of this study is the analysis of the influence of a country's level of development and inequality on the effectiveness of the KP. This study aims to analyze the impact of informal institutions—such as those of democracy, property rights, and legal rights—on the effectiveness of the KP. To account for the relationship between economic growth and energy use intensity, the model we use in this study also considers the relationship between environmental degradation and economic performance.

Our hypothesis is that isolated effect of the KP is small. Our second hypothesis is that KP effectiveness can be affected by levels of fairness and equity in a country, in addition to the country's institutional framework.

2.2 THEORETICAL FRAMEWORK

In this section, we provide an analytical background for the relationships between environmental degradation and economic activity; and between institutions and environmental regulation. The former considers the behavior of societies in relation to environmental degradation, based on historical evidence and microeconomic assumptions (Cole 1999). The latter takes into account that institutions, if effective, can shape human interaction and behavior in response to market failures such as free-riding and externalities (NORTH, 1990).

Taken together, environmental degradation as a negative externality represents a market failure. However, the party responsible for the externalities is not obvious, and neither is who is going to shoulder the cost of the externality or who should receive the benefit of the externality. Therefore, institutions can enforce environmental governance through providing rules and regulation that dictate to the involved parties who is responsible for externalities and what the consequences of externalities are (PAAVOLA; ADGER, 2005).

2.2.1 Anthropogenic emissions and economic activity

A theoretical background for the relationship between anthropogenic emissions and economic activity can be found in the environmental Kuznets curve (EKC), adapted from Kuznets (1955). Kuznets originally drafted an inverted U-shaped curve representing the trade-off between inequality and per capita income. The EKC, however, represents the trade-off between environmental degradation and per capita income. At low levels of per capita income, environmental degradation increases as income rises until a certain point, after which income then rises inversely with environmental degradation (Cole, 1999).

During the ascending part (first stage) of this curve, and in lesser developed countries, an environmental good is considered a luxury item and is consumed at higher income levels. In lesser developed economies, individuals tend to spend their income on consumer goods instead of environmental quality. As long as the marginal utility from consumer goods is decreasing, individuals demand more environmental quality as their income rises. A turning point in the curve occurs when the marginal utility for consumer goods equals the marginal utility for investments in environmental quality. After this turning point (the second stage), environmental quality is preferred over consumer goods. The marginal utility of consumer goods is less than that of environmental goods, and this net value is represented by the decreasing part of the inverted U-shape curve (Cole 2004; Moomaw and Unruh 1997).

These two stages can be exemplified using the periods before and after an industrialization process. The transition from an agricultural-based economy to an industrial economy implies an increasing level of environmental degradation due to higher consumption and higher mass production of goods, which also demands more energy. In addition, urban services such as solid and toxic waste disposal and basic sanitation are used as a country's economy achieves a certain level of urbanization and obtains the necessary technology. Furthermore, environmental education and democracy can lead to greater enforcement of environmental quality institutions (BRUYN; BERGH; OPSCHOOR, 1998; SELDEN; SONG, 1994).

Certain authors (BRUYN; BERGH; OPSCHOOR, 1998; THOMAS; CALLAN, 2014) suggest that as per capita income increases, the cost of mitigating environmental degradation also increases. Thus, before the first tipping point in the EKC, net environmental degradation will decrease until abatement costs outweigh pollution mitigation. After this point, the EKC turns upward because net environmental degradation increases. Meanwhile, abatement costs tend to rise due to the decreasing marginal productivity of technology, implying fewer investments in abatement technology since paying taxes or similar policies are preferred over investment in abatement technology. This tendency results in increasing net environmental degradation, and implies an N-shaped EKC.

In the case of CO_2 emissions, which represent 65% of total anthropogenic emissions, empirical evidence suggests that the turning point for reducing environmental degradation during rising per capita income is very difficult for a country to achieve (MOOMAW; UNRUH, 1997). Holtz-Eakin and Selden (1992) studied the EKC for CO_2 emissions using unbalanced panel data for 130 countries during the period of 1951 to 1986. They found the first turning point in the curve at US$35,000 annual per capita income and the second turning point at US$8,000,000 annual per capita income.

Cole, Rayner and Bates (1997) also used panel data to estimate an EKC of local and global polluters in seven world regions from 1960 to 1991. They found the first turning point at US$62,700 annual per capita income using a quadratic log functional form and the second turning point at US$25,100 annual per capita income on quadratic levels. At the time of their study, no available countries had achieved the second stage of the EKC.

Meanwhile, Cole (1999) showed that local air and water pollution emissions range from US$3,280 to US$14,700—an upper value that most countries observed in his study would reach. His findings can be explained according to the specific areas affected by these polluters—areas where local governance is less likely not to act. Shafik and Bandyopadhyaty (1992) studied 149 countries over the period of 1960 to 1990 using panel data and considered changes over time. The authors considered factors such as urban sanitation, lack of clean water, suspended particle matter, and local polluters, and found a range of US$2,000 to US$4,000 annual per capita income for the first EKC turning point. Cole, Rayner, and Bates (1997) found that international negotiations were slow, provided weak enforcement, and that therefore countries have little incentive to support investments in reducing environmental degradation of global polluters and pay for abatement.

The growth rate of global emissions from 2000 to 2010 was 2.2% per year (IPCC, 2014c). Stern (2006) found that emissions from western Europe accounted for nearly 4 $GtCO_2\ eq/yr$ in 2002 and he projected that emissions would increase 11% by 2025. The IPCC also found that US emissions were 6 $GtCO_2\ eq/yr$, and estimated they would rise 39% by 2025. The Panel found that China emissions were similar to those of western Europe, but projected emissions in China to increase 145% by 2025, similar to US 2025 levels. In addition, despite low emissions levels by Africa and India, and half of western Europe, the IPCC estimated the emissions in these regions would increase by 78% and 95%, respectively.

The heterogeneity of countries is an important consideration for estimation, as abatement technology and institutional environment are likely to be unequal among countries. Paavola and Adger (2005) argue that institutions are uneven among countries and that difficulties for environmental governance increase transaction costs.

2.2.3 Economics, institutions, and environmental regulation

Classical microeconomic theory aims to allocate maximum efficiency among resources, and its assumptions are based on the theory of competitive markets. A competitive market assumes perfect information; the firms are price-takers; that firms individually cannot influence market prices; that markets are freely entered and exited; and that firms are rational and maximize their objective function. In a competitive equilibrium, supply or demand surpluses are null given initial endowments, consumer utility is maximized, and good endowments are finite. Therefore, competitive equilibrium implies a Pareto optimum, with no possibility of maximizing an individual's utility without decreasing the utility of another. These assumptions lead to maximum possibly welfare. However, the failure to meet any of these assumptions is considered a market failure and will not provide maximum possible welfare (NICHOLSON; SNYDER, 2012; SILBERG; SUEN, 2001).

Market failure can occur in both monopolies and oligopolies, due to imperfect information, and with public goods and externalities, among other circumstances. Therefore, environmental economics aims to account for and model the costs or benefits of a market, while incorporating its sources of failure. With respect to environmental quality, the source of failure tends to be a public good[2]. Regarding the production or consumption of a good or service, positive externalities count as a benefit of production (or consumption) and negative externalities occur in the form of environmental degradation (Clarke, 1971).

Market failure of a public good appears when economic agents lack incentives to reveal their preferences, and therefore their willingness to pay for a good or service is unknown, leading to imperfect information. Then, if an economic agent *A*, receives the benefits of a good or service such as air or water quality, at the cost of another agent *B*, agent *A* is then considered to be free-riding. A solution for this problem is a government that provides public goods and services. Externalities are costs or benefits to a third party that was not involved in the production or consumption of a good or service. Thus, the involved parties do not take these benefits or costs into account in the price. Such is the case with fisheries that suffer from river pollution caused by a factory, or a farm that benefits from nearby beekeeping (Clarke, 1971)(THOMAS; CALLAN, 2014).

Agents face problems with uncertain outcomes and incomplete information, which incurs transaction costs. In addition, agent preferences and their objective function changes over time in response to reoccurring problems. Multiple equilibria may arise, due to unknown outcomes where agents cannot identify the best choice. Therefore,

[2]A public good is a good that is non-rival and non-exclusive, where non-rival means that the consumption of one agent does not constrain the consumption of another agent. Non-exclusivity means that the benefits of consumption are not restricted to determined agents (SAMUELSON, 1954; 1955).

considering market failures as an exception may not be realistic. Institutional approaches aim to answer questions where institutions are the center of analysis, given that human interaction is very complex, information is limited, and uncertainty is present (NORTH, 1990).

Institutions comprise the set of constitutive rules, procedures, and practices that collectively shape human interaction and behavior (NORTH, 1990; SEARLE, 2005). Searle (2005) gives the example of the twenty-dollar bill as an institution. The note, which in and of itself is not an institution, is instituted with the status of a twenty-dollar bill. The bill is defined by a set of rules and holds established and recognized deontic power[3] given by the society, and is therefore an institution.

These rules can be recognized as either informal and formal. Informal rules, such as modifications of formal rules, norms of behavior, and standards of conduct, are passed on from one generation to the next, and therefore constitute a culture. Formal rules, such as regulations, laws, and contracts, are established by more complex interactions, and through writing can formally establish property rights. Formal rules can complement and possibly enhance the effectiveness of informal rules, and both informal and formal rules are counted in transaction costs (NORTH, 1990).

Transaction costs are a pillar of NIE and exist as a result of imperfect information and uncertainty regarding stipulated contracts for exchanging goods. These contracts serve to minimize uncertainty, as automatic price regulation that dictates clear market mechanisms is not realistic (COASE, 1937). Transaction costs exist for the market for environmental goods, as the benefits and costs of this market are largely unknown, as gathering information is costly, and as information on the characteristics of environmental goods is obtained only over a period of time (PAAVOLA; ADGER, 2005; THOMAS; CALLAN, 2014). The effectiveness of an institution's outcome is a function of its institutional framework, and the ability of government to monitor, identify, and enforce regulation, all of which contribute to increased transactions costs. Therefore, local or regional solutions may be preferred to global solutions to enhance the effectiveness of environmental policies (Paavola and Adger 2005; Adger et al. 2003).

Coase (1960), in response to the treatment of externalities in welfare economics, argued that attributing property rights of a public good to a given party achieves an efficient allocation of resources by the interaction between parties given initial

[3]Concerns the obligation, permission, authorization, empowerment, and rights of the entity that possesses this power to enforce it (SEARLE, 2005).

endowments. Hardin, (1968), in his *The Tragedy of the Commons*, focuses on a situation of overutilization of common, exhaustible resources, which leads to the resource's depletion if the public is given freedom for exploitation. Therefore, regulation is necessary to avoid the *tragedy*. Regulation can be established to provide a party with property rights, which may either be successful or not, depending on the characteristics of the *common* (DIETZ; OSTROM; STERN, 2003). Presenting empirical research, Ostrom *et al.* (1999) understand that the tragedies of local and regional commons are real, but not inevitable. However, global challenges such as biodiversity and climate change present problems in the form of a greater number of parties involved, and greater heterogeneity such as cultural divergences and differing levels of industrialization.

Sandler and Arce (2003) highlight the contrast between the terms *common* and *public* goods. A common good is different from a public good, therefore implying a difference in conceptual understanding and policy applications. In the case of the commons problem, benefits belong to the individual and costs are shared by the group. In the case of public goods, all parties receive the benefits, while each party is responsible for its own costs. Therefore, optimally addressing incentives to contribute to a public good and addressing punishment to resolve the problem of the commons requires equity-motivated policies.

Nonetheless, a lack of information regarding the benefit and cost of a public or common good, in addition to an increased number of parties involved in negotiation, results in less incentive to pay for environmental quality. In addition, one must note that abatement costs are the responsibility of each party, while the benefits are global and would be enjoyed over the long term. Thus, the propensity to free-ride increases (NORDHAUS, 2015; PAAVOLA; ADGER, 2005).

Therefore, institutions must provide a set of rules, procedures, or/and practices to shape the interaction of economic agents. An institution is also effective if it alleviates the problem or lessens transaction costs in the process. To measure the effectiveness of an institution, the specific objective to be evaluated must be identified, and compared against the standards or monitoring of the institution. The methodology used to quantify or attribute a level of effectiveness must also be identified. A robust institution is considered to be resilient, meaning that it is able to adapt to changes in the environment without distancing itself from its initial purpose. On one hand, inflexible institutions may lack governance during changes. On the other hand, too much flexibility of a government can prove ineffective. Robustness can be measured as persistence over time. Thus, if effective, an institution is more likely to also be robust and transparent (YOUNG; UNDERDAL, 1997).

2.3 METHODOLOGY

2.3.1 Difference-in-difference model

The difference-in-difference (DD) estimator is commonly adopted in applied social sciences to evaluate the effectiveness of a policy intervention or policy changes on a group of individuals. It is measured using the characteristics of a group before and after policy application between treated and control. If only a part of the group is exposed to policy restrictions, then it measures the effectiveness of the policy by differentiating the effects on the exposed (treatment) group from the non-exposed (control) group (ABADIE, 2005; LECHNER, 2010).

One of the primary objectives of this study is to measure the effectiveness of the KP regarding the mitigation of GHG emissions. Thus, the DD model can be used to measure the effect of the KP by taking two differences. One takes the difference between the level of emissions of the countries that ratified their signature on the protocol and those that did not. The second takes the difference in emissions levels before and after the 1998 ratification. We opted to employ this model because the difference between differences can measure the isolated effect of the KP, the formal institution.

The DD estimator was first used in the area of public health to compare the propagation of disease vectors and sanitation infrastructure in London in the 19th century. Later, the DD estimator was broadly used in medicine to compare treatment and control groups, where the treatment group receives a medication and the control group does not receive the medication (i.e., under the condition of perfect clones). In the case of an economic problem, the treatment group is exposed to a given regulation, while the control group is not (LECHNER, 2010).

The employment of DD estimator models became more popular in the research of Lester (1946), analyzing wages and employment. He sought to investigate the relationship between the production and employment policies, and study profit maximization within firms using a marginal analysis. His objective was to investigate how the minimum wage affects employment. One of his key findings was that market demand is more important than the cost of paying wages in determining a firm’s decision to employ. He additionally found that the point of view of business executives has more influence over employment than a conventional marginal analysis of profit maximization.

2.3.2 Analytical model

DD models are panel data models involving the subtraction of one difference from a second difference. The first difference is of a dummy variable in the period of time before and after the implementation of a program, and the second difference is for the average between a treatment and control group. The treatment group includes observations of individuals affected by the program and the control group consists of observations of those unaffected by a given program. The last subtraction is between time difference and program difference. Using this procedure, we can measure the effectiveness of a program (ABADIE, 2005).

According to the method of Young and Underdal (1997), we define the following: the evaluated object is KP ratification; the control group is countries that did not ratify KP before 1998; the treatment group is the group that ratified; the quantifying method is a DD model using available data from 1970 to 2013 in an unbalanced panel. We also consider the time difference, which is treated as before and after 1998.

On one hand, we assume that the infrastructure a given country has built to mitigate GHG emissions does not expire if an RA country leaves the KP. On the other hand, if a country left the KP without mitigating its GHG emissions, this implies that ratification was not effective. In such cases, RA will not change.

We consider β_{DD} as the estimator of the DD model; Y the emissions level; $T = \{0,1\}$ the institution effect, where $T = 0$ represents the control group and $t = \{0,1\}$ represents the time effect; $t = 0$ the period before 1998; and Equation (1) represents the overall effectiveness of the KP (ABADIE, 2005; LECHNER, 2010).

$$\beta_{DD} = \{E[Y|T = 1, t = 1] - E[Y|T = 0, t = 1]\} \\ -\{E[Y|T = 0, t = 1] - E[Y|T = 0, t = 0]\} \tag{1}$$

The time difference measures if the trend before the KP remained the same as the trend after 1998. The difference value can be explained by the EKC hypothesis and time series evidence. The EKC hypothesis can be explained by whether or not an increase in per capita income decreased emissions, and either corroborates or does not corroborate the evidence of a long-run relationship between carbon dioxide emissions and per capita income. We evaluate the robustness of the KP by isolating its time effect. Specifically, we analyzed the trend in emissions before and after the implementation of the KP.

Expected values for time differences are represented in Equation (2) for the treatment group (RA countries) (ABADIE, 2005; LECHNER, 2010).

$$Y_{T0,t1-t0} = E[Y|T = 1, t = 1] - E[Y|T = 1, t = 0] \quad (2)$$

And in Equation (3) for the control group (NR countries) (ABADIE, 2005; LECHNER, 2010).

$$Y_{T1,t1-t0} = E[Y|T = 0, t = 1] - E[Y|T = 0, t = 0] \quad (3)$$

The treatment and control variables measure if countries in the RA group differed from those in the NR group. As treaty enforcement, obligations, and responsibility of the RA group may or not differ from those of the NR group, the measured difference value would take into account either differing or statistically equal emissions levels. Therefore, in considering the action of other institutions in the decision-making process for emissions mitigation under the KP, the measured difference value captures the effect of society's support of the KP. The treatment and control differences before KP ratification are represented by Equation (4) (ABADIE, 2005; LECHNER, 2010).

$$Y_{T1-T0,t0} = E[Y|T = 1, t = 0] - E[Y|T = 0, t = 0] \quad (4)$$

The treatment and control difference after the KP are shown in Equation (5).

$$Y_{T1-T0,t1} = E[Y|T = 1, t = 1] - E[Y|T = 0, t = 1] \quad (5)$$

By calculating the difference between (2) and (3) we obtain (1). The difference between (5) and (4) is equal to (1), rearranging the terms. Both differences measure the overall effectiveness of the KP, if structural changes and economic activity affected emissions and if the incentives to contribute to the KP were better than the option of free-riding. The result can be found by differentiating Equation (3) and Equation (2), which equals Equation (1). Alternatively, subtracting Equation (5) from Equation (4) results in the same value as Equation (1) (ABADIE, 2005; LECHNER, 2010).

The panel model follows Equation (6) (PEIXOTO et al., 2012).

$$Y_{it} = \alpha . X'_{it} + \gamma . T_{it} + \rho . t_{it} + \beta_{DD} . (T_{it} . t_{it}) + \varepsilon_{it} \quad (6)$$

Where Y_{it} is the emissions of carbon dioxide for each country i at a time t; X'_{it} represents the vector of variables capturing characteristics of each country i. These variables are: per capita GDP, squared per capita GDP*;* and per capita energy consumption. $T_{it} = \{0,1\}$ is a binary variable where $T = 1$ represents an RA country; $t_{it} = \{0,1\}$ is a binary variable where $t = 1$ is the period after 1998;β_{DD} is the effectiveness of the KP due to interaction between both binary variables; and e_{it} is the stochastic error in the regression.

Chang (2011) highlights that using dummy variables such as regional dummies does partially address the problem of sample heterogeneity, although it is an theoretical approach. Therefore, to consider heterogeneity while employing a theoretical approach, this study employs a stratified sample. We use the stratification of nine variables for country characteristics. We used an inequality index (Human Development Index of the United Nations) from 2000 and 2012, internet use as a percentage of the population, the surface area of the country, the percentage of urban population, the real interest rate, the Democracy Index (The Economist Intelligence Unit), and the Legal Rights Index (The World Bank).

We employed a cluster analysis to classify the nine variables and stratify the countries into three groups: development status; structural characteristics; institutional environment quality. Development status includes the Gini inequality index and the Human Development Index (HDI - United Nations) from 2000 and 2012. The variables used to account for structural characteristics were the percentage of internet use, the share of agricultural GDP, and the percentage of people living in urban areas.

In the institutional environment group, the real interest rate was used as a proxy for property rights, as countries with more fragile property rights generally have a higher real interest rate (NORTH, 1990). We place the democracy index—which includes information about electoral processes, civil liberties, political participation, and government functioning—from various countries in 2012 into the institutional environment group (EIU, 2013). We also used a 2012 legal rights index from the World Bank (World Bank, 2017) as a proxy for contract enforcement.

The Z_i in Equation (7) is a new vector that takes into consideration the characteristics for $z_{ip} \in Z_i$, where p denotes one variable out of nine, and i denotes the country. We formed clusters based on the Euclidean distance measure. Four clusters were calculated to divide the sample into three stratifications. Equation (7) shows the Euclidean distance between p variables for observations z_{ip} and z_{jp}, where $i \neq j$ and $i, j \in N$.

$$d_{ij} = \sqrt{\sum_{p=1}^{P=9} \left(z_{ip} - z_{jp}\right)^2} \tag{7}$$

The construction of clusters is influenced by outliers and the different magnitudes of variables. To avoid such variation within the sample, all variables were transformed into z-values according to a normal distribution with mean zero and a unitary standard deviation. The model specified in Equation (6) was estimated for each cluster group and for each stratification.

As natural resources can be necessary to increase economic income, and since the mining of natural resources requires economic resources, this relationship can incur issues of endogeneity (ARROW et al., 1995; LIST; GALLET, 1999). An econometric model with endogeneity problems can include biased parameters (Greene 2003). Therefore, to address any endogeneity issues, we employed a System Generalized Method of Moments (GMM) model specification (ARELLANO; BOVER, 1995). The System GMM uses the lag of the dependent variable and the past observations of independent variables as instrumental variables, running a total of 128 instruments. We employed the Hausman statistical test (HAUSMAN, 1978) to verify the validity of the instruments. Moreover, we tested the autocorrelation of residuals starting from the second lag using the Arellano-Bond test (ARELLANO; BOND, 1991).

2.3.3 Data, sources, and estimated model

Our data consisted of three main variables: per capita GDP (2010 USD), obtained from the World Bank national accounts data and the OECD National Accounts, electric power consumption (per capita KWh*)* from the International Energy Agency (IEA), and carbon dioxide (metric tons per capita) from the Carbon Dioxide Information Analysis Center as our dependent variable, to represent the detrimental effect of carbon dioxide emissions on the environment. The period used in our analysis was 1971 to 2012. The analysis included 133 countries and our estimation included 4,613 observations in an unbalanced panel. Countries with no available data for at least one variable were excluded.

