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.

ECONOMIC, DEMOGRAPHIC AND TECHNOLOGICAL ANALYSIS OF CO2 EMISSIONS

- CASE STUDY OF G20 ECONOMIES -

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ABSTRACT

This paper aims to identify and assess which are those anthropogenic factors that determine national carbon emissions evolution and whether decarbonisation of economies is being attained or not. For this purpose, G20 countries' economic, demographic and technological driving forces are subjected to study. Following European SDG7.2 and 7.3, especial attention will be paid to countries' energy mix transformation and energy efficiency improvements. The first part of the analysis is based on a stochastic version of the ImPACT identity whereas, the second one provides a more qualitative perspective of current panorama in terms of energy intensity and carbon intensity improvements and, their interaction with population and economic expansion. Results suggest that current technological gains are insufficient to attain international environmental pledges.

Key Words: G20, *Carbon Emissions, Energy Efficiency, Energy Mix, ImPACT Identity, SDG-7.*

RESUMEN

Este artículo tiene como objeto identificar y evaluar aquellos factores antropogénicos que determinan la evolución de las emisiones de carbono nacionales y, si se está logrando una descarbonización de la economía. Para ello, se van a someter a estudio las causas económicas, demográficas y tecnológicas de los países que conforman el G20. De acuerdo con los ODS 7.2 y 7.3, se va a prestar especial atención a la transformación del mix energético y las mejoras de eficiencia energética. La primera parte del análisis se base en una versión estocástica de la identidad ImPACT, mientras que la segunda, tratará de proporcionar, desde una perspectiva más cualitativa, cuál es el panorama actual en términos de intensidad energética e intensidad de carbono, y como estas interactúan con el crecimiento demográfico y económico. Los resultados sugieren que las mejoras tecnológicas actuales, son insuficientes para lograr los compromisos medioambientales a nivel internacional.

Palabras Clave: *G2O, Emisiones de Carbono, Eficiencia Energética, Mix Energético, Identidad ImPACT, ODS-7.*

CONTENTS

1. INTRODUCTION

Climate change has unarguably become a global urgent crisis which requires to be tackled immediately, as it has been endlessly repeated during the United Nations Climate Change Conference (COP26), that took place some weeks ago in Glasgow. As a consequence, identifying and understanding the main determinants driving CO2 emissions has become a hot topic in energy and environmental literature in recent times. Indeed, this issue is believed to be crucial when designing effective environmental policies.

It is widely accepted that, in order to constrain global warming, reducing CO2 emissions expelled to the atmosphere is a requirement. However, finding consensus regarding which is the optimal way of doing it is not that easy. Despite discrepancies, generally, experts agree that already adopted measures are not enough to fulfil the pledge of zero-emissions by 2050. In order to exemplify this impression, the International Energy Agency (2021) published right after the COP26 ending, a model conformed of three different scenarios (Appendix 1): *Stated Policies Scenario* that considers current policies, *Announced Pledges Scenario* which assumes recent COP26's pledge is actually put into practice and *Net Zero Emissions by 2050 Scenario* which sets out a narrow but achievable pathway to achieve this goal. In a nutshell, the model's essence is that "A new global energy economy is emerging, but the transformation still has a long way to go" (World Energy Outlook 2021 - IEA, 2021).

At the European level, the Commission's strategic choice has been to foster energy efficiency, the adoption of energy from renewable sources and the diversification of outside suppliers while supporting the creation of a single internal energy market to enhance energy security, so as to comply with Kyoto Protocol's set objectives. The KP international declaration of cooperation was signed as a result of the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 and entered into force in 2005. By means of this agreement every member belonging to the Organisation of United Nations at that time, with the remarkable exception of the United States and Canada among others, committed themselves to reduce Greenhouse gas (GHG) emissions by 5% with respect to 1990 levels. This signify the origin of international cooperation, in terms of environmental action. However, the most notable milestone did probably take place in 2015, when 195 countries- the largest gathering of world leaders in history (Doig, 2021)- congregated in Paris (COP21) and gave rise to the well-known Paris Agreement. This time the United States were included in the signing, even though, Trump's administration temporally withdrew its participation. This decreed the worldwide aim to keep global warming 'well below' the threshold of the 2º Celsius (Redmond-King, 2021).

Notwithstanding the signature of this global agreement, each nation's environmental policies and actions aimed at responding to the climate crisis, have differed significantly. As for the European Union, it has been at the forefront of the low-carbon transition, with the European Green Deal (EGD) and carbon-neutrality by 2050 as its creed. The EGD gathers the three guiding pillars of current European strategy: a minimum 40% cut in greenhouse gas emissions (with respect to 1990 levels), a minimum 32% of total final energy consumption originated from renewable sources and, a 32,5% improvement in energy efficiency by 2030 ("2030 Climate & Energy Framework", 2021)

Through, what experts and the literature name as the "*Brussel Effect*", European active response has influenced other countries' environmental policy in several ways. However, there are still many countries that do not seem to keep pace with the energy transformation. In concrete, the International Energy Agency (2021) stated in its annual Global Energy Review that "emerging markets and developing economies now account for more than two-thirds of global CO2 emissions, while emissions in advanced economies are in a structural decline". For instance, experts think it is unlikely that large developing countries like China could balance extremely rapid economic growth and constraining CO2 emissions. Indeed, it appears to be quite the opposite.

As the largest global carbon emitter, Chinese emissions amounted up to 30% of the whole, and its energy consumption is a quarter of world's energy consumption (Pan, 2021). Still, Pan (2021), current director of Institute for Urban and Environmental Studies- Chinese Academy of Social Sciences (CASS), recently claimed that "China has entered a transition period of economic development on a large scale, shifting from high-speed growth to high-quality development. To achieve this transition, China needs to shift the growth drivers and accept and adapt to the slowdown".

Similarly, India total CO2 emissions have grown significantly since the signing of the Paris Agreement. As GDP grows, which in turn has raised final energy consumption considerably, the weight renewable energetic sources used to have, has now lost the momentum. In fact, "with 22 operational nuclear reactors, India boasts tremendous nuclear energy potential to cut down on CO_2 emissions" (Ozgur, Yilanci & Kongkuah, 2021). However, Indian efforts are considered insufficient. Recently the IEA (2021) published that the increase in electricity coming from coal-fired sources is estimated to be three times the increase in renewable energy generation.

These are solely a few selected examples that reflect how, despite increasing international commitment and widespread acceptance of the vital role renewable sources will continue playing in the future, nations do not coincide when it comes to designing their environmental policies. Undoubtedly, country's resources endowments, developing stage or sectorial structure are crucial factors that should be contemplated.

Analysing divergences among countries in terms of their environmental strategy, economic structure and other development indicators, and how these determine country's ability to decarbonise the economy and accomplish international pledges, is the principal object of this study.

2. MOTIVATIONS AND OBJECTIVES:

This paper aims to examine the impact demographic, economic and technological historical circumstances of some of the most dominant economies have had- and could have in the future- on the environment throughout CO_2 emissions. In the same way it will attempt to identify the conjoint of aspects that characterized each nation and that explain its performance in terms of non-fossil fuel energies deployment, that substitute traditional sources, and energy efficiency improvements.

As it has been already mentioned, country's circumstances and way of confronting the climate crisis diverge widely. For this reason, the study will focus its attention on G20 world's largest economies. Conjointly, these support 86% of global GDP, 80% of international trade and two thirds of the world population and, therefore, inevitably these are responsible for 85% of world's energy-emissions (Dodi Heryadi & Hartono, 2016). Even though it is also true that, generally speaking, these same countries stand out due to their collective efforts to tackle carbon emissions.

Therefore, the units of study of this analysis will be nineteen countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom and United States and, the European Union. These countries are expected to show considerably different approaches dealing with current environmental situation which will provide the analysis with a representative, inclusive and enriching character.

In order to compare and contrast these countries' decisions related with efforts made so as to reduce their environmental impact; energy efficiency indicators, as well as the degree of carbon-free energies deployment will be evaluated. More specifically, the analysis will attempt to determine which of these two strategic choices lead to larger emissions reduction, as it is thought this consideration could be extremely useful when designing future environmental policies.

This paper is believed to contribute value in, at least, three ways. Due to the changeable nature of environmental performance, the wide variety of policies and actions implemented in recent years as well as, the numerous international readjustments of sustainable standards and long-term objectives; literature addressing this field is considered to be short-lived and perishable when representing current panorama. It is for that reason that this paper aims to provide novel conclusions and valuable remarks regarding today's CO2 emissions main causes and, confirm whether traditional ideas do still apply. Besides, thorough analysis regarding intertemporal and among nations differences will be presented. For this purpose, updated data will be employed and contextualized in contemporary European- as a global standard- environmental policy and plan of action.

In second place, analysis like this one, are consider extremely relevant for designing national and conjoint environmental policies. It is crucial to thoroughly understand how country's economic structural organization, societal aspects and international relationships affect carbon emissions, in order to implement tailored and effective policies. Moreover, despite the positive effect renewable energies have in society and the atmosphere is unarguably, it is crucial to take many considerations into account when deciding which is the most suitable strategic choice. For this reason, analysing which is the quantitative effect of, for instance, investing in renewable energies rather than in enhancing energetic efficiency, and vice versa, could be determinant for many companies and governments. Moreover, the advantages and drawbacks of nuclear plants dissemination will also be considered.

Lastly, the international scope of this paper is expected to boost the value of this research. Many times, disaggregated analysis, as the one that is presented next, are limited to a national level. However, this study will provide a comparative perspective that will help the reader understand each country's dynamics in terms of energy efficiency, energy's carbon intensity and other anthropogenic and economic factors that, in ultimate extent, determine nations' CO2 expelled to the atmosphere.

3. THEORETICAL FRAMEWORK:

Next, some conceptual aspects will be clearly stated so as to ease the reader this analysis comprehension. First of all, some basic and fundamental terms will be defined. Then the model on which the subsequent analysis is founded will be presented.

3.1 Energy Efficiency and Energy Intensity

Energy efficiency became a concern long before society started worrying about environmental issues. In the early 1800s this quantitative measure was crucial in order to determine which machine was more coal-intense, a scare and costly fuel material (Calwell, 2010).

More recently, Shi (2001) and Li (2012) defined *Energy Efficiency* (1) as the ratio of real GDP to energy use. This reflects a country's ability to create finished products and services, within a specific period of time, for each unit of energy consumed, which can be measured in Joules or any other energetic measure.

