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The Key Drivers of CO_2 Emissions of North America, Western Europe, China, and India, 1870-2019

A Decomposition Analysis

by

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Abstract

North America, Western Europe, China, and India are today the greatest emitters of carbon dioxide. This research aims to compare the development of North America and Western Europe with the Chinese and Indian ones. It is a comparison of the key factors that affects the emissions of CO_2 from fossil fuels. The key factors are the ones proposed by the Kaya identity, a particular type of decomposition analysis. These are: demographic change, economic growth, energy intensity, and carbon intensity. The main results of this thesis reveal that the economic growth of China has been the key driver of its carbon emissions after 2001. The Chinese values are enormously higher compared with the other zones. In addition, improvement in energy intensity in developed areas has significantly decreased carbon emissions after 1973. Also in China energy intensity has been a driver of carbon emissions reduction after 2008. The Indian case is not comparable with the Chinese one since the impact that the key drivers had on its carbon emissions is relatively marginal. Lastly, the shift from coal to other fuels has greatly contributed to carbon emissions reductions in North America and Western Europe since 1870. In China, this transition has started to contribute since 2008.

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1 Introduction

1.1 Research problem

The consumption of fossil fuels has become a major problem in the last century. Global warming is seen as a serious threat to society. The connection between fossil fuels and global warming comes from the fact that the combustion of coal, oil, and natural gas emits a dramatic quantity of CO_2 into the atmosphere. What is more, fossil fuels still represent the larger global share of energy sources (IEA, 2019). Indeed, in 2019, coal, oil and natural gas accounted for 79 per cent of the global energy consumption (IEA, 2019). In particular, coal, the most polluting fossil fuel, represented 25 per cent of the global share. We are in a global climate emergency since the CO_2 emissions do not seem to decrease. Instead, there is an increasing tendency according to the Intergovernmental Panel on Climate Change (IPCC) (Masson-Delmotte et al. 2018; Stocker, 2014).

Focusing on carbon emitters with an historical lens, the developed countries have been large emitters of CO_2 (Malanima, 2020). The United States has historically been the uncontested leader in carbon emissions since the second half of the 19th century, and Western Europe has followed them (Malanima, 2020). However, it should be noticed that two-thirds of the global historical CO_2 has been emitted after 1980 and 40 per cent after 2000 (IEA, 2019). In this context, the emerging economies have played a paramount role during recent decades. Their recent economic development has contributed enormously to the increase in global carbon emissions. In 2020, the highest share of carbon emissions has been registered in China (30 per cent), followed by North America (16 per cent), Western Europe (7 per cent), and India (7 per cent) (IEA, 2019). There is a causal relationship between the economic development of these areas and the increase in global carbon emission (Andreoni & Galmarini, 2016; Fan et al., 2006; Guan et al., 2009; Zhang et al., 2009; Ze-yuan & Jiang, 2006).

The relationship between environmental degradation and economic development is well postulated by the Environmental Kuznets Curve hypothesis (Grossman & Kreuger, 1995). According to this, the development of a country follows a trajectory that is characterized by two stages. Firstly, as soon as the country industrializes, there is both a growth in income per capita and in CO_2 emissions. Secondly, as soon as the nation has developed, income per capita continues to increase, while carbon emissions decline. This decrease in carbon emission is attributable to the use of greener technologies and the structural change from the industrial sector to the service one (Stokley, 1998; Stern, 2004). However, the greatest improvement in energy efficiency have been attributed to improvements within the industrial sector, while the contribution of the service one has resulted marginal (Henriques & Kander, 2010). Previous research seems to confirm the existence of a decoupling between environmental degradation and economic growth in developed countries (Suri & Chapman, 1998; Coondoo, D., & Dinda, 2008). In the same way, there is a broad consensus that emerging economies, like India, are still at the initial stage of the Environmental Kuznets Curve (EKC), and they have not already reached the decreasing stage (Tiwari, Shahbaz, & Hye, 2013).

One of the several methodologies used to analyse the relationship between economic development and environmental degradation is the decomposition technique. It is a methodology that permits to breaks down an aggregate variable into key factors. The sum of these key factors therefore results in the aggregate variable. An example of an aggregate variable, often used in energy studies, could be the amount of CO_2 produced by a nation. In this case, one of the key variables that could determine a change in CO_2 emissions could be energy intensity, such as the relationship between energy consumed to produce economic output. A type of decomposition is the Logarithmic Mean Divisia Index (LMDI) (Ang, 2004). It is broadly used because it has three main advantages. Firstly, it leads to clear results without residuals. Then, the data and calculations required are relatively accessible and simple. Lastly, it permits great flexibility in choosing in which periods to decompose the aggregate variable. An interesting type of LMDI decomposition model is the one developed by professor Y. Kaya (Kaya, 1995). The Kaya identity utilizes paramount variables in environmental studies. Indeed, it breaks the carbon emissions of an area or nation into demographic changes, energy intensity, fuel transitions in the energy mix, and economic development, as equation 1 illustrates.