All data were transformed into logarithms and named $lco2$ for carbon dioxide emissions, $lgdp$ for *per capita* GDP, and le for per capita energy consumption. To test the EKC assumptions, the values of $ldgp$ were squared in estimation and named $lgdp2$. Therefore, the variables from vector X'_{it} in Equation (6) are $lco2$, $lgdp$, $lgdp2$, and le. The full model includes the time dummy t and RA countries until the 1998 dummy, T, both from Equation (6). The DD dummy was Dif. The full model is presented in Equation (8), where α is the constant:

$$lco2_{it} = \alpha_0 + \alpha_1 lgdp2_{it} + \alpha_2 lgdp_{it} + a_4 lco2_{it-1} + \alpha_3 le_{it} + \gamma.T_{it} + \rho.t_{it} + \beta_{DD}.Dif + \varepsilon_{it} \tag{8}$$

To test the robustness of the model employing the EKC, for all data before stratification, we estimate (8) without $lgdp2$, thus Equation (9).

$$lco2_{it} = \alpha_0 + \alpha_2 lgdp_{it} + \alpha_3 le_{it} + a_4 lco2_{it-1} + \gamma.T_{it} + \rho.t_{it} + \beta_{DD}.Dif + \varepsilon_{it} \tag{9}$$

In Equation (8), we expect α_1 to be negative and α_2 to be positive due to the EKC hypothesis. Statistical significance of γ would indicate that the ratification of the KP before 1998 had an impact on emissions. In addition, the statistical significance of ρ would indicate a positive or negative impact of time on emissions. If parameter γ and ρ are negative, then both ratification and time were helpful in mitigating emissions. However, if the two are positive, the two variables contributed to increasing emissions. Finally, the parameter β_{DD} measured the effectiveness of KP. If β_{DD} is statistically significant and negative, the protocol was effective in mitigating GHG emissions. Table 1 summarizes the data used to estimate the model.

Table 2.1 – Descriptive statistics of the estimation of variables from 1971 to 2012

Variable	Name	No Obs	Mean	Std Dev	Min	Max
Per capita CO2 (metric tons)	lco2	5,135	0.78	1.60	-5.44	4.47
Per capita electricity use (KWh)	le	5,066	7.01	1.72	1.76	10.88
Per capita GDP (2010 USD)	lgdp	4,858	8.48	1.49	1.49	11.64
Squared per capita GDP (2010 USD)	lgdp2	4,858	74.06	25.23	23.82	135.52

Source: Data from World Bank, CDIAC, and IEA.

To take into account heterogeneity among countries, we employed the vector Z_i of variables, which are proxies for country characteristics. We use the Coefficient of Human Inequality of the United Nations Development Programme, which is an average of the inequality of access by a population to health, education, and income (UNDP, 2018). We employed the Human Development Index from 2000 and 2012, from the World Bank's World Development Indicators (WDI) database. From the same database, we used the difference of the percentage of the population with access to internet in 2012 compared to in 1990, to use as a proxy for access to information and infrastructure. We considered the agricultural share of GDP (%) as a proxy for a country's infrastructure (World Bank, 2017).

Regarding the theoretical approach of the EKC concerning the transition from a mostly rural economy to an industrial and urban economy and its effect of increasing emissions, we used the average percentage of urban population from 1993 to 2012, from

WDI data. We use the annual average real interest rate from 1970 to 2012 from WDI data as a proxy for property rights, as according to North (Ch. 6, 1990). Additionally, from the WDI database, we employed the Strength of Legal Rights Index, ranging from 0 (weak) to 12 (strong) enforcement of legal rights. For this last variable, we used data for 2013 as data for previous years were missing (World Bank, 2017).

The variables of the matrix Z_i of country characteristics, employed in the stratification, take into account three dimensions of characteristics. First, we use development level and social quality. Second, we use the structural and physical characteristics of the country. Third, we consider the institutional environment as defined by the IPCC AR5. Table 2.2 summarizes the information of the variables of vector Z_i, as described above.

Table 2.2 – Variable employed in stratification, variable description, source, unit, and year

Name	Description	Source	Unit	Year
Coefficient of Human Inequality	Simple average of inequalities in health, education, and income.	UNDP	Index, simple average	2012
Human Development Indicator 2000	Index assessed by years of schooling, life expectancy at birth, and per capita GNI.	UNDP	Index	2000
Human Development Indicator 2012	Same as HDI 2000.	UNDP	Index	2012
Agriculture share of GDP	The share of agriculture sector in the total GDP of a country.	WDI	Average Percentage	1993-2012
Urban Population	Share of population living in urban areas.	WDI	Average Percentage	1993 – 2012
Internet Use	Share of population that has used the internet in the last three months.	WDI	Difference Percentage	2012 – 1990
Interest Rate	Real interest rate from a country.	WDI	Average Percentage	1970 – 2012
Democracy Index	Index based on electoral processes, civil liberties, political participation, and culture.	EIU	Index	2012
Legal Rights Index	Laws protecting the rights of lenders and borrowers.	WDI	0 to 12 (strong)	2013

Source: Research results.

2.4 RESULTS OF DD MODEL AND DISCUSSION

We estimated the DD model using the GMM. We estimated this dynamic panel data model with 4,322 observations and for 128 countries. The estimation employed 129 instruments for estimating the endogenous variable equation with GMM-SYS. Autocorrelation was absent for the second lag at a 10% confidence level. The Hausman-Sargan test reported valid instruments with a 10% confidence level.

Table 3 reports the estimated parameters and their standard errors for the system GMM in controlling endogeneity in a DD model from Equation (7) and Equation (8). Equation (7) considers the specification of the EKC hypothesis, whereas Equation (8) does not.

Table 2.3 – Results of DD model for KP impact for all 128 countries before stratification, 1970 to 2012

			Equation (7)		Equation (8)	
Variable	Name	Parameter	Coeff.	Std. Error	Coeff.	Std. Error
Time Trend difference	time	ρ	0.022	(0.050)	0.027	(0.033)
Protocol ratification by 1998	sign	γ	0.001	(0.003)	0.001	(0.003)
Difference in Difference	dd	β_{DD}	-0.045	(0.115)	-0.055	(0.041)
Constant	c	α_0	-2.290	(11.772)	-1.655***	(0.473)
Squared per capita GDP	lgdp2	α_1	-0.008	(0.149)		
Per capita GDP	lgdp	α_2	0.313	(2.644)	0.171***	(0.053)
Per capita electric power consumption	le	α_3	0.062	(0.078)	0.057**	(0.025)
Lagged per capita CO2 emissions	L1co2	α_4	0.765***	(0.199)	0.776***	(0.061)

***,**,*: Statistically significant at 1%, 5% and 10%.

Source: Research results.

Table 2.3 shows the results for the model without data stratification. In the estimation of Equation (7) with the log of squared per capita GDP, no parameters—except for the lag of carbon dioxide emissions—were statistically significant. Although negative, the estimated parameter of the quadratic level GDP was not statistically significant. In the results of Equation (8), electric power consumption and per capita GDP positively affect carbon dioxide emissions.

For both models from Equation (7) and Equation (8), the time trend difference before and after the ratification of the KP did not change. For this study, from the period of 1970-1998 to 1999-2012 (Table 3), the time trend difference was not statistically significant. The difference between countries that ratified the KP (treatment group) and those that did not (control group) was positive, meaning that RA countries on average for this study and sample, had higher emissions after 1998 than countries that did not ratify the KP. However, this parameter was also not statistically significant. On average, the coefficient measuring the overall effectiveness of KP was negative and was also not statistically significant. A negative and significant coefficient for the KP would mean that the institution of the KP was effective. However, because the coefficient was not statistically significant, the value of the coefficient is null, implying that the effectiveness of the KP was also null.

The next section reports the results for stratified groups of development level, structural characteristics, and institutional environment quality. The countries were joined together in these groups using a previous cluster analysis and employing the method of the squared Euclidean distance with a centroid linkage. Three variables were included for each out of the three stratifications. For development level, we used the Human Development Index from 2000 and 2012 and the Gini wealth inequality index. To account for structural characteristics, we employed the share of agricultural GDP of total GDP, the urbanization rate, and the percent of the population with internet access. To take into account institutional framework, we used the real interest rate, the legal rights index from the World Bank estimates and the Democracy Index measured by The Economist Intelligence Unit. Before every cluster estimation, we standardized all variables into z-values.

2.4.2 Group estimation results

Table 2.4 shows the average values and standard deviation for per capita emissions, per capita GDP, per capita energy consumption, and for the development indicator proxy variables by each stratification. The countries within each cluster can be found in Appendix II. Per capita emissions, per capita GDP, and per capita energy consumption are all national annual average values from 1970 to 2012. These groups were stratified by cluster analysis. The cluster analysis considered the Human Development Indicator values for each country from 2000 and 2012, and the Gini wealth inequality index from 2012. In the first column, in parentheses, is the number of countries within each group out of the four groups.

Table 2.4 – Development level cluster groups – average and standard deviation

Group (no. countries)	Per capita emissions (MT of CO2 eq**)	Per capita GDP (US$)	Per capita Energy Consumption (kWh)	Gini Index*	HDI 2000*	HDI 2012*
1 (23)	0.61	1113.00	579.44	39.51	40.06	46.49
Std. Dev	(1.65)	(1113.74)	(2455.21)	(6.12)	(6.87)	(6.53)
2 (32)	2.31	4696.08	1231.02	50.95	63.50	68.83
Std. Dev	(2.33)	(2563.22)	(1197.29)	(5.59)	(6.49)	(6.55)
3 (25)	3.56	5310.20	1828.50	34.80	63.96	71.26
Std. Dev	(3.24)	(7145.80)	(1437.44)	(4.11)	(6.25)	(6.55)
4 (24)	9.89	31871.19	7918.41	31.56	81.20	86.83
Std. Dev	(5.35)	(17695.76)	(6284.97)	(4.28)	(5.40)	(4.47)

* Index from 0 to 100

** MT of CO2 eq: 10^6tons of CO_2 equivalent.

The countries within Group 4 presented the highest values for development indicator variables and also the highest values for emissions, GDP, and energy consumption. Group 1, on the contrary, presented the lowest values for all variables, except for the Gini index. The carbon dioxide equivalent is the standardization of other GHG into their potential warming effect that each gas would contribute to the greenhouse effect. Each out of 24 countries in Group 4 emitted approximately 10 MT of CO_2 equivalent per year from 1970 to 2012. This group also presented the lowest average inequality rate average (31%). Group 1 presented lower inequality than Group 2. Group 1 countries are also the poorest and the least-developed countries on average annually from 1970 to 2012.

Figure 2.1 reports the estimation of GMM model results for time, sign, and DD parameters. These results considered the stratification into four groups, according the clusters of development level indicators. The group number (one to four) is indicated on the horizontal axis (X-axis), and the values of parameters are shown on the vertical axis (Y-axis). The estimated parameters for time are the difference of the emissions trend from 1998 to 2012 and from 1970 to 1997. Sign parameters present the difference between countries that ratified the KP and countries that did not ratify the KP by 1998. The DD parameters show the DD measure, which corresponds to the isolated effect of the existence of the KP. A negative value represents a reduction in emissions and a positive value means an increase in emissions.

Figure 2.1 – Effect of development level on DD model parameters of time, sign, and overall effect

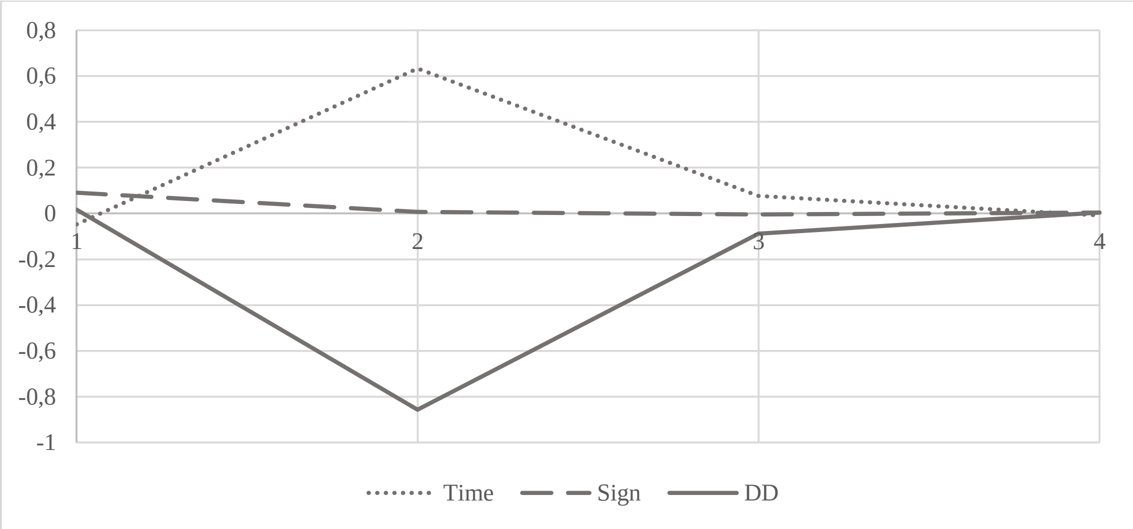


Figure 2.1 suggests that the ratification of the KP had little effect on emissions mitigation, as the coefficient was close to zero in all groups. The time parameters show that Groups 2 and 3 had positive values. These results indicate that countries from these two groups, on average, increased their emissions after 1998 compared to the trend before that year. In our model we assume that the time effect does not capture the KP institutional effect.

To capture the institutional effect, we introduce the effect of sign, the final effect (DD) of the existence of the KP, which was not necessarily strictly enforced, seemed to reduce emissions in Groups 2 and 3. The largest differences were found in Group 2. Group 2 presented the highest wealth inequality rate, and the second-lowest yearly GDP and development levels. The most developed countries with the lowest inequality indicators presented values close to zero for time, sign, and DD effects. While not mandatory in developing and developed countries, the KP emissions mitigation target was required for developed countries.

In Figure 2.1, Groups 2 and 3 presented a positive change in emissions considering the time parameter, which may suggest that changes towards a more developed country might have led to structural changes in these countries, according to the hypothesis of the EKC (BRUYN; BERGH; OPSCHOOR, 1998; COLE, 1999). Moreover, the negative value for the DD parameter, considering only the existence of the KP for Groups 2 and 3 may imply that by knowing that KP exists, these countries attempted to cooperate by not increasing their emissions as much as they would have if the KP did not exist.

The results for Groups 4 and 1 indicated that emissions neither increased nor decreased. The results imply emissions remained stable considering the three parameter indicators of time, sign, and DD.

Table 2.5 is similar to Table 2.4 and reports the average values and standard deviations for GDP, energy, carbon dioxide emissions, and proxy variables of each out of four groups. These groups were stratified using a cluster analysis and considering the Euclidean distance between observations from variables that captured information about the structural characteristics of a country. These variables considered agricultural GDP as a share of total GDP in 2012, the share of the urbanized population in 2012, and the share of the population with internet access in 2012.

Table 2.5 – Summary statistics of structural characteristic cluster groups

Group (countries)	Per capita emissions (MT of CO2 eq)	Per capita GDP (US$)	Per capita energy Consumption (kWh)	Agriculture* (%)	Urbanization * (%)	Internet Access* (%)
1 (24)	0.70	1280.20	636.10	19.67	31.73	12.17
Std. Dev	(1.33)	(974.83)	(942.85)	(13.07)	(12.11)	(8.93)
2 (20)	1.05	1262.15	631.31	26.70	41.21	19.73
Std. Dev	(1.30)	(843.97)	(729.05)	(5.04)	(11.91)	(13.42)
3 (38)	3.64	6100.15	1582.28	8.67	65.35	42.24
Std. Dev	(3.34)	(6326.97)	(1390.53)	(3.66)	(13.45)	(13.91)
4 (41)	11.19	28422.96	7267.11	3.35	76.34	74.70
Std. Dev	(8.49)	(18782.80)	(5934.30)	(2.77)	(12.02)	(13.73)

* Share of total GDP (Agriculture), surface area (Urbanization), people in percentage (Internet Access)

With respect to structural characteristics, the first group presented the lowest average for urbanization (32%) and the lowest average for internet access (12%) and average annual emissions (0.7 MT of CO2 eq). The fourth group had the lowest average value for agricultural share of GDP (3.35%) and the highest value for every other variable. The gap between the fourth and third group with regard to emissions, GDP, and energy consumption is relatively high in comparison with that of other groups. The relatively high gap is also suggested in Table 4, whose clusters were according to development level. Group 2 presented the highest values for agriculture percentage of GDP (26%) and the lowest annual averages for GDP and energy consumption.

Figure 2.2 shows the estimated difference parameters from the GMM model. Similar to Figure 2.1, group numbers are shown on the X-axis, and the parameter values are reported on the Y-axis. A negative value means that the specific group is likely to have reduced emissions. A positive value indicates an increase in emissions.

Figure 2.2 – Effect of structural characteristics on DD model parameters of time, sign, and overall effect

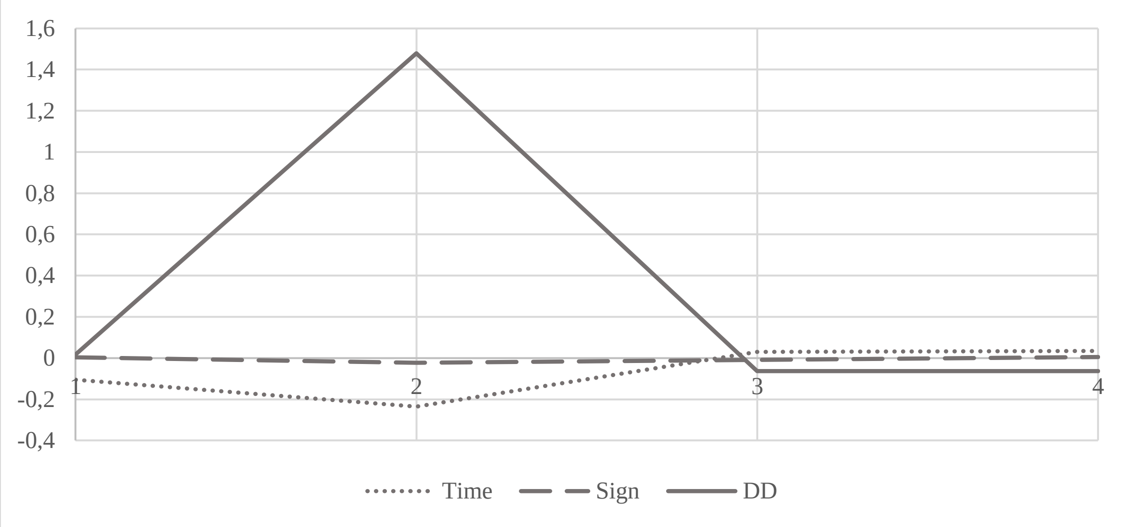


Figure 2.2 suggests a very low effect of protocol ratification, as these results for sign are very close to zero. The ratification of the protocol among the groups of countries stratified by structural characteristics had little effect. The effect of DD, which is the effect of the existence of the KP, had a positive impact on Group 2 and a low, negative impact on Groups 3 and 4. The time parameters suggests that Groups 1 and 2 could have decreased their emissions according to time, and that Groups 3 and 4 increased their emissions. Isolated from the institutional effects of the KP and enforcement following ratification of the KP, the time parameter is likely to indicate changes in the structure of a country. Average-to-low structure countries presented negative differences, while average-to-high countries presented positive differences.

A comparison between Figure 2.1 and Figure 2.2 indicates that the time and DD effects for Group 2 are the opposite. However, we must note that Group 2 from Figure 2 does not contain the same countries as Group 2 from Figure 2.2. The former is stratified according to development level, whereas the latter was stratified according to structural characteristics. As discussed earlier, in Figure 2.1 the positive time effect may consider changes in structure characteristics, according to the EKC hypothesis; and the negative sign effect is possibly linked to emissions that could have been emitted, but were not. Figure 2.2 indicates that countries with average-to-low structure characteristics (agricultural share in economy, lesser urbanization, and lesser internet use) emitted less after 1998 than before, and countries with average-to-high structural characteristics emitted more after 1998 than before, which supports the EKC hypothesis of structural characteristics that affect emissions (BRUYN; BERGH; OPSCHOOR, 1998; COLE, 1999). Concerning the DD effect, Figure 2.2 shows that Group 2 increased emissions and Groups 3 and 4 decreased emissions due to the existence of the KP. Groups 2 and 3 from Figure 2.1 decreased their emissions according to the same parameter (DD).

According to development level groups, medium-developed countries decreased emissions due solely to the existence of the KP and increased emissions by following changes in their structural characteristics, according to the time parameter. The groups according to structural characteristics presented opposite results, which possibly indicates emissions transfer. Specifically, developed countries whose imports come from developing countries leave emissions from production chain processes in those developing countries. Developing countries changed their structure to meet the increase in the demand of products for export, as demonstrated in Figure 2.1. As a result of the KP, developed countries may have transferred their emissions to developing countries to reduce their accountability for emissions, as emissions levels are measured according to their source, and not their final destination (PETERS et al., 2011). This transfer is also demonstrated in Figure 2.2.

Table 2.6 reports the summary statistics for the institutional environment quality cluster groups. It displays the average and standard deviation for six variables: per capita carbon dioxide (equivalent) emissions, per capita GDP, per capita energy consumption, the real interest rate as a proxy for property rights (NORTH, 1990), the legal rights index as a proxy for financial contracts enforcement, and the democracy index. The first group has been separated from the others as it includes 13 countries, all with negative, real interest rates.