The inverse of *Energy Efficiency* is *Energy Intensity* (2). This is computed as the amount of energy required to produce a unit of real gross domestic product. Although, it might sometimes be confusing, environmental performance is expected to improve as *Energy Efficiency* increases, or likewise, as *Energy Intensity* decreases. In other words, the higher the value of (1) is, the more efficient the use of energy is made. These two variables' definitions have been adopted for the purpose of this study.

$$Energy\ Efficiency = \frac{Real\ GDP}{Total\ Final\ Energy\ Consumption} \qquad (1)$$

$$Energy\ Intensity = \frac{Total\ Final\ Energy\ Consumption}{Real\ GDP} \qquad (2)$$

As Heryadi and Hartono (2016) exposed, another commonly employed measure when assessing energetic effectiveness and measuring the amount needed to generate output is energy elasticity. This ratio represents how much should energy consumption increase by a 1% increase in GDP.

As it was mentioned in previous sections of this text, enhancing *Energy Efficiency* is one of the main three targeted areas (SDG-7.3)[1] in which the European Union relies on the achievement of carbon neutral economies by 2050. The IEA supports this belief as it defends that “Energy efficiency plays an essential role in accelerating clean energy transitions and achieving global climate and sustainability goals” and also suggests “it is the one energy resource that every country possesses in abundance and is the quickest and least costly way of addressing energy security, environmental and economic challenges”. More concretely, within the framework of its ideal Sustainable Development Scenario (SDS 2020-2040) that serves as a route map to achieve carbon neutrality, *Energy Efficiency* is expected to responsible for more than 40% of the reduction in GHG emissions in the next two decades ("Energy efficiency - IEA", 2021). Is for that reason that, the international community has shown concern in recent years with regards to *Energy Efficiency* improvements stagnation (Appendix 2). In concrete, in 2017 *Energy Efficiency* was only raised by 1.7% compared to the 2.7% annual target. Furthermore, according to the IEA in 2018 the improvement was only 1,2% (IEA, 2021).

Coming back to the already mentioned COP26 and in relation with *Energy Efficiency*, it seems relevant to highlight the importance *Energy Efficiency* increase, through technology improvements, has gained in the signed pledge. This estimates that *Energy Efficiency* must increase in 4% each year between 2020 to 2030 so as to accomplish SDG-7.3 and achieve the zero-emission goal, which means doubling the pace at which it has grown during the last decade (IEA, 2021).

3.2 Energy Mix

According to Planete Energies (2021) “the term ‘energy mix’ refers to the combination of the various primary energy sources used to meet energy needs in a given geographic region”. In other words, it is a conceptual simplification that shows which are the different sources (fossil fuel, renewable and nuclear energy) primary supplied energy comes from, and in which proportion are these presented. This concept is slightly related with power generation mix that is defined as the different sources employed in the electricity production of a region.

[1] SDG 7.3: By 2030, double the global rate of improvement in energy (United Nations, 2021)

At this point, it seems relevant to specify that, as explained by Eurostat (2013) primary energy supply encompass “any extraction of energy products in a useable form from natural sources that has not been transformed” whereas, final energy consumption is defined as the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself. These two aggregated measures do not coincide as an important amount of energy, mainly in form of heat, is lost in the transformation process of primary energy that takes place in power plants.

The energy mix is frequently divided in fossil fuels like natural gas, oil and coal, renewable energies and nuclear sources. This disaggregation is very useful to understand national policies. Therefore, it will be a key point of this analysis.

Even though, “fossil fuels dominate the energy mix at the global level, accounting for over 80% of the total” (“What Is the Energy Mix?”, 2021), the multiple energy origins assortment and the peculiarity of each unit of energy consumption- being a country, a region or a company- entail a non-standardize way of exhibiting energy mixes. For instance, in Europe fossil fuels account up to 70% in favour of renewable energies that nowadays, represent 15% of final energy consumption (Eurostat, 2021). This diversity is explained by countries’ usable resources endowments or their ability to import them, particular energy needs and national policy choices, as exposed by Planete Energies (2021).

Fossil fuels usually refer to coal, oil and natural gas. These have historically dominated the energy mix but, not only that, in accordance with the last released report of the IEA, “demand for all fossil fuels is set to grow significantly in 2021. Coal demand alone is projected to increase by 60% more than all renewables combined”. This evidently is the counter-effect linked to the economic slowdown and, subsequent decrease in CO2 emissions, caused by the Covid-19 pandemic crisis (“Global Energy Review”, 2021) and, the consequence of emerging countries emissions growth pace.

Simultaneously, within the framework of European SDG-7.2[2] renewable energies such as hydraulic, wind, biofuel or solar sources’ dissemination has continued at an unprecedent pace. To a certain extent, it has been fostered by Covid-19 change of production, transportation and consumption paradigm. As per this year Global Energy

[2] SDG 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix (UN, 2021)

Review's data (2021), demand for renewables grew by 3% in 2020 and is set to increase across all key sectors – power, heating, industry and transport – in 2021. Besides, the report points out, these are prospected to represent 30% of total electricity generation, a weight never seen since the Industrial Revolution. Despite the contradictory impression, "China alone is likely to account for almost half the global increase in renewable electricity generation" followed by United States, the European Union and India (IEA, 2021). Of course, this fact is highly related with this country urgent need for energetic resources as it will also account for half of coal's demand increase. (IEA, 2021). As the chart presented Appendix 3 shows, China energy production has increased hastily along last decades, becoming the second largest regional producer. Moreover, Appendix 4 reflects how China share of world total energy supplied in 1973 was around 7% and now it encompass more than 20%. It seems remarkable the relative increase experimented by Non-OECD Asian countries. Likely this might be, to great extent, caused by the emerging Indian and Indonesian economies and their associated increasing energetic needs.

Lastly, there are some countries of which energy mix relies more importantly than others, on nuclear energy. In Europe, France is one of the countries which historically has bet on this kind of non-emitting GHG source.

As it might be inferred, energy sources distribution varies extensively among countries. Next, some of the under-study countries' power generation mix will be presented in order to reflect this variability.

Table 1: China, France and Brazil Power Generation Mix for 2020, 2021 and 2020 respectively.

	CHINA	**FRANCE**	**BRAZIL**
Fossil Fuel, Coal & Natural Gas	69.00%	12.00%	9.40%
Nuclear Energy	5.00%	72.00%	2.50%
Renewables (Hydropower- Wind-Solar-Others)	26.00%	16.00% (6% + 7% + 0%+ 3%)	88.1% (75% + 10% + 1% + 2%)

Source: Own elaborated table with data retrieved from the IEA and Gestionnaire du Réseau de Transport d'Electricité (RTE)- France.

In the graph, it is possible to observe that China's dependence on Fossil fuels is relatively high whereas, France's Power generation heavily relies on nuclear energies. Last, Brazil power generation mix could seem a bit surprising at first glance, as it produces almost 90% of its electric power with renewable energies.

3.3 IPAT Model

The environmental dilemma has been in research's spotlight for decades. However, the approach to address this topic has not always been the same. Ehrlich & Holdren (1972) after the controversial publication of "The Closing Circle" (1971) a book written by Commoner, who suggested that environmental impact was uniquely caused by technological shortcomings; were the first authors to bring up that population and country's economic development were the main causes of $CO2$ emissions to the atmosphere. They accused former author of adopting a "socially comfortable" position that solely blamed faulty technology instead of putting its corresponding blame on human activity (Ehrlich & Holdren, 1972).

Since then, despite the unarguably conception of the impact humans have on environment has been widely accepted, literature has failed to properly understand the dynamics of the anthropogenic (human-induced) drivers of global environmental change (US National Research Council, 1999). "A major factor inhibiting social scientific inquiry into the human- environment relationship is a paucity of appropriate analytic techniques and models that allow for a precise specification of the functional form of the relationship between anthropogenic driving forces and environmental impacts" (York, Rosa & Dietz, 2003). Probably, one of the most widely known attempts to shed light on this question is the IPAT [Impact of Population, Affluence and Technology] identity which emerged out of the aforementioned debate between Ehrlich-Holdren and Commoner in the seventies (York, A Rosa & Dietz, 2003).

$$I \equiv P \times A \times T \quad (3)$$

IPAT framework analyses the effect of human activity on the environment. In the model [I] stands for environmental Impact and can be measure as GHG emissions, $CO2$ emissions or any other pertinent measurement impact. On the right side of the equation, [P] is Population as it reflects the size of a country, [A] is Affluence and [T], Technology. [A] can be measure as GDP per capita as it represents the income derived from production. For its part, [T] is presented as the amount of resource or residue per unit of production.

It is assumed that as [A] increases, human impact is expected to crease- [I] will raise- since prosperity is associated with more consumption, which in turn increases production, entailing an increasing pressure on the environment. Similarly, the increase in population will directly increase consumption leading to a similar result. Moreover, the increase in *Energy Efficiency* and the promotion of renewable energies is foreseen to show a negative relationship with anthropogenic effect on the environment, but the magnitude of this impact is still unknown.

As York, Rosa & Dietz (2003) expound, IPAT identity's main contribution is the fact that it manages to represent the key driving forces behind global environmental impact in a simplified manner. Moreover, it also states that it provides valuable information regarding the relationship between these forces, as it reminds that "an important implication of this specification is that no one factor can be held singularly responsible for environmental impacts".

The IPAT model, regardless of being considered the first analytical framework that contemplated both technological and anthropogenic impacts, was a posteriori redefined by Waggoner & Ausubel (2002). These claimed that original IPAT specification, leave scant room for policy makers to interact with the model. In compliance with York, Rosa & Dietz (2003) words, "IPAT identity has typically been used as an accounting equation, in which known values of I, P and A are used to solve for T". York, Rosa & Dietz (2003) showed how the identity can be easily transformed into:

$$T = {}^{I}/_{PA} \qquad (4)$$

Where Affluence is measure as GDP per capita and therefore, the numerator can be substituted by total GDP. This results in the following formula that entails [T] is the environmental impact per unit of economic activity. It reflects how economic development and demographic expansion, require technological improvement – [T] drop as it is representing CO2 use by unit of added value- to compensate. Therefore, in order to lessen environmental impact without changing welfare or introducing restrictive demographic policies, technology postulates as the only feasible option. Consequently, this suggests that if policy makers want to reduce environmental impact without slowing down economy, technological improvements should be adopted.

$$T = {}^{I}/_{GDP} \qquad (5)$$

This model leaves scant room for more complex ideas. Due to its identity nature and the fact population, GDPpc and CO2 emissions are widely known, the only possible aspect to study is how technology has varied along time. However, it is believed there is additional background information that more sophisticated versions of the model could provide. Below, these more complex, transformed frameworks will be explained.

This explains why Waggoner & Ausubel (2002) claimed: “technology has been cast as both villain and hero and has been a mere residual left-over”. Consequently, they proposed a new model known as ImPACT or KAYA identity[3], which allows for identification of which economic agent could affect environmental impact [I] and throughout which variable, and express disaggregated [T] into [C] that represents *Energy Intensity* as energy per GDP- which depends on consumers-, and a redefined [T’] translated as *Carbon Intensity* which directly depends on producers and is measured as emissions per unit of energy employed. In other words, this last variable could be used as an energy mix’s proxy as it measures how polluting this is. This extended identity was presented as follows:

$$Im \equiv P \times A \times C \times T' \qquad (6)$$

As ImPACT authors explained “by identifying the necessary change in forces to cause a projected impact, ImPACT can assay the likelihood and practicability of environmental targets and timetables” (Waggoner & Ausubel, 2002). This is believed to be the main strength of this model which manages to provide additional information regarding different potential areas where policies can be implemented.

Nevertheless, both IPAT and ImPACT theories entail some limitations. In first place, as York, Rosa & Dietz (2003) explain this kind of mathematical identities do not permit hypothesis testing which is a very useful statistical tool employed in regressions. Secondly, and probably more importantly, the same authors claim these two theories assume proportionality in the functional relationship between considered factors. This for instance, is at odds with also famous Kuznets Environmental Hypothesis. This model claims that to a certain point country’s economic development, in other words, gross domestic product increase, causes a rise in emission levels. Then, there is a turning point when sufficiently developed economies raise awareness regarding climate change and adopt sustainable policies in order to preserve the environment. At that point, CO_2 emissions are expected to decrease as income continues increasing. This is incompatible with IPAT’s and ImPACT inferable logic that assumes that a doubling of population would lead to twice bigger global environmental change.

[3] For the purpose of this study, this identity will be referred as ImPACT identity.

As York, Rosa & Dietz (2003) expose “The development of socioecological theory requires that hypotheses about the relationship between anthropogenic factors and impacts be testable (falsifiable) with empirical evidence, rather than simply assumed within the structure of the model”. This was the main motivation behind the reformulation of the model carried out by Dietz & Rosa (1997) into a stochastic version of equation (3) which allowed the construction on more complex statistical models and can be utilised for hypothesis testing. This allows to conduct impact analysis in order to estimate the effect these variables have on the environment. Likewise, with this new version of the original IPAT model where e_i is the error term, the impact on [I] of a unitary increase of any of these variables can be estimated.

$$I_i = aP_i^b \times A_i^c \times T_i^d \times e_i \qquad (7)$$

Lastly, these same authors did one last transformation so as to create STIRPAT- *Stochastic Impacts by Regression on Population, Affluence and Technology*-, an additive regression model in which all variables are in logs so as to facilitate estimation and hypothesis testing (Dietz & Rosa, 1997). This last model have been written down in two different ways depending on the author. For example, Dodi Heryadi & Hartono (2016) presented as equation (8) shows whereas; York, Rosa & Dietz (2003) opted to estimate [T] as part of the error term rather than independently, as it is shown in equation (9), so as to avoid a perfect regression.

$$log\, I_i = a + b \cdot logP_i + c \cdot logA_i + d \cdot logT_i + e_i \qquad (8)$$

$$log\, I_i = a + b \cdot logP_i + c \cdot logA_i + e_i \qquad (9)$$

It seems particularly important, to enhance this transformed model’s advantages, which, oppositely to the original IPAT and ImPACT identities, can be subjected to regressive analytical methodology. In fact, it emerges of vital utility for this study as STIRPAT model will be employed so as to predict which are those country’s circumstances that have greater impact on carbon emissions.

4. DATA AND METHODOLOGY

This paper discussion is divided in two clear subsections in concordance with the two different methodologies employed to analyse the extent to which economic, social and technological factors explain countries’ CO2 emissions.

The first section will focus on the application and analysis of the STIRPAT model throughout panel data methodology, whereas the last part of the Analysis Section will be dedicated to extending previous results for some concrete countries. In concrete, this will be done by applying the ImPACT identity. The former section is expected to provide quantitative results that will guide the qualitative analysis of the latter.

4.1 Panel Data Analysis

In the first place, a panel Fixed Effects methodology will be employed. This study's panel consist of 19 countries, the European Union and the World average introduced as a benchmark and spans the period between 1990 to 2018, which has been merely determined by energy-related data availability. The panel is not perfectly balance due to the lack of complete energetic variables data series for the whole-time span. This is especially noticeable for developing countries. Additionally, a panel regression has been selected in order to explore the relationship between carbon emissions and other proxy variables which will be tested for their significance and how they do affect the dependent variable.

The construction of the model will be founded on the STIRPAT model presented above. However, in order to avoid multicollinearity among independent variables, alternative explanatory variables, expected to explain CO2 emissions behaviour will be introduced. As Heryadi & Hartono (2016) explained in their paper, technology [T] can be presented in various forms, such as technology innovation, social organization, institutions, infrastructure, and the utilization of new non-carbon energies. A selection has been conducted for both Affluence [A] and Technology [T] from the wide variety of potential explanatory variables found. Eventually, after testing different models and combinations, the following variables have been included for this study. To examine the impact *Carbon Intensity* gains- as a proxy for the Energy Mix-, have on environmental impact, both renewable and nuclear adoption will be included. These are expected to play a significant role on C02 emissions performance, as they contribute to maintaining energy consumption without expelling GHG to the atmosphere. Consequently, environmentally friendly energetic sources position themselves as potential substitutes for fossil fuels.

On the other hand, so as to study the impact *Energy Intensity* has, proxy variables like Energy Imports, logged Industry value added and Urban percentage population will be included. These are believed to implicitly explain how *Energy*

Intensity behaves. According to literature, Industrial and manufacturing activities employ energy intensive technologies and procedures. In Europe, for instance, it captures around 32% of final energy consumption (Eurostat, 2021). Therefore, in countries where the industrial sector is the primary contributor to GDP, *Energy Intensity* is forecasted to be higher as more energy will be required per unit of value added.

Nowadays, there is an ongoing trend to move from rural to urban areas, and as a consequence the world is becoming highly urbanized. In fact, according to the United Nations, in 2030, 60% of global population is expected to live in urban areas. The point is that these account for about 70% of global carbon emissions, as more people and economic activity concentrates there and energy needs increase ("Cities - United Nations Sustainable Development Action", 2015). Therefore, urban population is expected to affect positively CO_2 emissions.

Next, energy imports have also been included. At first glance, the more energy a country imports, it should be expected to mitigate its impact on the environment. Oppositely, energy exporters would have to assumed CO_2 emissions related to energy sold across borders. However, many times, traded energy is not transformed. Therefore, carbon is actually emitted at the destination country. On top of that, in concrete, in Europe 80% of energy imports correspond to petroleum products which transformation is highly polluting. As a consequence, it is not clear which will be the sign for this variable. Nonetheless, it has been included due to its relevance. In Europe, for instance, around 61% of consumed energy is imported and, consequently, some countries exhibit high energy dependency rates which risk energy security. This topic is gaining importance after recent occurrences that have questioned, for instance, European dependency on Russian crude oil and natural gas (Eurostat, 2021).

Lastly, exports value have been introduced as a potential explanatory variable for carbon emissions as it is believed that traditional exporting countries might have relatively more intense impact on the environment. This is explained by the fact, carbon emissions associated to goods and services produced and then exported, are included in the country-of-origin accounts. As a consequence, importing countries consume without polluting at the expense of other countries.

The table below shows these variables that, unless indicated otherwise, have been retrieved from the World Development Indicator (WDI) database.

Table 2: Variable definition and data source.

Variable	Description	Unit	Source
$CO2_{i,t}$	Total Carbon emissions	CO2 Million metric tons	*World Development Indicator (WDI) database: Carbon Dioxide Information Analysis Centre.*
$POP_{i,t}$	Total population	People	*World Development Indicator (WDI) database.: United Nations World Population Prospects.*
$EnerEffi_{i,t}$	*Energy Efficiency = GDP ($) / Total Energy Consumption* (GDP per unit of energy use)	Constant 2017 PPP $ per kg of oil equivalent	*World Development Indicator (WDI) database: Carbon Dioxide Information Analysis Centre*
$Renewpct_{i,t}$	Renewable energy consumption (% of total final energy consumption)	Percentage (%)	*World Bank, Sustainable Energy for All (SE4ALL) database from the SE4ALL Global Tracking Framework*
$Nuclear_{i,t}$	Alternative and nuclear energy (% of total energy use)	Percentage (%)	*World Bank, IEA Statistics OECD/IEA 2014*
$Enerimp_{i,t}$	Energy imports, net (% of energy use)	Percentage (%)	*World Bank, IEA Statistics OECD/IEA 2014*
$Industry_{i,t}$	Industry (including construction), value added (constant 2015 US$)	Constant 2015 US$	*World Bank national accounts data, and OECD National Accounts data files.*
$Urban_{i,t}$	Urban population (% of total population)	Percentage (%)	*World Bank, United Nations Population Division. World Urbanization Prospects:*
$Exportspct_{i,t}$	Exports of goods and services (constant 2015 US$)	Percentage (%)	*World Bank national accounts data, and OECD National Accounts.*

Source: Own elaborated table with data from the World Data Bank.

Therefore, the following econometric model *(10)* will be utilised in this section.

$$\boldsymbol{logCO2emi_{i,t} = \beta_0 + \beta_1 \cdot logPop_{i,t} + \beta_2 \cdot logEnereffi_{i,t} + \beta_3 \cdot Renewpct_{i,t} + \beta_4 \cdot Nuclear_{i,t} + \beta_5 \cdot logEnerimp_{i,t} + \beta_6 \cdot logIndustry_{i,t} + \beta_7 \cdot logExports_{i,t} + \beta_8 \cdot Urban_{i,t} + u_{i,t}} \quad (\mathbf{10})$$

When dealing with longitudinal data, several estimating models can be applied. Firstly, the analysis starts estimating the suggested framework (10) with a Pooled OLS model which will provide a panorama of what should be expected to be found next. *However, these results can only be utilised as an orientation as Pooled OLS model is inconsistent due to the presence of across units and time fixed effects. According to the nature of this study, "within variation" is expected to provide much more enriching and* *valuable insights*. In concrete, within variability estimates how a given country varies over time.