Table 2.6 – Summary statistics for institutional framework quality cluster groups

Group (countries)	Per capita emissions (MT of CO2 eq)	Per capita GDP (US$)	Per capita energy Consumption (kWh)	Interest rate (%)	Legal Rights Index (0 to 10)	Democracy Index (0 to 10)
1 (13)	6.88	4597.83	1721.21	-5.94	2.31	4.44
Std. Dev	(14.82)	(10748.19)	(3265.74)	(8.12)	(1.88)	(1.85)
2 (50)	4.89	11810.65	3309.44	5.84	5.93	6.40
Std. Dev	(5.16)	(14854.77)	(3965.68)	(3.89)	(1.64)	(1.71)

3 (31)	5.53	17553.88	4729.45	5.81	2.69	7.61
Std. Dev	(5.49)	(19726.05)	(6389.15)	(2.60)	(1.25)	(1.01)
4 (25)	5.32	8119.07	2304.40	11.75	1.93	4.22
Std. Dev	(9.75)	(15782.87)	(4058.42)	(10.76)	(1.26)	(1.56)

According to Table 2.6, the cluster groups have no clear order as Tables 2.4 and 2.5 indicated for development and structure cluster groups. The groups in Table 2.6 appeared to be more heterogeneous, as their standard deviations are wider than the standard deviations of the other two cluster groups. With respect to the average, a pattern is difficult to identify due to the wide values for standard deviation. This may reflect the difficulty in joining institutional measures, because institutions are very likely to differ according to culture, values, and traditions (CHANG, 2011).

To account for this heterogeneity, we employed the Euclidean distance cluster analysis for each of three proxy variables for institutional quality. The econometric DD model was employed for the stratification of the interest rate (property rights), Democracy Index, and Legal Rights Index (financial contracts). Therefore, the analysis conducted in Figures 2.1 and 2.2 was also conducted in Figures 2.3, 2.4, and 2.5.

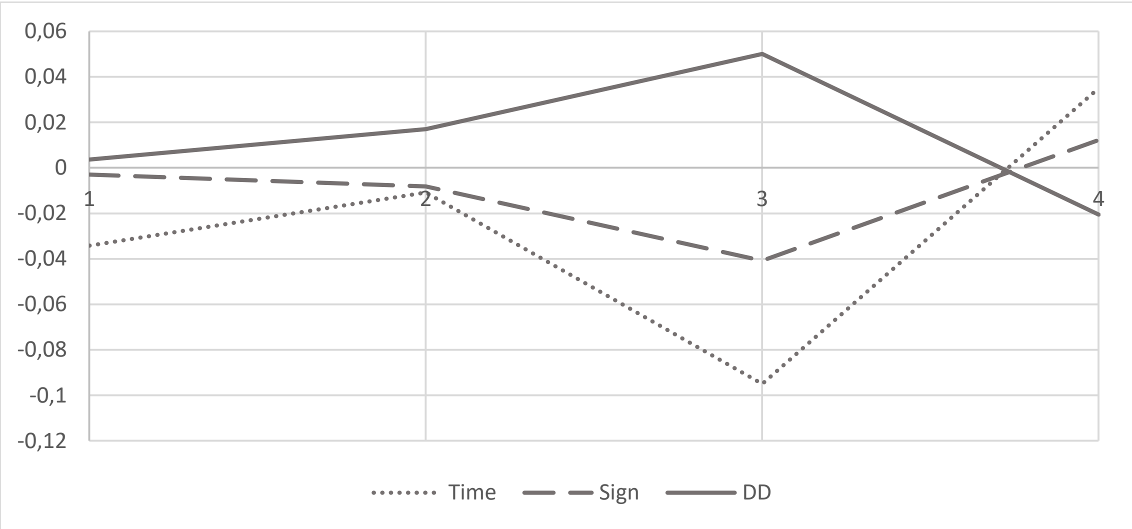
Table 2.7 shows the values of per capita emissions, per capita GDP, and per capita energy consumption, in addition to the corresponding values for real interest rate, the legal rights index, and the democracy index for each quartile of each of the three institutional proxies variables. Each quartile group for each variable does not necessarily shares the same countries. A more complete table is in Appendix I. This table shows the average and standard deviations for per capita emissions, per capita GDP, per capita energy consumption, real interest rate, the legal rights index, and the democracy index for each quartile for each variable.

Table 2.7 – Summary statistics for individual institutions quality cluster groups

Group	Real Interest Rate (%)	Democracy Index (0 to 10)	Legal Rights Index (0 to 10)
1	2.69	3.15	1.19
(Std. Dev)	(1.62)	(1.17)	(0.96)
2	5.72	5.88	2.97
(Std. Dev)	(0.74)	(0.61)	(0.41)
3	11.49	7.64	5.06
(Std. Dev)	(0.79)	(0.46)	(1.04)
4	13.52	8.78	8.27
(Std. Dev)	(6.41)	(1.45)	(0.92)

The summary statistics for the quartile groups in Table 2.7 for institutional environment quality information appear to reduce heterogeneity within samples, as the standard deviation of each group is less than those in Table 2.8. Figures 2.3, 2.4, and 2.5, present the results for the estimation of the GMM model parameters of time, sign, and DD for the property rights proxy, the financial contracts proxy, and the democracy index. The interpretation of the parameters of time, sign, and DD remains the same as in the other figures.

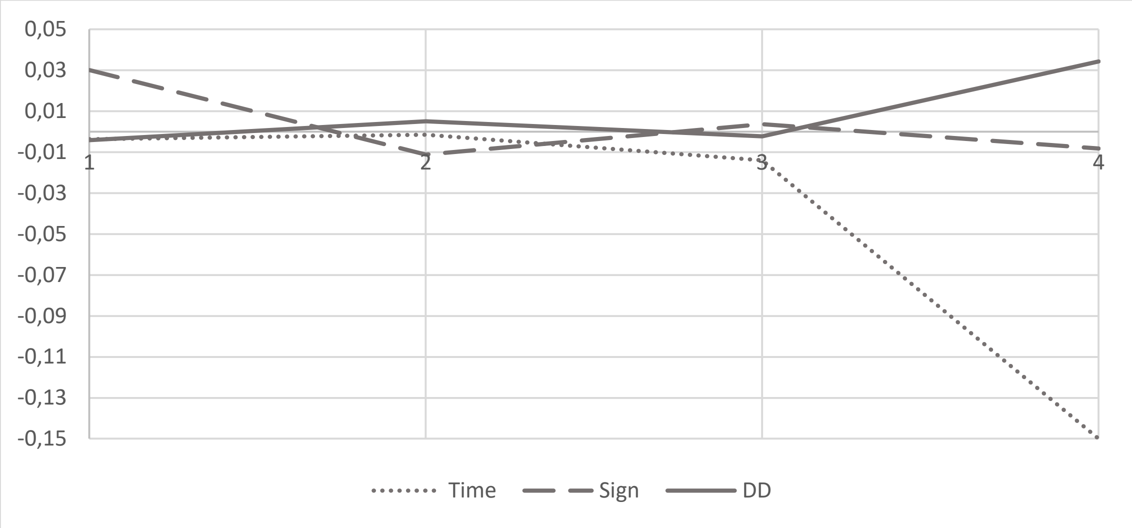
Figure 2.3 – Effect of real interest rate (property rights proxy) on DD model parameters for time, sign, and overall effect



The higher the real interest rate, the lower the rate of enforcement of property right laws and regulation. A high interest rate generally corresponds to an increased risk in investing in the given country. The minimum acceptable rate of return or the opportunity cost of having a (physical) business presence in that country is influenced by this risk that the stakeholders are willing to bear, which is directly affected by the capacity of law and regulation enforcement to guarantee property rights (NORTH, 1990).

Figure 2.3 reported very low parameter values compared to Figures 2.1 and 2.2. The results of Groups 1 and 2 demonstrate parameter values indicating a stable pattern of GHG emissions. Group 3, with an 11% average annual real interest rate, demonstrated results that suggest an increase in emissions due to the existence of the KP, and a reduction of emissions in response to time and KP ratification.

Figure 2.4 – Effect of democracy level on DD model parameters for time, sign, and overall effect



With the exception of the sign parameter for Group 1, emissions seemed to remain stable for the first three groups, considering the stratification by democracy level. The group with the highest democracy level presented an increase in emissions in terms of KP existence (DD effect) and a decrease in emissions in terms of time.

Figure 2.5 – Effect of the enforcement of financial contracts on DD model parameters of time, sign, and overall effect

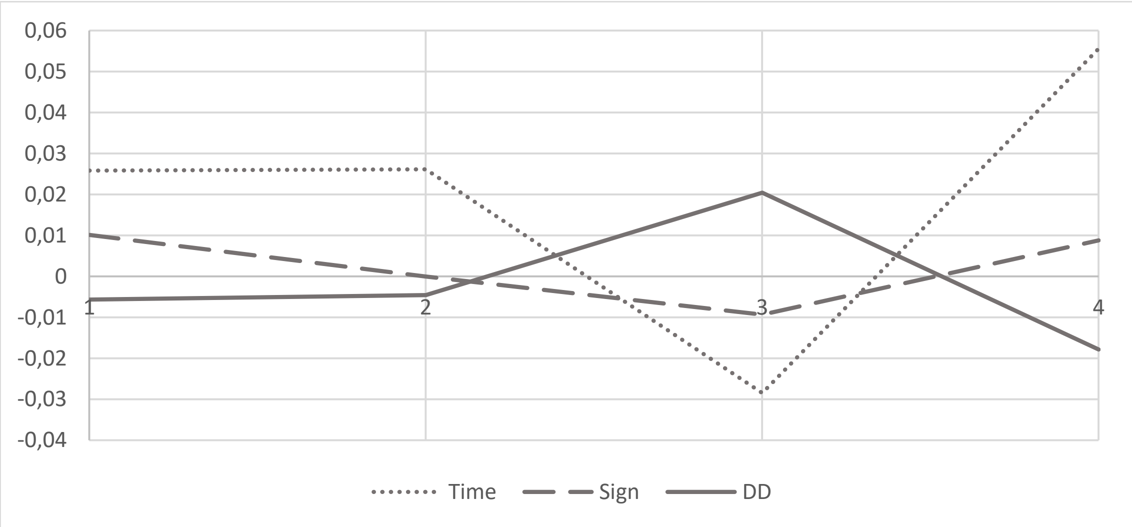


Figure 2.5 suggests that the existence of the KP (DD effect) influenced the countries with a high legal rights index more—or countries with high enforcement of financial contracts. The time effect appeared to affect Groups 3 and 4 in a way opposite to a DD impact. The time effect presented an increase in emissions for all groups, with the exception of Group 3.

The overall effect of time, sign, and DD were low when considering stratification by institutional environment quality compared to stratification by development level and structural characteristics. The effect of KP ratification seemed to have had a greater impact on the emissions of the countries grouped by institutional stratification compared to those grouped by developmental or structural characteristics.

2.5. CONCLUSION

This study evaluated the effectiveness of the KP by employing a panel data DD econometric model approach. This method also reports the influence of time differences in the emissions trend, which take into account technical and technological changes, demographic changes, and structural changes of the countries over time. This method also presents the effect of ratifying the KP, using the difference in emissions trends of RA and NR countries.

One of our original hypotheses was that the KP had a low effectiveness. Our second hypothesis was that the effectiveness of the KP can depend on the principles of equity and fairness, development level, the presence of informal institutions, and the feasibility of enforcement of these institutions.

Despite the KP’s negative effect on emissions, we found that the global average effectiveness of the KP was not statistically significant, implying a null coefficient. Neither the global average time trend difference coefficient nor the global average coefficient of ratifying the KP were statistically significant. Therefore, we can suggest that the KP demonstrated a low effectiveness from 1998 to 2012, on a global average. The variables for per capita electric power consumption and per capita GDP were statistically significant for the global model when squared per capita GDP was not included (EKC hypothesis). When squared per capita GDP was included, no parameters were significant.

In general, KP ratification demonstrated little effect. On one hand, regarding the stratification by development, the results indicated that medium-developed countries, Groups 2 and 3, presented a reduction in emissions due to KP existence (DD effect). On the other hand, these same groups reported an increase in emissions due to time effect. The time affect may be linked to the intensification of industrial processes, and changes in land use and infrastructure that occurred before 1998. These results support the EKC theory (BRUYN; BERGH; OPSCHOOR, 1998). The decrease in emissions due to the KP effect in Group 2 may imply that the increase in emissions could be higher without KP than with KP.

In terms of clusters by structural characteristics, there was a low effect for sign. The results suggested that while countries with greater structure presented a decline in emissions according to the existence of the KP, countries from Group 2 presented an increase in emissions due to the KP. Group 2 presented a reduction in emissions in terms of the time effect. The increase in emissions due to the effect of the KP in countries with less structure (and a higher agricultural share of GDP) and the decrease in emissions of countries with greater structure that isolated the KP effect suggests the transference of carbon emissions from more structured countries to less structured countries by exports from the latter to the former.

The institutional framework clusters aggregating the three proxy variables presented very heterogeneous groups with high standard deviations. Therefore, we chose to analyze each variable separately, and we found that the cluster stratification performed for individual variables presented much lower standard deviations. These groups were employed to analyze the influence of the quality of the institutional environment on KP effectiveness. The effect was much lower compared to development level and the effects of structural characteristics. Unlike the ratification of the KP effect (sign) from the results of the development and structure cluster, the sign effect seemed to be influenced by the level of institutional quality. Countries with poor democracy and low property rights, and high enforcement of financial contract institutions reported an increase in emissions.

Our results suggest that the countries that ratified the KP emitted more GHG from 1998 to 2012 than those that did not ratify the KP. This finding may indicate that the isolated effect of the KP could have contributed to the emissions increase in countries with a poorer quality of structural characteristics, and to a reduction in emissions in countries with higher quality structural characteristics. One potential explanation for these results is that carbon emissions sources have been transferred from countries with stronger infrastructure to countries with weaker infrastructure. A further investigation could therefore be conducted to analyze the effect of international trade on carbon transfers between countries.

Appendix I – Summary statistics for institutional environment quality quartiles

Quartiles	Group 1		Group 2		Group 3		Group 4	
Variables	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Real Interest Rate quartiles								
Per Capita Emissions (MT of CO2 eq)	5.71	(11.16)	7.89	(7.09)	4.68	(5.38)	3.24	(7.55)
Per Capita GDP (US$)	8857.00	(14533.17)	19502.05	(18439.50)	14204.51	(17533.60)	5938.90	(13160.48)
Per Capita Energy Consumption (kWh)	2369.28	(3554.81)	5845.71	(6050.72)	3495.20	(4973.68)	1282.21	(1800.79)
Interest Rate (%)	-1.67	(6.52)	3.97	(0.55)	6.30	(0.85)	17.09	(13.85)
Democracy Index (0 to 10)	5.10	(2.03)	7.15	(1.77)	6.41	(1.89)	5.40	(1.71)
Legal Rights Index (0 to 10)	3.25	(1.97)	5.05	(2.64)	3.63	(2.23)	3.75	(2.19)
Democracy Index (0 to 10) quartiles								
Per Capita Emissions (MT of CO2 eq)	7.24	(13.03)	1.97	(3.21)	3.25	(2.80)	8.58	(5.67)
Per Capita GDP (US$)	7743.37	(15751.84)	3947.71	(7809.56)	5268.67	(4790.38)	26222.02	(18817.78)
Per Capita Energy Consumption (kWh)	2549.38	(4242.70)	936.92	(1463.56)	1806.00	(1482.27)	7082.48	(6276.66)
Interest Rate (%)	5.89	(17.46)	6.25	(8.32)	8.09	(8.61)	5.18	(3.52)
Democracy Index (0 to 10)	2.83	(0.73)	5.16	(0.73)	6.73	(0.41)	8.42	(0.64)
Legal Rights Index (0 to 10)	2.22	(1.84)	3.83	(2.77)	4.29	(2.01)	4.45	(2.20)
Legal Rights Index (0 to 10) quartiles								
Per Capita Emissions (MT of CO2 eq)	6.36	(11.19)	5.88	(8.47)	3.50	(3.61)	5.63	(5.65)
Per Capita GDP (US$)	9829.34	(15424.46)	14915.89	(19286.50)	10353.48	(15967.58)	13245.46	(15629.94)
Per Capita Energy Consumption (kWh)	2395.97	(3697.68)	3062.60	(3396.16)	3785.77	(6551.46)	3817.57	(4016.71)
Interest Rate (%)	5.12	(11.18)	6.71	(5.21)	8.59	(13.69)	5.18	(5.85)
Democracy Index (0 to 10)	4.54	(2.06)	6.08	(2.05)	6.29	(2.10)	6.74	(1.56)
Legal Rights Index (0 to 10)	1.06	(0.67)	2.97	(0.41)	4.67	(0.41)	6.99	(1.28)

Appendix II – Country cluster groups: Development Status, Structural Characteristics, and Institutional Environment Quality (separated)

Development Cluster	Structural Char. Cluster	Interest Rate Cluster	Democracy Index Cluster	Legal Rights I. Cluster
Group 1	***Group 1***	***Group 1***	***Group 1***	***Group 1***
Angola	Angola	Albania	Algeria	Algeria
Bangladesh	Cambodia	Argentina	Angola	Angola
Benin	Cameroon	Australia	Armenia	Azerbaijan
Cameroon	Congo	Benin	Azerbaijan	Bahrain
Congo	Congo, DR of	Botswana	Bahrain	Belarus
Czech Republic	Egypt	Brunei Darussalam	Belarus	Bolivia
Congo, DR of	Eritrea	Bulgaria	Cameroon	Brazil
Ethiopia	Ethiopia	Canada	China	Costa Rica
Ghana	Guatemala	China	Congo	Cuba
Haiti	Honduras	Cote D'Ivoire	Cote D'Ivoire	Korea, DPR of
India	Indonesia	Czech Republic	Cuba	Dominican Republic
Kenya	Myanmar	Egypt	Korea, DPR of	Ecuador
Morocco	Namibia	Estonia	Congo, DR of	Egypt
Mozambique	Nepal	Ethiopia	Eritrea	Eritrea
Myanmar	Niger	Finland	Ethiopia	Haiti
Nepal	Senegal	France	Gabon	Iraq
Niger	Sri Lanka	Greece	Haiti	Iran, IR of
Pakistan	Swaziland	Iraq	Iraq	Italy
Senegal	Tonga	Ireland	Iran, IR of	Jordan
Sudan	Turkmenistan	Japan	Jordan	Kuwait
Timor-Leste	Tanzania, UR of	Kuwait	Kazakhstan	Lebanon
Tanzaniam, UR of	Vanuatu	Luxembourg*	Kuwait	Libya
Yemen	Viet Nam	Malaysia	Morocco	Malta
Zambia	Yemen	Malta	Myanmar	Morocco
Zimbabwe	Zambia	Mexico	Nepal	Mozambique
	Zimbabwe	Montenegro	Niger	Myanmar
		Nepal	Nigeria	Netherlands
		Niger	Oman	Nicaragua
		Portugal	Qatar	Oman
		Korea, Rep. of	Russian Federation*	Pakistan
		Romania	Saudi Arabia	Paraguay
		Senegal	Sudan	Philippines
		South Africa	Swaziland	Portugal
		Sri Lanka	Syrian Arab Republic	Qatar
		Swaziland	Turkmenistan	Saudi Arabia
		Switzerland	United Arab Emirates	Sri Lanka
		Tonga	Uzbekistan	Suriname
		G. Britain and N. Ireland	Viet Nam	Syrian Arab Republic
		United States	Yemen	Timor-Leste
		Viet Nam	Zimbabwe	Turkey

		Zambia		Turkmenistan United Arab Emirates Uzbekistan Yemen
Group 2	***Group 2***	***Group 2***	***Group 2***	***Group 2***
Argentina	Albania	Austria	Albania	Argentina
Bolivia	Armenia	Bahrain	Bangladesh	Armenia
Botswana	Bangladesh	Bangladesh	Benin	Austria
Brazil	Benin	Belgium	Bolivia	Belgium
Chile	Cote D'Ivoire	Bolivia	Bosnia and Herzegovina	Brunei Darussalam
Colombia	Georgia	Costa Rica	Bulgaria	Chile
Costa Rica	Ghana	Guatemala	Cambodia	China
Dominican Republic	India	Hungary	Colombia	Colombia
Ecuador	Kenya	Iceland	Dominican Republic	El Salvador
El Salvador	Kyrgyzstan	India	Ecuador	Ethiopia
Guatemala	Mongolia	Indonesia	Egypt	France
Honduras	Mozambique	Israel	El Salvador	Greece
Jamaica	Nicaragua	Italy	Georgia	Indonesia
Malaysia	Nigeria	Jamaica	Ghana	Kazakhstan
Mexico	Pakistan	Jordan	Guatemala	Luxembourg*
Namibia	Paraguay	Kenya	Honduras	Panama
Nicaragua	Moldova, Rep. of	Latvia	Indonesia	Russian Federation*
Panama	Sudan	Lebanon	Kenya	Slovenia
Paraguay	Syrian Arab Republic	Lithuania	Kyrgyzstan	Sudan
Peru	Thailand	Morocco	Lebanon	Swaziland
Russian Federation*	Timor-Leste	Namibia	Libya	Thailand
South Africa	Uzbekistan	Netherlands	Malaysia	Tunisia
Uruguay		New Zealand	Mongolia	Uruguay
		Norway	Montenegro	
		Oman	Mozambique	
		Philippines	Namibia	
		Russian Federation*	Nicaragua	
		Serbia	Pakistan	
		Singapore	Paraguay	
		Slovakia	Peru	
		Slovenia	Philippines	
		Thailand	Moldova, Rep. of	
		Tanzania, UR of	Romania	
		Yemen	Senegal	
			Serbia	
			Singapore	
			Sri Lanka	