Therefore, a potential estimating model that could be utilised when dealing with panel data, is Random Effects which studies within units' time-series variation and assumes entity fixed-effects as random effects drawn from a large population. Estimates for this model will be included so as to verify, that the initial intuition is correct and therefore, Fixed Effects methodology is the most suitable in order to assess across countries differences. Nonetheless, RE model entails a major advantage as it permits to estimate time invariant regressors. For instance, it allows to include dummy variables.

As mentioned above, after computing Hausman Test in order to test for validity of the model, panel Fixed-Effects methodology seems to be the most suitable so as to capture how the evolution of these variables has contributed to carbon emissions throughout time considering non-random individual-specific time-invariant effects. These individual-specific time-invariant effects can be understood as the specific constant effect of being a certain country over time. For instance, historically, France has counted with a considerable higher portion of nuclear energies than, for instance China, and exerts lower pressure on the environment. Therefore, conducting a simple across-country comparison would suggest that more intense nuclear energies depletion reduces CO2 emissions to the atmosphere without further explanation on country's individualities. Nonetheless, the interesting question would be to determine to which extent countries are more likely to mitigate CO2 emissions as they adopt renewable energies or not.

Moreover, it is crucial to keep in mind that panel regression methods emphasize correlation (or clustering) over time for a given individual, therefore, errors are likely to be correlated over time for a given individual, so we need to use cluster-robust standard errors that cluster on the individual, or what is the same: countries. Finally, even though this model is expected to provide consistent results, it constrains the ability to estimate the effects of time-invariant variables such as natural renewable resources endowments or unwavering environmental policies.

4.2 ImPACT Analysis

Once, panel Fixed-Effects model has been conducted, those countries exhibiting relatively more distinct results will be subjected to a more in-depth analysis based on the ImPACT identity (6). Due to its identity nature, the analysis will attempt to deduct how country's technological performance has evolved along time, taking into consideration their CO_2 emission levels and, trends in population and affluence. For this purpose, technology, will be one more time disaggregated, as Waggoner and Ausubel (2002) did, in *Energy Intensity* and *Carbon Intensity* and the evolution of these two variables will be subject to assessment.

5. RESULTS

Results, similarly, to former section, will be subdivided in two main subsections in order to expose them in a structured manner. First, panel results will be discussed and, afterwards, these will be extended throughout ImPACT model analysis.

5.1 Panel Data Results

This section presents and assesses results obtained from the conducted longitudinal study regarding factors affecting CO_2 emissions in G20 participant countries.

5.1.1. Descriptive Statistics

So as to introduce the analysis, some descriptive statistics will be commented in order to contextualise the reader. First of all, it seems crucial to understand the magnitude G20 countries' actions have on the global scope. Specifically, in 2018, these economies accounted up to 87,04% of global CO_2 emissions. In absolute terms this is equivalent to 29,630 MT out of global 34,041 MT of carbon emissions. However, it is possible to find wide differences across the twenty largest economies. For instance, the United States or the oil-producer Saudi Arabia generate 15.24 and 15.27 CO_2 MT per capita, whereas the highly populated India exhibits 1.80 MT of annual carbon emissions per capita. Another relevant variable to consider is GDPpc as it has been already mentioned, welfare is associated with consumption which exerts pressure on the environment. For example, India's 1797.76 annual dollars per capita stands out compared to US (58510.24), Australian (58510.24) or German (41259.18) annual dollars per capita.

In a similar way, nations display different economic structures. For instance, some economies rely heavily on exports. This implies that they are polluting for products and services that are not consumed at the country of origin. Indeed, this is a hot topic nowadays as some countries like China claimed this is an unfair situation. However, it is not the only affected country, for instance, Mexico's exports account up to 40% of its GDP.

Another, noteworthy aspect for the purpose of this study is nations' economic structural organization. Inevitably, due to its carbon-intensity nature, countries that rely heavily on the industrial sector, energy production or transport activities are more likely to display higher *Energy Intensity* values. Generally, industry plays a more important role in developing economies that might have not completed their transition towards service activities yet. In China, Saudi Arabia and Indonesia the industrial sector- which encompass energy production- represent around 40% of final GDP whereas, in European countries, United States or Australia it does not surpass 20%.

Besides, countries present considerable divergences in terms of their energy mix or their dependency on foreign imported energy. France stands out for its dissemination of nuclear energies, which amount up to 49% of total energy used in that country. It is followed, from far away by countries like Canada (19%) or, as a whole, the European Union (20%) where important efforts have been done in fostering green energies. Another interesting aspect to examine is countries' dependency on energy imports. In this case, Australia and Saudi Arabia position as clear energy exporters of coal and natural gas and, oil, respectively. Contrarily, Japan, Korea, Turkey and the EU stands out for the opposite reason, due to their high dependency on energy imports which, respectively, represent 93%, 81%, 74% and 51% of total energy use.

Notwithstanding, G2O countries, regardless of noticeable differences, display important similitudes due to the fact they all belong to the top-twenty world economies. For instance, in all of them, practically 100% of population has access to electricity. The only exception is South Africa – where 85% of population has access to electricity- that in recent years has spread hastily electricity availability.

5.1.2. Panel Data

The table below presents results for Pooled OLS, Fixed Effects (FE) and Random Effects (RE) estimates. Moreover, as it is possible to notice panel Random Effects model include an extra dummy variable that classifies units according to countries' development level. For this purpose, the well-known Human Development Index (HDI) has been considered. Inspired by the HDI classification suggested by the

United Nations Development Programme (UNDP) countries will be classified as *Very High Human Developed* if they display .800 or higher values, and *Less Human Developed* if they show values under .800. In reality, countries are actually subdivided as low HD (< .550), medium (.550- .699), high (.700-.799) and very high (>.800) index values. However, as under study nations belong to the top twenty economies, this own elaborated division seems more suitable to capture differences as no low or medium developed- except India- country is considered. In the first subgroup European countries, Australia, US, Canada, Japan, South Korea, Saudi Arabia, Argentina, Russian Federation and Turkey are found. These display HDI values form German .947 to Turkish .820. On the other hand, Mexico, Brazil, China, Indonesia, South Africa and, lastly, India are among less developed G20 countries (United Nations Human Development Index, 2021).

The output summarised in Table 3, shows that Pooled OLS estimates mostly every variation in CO2 emissions *(R^2=0.9748)* but these results cannot be trusted as it has been explained in section 4.1. The model is underpredicting standard errors due to the fact these are likely to be correlated within estimates, as each observation for a given country actually provides less than an independent piece of new variance. Nonetheless, if the reader takes a look to the first coefficient it is possible to observe that logged population is statistically significant, and it is shown with a negative value. This strikes surprising as, the original IPAT framework, suggest that demographic expansions, entail higher CO2 emissions. However, this might be explained by the fact that many of the top G20 economies have accomplished to reduce CO2 emissions while their population keep increasing. It is true that several other non-included global economies are supporting their demographic expansion with more intense energy consumption and, the consequent aggravated environmental impact. Normally, countries following this trend are in the process of development. Even so, in this sample, as the HDI indicates, every single included country exhibits high or very high human development levels- except India. Therefore, the sample might be biased towards economies which are decreasing their CO2 emissions as population continues increasing.

Oppositely, enhancing *Energy Efficiency* as well as, substituting fossil fuels with renewable and nuclear energetic sources, implies a significant and negative effect on CO2 emissions. Lastly, it is possible to notice that as energy imports or industry value added increase in an economy, CO2 emissions, are also expected to raise. Initially, this concur with suggested hypothesis. First, it seems logical to think that countries which's processes are relatively energy-intense and consume lot of energy, may sometimes find that their energetic resources are not enough, therefore they could feel obliged to import it from third countries. This might explain the positive sign shown for energy imports in this Pooled OLS model. In second place, the logic behind the positive industry's coefficient has already been explained, as this variable is associated to energy- intense consuming processes. Lastly, despite in this model neither exports nor urban portion of population's relationship with CO2 emissions is statistically significant, it is noticeable the fact the relationship seems to be positive as it was previously guessed. Nonetheless, with this model it cannot be statistically guaranteed.

Hausman Test provides a significant p.value 0,099 and therefore, permits to reject the Null-Hypothesis meaning Fixed Effects is more suitable then RE for this estimation. Next, results provided by this model will be commented. The output shows that FE model estimates 94% ($R^2=0.9436$) of the within and 63.31% of between variation experimented by CO2 emissions, which seems to be quite high. Additionally, it is possible to observe how standard error for the intercept point has increased considerably as only within variation of the data is being analysed with this model. As before, population is not significant. Nonetheless, remaining variables are all highly statistically significant. As before *Energy Efficiency* gains seems to be negatively related with CO2 emissions. Same happens with renewable and nuclear energy weight in the energy mix. Similar to previous output, the data suggests that former's environmental lever effect is considerable larger than the adoption of non-emitting energy sources. The logic behind might be related to the fact increasing in 1% the portion of value added generated by 1 unit of energy, has much more profound implications. Whereas deployment of renewable energies does not guarantee these substitute carbon emitting sources. Improving *Energy Efficiency* by 1% without altering GDP implies that energy used must have been reduced by far more than 1%. Therefore, apparently, this second effect has a more powerful effect on the environment.

In this model, energy imports are statistically significant and affect positively CO2 emissions as well as, industry value added. The main difference found in this model is the fact exports and urban population percentage have become significant. Both variables have a positive effect on CO2 emissions. In other words, as exports, in dollars, increase by 1%, a .07% increase in CO2 emissions is expected. Similarly, as an additional percentual point of population moves from rural to urban areas, carbon emissions are forecast to increase by .013%. Nonetheless, according to t-values *Energy Efficiency* and Industrial output position themselves as the most explanatory variables for emissions variance.

Next, one more time, when the Fixed Effects model is run and standard errors are clustered by individuals, standard error are enlarged for most coefficients. But, especially for the constant term. Moreover, the explanatory scope of the model does not suffer any variation.

Lastly, even though it has been proved that the most suitable model is FE, Random Effects will be included for comparative purposes. The major advantage associated to this model is the possibility to include a dummy variable that classifies countries into *Very High Human Developed* countries and *Less Developed* countries. If the same model is run without the development dummy variable and with it, it is possible to observe how the explanatory power of the model is maintained more or less constant as the new explanatory variable is included. Therefore, this classification does not provided lot of additional information. Nevertheless, the effect of this variable will be analysed as, even though statistically might not be very interesting, from the point of view of the analysis it is.

Now, Random Effects Estimator will be evaluated even though, as it has been already explained, is not an appropriate model since correlation between regressor and individual specific effects implies a theoretical problem. First, the RE model including *dum_hdi* but, without clustering standard errors which captures around 94% of the within and 96% of between variability, will be analysed. As before, a variable-by-variable analysis will be conducted in first place. The principal difference here is the fact logged population has become statistically significant and it presents, once again, a negative sign. The coefficients for the rest of proxy variables are considerably similar to previously examined results. However, the novelty is proportionated by the dummy variable. This suggests that belonging to very high developed countries (dum_hdi = 1), implies a positive effect on CO_2 emissions. Meaning, in general, carbon emissions are expected to be larger for these countries, ceteris paribus. At first glance, this might seem contradictory with Environmental Kuznets Curve theory as it defends that there is a turning point when top developed countries, as the ones encompass within *very high developed* subgroup, accomplish to reduce CO_2 emissions as their welfare level keeps raising. However, these two models' construction is considerable different. While EKC measures carbons emissions per capita, here absolute values have been considered. Moreover, HDI does not represent exactly the same as welfare. Also, this study's model does not consider the squared term of HDI, which should be included in EKC. Therefore, it should not be assumed these theories are opposites.

Lastly, the same model but, with cluster-robust standard errors model is presented. Here the development dummy variable strikes for its lack of significance, although its coefficient is close to be significant with a 10% significance level. Although, it cannot be statistically guarantee, the direct relationship between belonging to developed countries and CO2 emissions is inherited from the positive coefficient.

Just to finish with this section, some general comments are going to be pointed out. First, it seems relevant to mention that, although most of the initial presentiments coincide with statistical evidence, the interpretation of population coefficient's sign is somehow surprising if IPAT logic is applied. Same happens with energy imports.

Additionally, it seems important to stress the fact FE and RE models are capable of capturing similar portion of within variation of the dependent variable, while Random Effects explain more between-variation of it. Regardless, FE model does not explain as much variability as RE, former model has been proved to be the most suitable one for the purpose of this analysis.

Lastly, regarding one of the principal questions of this model, it seems like *Energy Efficiency* gains do contribute in a much larger scale to carbon emissions reduction that the deployment of renewable and nuclear energies. This does not concur with Heryadi, & Hartono (2016) results which suggested that the adoption of renewable energies was more efficient when attempting to reduce carbon emissions. However, their model was not set out in the same way as theirs is a mere reproduction of the ImPACT identity where only technology is proxied. In spite of this paper's limitations and generalizations, it seems advisable to enhance and foster policies which focus on the former action path rather than on the energy mix itself. However, this should be studied more deeply and applying more complex and inclusive models. Additionally, many other economical, operational or social factors should be included when this kind of policies are designed. Nonetheless, this seems to be a good starting point to address them.

Table 3: Panel estimated results of equation (10)

Variables	Pooled OLS (Rob-S.E.)	Fixed Effects	Fixed Effects (Rob-S.E.)	Random Effects	Random Effects (Rob-S.E.)
Constant	- 6.2352 ***	- 13.7846 ***	-13.7846 **	- 8.7324 ***	- 8.7324 ***
	(1.5388)	(1.5906)	(4.7814)	(.7294)	(1.3483)
lnpop	- .4050 ***	- .0817	- .0817	- .3155 ***	- .3155 **
	(.1010)	(.0930)	(.3497)	(.0430)	(.1418)
lnenereffi	- .4329 ***	- .8471 ***	- .8471 ***	- .7110 ***	- .7110 ***
	(.1237)	(.0468)	(.0852)	(.0439)	(.0860)
renewpct	- .0159 ***	- .0097 ***	- .0097 ***	- .0127 ***	- .0127 ***
	(.0046)	(.0012)	(.0019)	(.0011)	(.0025)
nuclear	- .0101 ***	- .0089 ***	- .0089 ***	- .0089 ***	- .0089 ***
	(.0019)	(.0013)	(.0014)	(.0012)	(.0022)
lnenergyimports	.0695 **	.0322 ***	.0322 *	.0269 ***	.0269 *
	(.0302)	(.0099)	(.0170)	(.0093)	(.0152)
lnindustry	.4414 ***	.4935 ***	.4935 ***	.4351 ***	.4351 ***
	(.1340)	(.0278)	(.0916)	(.0275)	(.0888)
lnexports	.4414	.0718 ***	.0718 *	.0993 ***	.0993 ***
	(.1340)	(.0173)	(.0360)	(.0166)	(.0325)
urban	.0620	.0128 ***	.0128 **	.0113 ***	.0113 **
	(.0756)	(.0015)	(.0047)	(.0013)	(.0051)
dum_hdi		(omitted)	(omitted)	.2995 ***	.2995
				(.1057)	(.1853)
N	274	274	274	274	274
R-squared					
within		.9436	.9436	.9398	.9398
between		.6331	.6331	.9631	.9631
overall	.9748	.6774	.6774	.9631	.9631
Prob > F	.0000	.0000	.0000		
Prob > chi2				.0000	.0000

Note: Values in parenthesis are standard errors. (***), (**) and (*) represent 1%, 5% and 10% significance level, respectively. All the models and coefficients have been estimated with STATA. For further information regarding variables check Table 2.

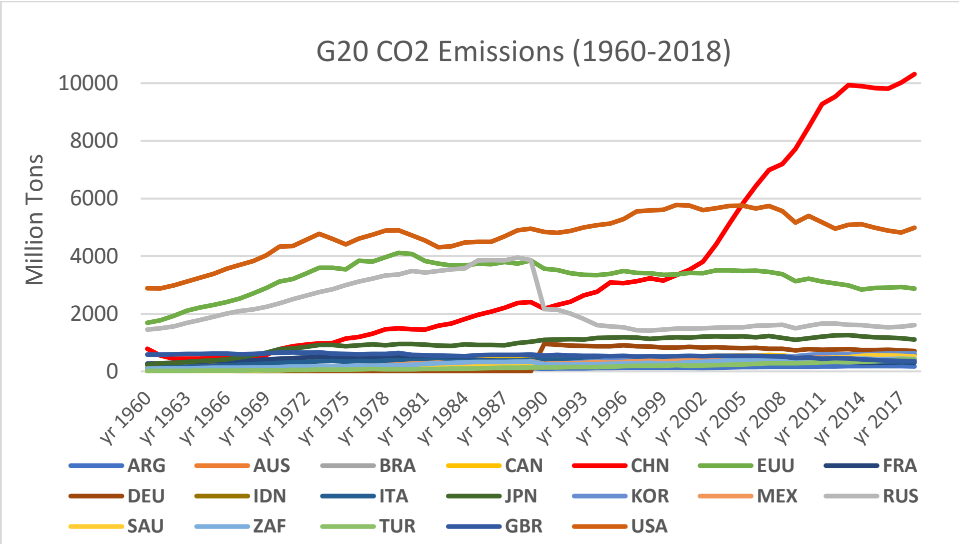
5.2 ImPACT Results

Once panel data results have been analysed, it seems interesting to provide the reader with a general panorama of some countries' historic unfolding from ImPACT's framework standpoint. In other words, national CO2 emissions, population and gross domestic product evolution is going to be analyse, so as to determine technological development [T] of countries throughout time. Theoretically, there should exist concordance between identity (4) and the data extracted from the World Data Bank. Moreover, a disaggregate analysis regarding national technological improvements levers is going to be conducted. For this purpose, Technology will be divided into

Energy Intensity-energy use per unit of GDP- and *Carbon Intensity*- CO2 emissions per unit of Energy Used-.

For this purpose, a brief inquiry of a few of the G20 countries will be presented. Additionally, in some cases, most relevant nations' performance will be assessed with respect to its (Intended) National Determined Contributions – (I)NDC. These are a series of voluntary pledges UNFCCC participating countries have agreed on, so as to fight against GHG emissions and, more broadly, climate change ("All About the NDCs", 2021)

Figure 1: G20 Total C02 Emissions by Country (1960-2018).



Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

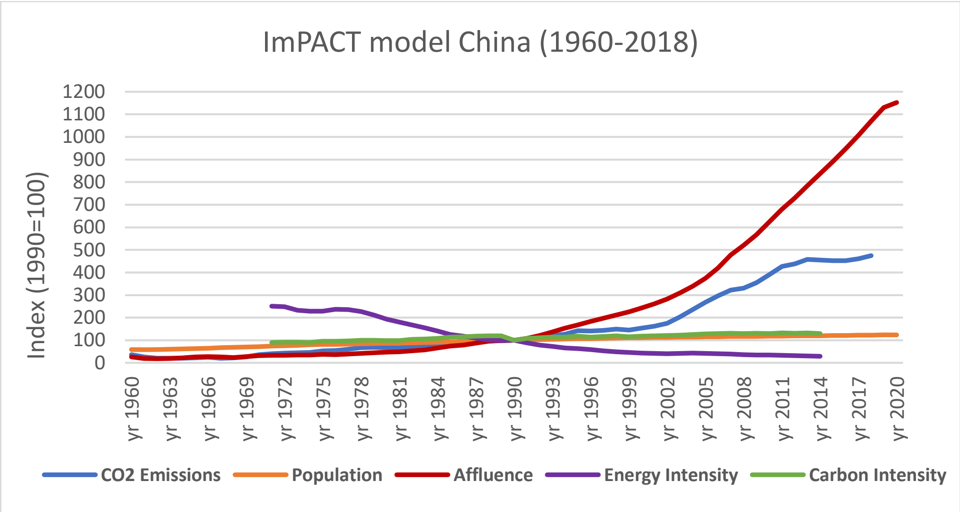
As shown in Figure 1, in terms of national carbon emissions, two clearly differentiated trends can be found among G20 countries. On the one hand, historical global powers like Germany, France and, more notably, USA have reduced their environmental impact in terms of total CO2 emissions. On the other hand, emerging and promising economies such as China, South Korea and India, have supported their astonishing economic growth with GHG emissions intensification. It seems important to highlight the exception of Russia which emissions dropped drastically with the fall down of the Soviet Union. This inevitably has caused a reorganisation of national's proportional contribution to global CO2 emissions.

Figure 2 exhibits China's historic evolution. It seems noticeable the increase CO2 emissions experimented from the beginning of this century until 2010, amounting up to five times emissions in 1990. This is believed to be directly related with the burst of economic acceleration, while population continued increasing and technology improvements proved insufficient to constrict CO2 emissions.

Since then, emissions seem to have plateaued. According to the charts, neither population nor welfare have dropped therefore, applying ImPACT identity, the only feasible explanation is associated with technological improvements which seems to be associated with *Energy Intensity* upgrades. However, no major improvements are observed when it comes to *Carbon Intensity.*

In their article, Zheng, Mi & Coffman (2019) proposed seven different Chinese CO2 emissions drivers. In accordance with his Logarithmic Mean Divisia Index (LMDI) model's results, they stand out *Carbon Intensity* gains as the principal driving force of latest years change of trend. It seems important to highlight efforts made to reduce it. In concrete, "between 2016 and 2019, China's energy intensity dropped by 13.1%, with an average annual growth of 2.9% in energy use against an average annual economic growth of 6.6%, indicating that energy production efficiency has increased substantially" (United Nations Framework Convention on Climate, 2021).