			Suriname Thailand FYR Macedonia Tunisia Turkey Tanzania, UR of Zambia	
Group 3	***Group 3***	***Group 3***	***Group 3***	***Group 3***
Albania	Algeria	Bosnia and Herzegovina	Argentina	Albania
Algeria	Argentina	Cameroon	Belgium	Bangladesh
Armenia	Azerbaijan	Chile	Botswana	Benin
Azerbaijan	Belarus	Colombia	Brazil	Bosnia and Herzegovina
Belarus	Bolivia	Dominican Republic	Chile	Botswana
Bulgaria	Bosnia And Herzegovina	El Salvador	Costa Rica	Cameroon
China	Botswana	Haiti	Croatia	Congo
Croatia	Brazil	Mozambique	Czech Republic	Cote D'Ivoire
Egypt	Bulgaria	FYR Macedonia	Estonia	Croatia
Estonia	Chile		France	Czech Republic
Gabon	China		Germany	Congo, DR of
Georgia	Colombia		Greece	Denmark
Indonesia	Costa Rica		Hungary	Estonia
Ireland	Cuba		India	Finland
Iran, IR of	Dominican Republic		Israel	Gabon
Jordan	Ecuador		Italy	Germany
Kazakhstan	El Salvador		Jamaica	Ghana
Kyrgyzstan	Gabon		Japan	Hungary
Latvia	Ireland		Latvia	Iceland
Lithuania	Iran, IR of		Lithuania	India
Mauritius	Jamaica		Malta	Ireland
Mongolia	Jordan		Mauritius	Israel
Portugal	Kazakhstan		Mexico	Jamaica
Moldova, Rep. of	Lebanon		Panama	Japan
Romania	Mauritius		Poland	Kenya
Sri Lanka	Mexico		Portugal	Kyrgyzstan
Syrian Arab Republic	Morocco		Korea, Rep. of	Lithuania
Thailand	Panama		Slovakia	Malaysia
Tonga	Peru		Slovenia	Mauritius
Tunisia	Philippines		South Africa	Mexico
Turkey	Romania		Timor-Leste	Mongolia
Uzbekistan	Saudi Arabia		G. Britain and N. Ireland	Namibia
Viet Nam	South Africa		United States	Nepal
	Suriname		Uruguay	Niger

	FYR Macedonia Tunisia Turkey Uruguay			Nigeria Norway Peru Poland Korea, Rep. of Moldova, Rep. of Senegal Serbia Singapore Slovakia South Africa Switzerland FYR Macedonia G. Britain and N. Ireland Tanzania, UR of Viet Nam Zambia Zimbabwe
Group 4	***Group 4***	***Group 4***	***Group 4***	***Group 4***
Australia Austria Belgium Canada Denmark Finland France Germany Greece Hungary Iceland Iraq Israel Italy Japan Luxembourg* Malta Netherlands Norway Korea, Rep. of Slovakia Slovenia Switzerland G. Britain and N. Ireland United States	Australia Austria Bahrain Belgium Brunei Darussalam Canada Croatia Czech Republic Denmark Estonia Finland France Germany Greece Hungary Iceland Iraq Israel Italy Japan Kuwait Latvia Lithuania Luxembourg* Malaysia	Armenia Azerbaijan Congo Croatia Congo, DR of Denmark Ecuador Gabon Georgia Germany Honduras Kyrgyzstan Mauritius Mongolia Nicaragua Panama Paraguay Peru Poland Moldova, Rep. of Timor-Leste United Arab Emirates Uruguay Vanuatu	Australia Austria Canada Denmark Finland Iceland Ireland Luxembourg* Netherlands New Zealand Norway Switzerland	Australia Bulgaria Cambodia Canada Georgia Guatemala Honduras Latvia Montenegro New Zealand Romania Tonga United States Vanuatu

	Malta Netherlands New Zealand Norway Oman Poland Portugal Korea, Rep. of Russian Federation* Singapore Slovakia Slovenia Switzerland United Arab Emirates G. Britain and N. Ireland United States			

3. ECONOMIC AND ENVIRONMENTAL PERFORMANCE ON GREENHOUSE GASES MITIGATION: THE INFLUENCE OF INSTITUTIONS

Resumo: O presente estudo analisou a relação entre crescimento econômico e a emissão de gases de efeito estufa. O estudo também considerou a influência de instituições, pelos efeitos dos diferentes graus da democracia e da eficácia cumprimento das leis e regulamentos na forma de contratos. O método empregado foi a análise de Fronteira Estocástica e três modelos foram estimados: um considerando as emissões GEEs como um insumo produtivo; um segundo que considera duas tecnologias, em que a partir da tecnologia de geração de Produto Interno Bruto, há uma tecnologia residual, em que são produzidas as emissões de GEEs; e um terceiro modelo, também considerando os GEEs como produto residual e levando em conta a heterogeneidade entre grupos de países. Os resultados sugerem que os retornos de escala da função de produção do PIB são constantes, na média. A variáveis Capital apresentou a maior elasticidade entre os insumos. Para os três modelos, a performance econômica, mensurada pela eficiência técnica (TE), foi maior do que a performance ambiental, mensurada pela eficiência ambiental (EE). De acordo com os modelos, a influência do ambiente institucional sobre a TE e a EE apresentou resultados diferentes, os Modelos 1 e 2 apresentaram resultados similares; enquanto o Modelo 3 sugeriu que os efeitos da heterogeneidade entre os grupos de países podem influenciar no resultado dos sinais dos parâmetros do modelo.
Palavras-chave: Eficiência técnica; Eficiência ambiental; Instituições; Fronteira Estocástica; Multi-produto

Abstract: This study analyzed the relationship between economic growth and the emission of greenhouse gases. The study also took into consideration the strength of a country’s democratic foundation and adherence to the rule of law as it relates to the enforcement of contractual stipulations. The Stochastic Frontier method was used in the analysis, and three models were estimated: one considered GHG as a detrimental input; the second considered GHG as a residual output that is produced together with the main output, which is economic growth; and the third also considered GHG as a residual output and added controls for heterogeneity among countries. The results suggest that returns to scale are likely to be constant, on the average. The variable Capital showed the highest elasticity. For all three models, average economic performance, measured as technical efficiency (TE), was higher than average environmental performance, measured as

environmental efficiency (EE). According to the three models, the impacts on TE and EE from a country's institutional framework, defined by norms, rules, practices, traditions, and other specific characteristics, were mixed, with Models 1 and 2 presenting similar results for both economic and environmental performance, while Model 3 suggested that the institutional and structural parameter signals were greatly affected by heterogeneity among countries.

Keywords: Technical efficiency; Environmental efficiency; Institutional framework; Stochastic Frontier; Multi-output

3.1. INTRODUCTION

The level of greenhouse gas (GHG) emissions differed among countries, and it is likely that the cost to each country arising from these emissions is unequal. In 2012, of the total emissions from the 191 studied countries, a 25% came from China, 14.4% came from the United States, the 28 countries of European Union accounted for 10% of overall GHG emissions, and Brazil, India and Russia contributed 14.7%, together. In total, the BRIC countries were responsible for almost 40% of the 191 countries GHG emissions in 2012 (CAIT, 2018).

In order to mitigate climate change, the concentrations of greenhouse gasses in the earth's atmosphere must be stabilized so that temperature changes occur at a pace that allows natural systems to adapt, thereby eliminating threats to food security caused by increasing temperatures while permitting economic development. Based on estimates made by the Intergovernmental Panel on Climate Change (IPCC), the United Nations adopted a target carbon dioxide concentration of 450 ppm by 2100 as a level that would satisfactorily mitigate the negative impacts of climate change. To achieve this goal, the accumulated emissions from 1870 to 2100 must be 2900 $GtCO_2$, at most. Between 1870 and 2011, 1900 $GtCO_2$ had been emitted. Even taking into account previous mitigation efforts, such as the Kyoto Protocol, international cooperation to reduce GHG emissions may not be adequate. The annual GHG emission level in 2014 was 49 $GtCO_2$, and that rate has been growing by 2.2%/yr since 2000. To achieve the United Nation's target, the annual average GHG emission level should be 11 $GtCO_2$ (IPCC, 2014b).

The benefit from GHG emission mitigation is that it would reduce the negative impacts from a universal rise in the earth's temperature. This benefit, if achieved, is simultaneously given to all countries without restriction and not denied to other individuals or parties (OSTROM, 2003; SANDLER; ARCE 2003). If the current GHG emission trend continues, average worldwide temperatures are likely to rise 4ºC in this century (IPCC, 2014a), but the goal of the Paris Agreement (UNFCCC, 2015) was to hold the maximum average temperature increase to 2ºC by the end of the century.

The costs to mitigate climate change accrue to the individual, meanwhile the benefits are global (COLE, 1999; SANDLER; ARCE 2003). Although international cooperation is needed to effectively mitigate GHG emissions, countries have little incentive to cooperate in mitigation efforts if their abatement costs reduce economic performance. The equation is simple, for mitigation goals to be achieved, abatement costs must be minimized to improve the chances for worldwide cooperation in the mitigation effort (IPCC, 2014a).

The costs of climate change are not shared equally among countries. This heterogeneity can be adjusted for by applying the principal of equity and fairness, a principal that implies that the responsibility for GHG mitigation is conferred to each country according to that country's technical and social capabilities (UNFCCC, 1992a). According to this principle, a country's ability to reduce emissions should be contingent on its level of technology, its population's and government's ability to adopt innovative solutions and adapt to change, its society's cohesiveness, and the local ecosystem (ADGER, 2001).

A country's institutional framework is consisted of formal and informal norms, rules, practices and traditions that are defined by its culture and societal values, and thus an institutional framework determines many aspects of a country's behavior (NORTH, 1990). A robust institutional framework can be adapted to social and economic changes without diverging from its original goals, and these goals tend to be accepted by its society (YOUNG; UNDERDAL, 1997). An institutional framework can only be effective if it is collectively understood and accepted by the society it operates in (SEARLE, 2005).

The Kyoto Protocol and Paris Agreement established a formal international institutional framework to establish climate change mitigating goals. To reach these goals, national and subnational formal and informal institutional frameworks, defined by a society's values and its adherence to these values, must play a role in the attempt to mitigate the effect of climate change. These more local bodies can establish and enforce climate policies and appropriately manage the common pool of environmental goods and services (ADGER, 2001; OSTROM, 2003, 2010).

The capacity to mitigate GHG emissions is influenced by the institutional framework on both the international and the local scale. A country's level of economic development should be a determinant of its institutional framework and impact its population's demand for more or less environmental goods and services. The urgent need for implementation of GHG emission mitigation policies should be conditioned by an understanding of these policies' effect on a country's economic performance, the capabilities of its institutional framework, and the local population's acceptance, all the while acknowledging the risks that climate change imposes (PAAVOLA; ADGER, 2005).

The objective of this chapter is to analyze country level economic performance; measured by technical efficiency; country level GHG emission mitigation performance, measured by environmental performance; and the impact of the existing institutional framework on economic and environmental performance. A stochastic frontier approach is employed to analyze both technical and environmental efficiencies.

It is hypothesized that an institutional framework in which contracts, laws and regulations are less rigidly enforced is likely to negatively affect environmental efficiencies. Considering North (1990), technical efficiency is bound to be lower in a place where the institutional framework is sloppy.

Technical efficiency refers to enterprise productivity and the cost of inputs or resources used in the enterprise's productive processes. Environmental efficiency refers to enterprise productivity as it relates to the amount environmental damage caused by the enterprise's productive processes and the processes needed to provide production inputs. The production process with the lowest total input costs is the most technically efficient production process; similarly, the productive process causing the fewest direct and indirect negative environmental impacts is the most environmentally efficient. Indirect environmental impacts are those caused by the production of inputs. In this paper, the term economic performance is gauged by technical efficiency and environmental performance is gauged by environmental efficiency

This work contributes to the literature by analyzing empirical evidence regarding institutional settings, as proposed by Paavola and Adger (2005). The estimation of a stochastic frontier model for country level panel data focusing on environmental efficiencies will also augment literature on the use of stochastic frontier analysis. More importantly, this work provides empirical evidence addressing an institutional setting's influence on economic and environmental performance.

3.2. THEORETICAL FRAMEWORK: INSTITUTIONS, ECONOMIC PERFORMANCE AND ENVIRONMENTAL AND TECHNICAL EFFICIENCIES

3.2.1. Institutional enforcement of GHG emission reduction measures

The benefits gained through the mitigation of climate change by reducing GHG emissions has the characteristics of a public good because it is non-rival and non-excludent (IPCC 2014, Chapter 13). The benefits gained from reducing the risk of damaging climate change events occurring are non-exclusive and can be applied to and received by any individual or party. Simultaneously, the benefits received by one party do not reduce the potential benefits to another party (non-rivalry) (OSTROM, 2003).

A consequence of being a public good is that individuals and parties have an incentive to 'free-ride,' as the benefits are all inclusive and the costs are individual (SANDLER; ARCE, 2003). Even if a party does not contribute to reduce abatement costs, that party will receive the benefits, in this case a reduced risk of negative events due to climate change (COLE, 1999; OSTROM, 2010). One government role is to enforce mitigation actions and regulations, thereby reducing the incentive to 'free-ride,' and motivate disparate parties to cooperate with mitigation regulations (ADGER, 2001; DIETZ; OSTROM; STERN, 2003; OSTROM, 2010).

A polycentric governing system is needed to solve collective action problems. A polycentric system contains "power" centers that have the authority to independently make rules and set practices that apply to specific domains. These centers range from the local to the international and can be families; firms; state, provincial and national governments; or international bodies. By enhancing trustworthiness, understanding, and innovative thinking among those inside and outside their domains, these centers cooperate to achieve goals. Although the problem of 'free-riders' will always exist and remain unnoticed or beyond the control of national and international power centers, local centers often have the ability and the focus needed to maintain public environmental services and mitigate environmental degradation (OSTROM, 2010).

Tackling local direct polluters, such as GHG emitters, is less costly than tacking regional polluters, and even less in regards to global polluters (COLE, 1999). The public's demand for a more efficient sanitation system or improved air quality in a city or town can instigate action by a local authority (COLE, 1999; COLE; RAYNER; BATES, 1997). Although global enforcement of GHG emissions standards is needed, local responses are more immediate and more immediately effective; however, local responses depend on the local economic, political and institutional capabilities (ADGER, 2001).

Local responses and global enforcement intersect in the need for equity as it corresponds with the Principals embodied in Article 3 of the United Nations Framework Convention on Climate Change (UNFCCC, 1992a). The notion of equity must take into account social and economic heterogeneity so that responsibilities to mitigate GHG emissions are fairly distributed according to each party's capabilities (ADGER, 2001; IPCC, 2014a; UNFCCC, 1992b).

If international level mitigation targets are to be reached, there must be cooperation among countries. This cooperation is more likely to occur if the institutional capabilities of potential cooperating parties and the social and economic impacts of any mitigation actions are given priority when setting actual GHG reduction goals. The need for cooperation, flexibility and compromise are implicitly evidenced in the 5th Assessment Report of the Intergovernmental Panel on Climate Change's discussion of factors that must be addressed when setting individual country, environmentally effective mitigation targets. Of course these factors include GHG emission sources and levels but for reasons of fairness and feasibility they also include the country's aggregate economic performance, cultural capabilities and values, and institutional framework. (IPCC, 2014a).

3.2.2 Environmental efficiencies, technical efficiencies, and institutional impacts

Reinhard, Lovell and Thijssen (2000) consider that the level of a process's environmental efficiency is determined by how close it comes to generating a determined level of production using the minimum feasible quantity of environmentally detrimental inputs. In a later section, I expand on Reinhard, Lovell and Thijssen's (2000) conception by considering a production process's bad outputs, such as GHG emissions, as inputs to that production process.

The level of an enterprise's technical efficiency is determined by the amount of inputs needed to produce a quantity of goods or services. A technically efficient enterprise is one that uses the minimum amount of inputs to produce a determined quantity of goods or services or maximizes the quantity of goods and services produced with a given set of inputs (KUMBHAKAR, LOVELL, 2003).

Figure 3.1 illustrates the concept of environmental efficiency (based on KOPP, 1981; REINHARD, LOVELL, THIJSSEN, 2000).

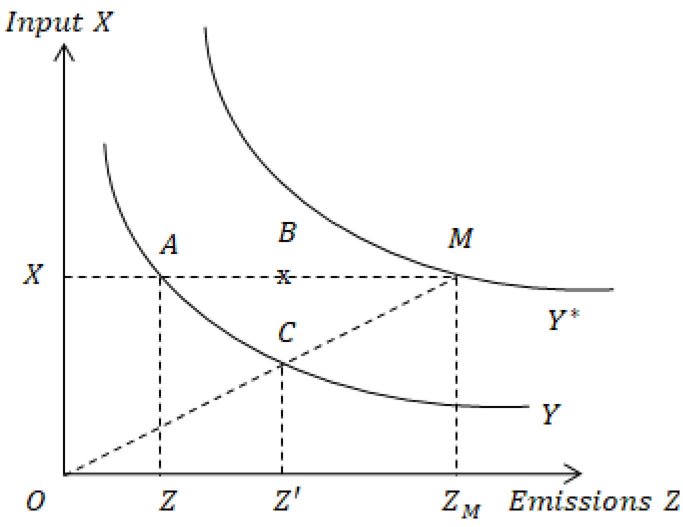


Figure 3.1 – Environmental efficiency with axis Z representing GHG emissions
Source: Adapted from Reinhard; Lovell; Thijssen (2000).

Where non-detrimental input X is represented on the vertical axis and the quantity of detrimental input Z (GHG emissions) is on the horizontal axis. For economy A, given a quantity X of non-detrimental input for the production of Y, environmental efficiency is the ratio $|OZ|/|OZ_M|$. In another case, economy B is not environmentally efficient, since its production level did not reach Y^*. Considering that the optimal production level is Y^*, technical efficiency can be calculated by the ratio between $|OC|/|OM|$. Economy A is technically efficient, but B is not. As the segment OM represents the optimum feasible production pathway given the combination of the two inputs, then economy C is both technically and environmentally efficient. A change to the use of lower carbon technologies would move segment OM counter-clockwise.

One set of inputs can lead to higher GHG emission than another set. Assume that economy A has a GHG emissions level of Z and produces Y of economic product is compared to economy B that has an GHG emissions level of Z', which is higher than Z, and also produces Y of economic product. Economy B can be considered less environmentally efficient than A. If two economies use the same types of inputs to produce Y, the more environmentally efficient economy is the one that uses fewer of the detrimental inputs. Figure 3.2 shows the production frontier for production of y using two inputs: Z input is environmentally detrimental, and Xis not.

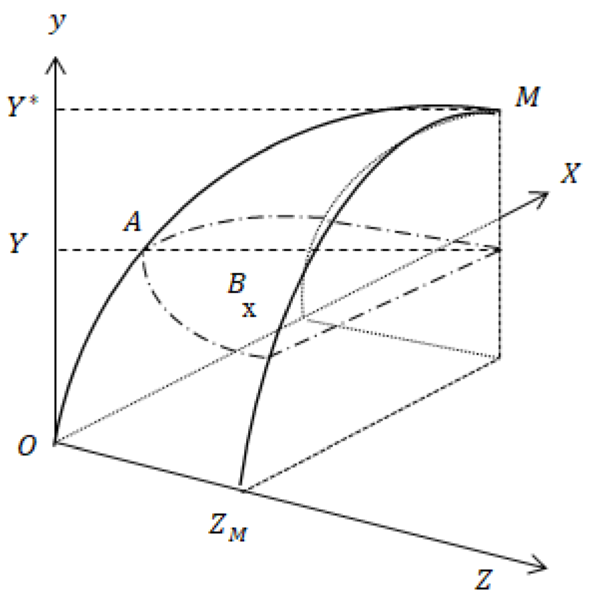


Figure 3.2 – Production frontier with one detrimental environmental input, Z, and one non-detrimental input, X, for economies A and B

Source: Adapted from Reinhard; Lovell; Thijssen (2000).

A country's environmental and technical efficiency levels are linked with the country's institutional framework (REINHARD; LOVELL; THIJSSEN, 2002). An institutional framework is a reflection of a society's principles of equity and fairness and is an important determinate for what is feasible if that society is to move toward sustainable development (ADGER, 2001). A robust institutional framework reflects collectively accepted societal norms and is therefore more likely to be effective (SANDLER; ARCE, 2003), but effective does not always mean just and fair.

A persistently extractive institutional framework may be robust but can skew income distribution, increase poverty and encourage governmental corruption (ACEMOGLU; ROBINSON, 2012). According to the IPCC (2014b), natural systems and human systems are more vulnerable when submerged in an extractive institutional framework. If a country's institutional framework is either frail or extractive, chances that the country's government will cooperate in international GHG mitigation efforts are slight. Where these types of institutional frameworks exist, the principles of equity and justice are not likely to be deeply rooted in the culture's psyche, and institutional enforcement of mitigation regulations may be unimportant or infeasible. Even the provision of financial aid or the transfer of new technologies does not insure that international policy goals will be met in a country with a an extractive institutional framework, as these benefits are quite likely to be used to preserve and enhance institutional authority (ACEMOGLU; ROBINSON, 2012).

Intermediate paths that lead to improved environmental and technical efficiencies can be found if one has a top-to-bottom understanding a country's institutional framework (ACEMOGLU; ROBINSON, 2016). These paths often focus on subnational collective action and democratic solutions to vexing problems. As each problem is solved, the institutions implementing the solution become more accepted and the institutional framework, although it may be subnational at the onset, will become more robust and effective in a positive way (SANDLER; ARCE, 2003).