Figure 2:: ImPACT Model for China (1990=100). (1960-2018).

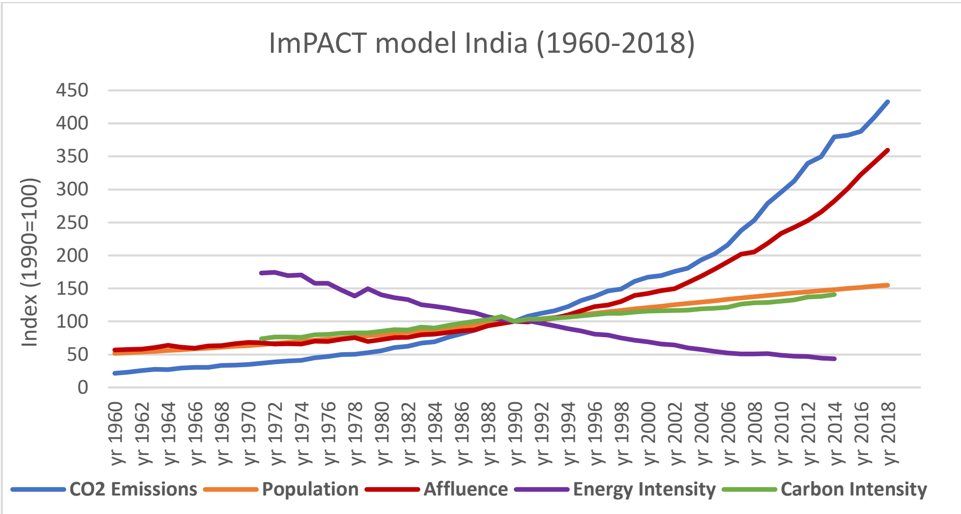


Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

Likewise, in its last UNFCCC NDC report (2021), China was praised for accomplishing a 52% reduction in carbon-intensity with respect to 2005 levels, considerably above the established NDC of 40-45% reduction. As it has been commented, these improvements are mainly caused by *Energy Intensity* gains. However, there is no certainty that these improvements will be enough to achieve carbon-peak before 2030 and carbon-neutrality by 2060, as was pledged by China in COP26 (United Nations Framework Convention on Climate, 2021).

In the case of India, special attention to detail has to be paid due to its particular national circumstances. "India accounts for 2.4% of the world surface area but supports around 17.5% of the world population. It houses the largest proportion of global poor (30%), around 24% of the global population without access to electricity (304 million)" (India's Intended Nationally Determined Contribution, n.d.). Therefore, reducing carbon emissions in this context strikes as a formidable and tough challenge.

Figure 3: ImPACT model for India (1990=100). (1960-2018).



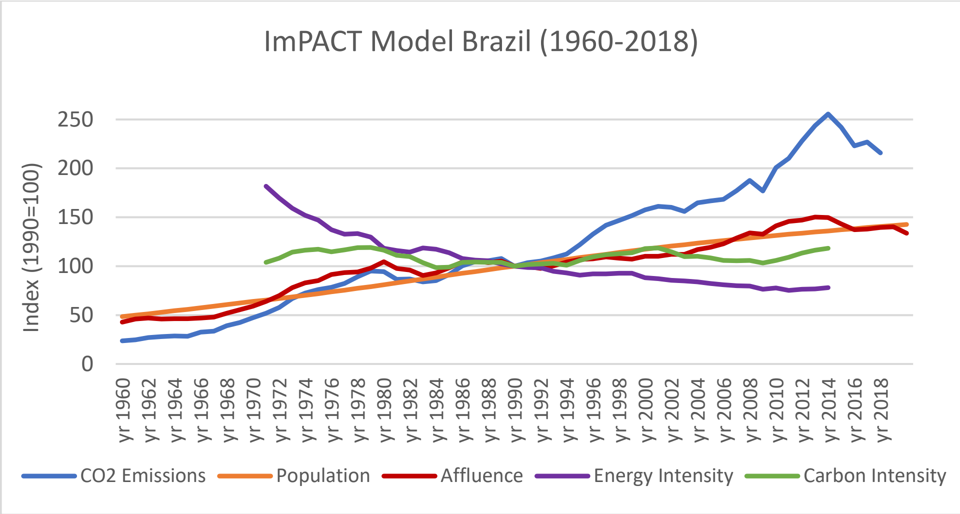
Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

Figure 3 represents how Indian GDP has grown at an historic pace for the last decades, and it is expected to continue this way. In addition, population has increased outstandingly compared to Chinese population for instance, especially in the last two decades. Consequently, even though some technological improvements in terms of *Energy Intensity* – no with respect to *Energy Efficiency*- have been accomplished, CO2 emissions have taken off significantly. These technological improvements are believed to be driven in great extent by recent gains with regard of energy employed per unit of GDP rather than by reductions of the amount of CO2 emissions these energetic sources expel. This suggest that even though, installations and infrastructures seems to be more efficient, there is a tendency to support intense CO2-emitting energetic sources. As Ozgur, Yilanci and Kongkuah (2021) claim in their article, nuclear energy positions itself as a potential alternative to struggle with Indian increasing need for energy sources. It is also suggested that, despite indisputable risks associated with this kind of power source, generated benefits are expected to exceed its drawbacks.

According to the UNFCCC (2021), Indian principal (I)NDC was to decrease the amount of carbon emitted per unit of production, by 20-25% with respect to 2005 values by 2020. As former Union Environment Minister Prakash Javadekar lauded “India has achieved its voluntary target of reducing emissions intensity of its GDP by 21 per cent over 2005 levels by 2020 and is poised to achieve 35 per cent reduction well before the target year of 2030" ("India to achieve target of reducing 35 pc emissions intensity before 2030: Javadekar", 2021). However, this statement might easily lead to misunderstandings. It is true *Carbon Intensity* has been reduced, however emissions have continued increasing hastily. The logic behind here is the fact that GDP has grown at a faster pace than emissions. In fact, Indian CO2 emissions are likely to keep raising as Indian economy continues expanding and population growing.

Next, Brazil’s exhibits- Figure 4- are going to be commented due to the country uniqueness in terms of renewable energies deployment and its relevance within the energy mix. The fact emissions, population and GDP increases have tandem along years is clearly displayed. In this particular case, it outstand how fluctuations in environmental impact are principally caused by changes in country’s affluence and technological, in specific *Carbon Intensity*, bumpiness. As India and China, Brazil has accomplished to reduce *Energy Intensity* however it has been somehow compensated by *Carbon Intensity* worsening in recent years. However, it seems important to highlight the fact, Brazil’s *Carbon Intensity* is considerably low compared to other developing countries. For some people it might be surprising but, in 2019, “renewable sources accounted for 83% of power generation, 46% of automobile fuel consumption, and 41% of primary energy in Brazil”, values significantly above global average (Paris Agreement Brazil’s Nationally Determined Contribution, n.d.)

Figure 4: ImPACT model for Brazil (1990=100). (1960-2018)

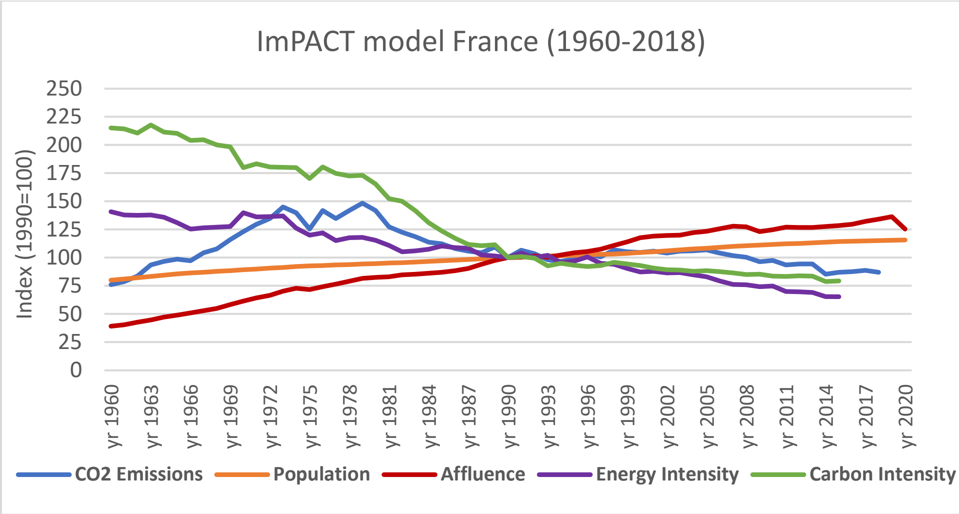


Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

As India, Brazil's main Intended National Determined Commitment, is to achieve carbon neutrality by 2060 (Paris Agreement Brazil's Nationally Determined Contribution, n.d.). Following this trend, emissions have been significantly reduced in recent years.

On the other hand, it also seems relevant to analyse some European countries throughout time performance since meaningful differences are expected to be found. Unlike previously commented countries, in Figure 5, France shows an undeniable reduction in total CO2 emissions since the eighties -accentuated between 1975 and 1990- despite growing population and welfare improvement. What stands out the most about France display is its extraordinary ability to reduce energetic sources' *Carbon Intensity* along time. As Bodansky (2007) expounds in its book *Nuclear Energy*, "during this period, electricity generation in France more than tripled and total energy supply rose 56%, while carbon emissions and petroleum use each dropped 16%". The author explains that this was accomplished above all by an unprecedented replacement of emitting energetic sources by nuclear energy. More precisely, "the fossil fuel share of electricity generation dropped from 62% to 8% in this period while the nuclear share increased from 6% to 77%" (Bodansky, 2007). Lastly, in his book, Bodansky (2007) discusses that other OECD/European countries did not experience such a reduction in total CO2 emissions even though per capita emissions lessened slightly.

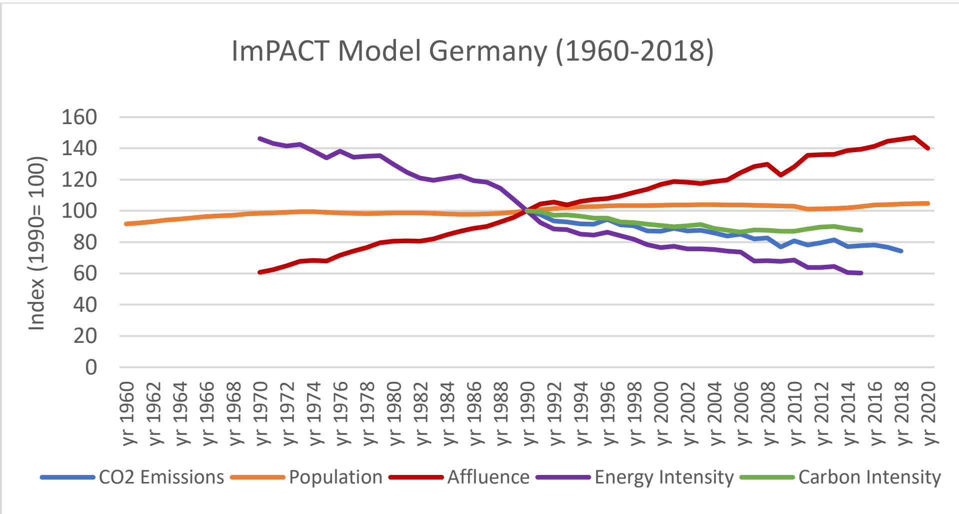
Figure 5: ImPACT model for France (1990=100). (1960-2018)



Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

In order to verify Bodansky's comparison between France and other European countries' performance, German and Spanish trajectories will be discussed next due to their singular performance.

Figure 6: ImPACT model for Germany (1990=100). (1960-2018).



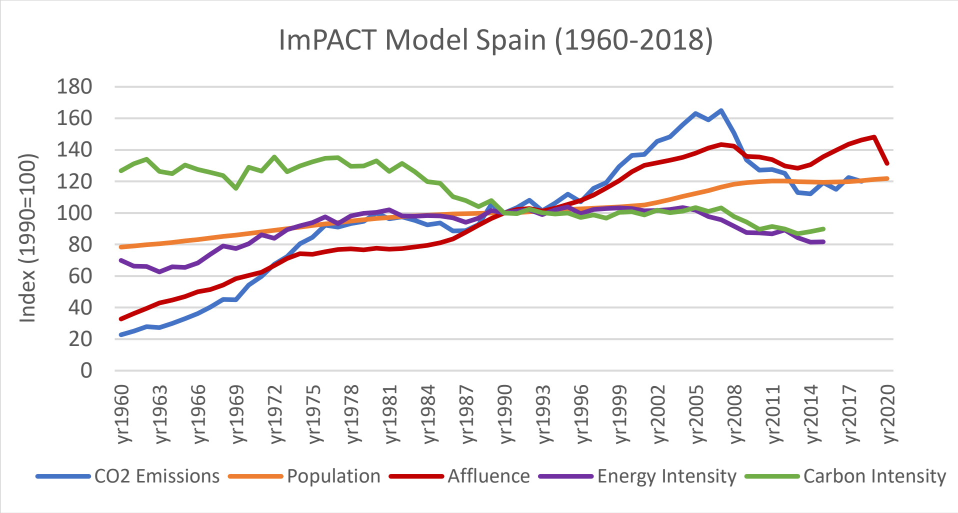
Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

Unfortunately, as it is observable in Figure 6, for Germany the only energy-related available data is subsequent the fall of the Berlin Wall. Nonetheless, it is possible to realise that since then, emissions have dropped as GDPpc grew significantly, due to a noteworthy technological improvement, both in terms of *Energy Intensity* as well as, *Carbon Intensity*. Germany is one of the few countries which has managed to accomplish improvements in both technological scopes. According to experts, this has been caused by unarguable *Energy Intensity* improvements, combined with German recognized phase-out policies towards renewable energies- the so called *Energiewende (*Rogge & Johnstone, 2017).

With regard to Spain, in Figure 7 it stands out how CO2 emissions have not been ruled by a constant tendency. In general terms, Spanish CO2 emissions have risen since data is available. However, these experimented a much faster increase at the beginning of this century. A priori this might seem to be in contradiction with Kyoto's and subsequent European Union members' commitments to reduce CO2 emissions by an average 5% and, 8% below 1990 levels, respectively ("Kyoto 1st commitment period (2008–12)", 2021). However, this results from the fact these pledges were formulated at an aggregate level. In fact, each nation adopted national-wealth tailored objectives. For instance, according to the Official Journal of European Communities, Germany and Denmark complied with a reduction of 21% below 1990 emissions. Otherwise, these agreements considered that France with its investment in nuclear plants, had contributed to the global goal sufficiently, and as a consequence it was not asked to accomplish further reductions. For Spain, and other Mediterranean countries such as Portugal or Greece, the situation was notably different. These were allowed to reach higher CO2 emissions levels than in 1990 so as to avoid a restrictive effect on economic development. In concrete as for Spain, its threshold was set at a maximum 15% increase with respect 1990 levels. Eventually, according to the data provided by the European Commission in its website, CO2 emissions were cut down by 19% during the first stage (2008-2012) of Kyoto's protocol ("Kyoto 1st commitment period (2008–12)", 2021).

Lastly, it seems noteworthy efforts made by Spain in the last decade since it has managed to reduce C02 emissions through important technological improvements. During the last quarter of last century energy needs – per unit of GDP- increased probably, due to Industrial Reconversion Plans implementation during Spanish Transition which fostered industrialization and energy-intensive sectors development. Afterwards, it is possible to observe how this tendency is reversed, likely as a consequence of structural transition towards a service-based economy and efficiency improvements in *Energy Intensity* terms.

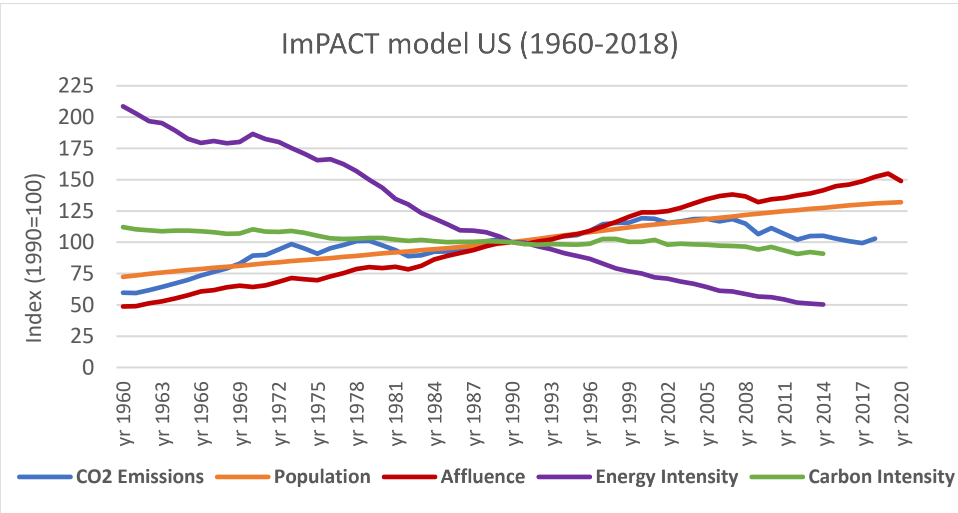
Figure 7:ImPACT model for Spain (1990=100). (1960-2018).



Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

Before terminating IPAT's discussion, it strikes unavoidable to bring up for discussion of how the United States have behaved in terms of the IPAT identity for the last decades. Likewise, previously analysed developed countries, the United States have made progress in terms of decarbonization of its economy. As the graph displays, in 2018 carbon emissions levels were similar to those in 1990, which is this graph's reference year. However, what stands out the most about its evolution, is the steadily gains in *Energy Intensity* since early times. According to Lamb (2021), the drivers behind Europe and United States' decarbonization are the transition towards non fossil fuel energies and the increasing penetration of renewable energies.

Figure 8: ImPACT model for US (1990=100). (1960-2018).



Source: Own elaborated graph based on data retrieved from the World Bank Dataset.

6. CONCLUSIONS

Generally, measuring the environmental impact nation's actions, economic activities or implemented policies have, strikes extremely complex, immeasurable and, eventually many times, inaccurate. Regardless of this limitation, this study's results are believed to shed light on some crucial aspects regarding society's impact on the environment.

It is widely accepted, as the IPAT identity reflects, that both humans and its economic activities are responsible for CO2 emissions and that this can only be reverted by technological advances. By reformulating this simple thought into a more complex and disaggregated alternative stochastic model, it has been possible to arrive to some relevant conclusions regarding which are those aspects within the wide range of possible explanations, that determine the dimension of country's environmental effects.

As it has been repeatedly stated, every nation's current productive structure and consumption habits, are entailing irreversible consequences on the environment. However, not every country is responsible to the same extent, it highly depends on some of the factors exposed now. Based on this paper's quantitative results, it can be concluded that highly industrialised countries exert more pressure on the environment, since this variable has a statistical positive relationship with impact dependent variable. Moreover, those countries which, to a certain extent rely on third parties to get necessary energy provisions, do exert more intense pressure on the environment. In a similar way, larger carbon emissions contributions are associated to historically exporter countries. Next, as it was suggested, G20 countries in which population tends to gather in urban nucleus, where daily activities require higher energy provisions, have been proven to be more polluting in terms of CO2 emissions.

Also, the model lays the foundations to extend the study of clashing issues like the relationship between countries' HDI or demographic expansion and CO2 emissions.

Nonetheless, this study have also proved that efforts made by society in terms of *Energy Efficiency* gains, deployment of renewable and nuclear clean energies contribute to carbon emissions lessening. This is consistent with initial hypothesis and current implemented policies, in specific the EU Green Deal or UNFCCC's (I)NDC, that propose these actions as potential solutions to mitigate human environmental impact. Therefore, although policies are oriented in the right direction, there is still a long path to go both in terms of *Energy Efficiency* and renewable energies.

Additionally, this research aim was to determine which of these alternatives is more powerful as for carbon emissions expelled to the atmosphere reduction. According to the longitudinal analysis' results, energy efficiencies gains are considered more efficient in this sense. However, as it has been already suggested, many other financial, operational and societal factors should be included when mitigating policies are designed.

Once these conclusions have been reached by interpreting panel data results, the research has moved to the application of the ImPACT framework from a descriptive point of view. Selected countries' evolution has given the impression that nowadays, there exit two different tendencies among the largest economies. Develop countries, led by the European Union, have somehow managed to reduce CO2 emissions for the last two decades. While developing economies struggle to catch up with former economies' environmental accomplishments since they continue exerting relatively more pressure on the environment due to their rapid economic growth and socioeconomic transformation. It strikes unlikely that this tendency will be reverted for now, as the latter seem to have prioritised and dedicated their resources to grow economically rather than to fight climate change.