Figure 3.3 shows the interaction between technical and environmental efficiency and some of the principles mentioned above:

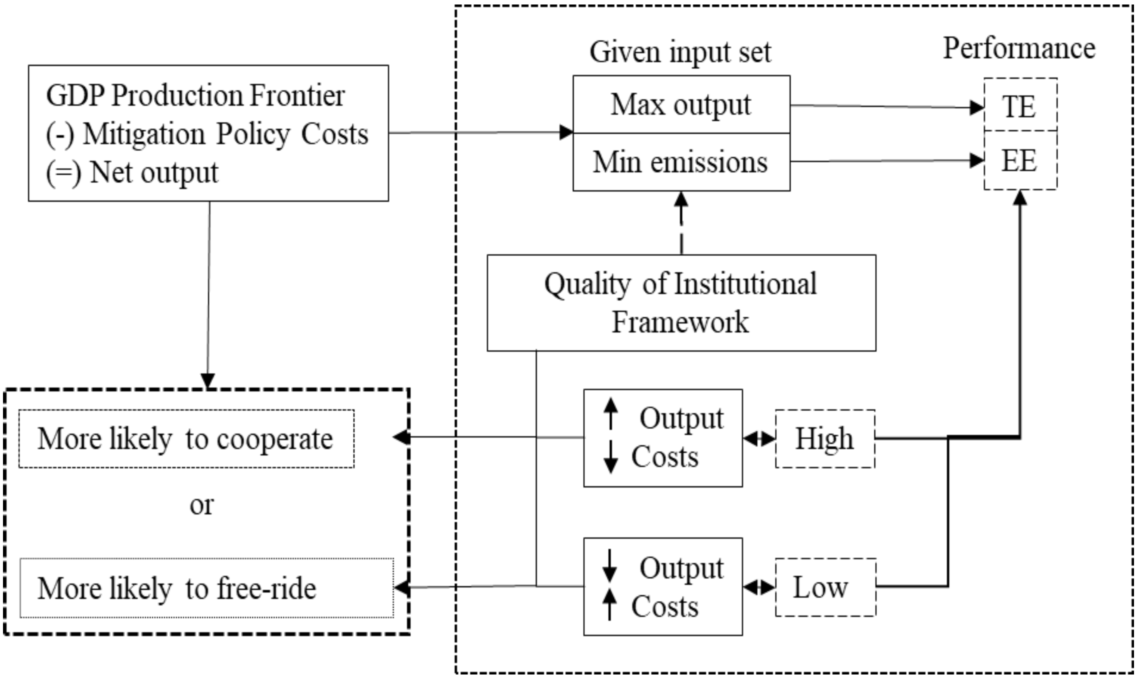


Figure 3.3 – Relationship between one economy's economic and environmental efficiencies and the likelihood of cooperation with other economies to mitigate GHG emissions

Source: author (based on Reinhardt; Lovell and Thijssen, 2002; IPCC, 2014b; Acemoglu and Robinson, 2012; Sandler and Arce, 2003)

3.2.3. Production frontier and technical efficiency

According to classic microeconomic theory, given a set of inputs, $X(x_1, x_1 \dots x_n)$, and a determined technology, the resulting output y_i is a function $y_i = f(X; p)$, where p is the price of the product (NICHOLSON; SNYDER, 2012). The observed output may not be the same as calculated output y_i with the difference assigned to random production shocks, technical inefficiency, and economic inefficiency. Eventual losses from careless handling or product damages are random shocks.

In regards to technical inefficiency, productive unit A may be better able to manage their work force or employ better trained specialists than productive unit B, which would lead to unit A making more efficient use of the labor input. A firm's ability to acquire and replace capital goods or access credit are also attributes linked with technical efficiency. Technical efficiency also is affected by a firm's skill in adapting to short and long-term market fluctuations, and this flexibility is a reflection of the firm's decision makers' abilities and its management structure (Aigner and Chu 1968).

Aigner and Chu (1968), Afriat (1972) and Richmond (1974) worked towards the introduction of a stochastic error into the production frontier. This error was introduced in the pioneering study "Formulation and Estimation of Stochastic Frontier Production Function Models" by Aigner; Lovell and Schmidt (1977). In the same year, Meeusen and van den Broeck (1977) independently developed the stochastic error frontier analysis approach. The stochastic error density probability distribution can be found in Afriat (1972) and was further developed with Richmond's (1974) work.

Aigner, Lovell, and Schmidt (1977) proposed that the stochastic error term is composed by two independent errors: one considers the random shocks on the production frontier; the second captures technical efficiency, which can be written as $\varepsilon_i = v_i + u_i$, with v_i representing random shocks and u_i representing technical efficiency. Technical efficiency can be input or output oriented. Input oriented technical efficiency measures inefficiency in the production process given a pre-determined level of output. Output oriented technical efficiency concerns the maximum feasible output given a pre-determined quantity of inputs. Figure 3.4 shows a production function with only a set of non-detrimental inputs X and y_A output (KUMBHAKAR; WANG; HORNCASTLE, 2015).

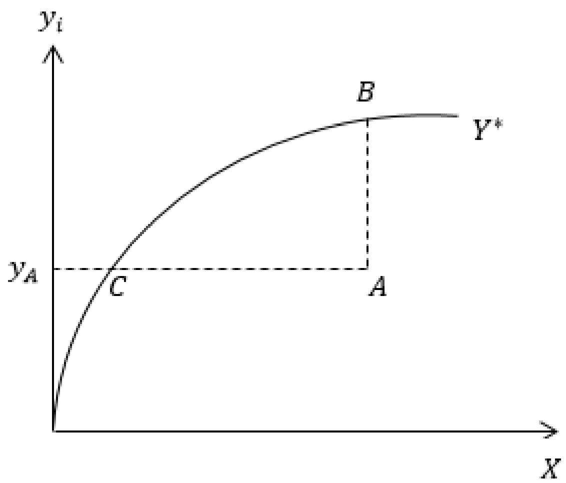


Figure 3.4 – Illustration of input and output oriented technical efficiency
Source: Adapted from Reinhard; Lovell; Thijssen (2000).

In Figure 3.4, given optimal output Y^*, segment AB shows output-oriented technical inefficiency because the set X is fixed. The segment AC represents input-oriented inefficiency due to input overuse to reach output level y_A.

Schmidt and Sickles (1984) pointed out that cross-sectional approaches to the estimation of technical efficiencies are subject to three limitations: limitations: the variance of conditional technical efficiency error terms does not vanish even with increasing sample size; statistical noise, which is the random shocks error term, is difficult to separate from technical efficiency: the assumption of independency of technical efficiency and the other dependent variables can be incorrect, as the input choice can be correlated with efficiency level.

Some of these limitations can be reduced through use of a panel data approach; although, this approach may introduce the need to make other assumptions. Estimations by panel data have the advantage of controlling non-observed characteristics within the sample. In other words, panel data can control sample heterogeneity (KUMBHAKAR; WANG; HORNCASTLE, 2015). Stochastic frontier analysis through the use of panel data analysis had been conducted by Pitt and Lee (1981) and Schmidt and Sickles, (1984), and Kumbhakar and Wang (2005) used the stochastic frontier approach and panel data to study the convergence of economic growth between countries while considering country heterogeneity.

The technical efficiency level of an enterprise that produces multiple outputs can also be calculated. Figure 3.5 illustrates a production possibility frontier for products y_1 and y_2, given fixed input set X. If an economy that produces on point A using input set X could produce on point B using the same set of inputs, this economy is inefficient by distance AB. Both outputs y_1 and y_2 can be increased without varying the quantity of X (KUMBHAKAR; WANG; HORNCASTLE, 2015).

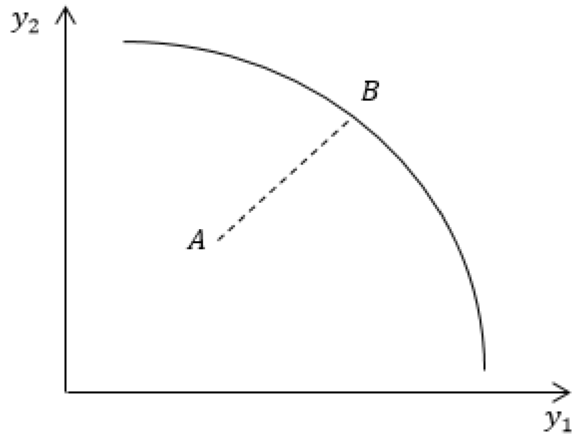


Figure 3.5 – Technical inefficiency considering two possible outcomes
Source: Adapted from Reinhard; Lovell; Thijssen (2000).

3.2.4. The multiple output approaches: residual output

The multiple outputs approach allows the consideration of “good” and “bad” outputs as the result of the production technology. The “bad” is a product which can be considered undesirable, such as the environmentally detrimental surplus nitrogen output from dairy farms (FERNÁNDEZ; KOOP; STEEL, 2002). Färe et al. (2005) argue that fossil fuel utilization generates electricity (good output) and sulfur dioxide (bad output). Also, they point out that treating the bad output as a detrimental input can have some limitations due to the outputs’s inherent “disposability” properties.

Färe *et al.* (2005) conclude that disposability can be strong or weak and that a production technology generates good outputs and bad outputs. Strong disposability assumes that any good-bad output vector with less of the good output is feasible and that the good output is “freely” disposable. This assumption implies that if a production frontier exists where a set of inputs generates a determined quantity of a strongly disposable good output and a determined quantity of bad output, then lowering production of the good output may not reduce the bad output. Weak disposability implies that the bad output can be reduced by proportionally reducing production of the good output. In terms of GHG emission mitigation, producers of weakly disposable good outputs may require motivation and limit the production of bad outputs by reducing production of the good outputs and this motivation may require enforcement of pollution mitigation targets (FÄRE *et al.* 2005).

Reinhard, Lovell, and Thijssen (1999, 2000) employed a single production function where bad outputs were treated as bad inputs. Environmental efficiency was calculated from a previous stochastic frontier estimation of the production function. There are a number of implications when a bad output, say GHG emissions, is treated as an input. Because the inputs are considered to be strongly (freely) disposable, reduced production of the good could incur in additional costs. From an engineering point of view, a reduction of GHG emissions (bad output treated as input) would maintain GDP (good output) only if more good inputs were used, and thus increasing costs while keeping inefficiency constant (KUMBHAKAR; TSIONAS, 2016).

Another issue pointed out by Kumbhakar and Tsionas (2016) concerns the implications of microeconomics production theory and the assumption that the input and output set is monotonic. The transformation possibility frontier (TPF) between two outputs is assumed to be concave: $F(y_i; s_i; x_i; z_i) = 1$, where y_i are good outputs, s_i are bad outputs, and x_i and z_i are good and bad inputs, respectively. Considering two good outputs, y_1 and y_2, and two bad outputs, s_1 and s_2, an implication of the concavity of TPF given a limited and convex set of inputs is that an increase in the production of y_1 should imply less production of y_2, because there would be less inputs for the production of y_2; and the same should apply for bad outputs. Mathematically, this relationship can be described as $\partial y_1/\partial y_2 < 0$ and $\partial s_1/\partial s_2 < 0$. On the other hand, bad outputs, say carbon dioxide and methane emissions, might not be complementary outputs: more carbon dioxide emissions do not necessarily imply more methane emissions. Meanwhile, if a single TPF is used, a decrease in the production of good output y_i implies the reduction of bad outputs s_1 and s_2; thus, $\partial s_1/\partial s_2 > 0$, which is contradictory.

As an alternative to Reinhard, Lovell, and Thijssen's (1999, 2000) method, Fernández, Koop, and Steel (2002) devised the multiple outputs stochastic frontier approach to consider technical and environmental efficiencies. The former authors considered nitrogen surplus to be an environmentally detrimental input, while the latter authors considered nitrogen surplus as a bad output from a multiple output technology. Using the same data, Fernández, Koop, and Steel (2002) obtained results similar to those obtained by Reinhard, Lovell, and Thijssen (1999) for technical and environmental efficiencies. Both studies, found environmental efficiency values to be lower than technical efficiency values.

In the same vein as Fernández, Koop, and Steel (2002), Kumbhakar and Tsionas (2016) suggest "by-production" (BP) technology, which is based on the idea that the technology used to produce an intended product can be considered as two sub-technologies working simultaneously, one producing the good output and a residual technology producing the bad output: the by-product. The production of the good and the bad outputs are independent, which respects the strong (free) disposability property. Because the bad output is derived using a separate technology, it can be produced by good inputs, bad inputs, or both types of inputs.

It is expected that the quality of inputs and production processes differ among countries. One country may not be able to use strongly disposable inputs due to economic and/or technological limitations, while another may employ these inputs. Environmental and technical efficiency results derived from conventional stochastic frontier analysis can be misleading if multicountry heterogeneity is not considered (KUMBHAKAR; WANG; HORNCASTLE, 2015).

Technological heterogeneity is often related to country specific socioeconomic factors not considered inputs, such as the level of economic and educational development, differentiated economic resource bases, geographic dissimilarities, and time effects. Latruffe et al. (2017) and Kumbhakar and Lien (2010) proposed a model that takes into account factors that influence the production frontier but are not classically defined inputs or are endogenous inputs correlated with the exogenous variables and the model's stochastic error.

The capital variable is correlated to the frontier stochastic error and can be considered endogenous because invested capital can shift technology, change the scale, accelerate R&D, and improve the human capital base (ELIASSON, 1985). The level of an economy's development can influence output, as more developed economies may have a greater choice among production technologies, transportation means, and allocable inputs. The factor intensity of an input relies on the technology in use, for example, the percentage of the production process dependent on human labor and the percentage dependent on capital goods.

The residual output or "by-production" technology that leads to GHG emissions can also be affected by the heterogeneity between countries noted above. The development and use of GHG mitigation technology and its transference from more developed countries to less developed countries are goals incorporated into the Paris Agreement (UNFCCC, 2015) and also appear in the AR5 report (IPCC, 2014c).

3.3 METHODOLOGY: APPROACHES TO THE CALCULATION OF ECONOMIC AND ENVIRONMENTAL PERFORMANCE

This study employs three different models that use three different techniques to calculate environmental efficiency. Model 1 follows the methodology developed in empirical research by Reinhard, Lovell, and Thijssen (1999, 2000) in which environmental efficiency is measured by calculating inefficiency and treating a bad output as a bad input. Model 2 was derived from studies by Fernández, Koop, and Steel (2002) and Kumbhakar and Tsionas (2016) in which environmental efficiency values are estimated using a model that considers that bad output is the result of a residual output technology. Model 3 followed the design of a model used by Latruffe et al. (2017) and Kumbhakar and Lien (2010). This model used the residual output approach but also takes into account capital as an endogenous input and factors that influence the technology in place but are not inputs (the time trend, socioeconomic conditions, and location). The inclusion of factors that are not normally considered inputs in Model 3 is intended to adjust for heterogeneity among countries.

3.3.1. Single production frontier approach: the case of a bad input as a bad output

This subsection presents Model 1. The model was developed using an approach that Reinhard, Lovell, and Thijssen (1999, 2000) employed to calculate environmental efficiency from a stochastic frontier where a bad output is considered as a bad input. Equation (3.1) represents specification of a cross section country level stochastic production frontier (KUMBHAKAR; LOVELL, 2003):

$$y_i = f\left(X_{ip};\beta\right).\,e^{(-u_i)}.\,e^{v_i} \tag{3.1}$$

Production from economy y_i is determined by function $f\left(X_{ip};\beta\right)$, where X_{ip} represents the inputs, and the two error components are represented by u_i and v_i. As noted in Aigner, Lovell, and Schmidt (1977), the stochastic error of the production frontier can be decomposed as $\varepsilon_i = u_i + v_i$, where u_i represents the technical inefficiency (TE), thus $u_i < 0$; and v_i is the random shocks component.

A general production function which considers an environmentally detrimental input is specified in Equation (3.2):

$$y_i = f\left(X_{ip};Z_{ij};\beta;\gamma;\xi\right).\,e^{(-u_i)}.\,e^{v_i} \tag{3.2}$$

Along with the non-detrimental input set X_{ip}, each country can also employ Z_{ij} detrimental inputs to produce y_i level of output. The Greek letters β, γ and ξ are the econometric parameters of non-detrimental inputs, detrimental inputs and the interaction between both, respectively. The stochastic errors are under the assumption that u_i is positive and follows a half-normal distribution, and v_i is the standard errors and follows a normal distribution (REINHARD; LOVELL; THIJSSEN, 2000).

Equations (3.3) to (3.5) were based on Reinhard, Lovell, and Thijssen (1999, 2000): Transforming Equation (3.2) into a translog functional form results in Equation (3.3):

$$\begin{aligned}\ln y_i = \alpha + \sum_{p=1}^{P} \beta_{pi}.\ln X_{pi} + \sum_{j=1}^{J} \gamma_{ji}.\ln Z_{ji} + \frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} \beta_{pm}.\ln X_{pmi} \\ + \frac{1}{2}\sum_{j=1}^{J}\sum_{n=1}^{N} \gamma_{jn}.\ln Z_{jni} + \frac{1}{2}\sum_{p=1}^{P}\sum_{j=1}^{J} \xi_{pj}.\ln X_{pi}.\ln Z_{ji} + v_i - u_i\end{aligned} \tag{3.3}$$

where $X_{pm} = X_{mp}$ and $Z_{jn} = Z_{nj}$.

Assuming a 100% technically efficient economy and $u_i = 0$, then replacing $\ln Z_{ji}$ with $\ln Z_{ji} = EE.Z_M$ leads to Equation (3.4):

$$\begin{aligned}\ln y_i = \alpha + \sum_{p=1}^{P} \beta_{pi}.\ln X_{pi} + \sum_{j=1}^{J} \gamma_{ji}.\ln(Z_M\, EE_i) + \frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} \beta_{pm}.\ln X_{pmi} \\ + \frac{1}{2}\sum_{j=1}^{J}\sum_{n=1}^{N} \gamma_{jn}.\ln(Z_M EE_{ni}) + \frac{1}{2}\sum_{p=1}^{P}\sum_{j=1}^{J} \xi_{pj}.\ln X_{pi}.\ln(Z_M\, EE_i) + v_i\end{aligned} \tag{3.4}$$

This replacement is possible because environmental efficiency (EE) is the ratio between minimum input utilization $Z = Z_{ji}$ and the utilization of Z_M detrimental inputs ($EE = Z/Z_M \rightarrow Z = EE.Z_M$).

By solving Equations (3.4) and Equation (3.3), $\ln EE_i$ can be isolated and Equation (3.5) can be obtained. Solving Equation (3.5) using the square formula and applying $EE_i = \exp(\ln EE_i)$ gives the environmental efficiencies for each country:

$$lnEE = \left[-\theta_{Di} \mp \left(\theta_{Di}^2 - 2u_i \sum_j \sum_n \gamma_{jn}\right)^{0.5}\right] / \left(\sum_j \sum_n \gamma_{jn}\right) \tag{3.5}$$

where θ_D is the sum of detrimental input elasticities. The mathematical expression for θ_D is $\Sigma_j \gamma_j + \Sigma_p \Sigma_j \xi_{pj} \ln X_{ji} + \frac{1}{2}\Sigma_j \Sigma_n \gamma_{jn}(\ln Z_j + \ln Z_k)$. Only the positive root is applied.

Equation (3.6) shows the Schmidt and Sickles (1984) fixed effects approach used to consider cross country panel data:

$$y_{it} = \beta_0 + X_{it}\Gamma + v_{it} - u_i, \tag{3.6}$$

where Γ represents the parameters of panel data frontier analysis. Fixed effects panel data accounts for heterogeneity among unobservable characteristics where the TE term is mixed with the fixed effects term by $\alpha_i = \beta_0 - u_i$. However, TE values can be obtained using Equation (3.7) (SCHMIDT; SICKLES, 1984):

$$TE_i = \exp(-u_i) = \max_i\{\alpha_i\} - \alpha_i \geq 0 \tag{3.7}$$

Similar to the panel model approach, a random effects frontier panel model provides more efficient estimates than a fixed effects model in cases of no correlation between unobservable characteristics and other regressors, X_{it}, and Z_{it} in the case of the detrimental inputs being considered. If the regressors are correlated with unobservable characteristics, then a fixed effects model is likely to be preferable (GREENE, 2003). A fixed effects frontier panel model was employed in the current efficiencies study since the regressors are correlated with unobservable characteristics.

In a second stage, the technical efficiency estimated value can be employed as a dependent variable, in which the independent regressors must not be correlated with the regressors in the first stage (X and Z). The model for technical efficiency is specified in (3.8):

$$\ln TE = u_i = g(Q_{it}; \psi), \tag{3.8}$$

where Q_{it} is a vector of variables that explain technical efficiency; N_{it} is a vector of variables that explain the environmental efficiency and ψ is the vector of the parameters to be estimated.

Because environmental efficiency is calculated using the method specified in Equation (3.5), there are no assumptions for its distribution (REINHARD; LOVELL; THIJSSEN, 2002); and it is possible to estimate a function of variables which explain the environmental efficiency, as specified by Equation (3.9).

$$\ln EE = \eta_i = h(N_{it}; \Lambda), \tag{3.9}$$

where N_{it} is a vector of variables that explain the environmental efficiency, and Λ is the vector of the parameters to be estimated. For comparison in this study's analysis, I assume that $Q_{it} = N_{it}$. Proxy variables representing a country's development level, such as structural characteristics and institutional framework, were employed in both these vectors.

Time-varying technical efficiency is addressed to account for the fact that countries can learn from past experience and improve efficiency (KUMBHAKAR; WANG; HORNCASTLE, 2015; KUMBHAKAR; WANG, 2005; WANG, 2007). This is accomplished by assuming that technical inefficiency is coupled with a time function $G(t)$ (CORNWELL; SCHMIDT; SICKLES, 1990; KUMBHAKAR; WANG; HORNCASTLE, 2015; LEE; SCHMIDT, 1993), where $v_{it} \sim N(0, \sigma^2)$ and $u_{it} \sim N^+(\mu, \sigma_u^2)$.

In a production process that generates at least two outputs, one of which is considered environmentally detrimental ("bad") and the other is the main output, ("good"); the residual "by-production" frontier is a technology that generates the bad using the technology employed to produce the main output. Because the bad was only generated due to the production of the good, the bad output can be called the "by-production" residual frontier in the manner of Kumbhakar and Tsionas (2016).

Equation (3.10) specifies a general residual production function that considers s_i an environmentally detrimental output:

$$s_i = h\left(y_i; Z_{ji}; \delta; \tau; \varphi\right). e^{(-\eta_i)}. e^{\epsilon_i}, \qquad (3.10)$$

where y_i is the output level for each country i and Z_{ij} is the set of detrimental inputs. The Greek letters δ, τ and φ are the parameters matrix. The δ stands for production of the good output, which is GDP, τ is the parameters for the bad inputs, which is this study is only the non-renewable energy, and φ stands for the interaction of variables in the translog functional form.