It should be pointed out that, in general, most countries have managed to reduce *Energy Intensity* in a considerably way. This means that countries have accomplished to lessen the amount of energy they need to produce goods and services. However, it seems important to highlight the fact this does not signify that the amount of utilised energy has been reduced. Quite the contrary, it is increasing but at a slower pace than GDP. This might be provoked by the fact these economies are starting to rely more heavily on service sectors which are not that intense in energy consumption as industries. Another potential explanation resides on technological improvements and efficiency gains in existing economic activities. However, this question leaves the door open for further research.

Technological and installation improvements have been promoted ceaselessly by the European Union and the COP. However, it seems important to highlight the fact that improvements have slowdown in developed countries whereas, developing countries such as China and India, have accomplished more important gains in *Energy Intensity*, precisely, because these started at significant worse *Energy Intensity* values.

Oppositely, it has been found that developed economies, with the exception of France, *Carbon Intensity* gains are considerably insufficient. Simultaneously, under study developing countries have struggle to improve *Carbon Intensity* at all. This means that latter economies are becoming more dependent on intense emitting energy sources as their economies expand and population grows. As the amount of CO2 annual emissions expelled to the atmosphere is increasing at a faster pace than the rate at which energy consumption grows, this suggests that aggravated energy needs are being supported with carbon-intense energetic sources.

This research results and previous discussion have evinced those tremendous disparities can be found among G20 economies. Differences exist in term of environmental policies, historic emissions records and current societal and economic organization as well as, technological achievements. This, inevitably, has led to widely assorted results and conclusions that are considered extremely useful to properly understand current global panorama, which is crucial to design and implement effective, tailored and vanguardist environmental policies that respond to global climate crisis.

Regardless, all these divergences, something seems to be clear. If countries want to accomplish established environmental prospect, pledges should be toughened and carefully defined so as to avoid paradox like the Chinese. As it has been exposed, China boast about accomplishing its NDC while its CO2 emissions raise at an extraordinary rate, regardless the immense global implications this entails. Therefore, in order to do so, it is thought that more precise, emission reduction-oriented and applicable measurement and reporting tools should be developed so as to monitor countries' performance and attainments.

Lastly, even though this study has repeatedly focused its attention in improving *Energy Efficiency* and transforming the energy mix, it is truly believed that the most effective manner of reducing the impact our actions have on the environment, is to tackle the root of the problem by reducing overall energy consumption. This might require a redefinition of *Energy Efficiency* gains which besides considering energy needs per production unit, directly includes reductions in overall energy needs. This would inevitably require the application of SDG 7.3 to be expanded to many other quotidian aspects by enhancing SDGs interrelations as well as, a radical change of paradigm in terms of consumption and production habits.

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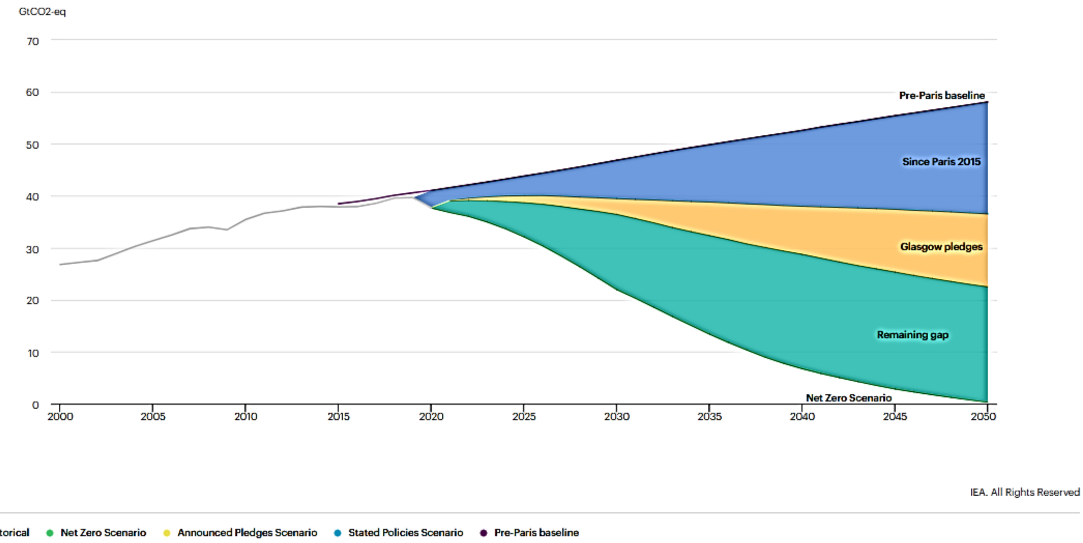
APPENDIXES

APPENDIX 1:

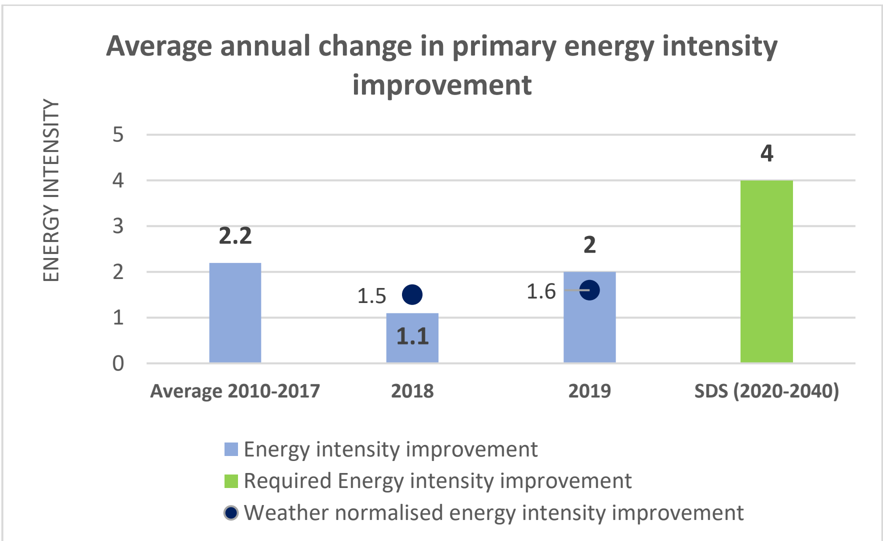
Figure 9: IEA, Global emissions by scenario, 2000-2050. (IEA)



Source: IEA (2021) Retrieved from https://www.iea.org/data-and-statistics/charts/global-emissions-by-scenario-2000-2050

APPENDIX 2:

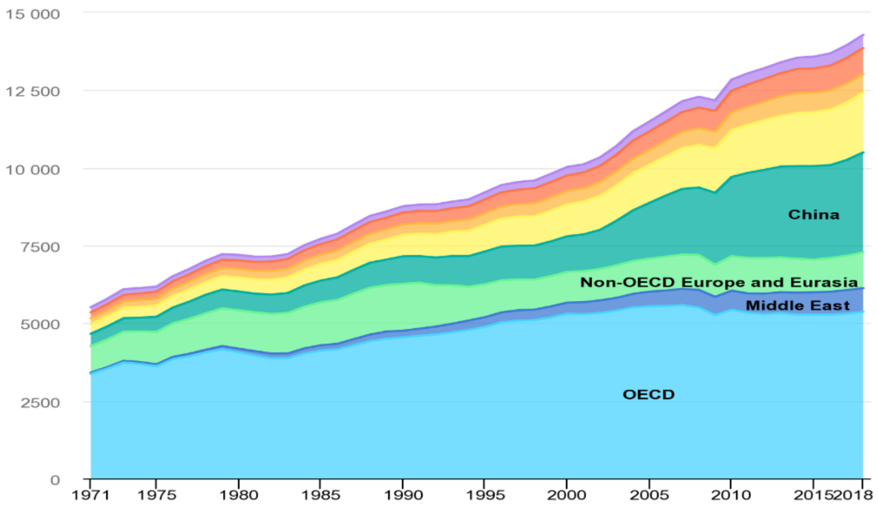
Figure 10: Average Annual Change in Primary Energy Intensity Improvement historically and in the Sustainable Development Scenario, 2010-2040 for EU countries.



Source: Data extracted from the International Energy Agency. Own elaborated graph.

APPENDIX 3:

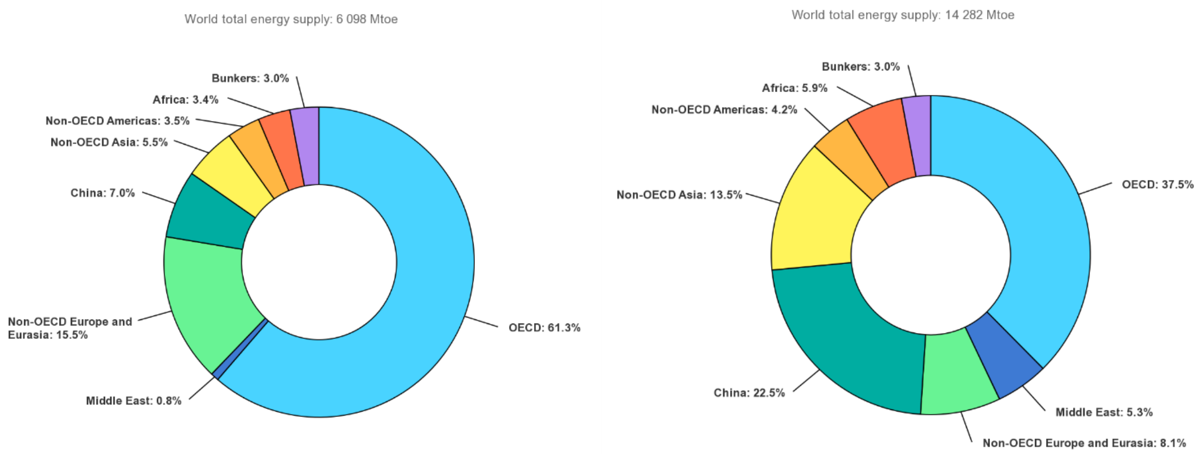
Figure 11: IEA, World total energy supply by region, 1971-2018.



Source: IEA, Paris. Retrieved from https://www.iea.org/data-andstatistics/charts/world-total-energy-supply-by-region-1971-2018

APPENDIX 4: Regional Portion of World Total Energy Supply (1973-2018)

Figure 12: IEA, Share of total energy supply by OECD region, 1973-2018.



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