The production function of good output y_i follows the same specification as in Equation (3.2), which is shown in Equation (3.11):

$$y_i = f\left(X_{pi}; Z_{ji}; \beta; \gamma; \xi\right). e^{(-u_i)}. e^{v_i} \qquad (3.11)$$

The by-production (BP) approach allows one to estimate a system consisting of equations (3.10) and (3.11) because both s_i and y_i are considered endogenous.

The econometric specification of Equation (3.11) can be written equal to Equation (3.3). This specification is the standard stochastic production frontier, not a transformation function or input oriented distance function (Fernández, Koop, and Steel, 2002; Kumbhakar and Tsionas, 2016) because only one good output is produced from the model and inputs are considered to be exogenous.

Equation (3.12) shows the econometric specification of Equation (3.11). This specification follows a translog functional form and represents the good output ($\ln y_i$) and the inputs used to produce it.

$$\ln y_i = \alpha + \sum_{p=1}^{P} \beta_{pi}.\ln X_{pi} + \sum_{j=1}^{J} \gamma_{ji}.\ln Z_{ji} + \frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} \beta_{pm}.\ln X_{pmi} + \frac{1}{2}\sum_{j=1}^{J}\sum_{n=1}^{N} \gamma_{jn}.\ln Z_{jni} + \frac{1}{2}\sum_{p=1}^{P}\sum_{j=1}^{J} \xi_{pj}.\ln X_{pi}.\ln Z_{ji} + v_i - u_i \tag{3.12}$$

where v_i is the idiosyncratic error term with $N(0,\sigma^2)$. Error u_i is the truncated normal error component from a standard stochastic frontier, which represents the technical efficiency term.

The residual BP technology for the bad output, from Equation (3.10), is specified in Equation (3.13):

$$\ln s_i = \omega + \delta_i.\ln y_i + \sum_{j=1}^{J} \tau_{ji}.\ln Z_{ji} + \frac{1}{2}\delta_{pi}.\ln y_i^2 + \frac{1}{2}\sum_{j=1}^{J}\sum_{n=1}^{N} \tau_{ji} \ln Z_{jni} + \frac{1}{2}\sum_{j=1}^{J} \varphi_j.\ln y_i.\ln Z_{ji} + \epsilon_i + \eta_i \tag{3.13}$$

where ϵ_i is the idiosyncratic error term with $N(0,\sigma^2)$. The error η_i is the environmental inefficiency term, which econometrically is represented by a cost frontier and follows a truncated normal distribution $N^+(\mu,\sigma_\eta^2)$. Because it is represented as a cost frontier, the signal of $\eta_i > 0$ is positive.

Again, to consider the specification for panel data, Equation (3.14) (the same as Equation (3.6)) shows the fixed effects model for the stochastic frontier and follows Schmidt and Sickles (1984):

$$y_{it} = \beta_0 + X_{it}\Gamma + v_{it} - u_i \tag{3.14}$$

To this point, the study has employed two approaches for the calculation of environmental efficiency. In the first model specification (Model 1), the bad output was considered to be a bad input in the econometric specification. In the second model (Model 2), there are two outputs, one is good (GDP) and the other is a bad (GHG). This model considers BP technology in which the bad output (GHG emissions) is the result of a residual technology utilized in the production of the good output, which is GDP.

As noted previously, monotonicity constraints are important when considering the assumptions of production theory (KUMBHAKAR; TSIONAS, 2016). To impose monotonicity constraints, I employed the three step method proposed by Henningsen and Henning (2009).

The first of the three steps consists in estimating a conventional, unrestricted stochastic production frontier as shown in Equation (3.15):

$$\ln y_{it} = f\left(\ln X_{it}\,; \hat{\beta}\right) + v_{it} - u_i \tag{3.15}$$

$$E(u_i) = g(Q_{it}; \psi) \tag{3.16}$$

In Equation (3.15), v_{it} is a single output, X_{it} is the inputs vector, u_i is the technical efficiency term, v_{it} is the standard error term, and $\hat{\beta}$: is a vector of frontier parameters to be estimated. In Equation (3.16), Q_{it} is a vector of variables that explain technical efficiency, and ψ is a vector of parameters of the technical efficiency equation to be estimated. Equation (3.16) gives environmental efficiency values from estimation of the residual technology and is equivalent to Equations (3.8)'s mathematical specification.

The second step consists of estimating a vector of restricted parameters $\hat{\beta}^0$ employing the minimum distance estimation shown by Equation (3.17):

$$\hat{\beta}^0 = \arg\min(\hat{\beta}^0\text{-}\hat{\beta})\ \hat{\textstyle\sum}_{\beta}^{-1}(\hat{\beta}^0\text{-}\hat{\beta}) \tag{3.17}$$

where $\hat{\beta}^0$represents the unrestricted parameters of the production frontier, and $\hat{\sum}_{\beta}$ is its variance-covariance matrix.

In the final step, the efficiency estimates from equations (3.15) and (3.16) with monotonic imposed constraints of the production frontier is calculated. Equation (3.18) specifies a production frontier with the estimated monotonic output $\tilde{y}_{it} = f\left(X_{it}; \hat{\beta}^0\right)$:

$$\ln\ y_{it} = f\left(\ln X_{it}\,; \hat{\beta}^0\right) + v_{it}\text{-}u_i, \tag{3.18}$$

where all values of $y_{it} = f(X_{it}; \beta)$ should be positive for any values of X_{it} or β.

The imposition of monotonicity constraints allows one to estimate the production frontier, Equation (3.16), separated from the residual "by-production" technology estimated using Equation (3.14) (Kumbhakar and Tsionas, 2016). The results for environmental efficiency from an estimation of the residual technology can be obtained using Equation (3.16).

3.3.2. Residual "by-production": taking into account heterogeneity among countries

To take into consideration heterogeneity of technologies—both production and residual—among countries, Model 3 was constructed using the method Latruffe et al. (2017) devised to conduct a stochastic frontier analysis with one endogenous input and a vector of variables that influence output but are not inputs. Latruffe et al's. (2017) study considered a similar method developed by Kumbhakar and Lien (2010), while making improvements with implementation of a method of moments estimation.

Model 3 takes a Cobb-Douglas functional form and accounts for one endogenous variable that is correlated with the technology and the stochastic error. For this study, the capital stock is assumed to be endogenous. Capital stock can influence the stochastic error by shifting an economy's production technology. The specification of the model is shown in Equation (19):

$$y_i = f\left(X_{pi};\ \tilde{X}_{1i}; Z_{ji}; C_{ki}; \beta; \gamma\right). e^{(-u_i)}. e^{v_i} \quad (3.19)$$

where X_{pi} is a vector of non-environmentally detrimental input variables; Z_{ij} is a vector of environmentally detrimental variables;C_{ki} is a vector of control variables that influences the output (heterogeneity of technology), but are not inputs; the Greek letters are vectors of parameters to be estimated and $\tilde{X}_{i1}$ is the one endogenous variable (capital stock).

The estimated econometric model employs a panel data set where the time series corresponds to yearly data from 1998 to 2012 and cross sectional data corresponds to countries around the globe. Equation (3.20) shows Model 3's stochastic specification:

$$\ln y_i = \alpha + \sum_{p=1}^{P} \beta_{pi}. \ln X_{pi} + \tilde{\beta}_{1i}. \ln \tilde{X}_{1i} + \sum_{j=1}^{J} \gamma_{ji}. \ln Z_{ji} + \sum_{k=1}^{K} \Theta_{ki}. C_{ki} + v_i^{TE} \quad (3.20)$$

$$u_i = g(Q_i^e; \psi^e) \quad (3.20.2)$$

$$\ln \tilde{X}_{1it} = \ln \tilde{X}_{1i(t-2)} + \ln \tilde{X}_{1i(t-3)} + e_{1it} \quad (3.20.3)$$

Equation (20.2) specifies a vector of variables Q_i^e that explain the technical efficiencies. The superscript e means that $Q_i^e \neq Q_i$, this latter from Equations (8) and (18). Equation (20.3) is the instrumental variable equation, where the lags of capital stock variable works as the instruments. It is assumed that there is no autocorrelation of order 2 or 3 in the model.

Equations (3.21), (3.21.2) and (3.21.3) are the residual technology equations for the detrimental output:

$$\ln ghg_i = \alpha^b + \tilde{\beta}_{1i}. \ln \tilde{y}_{1i} + \gamma_{ji}. \ln nren_i + \sum_{k=1}^{K} \Theta_{ki}. C_{ki} + v_i^{EE} \quad (3.21)$$

$$\eta_i = g(Q_i^e; \psi^e) \quad (3.21.2)$$

$$\ln \tilde{y}_{1it} = \ln \tilde{y}_{1i(t-2)} + \ln \tilde{y}_{1i(t-3)} + e_{1it} \quad (3.21.3)$$

where α^b is the constant in the model's equation and represents the residual detrimental output, and the endogenous variable is the output (GDP level). Non-renewable energy consumption is one environmentally detrimental input considered. Equation (3.21.2) is specified with the same variables as (3.20.2) but now explains a country's level of environmental efficiency. Equation (3.21.3) is the instrumental variable equation, with previous periods' output levels used as the instruments. It is assumed that there is no order 2 or 3 autocorrelation in the model.

According to Guan et al. (2009), the standard maximum likelihood frontier method can be employed to estimate technical (TE) and environmental efficiencies (EE) via the MM algorithm by using the residuals estimates from equations in the (3.20) and (3.21) series, as shown in equations (3.22.1) and (3.22.2):

$$v_{it}^{TE} = \Theta_{it} C_{it} + \lambda_{it}^{TE} + u_{it} \quad (3.22.1)$$

$$v_{it}^{EE} = \mathit{\Theta}_{it} C_{it} + \lambda_{it}^{EE} + \eta_{it} \quad (3.22.2)$$

where Θ_{it} is the same vector of equations (3.20) and (3.21), and Θ_{ki}; C_{it} is the vector of variables which influences the technology output, but are not inputs. The u_{it} and η_{it} are the efficiency terms and are assumed to belong to a half-normal truncated distribution where $u_{it} \geq 0$ and $\eta_{it} \geq 0$. The λ_{it} is the term for random stochastic error and is assumed to belong to a normal distribution.

Table 3.1 sums up the three models and their specifications, showing the relevant equations, the theoretical concepts, and method references.

Table 3.1 - Summarize of models and its equations by theoretical concept and method references

Model	Equation numbers		Theoretical concept	Method references
	Standard technology	Residual technology		
M1	(3.3)		Detrimental output as an input in SFA	(HENNINGSEN; HENNING, 2009; REINHARD; LOVELL; THIJSSEN, 1999, 2000)
M2	(3.12)	(3.13)	Residual (detrimental) output	(HENNINGSEN; HENNING, 2009; KUMBHAKAR; TSIONAS, 2016)

M3	(3.20)	(3.21)	Residual (detrimental) output	(GUAN et al., 2009; KUMBHAKAR; LIEN, 2010; LATRUFFE et al., 2017)

Source: Own elaboration.

3.3.3. Data, sources and estimated models

The final data used in this study consisted of cross-sectional data from 116 countries and covered 20 years (1993-2012) with a time series made up of annual data points. The data employed (mix between panel data and time series data) was unbalanced because some observations were dropped if the data presented missing values or gaps.

Table 3.1 above summarized the methods used to estimate Model 1, Model 2 and Model 3. Table 3.2 gives a description of the variables considered in this study's models, their names in econometric specification, units of measure, and their data sources.

Table 3.2 – Variables names, description, measuring unit and source of variables used in Models 1 to 3.

Variable	Name	Description	Unit	Source
Gross Domestic Product	ly	GDP at purchaser's prices is 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 products.	Constant 2010 US$, in billions.	World Bank.
Greenhouse gases emission	lghg	Total greenhouse gas emissions are composed of CO2 totals excluding short-cycle biomass burning , but including other biomass burning and all anthropogenic CH4 sources, N2O sources and F-gases (HFCs, PFCs and SF6).	Mt of CO2 equivalent.	World Bank.
Capital	lk	Outlays on additions to the fixed assets of the economy plus net changes in the level of inventories.	Constant 2010 US$, in billions.	World Bank.
Renewable energy consumption	lren	Energy use refers to use of primary energy before transformation to other end-use fuels.	kt of oil equivalent.	World Bank.
Non-renewable energy consumption	lnren	Energy use refers to use of primary energy before transformation to other end-use fuels.	kt of oil equivalent.	World Bank.
Labor	ll	Labor force comprises people ages 15 and older who supply labor for the production of goods and services during a specified period.	Hundred thousand of people.	World Bank.

Time trend dummy	t	Time dummy.	From 1993 to 2012.	
Localization dummy	localdum	Country dummy.	By region, not income.	
Human Development Index	hdi	The HDI is the geometric mean of normalized indices for each of the three dimensions: education, income *per capita* and life expectancy at birth.	From 0 (lowest) to 1000.	United Nations Development Programme (UNDP).
Legal Rights Index	legalr	The index ranges from 0 to 12, with higher scores indicating that collateral and bankruptcy laws are better designed to expand access to credit.	From 0 (lowest) to 12.	World Bank.
Agriculture percentage of GDP	agricp	The percentage of Agriculture's product share in country's GDP.	Percentage.	World Bank.
Manufacturing percentage of GDP	manufp	The percentage of Manufacturing industry's product share in country's GDP.	Percentage.	World Bank.
Access to internet	internet	Internet access is defined as the percentage of households who reported that they had access to the Internet.		World Bank.
Gini inequality coefficient	Gini	Measures the distribution of income (or household expenditure in some cases) within the country.	From 0 (perfect equality) to 100.	World Bank.
Democracy Index	democ	Democracy Index is based on five categories: electoral process and pluralism; civil liberties; the functioning of government; political participation; and political culture.	From 0 (low democracy) to 10.	The Economist Intelligence Unit.
Signature of KP until 1998 dummy	kp	A dummy variable. 1 stands for countries that ratified the Kyoto Protocol until 1998.	0 or 1.	United Nations Framework Convention on Climate Change.

Source: own elaboration.

Equations (3.23) to (3.27) sum up the econometric specification for each of the three models. Equation (3.3) corresponds to Model 1 [Eq. (3.23)]. Equation (3.12) and Equation (3.13) correspond to Model 2 production technology [Eq. (3.24)] and residual technology [Eq. (3.25)], respectively. Equation (3.20) and Equation (3.21) correspond to

Model 3 production technology [Eq. (3.26)] and residual technology [Eq. (3/27)], respectively.

Model 1: employing the GHG emissions as an input.

Production technology equation.

$$y_{it} = a_i + \beta_1 \ln l_{it} + \beta_2 \ln k_{it} + \beta_3 \ln ren_{it} + \gamma_1 \ln nren_{it} + \gamma_2 \ln ghg_{it} \tag{3.23}$$

$$+ \beta_{11} \ln l_{it}^2 + \beta_{22} \ln k_{it}^2 + \beta_{33} \ln ren_{it}^2 + \gamma_{11} \ln nren_{it}^2$$

$$+ \gamma_{22} \ln ghg_{it}^2 + \beta_{12} \ln l_{it} \ln k_{it} + \beta_{13} \ln l_{it} \ln ren_{it}$$

$$+ \beta_{23} \ln k_{it} \ln ren_{it} + \gamma_{12} \ln nren_{it} \ln ghg_{it}$$

$$+ \xi_{11} \ln l_{it} \ln nren_{it} + \xi_{21} \ln k_{it} \ln nren_{it}$$

$$+ \xi_{31} \ln ren_{it} \ln nren_{it} + \xi_{12} \ln l_{it} \ln ghg_{it}$$

$$+ \xi_{22} \ln k_{it} \ln ghg_{it} + +\xi_{32} \ln ren_{it} \ln ghg_{it} + v_{it} - u_{it}$$

Where ....

Efficiency level equations for TE and EE.

$$\ln TE = u_{it} = \alpha_{it} + \psi_{1it} legalr_{it} + \psi_{2it} agricp_{it} + \psi_{3it} manufp_{it} \tag{3.23.2}$$

$$+ \psi_{4it} democ_{it} + \psi_{5it} kp_{it} + \psi_{6it} gini_{it} + e_{it}^u$$

$$\ln EE = u_{it} = \alpha_{it} + \Lambda_{1it} legalr_{it} + \Lambda_{2it} agricp_{it} + \Lambda_{3it} manufp_{it} \tag{3.23.3}$$

$$+ \Lambda_{4it} democ_{it} + \Lambda_{5it} kp_{it} + \Lambda_{6it} gini_{it} + e_{it}^\eta$$

Model 2: employing the BP residual technology for GHG emissions considering another technology for the production frontier.

Production technology equation.

$$y_{it} = a_i + \beta_1 \ln l_{it} + \beta_2 \ln k_{it} + \beta_3 \ln ren_{it} + \gamma_1 \ln nren_{it} + \beta_{11} \ln l_{it}^2 \tag{3.24}$$

$$+ \beta_{22} \ln k_{it}^2 + \beta_{33} \ln ren_{it}^2 + \gamma_{11} \ln nren_{it}^2 + \beta_{12} \ln l_{it} \ln k_{it}$$

$$+ \beta_{13} \ln l_{it} \ln ren_{it} + \beta_{23} \ln k_{it} \ln ren_{it} + \xi_{11} \ln l_{it} \ln nren_{it}$$

$$+ \xi_{21} \ln k_{it} \ln nren_{it} + \xi_{31} \ln ren_{it} \ln nren_{it} + v_{it} - u_{it}$$

Residual technology equation.

$$ghg_{it} = \omega_i + \delta \ln y_{it} + \tau_1 \ln nren_{it} + \delta_{11} \ln y_{it}^2 + \tau_{11} \ln nren_{it}^2 + \phi_{11} \ln y_{it} \ln nren_{it} + \epsilon_{it} + \eta_{it} \quad (3.25)$$

The efficiency level equations are the same as Model 1, equations (3.23.2) and (3.23.3).

Model 3: employing the BP residual technology approach taking into account country heterogeneity.

Production technology equation.

$$\ln y_{it} = \alpha + \beta_1 \ln l_{it} + \beta_2 \ln ren_{it} + \tilde{\beta}_{1i}.\ln \tilde{k}_{1i} + \gamma_1 \ln nren_{it} + \Theta_{1it} hdi_{it} + \Theta_{2it} localdum_{it} + \Theta_{3it} t_{it} + \Theta_{4it} gini_{it} + v_{it}^{TE} - u_{it} \quad (3.26)$$

$$\ln TE = u_{it} = \alpha_{it} + \psi_{1it}^e legalr_{it} + \psi_{2it}^e agricp_{it} + \psi_{3it}^e manufp_{it} + \psi_{4it}^e democ_{it} + \psi_{5it}^e kp_{it} + e_{it}^{ue} \quad (3.26.2)$$

$$\ln \tilde{k}_{1it} = \ln \tilde{k}_{1i(t-2)} + \ln \tilde{k}_{1i(t-3)} + e_{1it} \quad (3.26.3)$$

Residual technology equation.

$$\ln ghg_{it} = \alpha^b + \tilde{\beta}_{1i}.\ln \tilde{y}_{1i} + \gamma_{ji}.\ln nren_i + \Theta_{1it} hdi_{it} + \Theta_{2it} localdum_{it} + \Theta_{3it} t_{it} + \Theta_{4it} gini_{it} + v_{it}^{EE} - \eta_{it} \quad (3.27)$$

$$\ln EE = u_{it} = \alpha_{it} + \Lambda_{1it}^e legalr_{it} + \Lambda_{2it}^e agricp_{it} + \Lambda_{3it}^e manufp_{it} + \Lambda_{4it}^e democ_{it} + \Lambda_{5it}^e kp_{it} + e_{it}^{\eta e} \quad (3.27.2)$$

$$\ln \tilde{y}_{1it} = \ln \tilde{y}_{1i(t-2)} + \ln \tilde{y}_{1i(t-3)} + e_{1it} \quad (3.27.3)$$

3.4. RESULTS OF TECHNOLOGY ESTIMATION AND DISCUSSION OF ECONOMIC AND ENVIROMENTAL PERFORMANCE

Models 1, 2 and 3 were estimated using R-Studio software and “frontier”, “sfadv,” and “quadprog” packages and their dependencies. Table 3.3 summarizes the variables descriptive statistics.

Table 3.3 – Descriptive statistics of the variables technology, production of GDP, production of GHG, and the variables that explain efficiency levels

Variable	Mean	Std. Dev	Minimum	Maximum
y	538.00	1550.00	0.76	15542.16
l	266.30	914.50	0.07	7840.00
k	123.10	359.60	0.12	3289.27
ren	441.50	983.80	0.00	13887.09

nren	1967.00	2065.45	4.28	15059.67
ghg	390.70	1100.03	2.16	12455.71
hdi	0.71	0.15	0.25	0.94
legalr	4.87	2.58	0.00	12.00
agricp	10.56	10.03	0.00	52.70
manufp	16.83	6.20	2.30	39.00
internet	23.26	26.70	0.00	96.20
Gini	0.71	0.15	0.25	0.94
democ	6.43	2.00	1.71	9.93
KP	0.60	(binary)	0.00	1.00

Source: World Bank, UNDP, UNFCCC, The Economist Intelligence Unit.

3.4.1. Model 1: detrimental output as a detrimental input in SFA

The elasticities of inputs from the Model 1 translog functional form are presented in Table 3.4, which also shows the returns to scale of all inputs used in the production function. Model 1 considered greenhouse gases emissions as a bad input. In this case, the more environmentally efficient (EE) country is the one that can produce the same amount of GDP employing fewer detrimental inputs, with detrimental inputs being the consumption of energy from non-renewable sources and GHG emissions (the detrimental output that was considered as an input in Model 1).

In this case, the more environmentally efficient (EE) country is the one that uses less GHG and less non-renewable energy and produces the same output compared to another country which uses more of these detrimental inputs.

Table 3.4 – Production frontier input elasticities and returns to scale from Model 1

	lren	lnren	ll	lk	Lghg	RTS
Average	0.051	0.078	0.027	0.774	0.063	0.993
Std. Dev	(0.024)	(0.022)	(0.011)	(0.091)	(0.026)	(0.024)
Median	0.052	0.078	0.027	0.771	0.064	0.995
Minimum	0.006	0.016	0.001	0.517	0.002	0.928
Maximum	0.112	0.140	0.049	1.021	0.117	1.077

Source: study results.

Results shown in Table 3.4 indicate that the average RTS is almost one, which means constant returns to scale. The variable Capital had the highest output elasticity. GHG emissions and the use of both renewable and non-renewable energy had similar elasticities. The sum of detrimental input elasticity was 0.141, accounting for 14.2% of the RTS value.

Table 3.5 presents Model 1's estimated results for technical efficiency (TE) and environmental efficiency (EE) considering GHG emissions as a detrimental input and imposing monotonicity constraints on the production frontier.

Table 3.5 – TE and EE for Model 1, imposing monotonicity constraints

	TE	EE
Average	0.745	0.012
Std. Dev	(0.107)	(0.019)
Median	0.759	0.004
Minimum	0.519	0.000
Maximum	0.942	0.087

Source: study results.

Table 3.5 shows that average TE was 74.5% and that EE calculated by this method presented much lower values than TE. Considering that the minimum EE value was zero, at least one country was 100% environmentally inefficient. Referring to Figure 3.1, the linear distance of this country from the production frontier was only due to technical inefficiency. The correlation between TE and EE was -0.69, indicating that countries with high TE are likely to have a low EE performance. Figures 3.6 and 3.7 present the distribution of TE and EE, respectively. The observations depicted on the figures' histograms were made considering each country's weighted average over the different periods, because data allowed only an unbalanced panel.

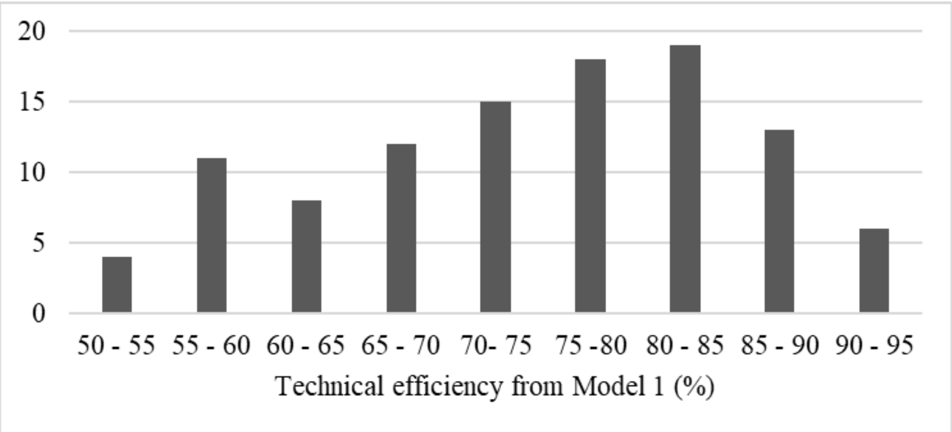


Figure 3.6 – Distribution of TE from Model 1 results

Source: study results.

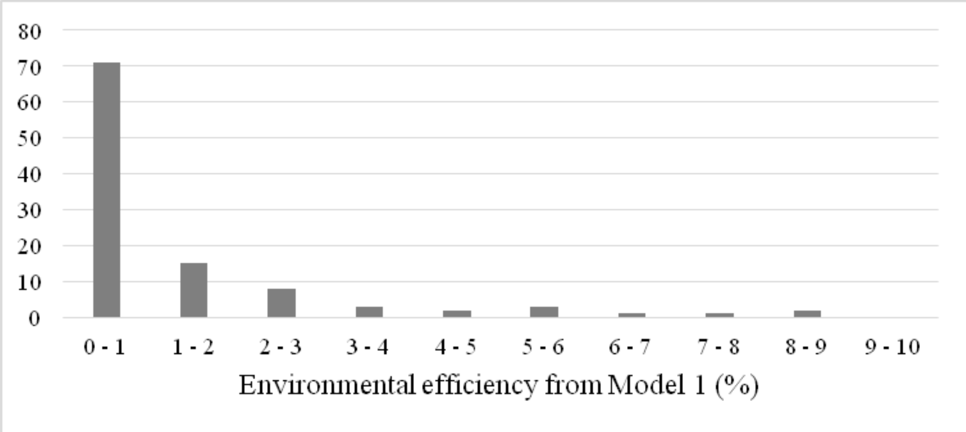


Figure 3.7 – Distribution of EE from Model 1 results

Source: study results.

By and large, the distribution of EE is concentrated between 0 and 1%, with Model 1 indicating that most countries are 99%, or more, environmentally inefficient. On the other hand, Figure 3.6 indicates that all the countries are, at least, 50% technically efficient. Almost 40% of the countries have a TE for between 75% and 85%.

Human and natural systems are more vulnerable when a country's institutional framework is extractive. As has been noted earlier, an extractive institutional framework can have an intense corruptive effect on government (Acemoglu and Robinson 2012) and create an environment where enforcing contracts adds additional costs that reduce TE and EE. Table 3.6 and Table 3.7 present results from the TE and EE equations [equations (3.12) and (3.13), respectively]. The more distant the observation is from the optimal production frontier, the higher u_i. Thus, a higher u_i means less TE because $TE = exp^{(-u_i)}$.

Table 3.6 – Factors that can explain the TE level considering Model 1 $-u_i$ estimates

Variable	Parameter	Std. Error	P-value	Significance
Intercept	-0.002	0.033	0.947	
legalr	0.019	0.003	0.000	***
agricp	0.011	0.001	0.000	***
manufp	0.013	0.001	0.000	***
democ	-0.015	0.005	0.003	***
KP	-0.090	0.019	0.000	***
Gini	-0.018	0.062	0.767	

Source: study results.

Seria um pouco frágeis estes indicadores?

Generally, results indicate that the higher the legal rights index, the lower TE level. This would mean that countries that facilitate lending (credit) would likely have a lower TE than countries that have a tight or restrictive credit regime. This might occur if the amount of credit lent did not increase the country's productivity proportionally. Perhaps, facilitating credit might also incur more debt, which can constrain productivity.

Higher participation of the agriculture and manufacture's sectors to GDP can also decrease TE. Agriculture and manufacturing activities, on the average, can produce less output than they should or produce less than service sector, which includes the banking and transportation sectors.

The democracy index (where higher levels indicate more freedom) showed that more democratic countries often have a higher TE than less democratic countries. This is consistent with the determination made by Acemoglu and Robinson (2006) that countries with a more participatory civil society consistently show relatively better economic performance.

The Kyoto Protocol seemed to reduce transaction costs, thus increasing TE. Possibly, the transition to a more environmentally oriented production technology stipulated by the Kyoto Protocol also led to an increase in productivity due to innovation and modernization.

Table 3.7 – Factors that can explain the EE level as calculated using Model 1

Variable	Parameter	Std. Error	P-value	Significance
Intercept	3.347	0.610	0.000	***
legalr	0.173	0.084	0.040	**
Agricp	0.018	0.007	0.011	**
Manufp	0.067	0.007	0.000	***
Democ	0.215	0.061	0.000	**
Kp	-0.810	0.250	0.001	**
Gini	-14.160	0.677	0.000	***

Source: study results.

Greater legal rights enhance the EE level, which is expected, because well understood, accepted legal rights reduce contract enforcement costs, especially were large financial contracts are concerned.

Agricultural activities increase GHG emissions through deforestation and land use alteration; although, the sector's monetary contribution was beneficial to EE, even though this parameter's value was lowest. Manufacturing activities also presented a positive contribution to EE.

Countries that are more democratic recognize and try to satisfy a variety of its population's interests, and the enforcement of environment laws can be of great interest to a large number of people. Although law enforcement in a strong democracy can increase costs, whether to enforce contracts, regulations, or perhaps, combat corruption, strong democracies also enforce environmental laws, which reasonably appears to increase to EE.

Countries that ratified the Kyoto Protocol tended to present lower EE. Evidence shows that in spite of setting GHG emissions mitigation goals, the concentration and emission of GHG increased over the past decades. It was also found that the higher a country's Gini coefficient, the lower its EE level. This last result follows the earlier noted theory of extractive institutions, as a higher Gini coefficient means more demographic inequality; usually an indication of an extractive institutional framework. This result indicates that the more demographic equality a country is, the higher its EE.

Talvez uma literatura empírica sobre estes aspectos institucionais.

3.4.2. Model 2: two technologies, a production technology and a residual technology producing environmentally detrimental output

The elasticities of inputs and returns to scale (RTS) obtained from Model 2 are presented in Table 3.8. Model 2 consists of two equations: a production frontier equation and a residual output frontier equation. The residual output frontier equation is used to estimate outputs from a detrimental production technology and a good output production technology. A translog functional form with imposed monotonicity constraints was specified for both equations.

Table 3.8 - Production frontier input elasticities and returns to scale from the Model 2 production frontier

	lren	lnren	ll	Lk	RTSg
Average	0.052	0.087	0.061	0.789	0.989
Std. Dev	0.025	0.017	0.031	0.085	0.023
Median	0.053	0.087	0.061	0.783	0.989
Minimum	0.000	0.000	0.000	0.457	0.912
Maximum	0.139	0.155	0.161	1.111	1.111

Source: study results.

The average of RTSg (good output RTS) is almost one, which means that the return from production is constant if standard deviation is taken into account. Capital is the most influential production input. The share of capital against RTSg is 80%. The detrimental input, which is non-renewable energy (nren), is the second most influential input, but there is a huge gap between capital and “nren”.

Table 3.9 points out the results from the residual output frontier, also estimated by ML as was the production frontier above.

Table 3.9 – Production frontier input elasticities and returns to scale from Model 2 residual output frontier

	cly	lnren	RTSd
Average	0.723	0.107	0.830
Std. Dev	0.049	0.037	0.016
Median	0.721	0.110	0.830
Minimum	0.579	0.000	0.783
Maximum	0.927	0.207	0.927

Source: study results.

The environmentally detrimental output technology (RTSd) was lower than RTSg. This result can indicate that, on the average among countries and time periods, the returns to scale of GHG emissions was lower than the returns to scale of GDP production, also considering that the latter influences production of the former. The elasticity of non-renewable energy was lower than GDP elasticity in RTSd. Estimated monotonic production presented a share of more than 94% of RTSd.

Table 3.10 gives the results for Model 2 TE and EE. The former was estimated by a production frontier additional error $-u_{it}$, and the latter was estimated by a cost frontier econometric specification adding error $+\eta_{it}$.

Table 3.10 – TE and EE for Model 2, imposing monotonicity constraints

	TE	EE
Average	0.767	0.546
Std. Dev	0.108	0.236
Median	0.780	0.573
Minimum	0.500	0.016

Maximum	0.994	0.898

Source: study results.

The average, minimum and maximum TE was higher than its corresponding EE. The mean average TE result could possibly indicate the world was more TE oriented than EE oriented during the 1993 through 2012 period; however, the correlation between TE and EE was only 0.578. EE presented a higher standard deviation and amplitude between values than TE, which means that EE was more heterogeneous among the countries over the studied time period than TE. Figures 3.8 and 3.9 illustrate the TE and EE distributions, respectively.

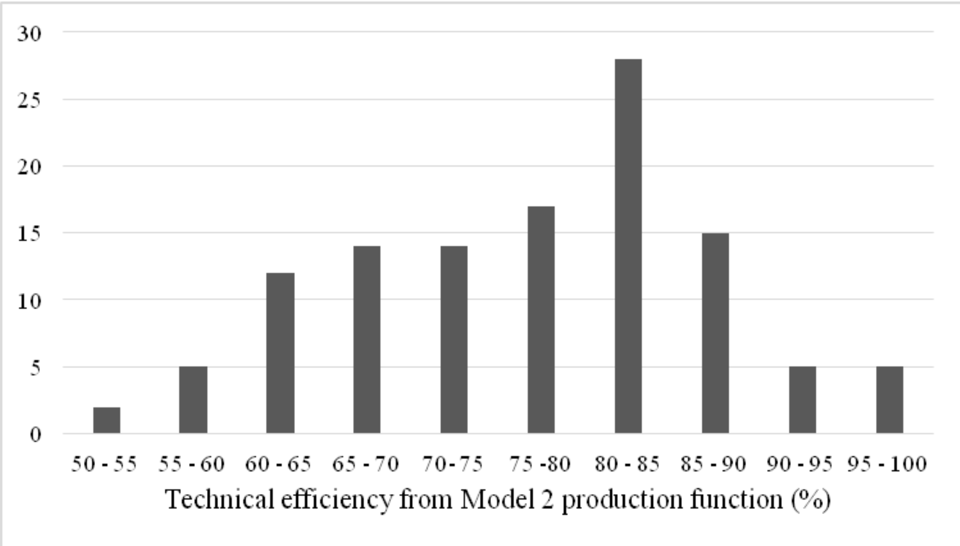


Figure 3.8 – Distribution of TE from Model 2 results

Source: study results.

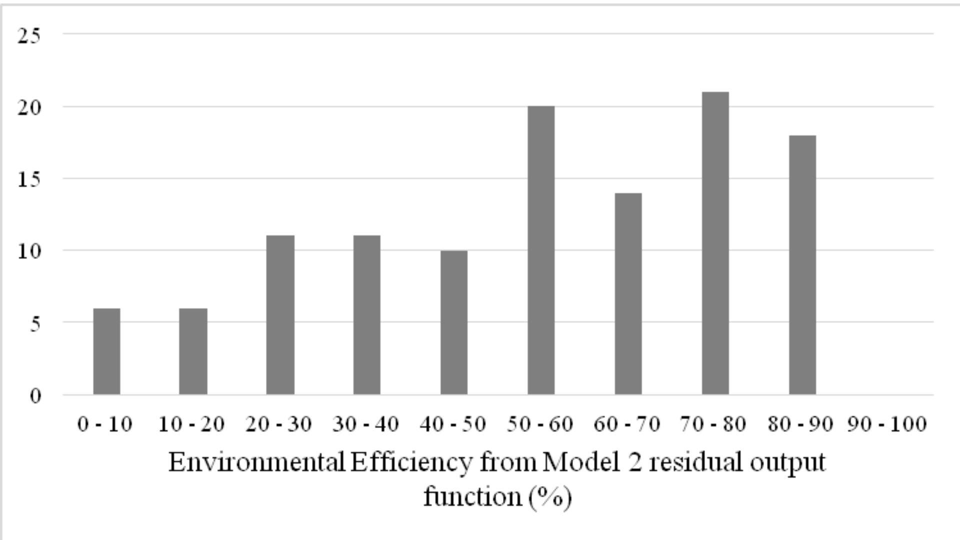


Figure 3.9 – Distribution of EE from Model 2 results

Source: study results.

The TE distribution shown in Figure 3.8 is skewed to the right and ranges from 55% to 100% efficiency. In Figure 3.9, the EE distribution, although also skewed, is less so than Figure 3.8 and is more evenly distributed than the TE values. Model 2's EE values were generally higher than the values from Model 1.

On the average, Model 2 TE results were higher than its EE results, similar to the results from Model 1 but the EE values from Model 2 were noticeably higher than those from Model 1. One reason for this divergence is that by treating GHG emissions as an input in Model 1, rather than as a residual output as in Model 2, all studied countries efficiency values will be reduced.

An ML estimation was employed to try and specifically determine the effect the IPCC's principles of equity and a particular country's various rules, regulations, laws and practices have on TE and EE levels. The estimations are shown in tables 3.11 and 3.12 for TE and EE, respectively.

Table 3.11 – Factors that can explain the TE level considering TE estimates from Model 2 production frontier technology

Variable	Parameter	Std. Error	P-value	Significance
Intercept	-0.006	0.030	0.835	
legalr	0.016	0.002	0.000	***
agricp	0.010	0.001	0.000	***
manufp	0.012	0.001	0.000	***
democ	-0.010	0.004	0.016	**
KP	-0.087	0.015	0.000	***
Gini	0.002	0.051	0.964	

Source: study results.

The legal rights index, in which the higher values represent more effective enforcement of financial contracts, negatively affected TE, replicating Model 1's results. Based on the data and results obtained from this study, a higher democracy index, in which higher values mean a more liberal and democratic society, might enhance in TE. According to Acemoglu and Robinson (2006), democratic societies have a more embedded, inclusive institutional set; and inclusive institutions often lead to a more prosperous country by uniting its population to achieve the universal goals of security, freedom, and prosperity.

Table 3.12 – Factors that can explain the EE level considering EE estimates from Model 2's residual output frontier

Variable	Parameter	Std. Error	P-value	Significance
Intercept	-3.976	0.101	0.000	***
legalr	0.064	0.029	0.030	**
agricp	0.104	0.008	0.000	**
manufp	0.065	0.012	0.000	***
democ	-0.275	0.047	0.000	***
KP	0.157	0.156	0.311	
Gini	-3.451	0.831	0.000	***

Source: study results.

Effective financial contract enforcement can increase EE, despite its positive value, because positive parameters increase $+\eta_{it}$ causing less efficiency in the production of detrimental outputs (cost). The Intercept parameter considered the percentage of contribution from the services sector to GDP$(1-(agricp+manufp)=services\ percentage)$. On the average, a higher percentage of GDP coming from both agriculture and manufacturing tended to increase EE. On the other hand, increased services sector output can decrease EE. Thus, on average, higher service sector GDP participation, which includes the banking and transportation subsectors, might have decreased EE. In contrast to TE, the average results indicated that higher agriculture and manufacturing sector participation in GDP would increase EE, but greater services sector participation would decrease EE.

Democracy appeared to have contributed negatively to EE. The higher the democratic standards that exist in a country, the lower the country's EE. Results for the effect of the Kyoto Protocol show that countries which ratified the KP by 1998 had, on average, higher EE than countries that had not ratified the accord, but evidence shows that GHG concentrations and emissions have increased over the last 20 years.

For underdeveloped countries that ratified the Protocol, attainment of its emissions mitigation goals was discretionary. There is a concern that GHG emissions are bound to rise, or have already risen, in countries whose economies are in transition and in developing countries (STERN, 2016). Among the factors that these two types of countries have in common is that wealth distribution, as measured by the Gini Index, is more unequal that in the developed countries. It may be that greater wealth distribution inequality decreases EE, with an increase of Gini leading to an increase in $+\eta_{it}$ that decreases EE.

3.4.3. Model 3: production and residual technologies under heterogeneity considerations

Table 3.13 shows the results from Model 3. This model takes into account heterogeneity among countries by employing a vector of variables that influence production despite being inputs. This vector considered the country's development level, income inequality (Gini), time trend, and a localization dummy representing the World Bank's aggregation of regions. Model 3 consists of two equations: one is the production frontier, and the other accounts for production of the residual detrimental output. Both functional forms are Cobb-Douglas, thus elasticity is the parameter's value itself.

Table 3.13 – Results for heterogeneity measurement from the variables which influence output but are not inputs

Production frontier				
Variable	Parameter	Std. Error	P-value	Significance
hdi	0.028	0.349	0.936	
localdum	0.036	0.012	0.002	**
t	-0.012	0.002	0.000	***
Gini	1.010	0.622	0.104	
Residual technology				
hdi	3.707	2.335	0.112	
localdum	-0.017	0.037	0.650	
t	0.014	0.006	0.014	*
Gini	-9.541	2.379	0.000	***

Source: study results.

The localization dummy positively affected GDP, while the time trend negatively affected GDP. A possible explanation for these phenomena is that developed countries increase their GDP at decreasing rates. In theory, this can be due to decreasing marginal returns from production inputs.

The positive value for the time trend parameter in the residual equation can indicate that GHG emissions increased at increasing rates. According to AR5 from the IPCC, this result is plausible, especially taking into account the period since 2000s, during which GHG emissions rates were above the average 1990s rate. GHG emissions rates have been increasing since 1990 (IPCC, 2014a).

Table 3.14 presents the estimated values for inputs elasticities and the returns to scale from Model 3.

Table 3.14 - Production frontier input elasticities and returns to scale from Model 3 production and residual frontiers

Production frontier		Residual technology	
Ren	0.022	nren	0.238
Nren	0.012	y (end)	0.638
Ll	0.085	-	-
lk (end)	0.860	-	-
RTSg3	0.979	RTSd3	0.876

(end) stands for Endogenous variable

Source: study results.

The mean average good production technology, RTSg3 (with g3 indicating Model 3 good output), was 0.979, indicating constant returns to scale. Similar to Model 2, the residual technology, RTSd3 (with d3 representing Model 3 detrimental output), presented a lower value for. Capital presented the highest elasticity for the production frontier, and GDP presented the highest elasticity for the residual frontier.

Table 3.15 presents the Model 3 estimated TE and EE for the production and residual frontiers. The model takes into account heterogeneity among countries beyond the fixed and random effects and endogeneity of inputs.

Table 3.15 – Estimated TE and EE from Model 3

	TE	EE
Average	0.341	0.307
Std. Dev	0.204	0.191
Median	0.326	0.284
Minimum	0.007	0.006
Maximum	0.732	0.685

Source: study results.

The average Model 3 median, minimum, and maximum TE vales are higher than the EE values. The correlation between TE and EE is 0.988, indicating that technically efficient economies are also more environmental efficient. The standard error for TE is slightly greater than for EE.

Figures 3.10 and 3.11 illustrate the distribution of TE and EE from Model 3's production and residual frontiers.

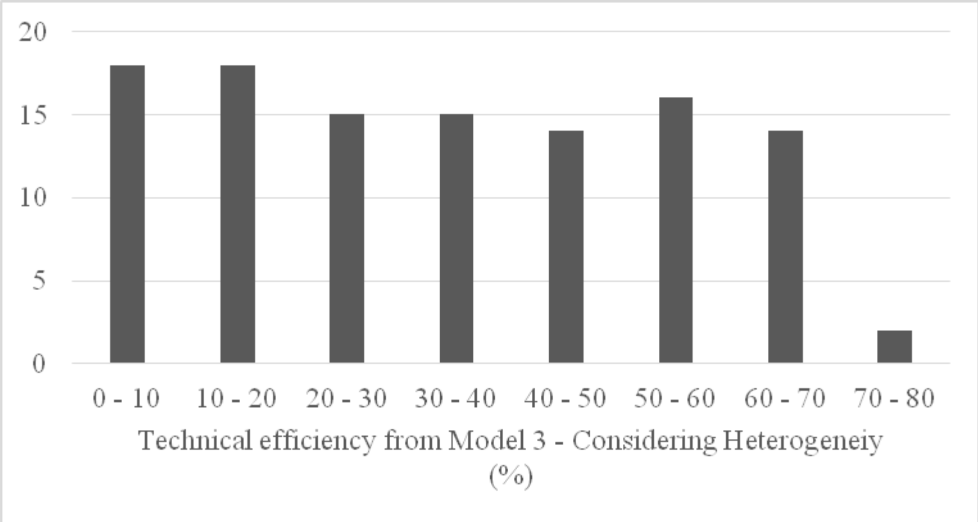


Figure 3.10 - Distribution of TE from Model 3 estimated results
Source: study results

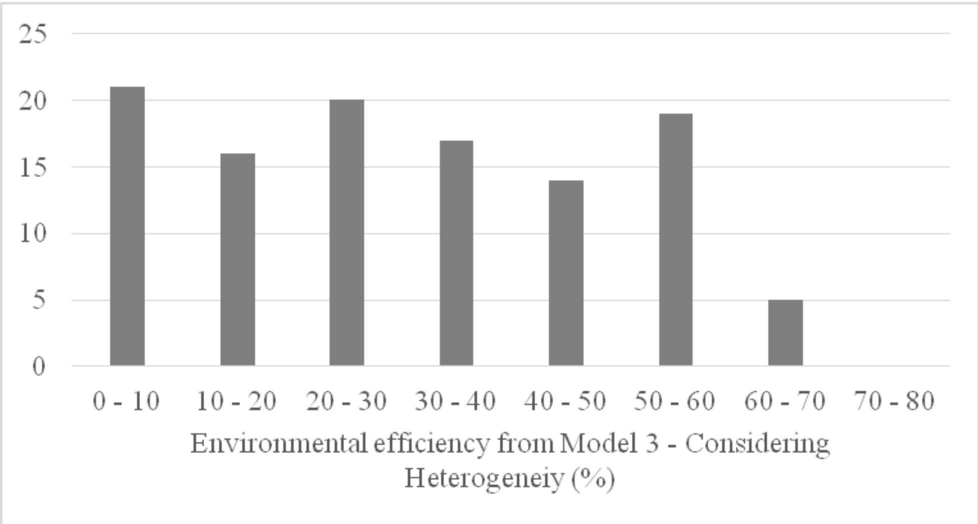


Figure 3.11 - EE distribution from Model 3 estimated results
Source: study results.

Figure 3.10 shows that 32% of the countries had a TE between 0% and 20%, 27% of the countries had a TE between 20% and 40%, and 27% of the countries had a TE between 40% and 60%. The TE distribution is not concentrated on one percentage band.

Likewise, TE and EE seem to follow the same pattern, which is not surprising due to high positive correlation between TE and EE.

Tables 3.16 and 3.17 display the results for variables which explain efficiency levels estimated using Model 3. These variables were proxies for the sample's institutional framework. Table 3.16 concerns the production frontier results from Model 3; Table 3.17 presents residual detrimental output frontier results, also from Model 3. The interpretations of Table 3.16 and 3.17 are similar because in the case of Model 3 $u_{it} < 0$ and $\eta_{it} < 0$.

Table 3.16 – Model 3 residual output frontier factors that explain the TE level

Variable	Parameter	Std. Error	P-value	Significance
Intercept	-0.144	1.119	0.898	
legalr	-0.028	0.007	0.000	***
agricp	-0.038	0.003	0.000	***
manufp	-0.013	0.003	0.000	***
democ	0.057	0.014	0.000	***
KP	0.068	0.048	0.154	

Source: study results.

The higher the legal rights index is, the higher the TE. Taking into account the vector of non-input variables that can influence production, the contribution of legal rights to TE shifted in Model 3 from that discerned in models 1 and 2. Legal rights could have increased TE according to the regional aggregate, HDI level, and inequality rate. The higher percentage of contribution from agriculture and manufacture to GDP also enhanced TE. The effect of the democracy index (where higher levels indicate more freedom) indicated that countries that are more democratic are likely to have a lower TE than less democratic countries. Possibly, more democratic countries have a greater variety of laws and interests must be considered, thereby, elevating transaction and enforcement costs. When considering country specific characteristics, both the Kyoto Protocol and the services sector (intercept) were not statistically significant.

Table 3.17 – Factors that can explain Model 3 residual detrimental output frontier EE levels

Variable	Parameter	Std. Error	P-value	Significance
Intercept	0.451	1.574	0.774	
legalr	-0.050	0.007	0.000	***

agricp	-0.012	0.004	0.001	***
manufp	-0.010	0.004	0.007	**
democ	0.108	0.014	0.000	***
KP	0.368	0.052	0.000	***

Source: study results.

Table 3.17 points out that, on the average, countries where credit requirements are stringent have a higher EE; thus, relatively easy access to credit negatively affects EE. The higher agriculture and manufacturing sector production seemed to reduce EE when considering the regional aggregate, HDI, inequality and each country's time trend. This result is quite different than the agriculture and manufacturing participation in GDP result from either model 1 or 2.

Model 3 results show that stronger democratic institutions appear to contribute positively to EE, which can be due to civil society's demand for environmentally oriented economic prosperity. The Kyoto Protocol's attempt to address observed heterogeneity among countries seems to have enhanced EE, a result that conflicts with Model 1 results but agrees with Model 2 results.

To this point, I've discussed three models that analyze economic and environmental performance as represented by TE and EE. These models' results were often very similar but there were some distinct differences. The next subsection presents a comparison of the three models' results.

3.4.4 Comparison of the three models' results

The three models presented a RTS of nearly one in regards to the production frontier: 0.993, 0.989 and 0.979 for models 1, 2, and 3, respectively. The RTS for the residual detrimental output frontier, only available from models 2 and 3, presented lower but similar values: 0.830 and 0.876, respectively. The elasticity of capital was the highest in all the three models, with a huge gap between the elasticity of capital and the second highest elasticity: labor for models 2 and 3 and non-renewable energy consumption in Model 1. For the residual frontier, the highest elasticity was for the level of output (GDP).

Although mean average TE levels from models 1 and 2 were similar, 74.5% and 76.7%, mean EE was much lower in Model 1 than in the other models, with an average of 1.2% efficiency. Mean TE and EE values from Model 3 were similar: 34.1% and 30.7%, respectively. On the average, TE levels were higher than EE levels considering the three models. The correlation between TE and EE was different for each model: -0.67 for Model 1; 0.58 for Model 2; and 0.99 for Model 3.

In regards to the variables that can explain these average production frontier efficiencies levels, the effect of KP ratification and democracy seemed to reduce overall TE in models 1 and 2, but when the observed heterogeneity among countries is taken into account in Model 3, democracy seems to positively impact TE, while the KP was not statistically significant. Again, when not considering country heterogeneity, stronger legal rights (contract enforcement) and greater agricultural and manufacturing participation in GDP were indicated to be factors that reduce TE. However, after taking into account country heterogeneity in Model 3, the relationship shifts and increased values for these variables appeared to increase TE.

For models 1 and 2, the Gini inequality coefficient was negative, which can suggest that less inequality contributes to EE. In Model 1, democracy seemed to increase EE while KP decreased EE. In contrast, Model 2 results suggest that democracy can reduce EE but that KP enhanced it. Model 3 results indicate that democracy and the KP increased EE. Legal rights seemed to enhance EE in models 1 and 2, but decrease EE in Model 3. These comparisons point to a noticeable divergence in the three model's results for the effects of legal rights, democracy, and KP on TE and EE, as do the results for sectoral participation in GDP.

Results from models 1 and 2, which did not distinguish the effect of heterogeneity among countries, implied that higher agriculture and manufacturing sector shares of a country's GDP would increase EE. Results from Model 3, which adjusted for heterogeneity, showed that greater participation of a country's agriculture and manufacturing sectors in a country's GDP had a negative effect on its EE levels.

Figure 3.12 graphically illustrates Model 2 individual country TE and EE results with a scatterplot graph. The vertical axis presents EE and ranges from 0 to 100%; the horizontal axis presents TE and ranges from 45% to 95%.

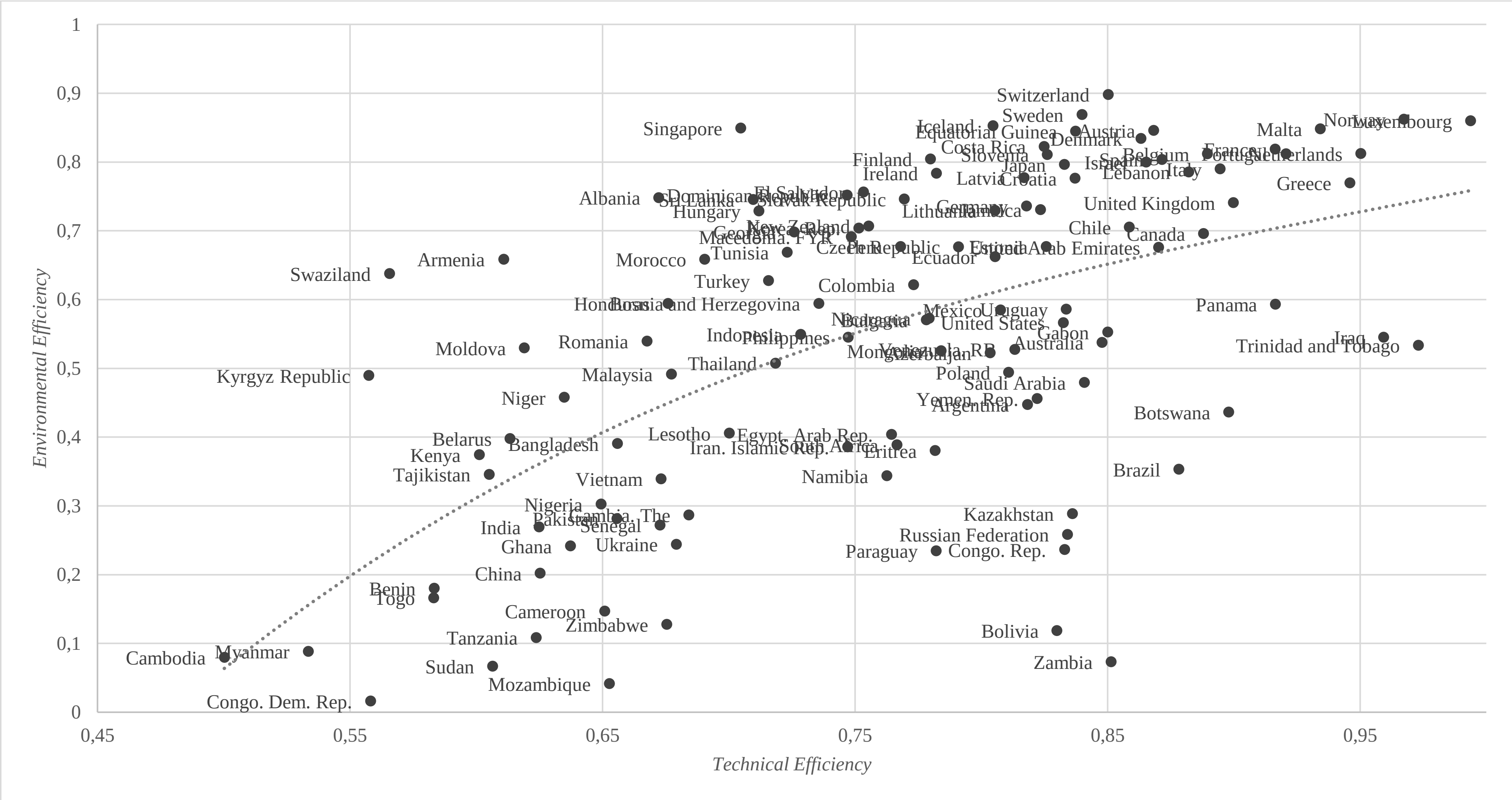


Figure 3.12 – Scatterplot of EE and TE combinations for countries, constructed using results from Model 2

Source: study results

The country values for TE and EE are the average values for the entire period: from 1993 to 2012. The dotted line crossing the graph is a data trend line. The equation follows $EE = 3.34.TE^3 - 9.723.TE^2 + 10.15.TE - 3$, and the R-squared was 0.35. The trend follows a concave function, and the first derivate is positive for every TE in the 0.45 to 1.00 range.

On average, countries which are technically efficient are not always environmentally efficient at the same level. Most highly developed countries are above the curve, where both TE and EE are high. Many OCDE countries had TEs between 75% and 95% and EEs between 70% and 90%. The BRICS (Brazil, Russia, India, China and South Africa) are below the curve, with TE seemingly a higher priority than EE. The TE values for countries from Latin America are mostly within 75% to 85% range, while EE ranges from 10% to 80%. Most Southeast Asian Tiger Cub economies presented TEs ranging from 65% to 75% and EEs between 30% and 70%. The EE range for less developed countries is much greater than that for TE; on the other hand, the range of both TE and EE for most developed countries is nearly identical.

3.5. CONCLUSIONS

This study analyzed worldwide technical and environmental efficiencies, specifically measured by a country's GDP and GHG emissions. The analysis was carried out to determine if there is a relationship between a country's economic performance and the achievement of its GHG emission mitigation goals, goals to a great extent motivated by the Fifth Assessment Report (AR5) of Intergovernmental Panel for Climate Change (IPCC).

Three models were estimated: Model 1 considered GHG emissions as a detrimental input; Model 2 assessed the GHG emissions as a residual output technology, where the main output is GDP; similar to Model 2, Model 3 also considered GHG emissions as a residual output technology, but the model also took into account heterogeneity among countries.

Results from the three models suggest that the input elasticity of capital is higher than labor and energy elasticities. A percentage increase in capital input is likely to increase GDP more than the same percentage increase in labor or energy, assuming use of this study's estimated average production technology. Returns to scale (RTS) for the production frontier were constant, and the RTS of residual output technologies (Model 2 and 3) were slightly lower than those of production frontier.

Model 1 and Model 2 presented similar TE levels but different EE levels, with EE levels from Model 1 much smaller than from Model 2. The difference between Model 1 and Model 2 is that the GHG emissions variable was included as an input in Model 1: modeling emissions as an input reduced the average EE. The TE results from Model 3, the only model that adjusted for individual country development level, location, and wealth, were the lowest among the models, while its calculated average EE value was between the two other models' averages.

The values of TE and EE were employed as the three models' dependent variables. Proxy variables representing institutional quality and other country characteristics were included to capture these variables' influences on TE and EE. Study results for the effect of institutional quality were mixed. Values for the proxy variables were employed in both TE and EE vectors and came from the Economist Intelligence Unit's Democracy Index and the World Bank's Legal Rights Index.

Results from models 1 and 2 for the agricultural and manufacturing sectors' impacts on TE and EE were quite different than those from Model 3. In models 1 and 2, countries with greater agricultural and manufacturing sector participation in their GDPs tended to have lower TE and higher EE values, on the average. These sectoral participation results from Model 3 were the opposite.

According to the Model 2 scatterplot of TE and EE, most highly developed countries presented high TE and high EE values; the BRICS countries presented a higher TE than EE; and Latin American and Southeast Asian Tiger Cub countries presented relatively high TE and had a very wide range of EE values.

By and large, the results indicate that not necessarily the economic performance is followed by environmental performance. The economic performance is more likely to prevail over environmental performances on the average. The institutional framework influenced the performances, but its influence was mixed among the different institutional assessment metric proxies.

A limitation of this study is that Model 3 is not as broadly based as Model 2 because the models' functional forms are different. Another limitation is that many countries (underdeveloped countries in the majority) were not taken into account due to a lack of available data.

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Appendix 3.I – Adjustment criteria of Model 1, Model 2 and Model 3

Model 1: employing the GHG emissions as an input				
Log -Likelihood	156.9267			
Observations	1737			
Wald chi-sq	277.18	p-value	0.00	(H_0: All parameters = 0)
log-lik ratio	304.2846	p-value	0.00	(H_0: Unrestricted model is better than restricted model)
Model 2: employing the BP residual technology for GHG emissions considering another technology for the production frontier				
Production frontier (GDP)				
Log -Likelihood	130.574			
Observations	1737			
Wald chi-sq	329.120	p-value	0.00	(H_0: All restrictions = 0)
log-lik ratio	345.580	p-value	0.00	(H_0: Unrestricted model is better than restricted model)
Residual frontier (GHG)				
Log -Likelihood	-1738.4			
Observations	1737			
Wald chi-sq	9201.700	p-value	0.00	(H_0: All restrictions = 0)
log-lik ratio	358.296	p-value	0.00	(H_0: Unrestricted model is better than restricted model)
Model 3: employing the BP residual technology approach taking into account country heterogeneity				
Production frontier (GDP)				
Adjusted - R^2	0.9014			
Observations	1549			
F-stat	1012	p-value	0.00	(H_0: All parameters = 0)
F-stat instruments	39.8	p-value	0.00	(H_0: Instrumental equation all parameters = 0)
Sargan - Hansen test p-value	0.058			(H_0: Instruments are valid)
Residual frontier (GHG)				
Adjusted - R^2	0.8737			
Observations	1549			
F-stat	893.4	p-value	0.00	(H_0: All parameters = 0)
F-stat instruments	41.56	p-value	0.00	(H_0: Instrumental equation all parameters = 0)
Sargan - Hansen test p-value	0.0331			(H_0: Instruments are valid)

Source: study results, own elaboration.

5. CONCLUSION
5. CONCLUSION

There were four questions regarding this study: was the Kyoto Protocol (KP), effective as an institution?; does the institutional framework influence the mitigating GHG institutions (KP)?; the economic performance of an economy corresponds to its environmental performance?; do the economic and environmental performances are related to the institutional framework and institutions? The first two questions were answered in the second chapter, meanwhile the last two were respective to the third chapter.

The KP was considered to be an institution under the influence of an institutional framework of a country. Its effectiveness regards to achieving a 5% average per year emissions reduction based on 1990 emissions level. In this study was employed a difference in difference panel data model. By and large, the KP presented a low average effectiveness, both in world average and in stratified countries groups average. Most results suggested that emissions remained stable with the effect of KP. The results indicated that it is possible that emissions would have increased more than it did until 2012 if KP had not been active.

Following the Environmental Kuznets Curve (CAK), the time effect for development status reported an inverted-U shape for parameter values, comparing the stratified groups. The medium development index countries presented an increase in emissions, relatively to low developed and high developed index countries. There was an increase in emissions due to KP for low structure countries at the same time that high structure countries presented stable emissions. There is a possibility that high structure countries switched the source of GHG emissions to low structure countries in concern of manufacturing process. This can be investigated further in other analysis. The effect of ratifying the protocol parameter was more volatile within institutional clusters estimations. It may suggest that the institutional framework can influence the enforcement of KP. Despite of it, different institutions within a country's institutional framework are likely to affect unequally: low democracy and low property rights countries presented emissions increase, but also high contract enforcement also presented increased emissions.

The Stochastic Frontier Analysis results were based on three models. The first model considered GHG emissions as an input; the second took into account two technologies, where one is the GDP output technology and the other is a residual, "by-production" technology which produces GHG. These models measured the economic and environmental performances by considering, respectively, Technical and Environmental Efficiencies (TE and EE). The three models presented an average of constant returns to scale for the GDP production frontier (Model

1 only had the GDP frontier); and Model 2 and Model 3 presented an average of lower than one returns to scale of GHG production frontier. The variable Capital presented the highest elasticity.

On the average, the TE was higher than EE over the analyzed period (1993 – 2012), suggesting that the countries were more economic performance oriented than environmental performance oriented. Moreover, the correlation between TE and EE reiterate that not necessarily a high TE country should present a high EE, though it is likely.

The results displayed by Model 1 and Model 2 were similar. Countries with higher democracy level tended to present higher economic performance, but lower environmental performance. Countries with higher EE presented lower wealth inequality and high development level. Credit lending facilitation presented a negative impact in economic performance, but a positive influence in environmental performance. The results of Model 3 suggest contrary associations, thus suggesting that heterogeneity among countries plays an important role according to institutional framework assessment on GHG emissions.

In both Chapter 2 and Chapter 3, the influence of KP was fairly low, with not statistically significant results, although it seemed that KP can increase environmental performance and that emissions could have increased more than it did if KP had not existed. The “institutional framework quality” seemed to be a heterogeneous classification, thus exploring each “institution quality” individually reported more consistent results. Also in both chapters, the higher was financial contract enforcement and credit lending facilitation, also higher was its emissions, and lower was its environmental performance. Development can be a key factor of achieving KP effectiveness and higher environmental performance.

For policy issues, this study analyzed the effectiveness and efficiency of a global climate policy under the effects of countries’ institutional framework. Also, this study took into consideration the role of institutional framework on environmental and economic performances. The results presented that not every institution from the local institutional framework can enhance environmental performance. Policy-making applied to environmental issues might be successful only if the enforcement of other institutions is also effective. Alongside with free-riding problems, switching the source of pollution from a country to another by international trade is likely to be another collateral damaging source of global agreements of pollution reduction.

Future studies are encouraged to focus on heterogeneity among countries, regional and spatial analysis of institutional framework influence on production and “by-production” technologies, and international trade concerning GHG production source and consumption.

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