$$CO_2 = Populat \cdot \underbrace{\frac{GDP}{Populat}}_{\text{Income}} \cdot \underbrace{\frac{Energy\ Tot}{GDP}}_{\text{Energy Intensity}} \cdot \underbrace{\frac{CO2}{Energy\ (Fuels)}}_{\text{Carbon Intensity}} \tag{1}$$

There are numerous decomposition studies that utilize the Kaya identity to analyse the causes of CO_2 emissions in the most polluted zones of the planet, such as North America, Western Europe, China, and India (Fan et al., 2006; Guan et al., 2009; Tavakoli, 2018; Zhang et al., 2009; Ze-yuan & Jiang, 2006). The general trend seems to confirm that population growth and economic development have been the main driver of an increase in CO_2 emissions. On the contrary, the decreasing trend is entrusted to the other two variables of the Kaya equation, such as the improvement in energy efficiency and the transition towards greener fuels.

However, these studies have not compared North America, Western Europe, China, and India from a historical perspective. Similar research was conducted by Marcucci & Fragkos (2015). They studied the same area and with the same methodology, but with a future perspective, not an historical one. The main contribution of this research is to do an historical comparison between these areas using a recent historical database by Malanima (2020). A Kaya decomposition analysis of these areas and with this recent database is a complete novelty.

1.2 Research purpose and questions

The following research has the objective to compare in a historical way, between the end of the 19th century until today, the driving forces of the emissions of CO_2 by the most pollutant areas of the planet, such as North America, Western Europe, China, and India. The whole period is going to be subdivided into six subperiods. These subperiods starts with the most significant events in the history of these four zones, such as the end of the two World Wars (1918 and 1945), the oil crisis of 1973, the entrance of China into the World Trade Organization in 2001(WTO), and the global financial crisis of 2008. This thesis aims therefore to test the Environmental Kuznets Curve (ECK) through the decomposition of the carbon emissions of the four areas between 1870 and 2019.

At this point, this research aims to answer the following research question:

- *To what extent did the four key factors – namely, (i) demographic change, (ii) economic growth, (iii) energy intensity, and (iv) carbon intensity – contribute to changes in carbon emissions, caused by fossil fuels, in North America, Western Europe, China, and India, from 1870 to 2019?*

The expectations of this research are that the two developed areas and the two emerging economies will confirm the EKC hypothesis. For this reason, we expect North America and Western Europe to follow the earlier and later stage of the EKC. In particular, the decreasing trend in carbon emissions is expected to be caused by an improvement in energy intensity, and changes in the economic and energy structures. On the other side, we expect China and India to be at the initial stage of the Environmental Kuznets Curve. Their large carbon emissions would be attributable to their recent economic development.

What is more, in a comparison between the developed and developing countries, we expect that the economic growth factor will be more relevant for the emerging economies. This is because, as it has been mentioned before, after 2000, globalization and international trade of emerging economies have increased enormously, together with carbon emissions. But the economic growth factor is not the only cause of carbon emissions. Regarding the population variable, we expect that it should be more relevant for the countries that have the most pollutant lifestyle. Population growth in developed countries like the United States and Western Europe, is expected to play a major in carbon emissions.

Moving from the two pollutants key factor, such as economic and population growth, to the two that could cause a decrease in carbon emissions, we expect the energy intensity variable to greatly contribute to CO_2 reduction because of the Information and Communication Technology (ITC) revolution, together with the structural change from the industrial economy to the service one. Lastly, the transition from coal to other fuels is expected to decrease carbon emissions and to influence the carbon intensity variable of our model. Even the transition from coal to other fossil fuels, like oil and natural gas, is expected to greatly decrease carbon emissions.

Talking about fuels brings us to the limitations of this thesis. This research does not provide the direct impact of non-fossil fuels. Since energy generated by sources like renewables and nuclear power contributes to a minimal or even null amount of CO_2, their impact on CO_2 emission cannot be directly quantified in the decomposition model. The relevant impact of non-fossil fuels will be calculated, but just indirectly, i.e., as a decrease in fossil-fuels energy consumption because of a greater use of renewables and nuclear power.

There are also limitations in the availability of the data. Indeed, there is a lack of data on the Chinese and Indian energy consumption of fossil fuels before 1965. Nevertheless, data on the CO_2 emissions by fossil fuels are available. In this way, it has been possible to do a conversion between carbon emissions and energy consumption, to have the lacking data. In addition, the two developing regions did not have a huge amount of fuel combustion before that time. Indeed, the starting point of the fuel consumption in 1965 was relatively low, as we will see in section 5.

At this point, the outline of the thesis will be organized in the following way. Chapter 2 introduces the Environmental Kuznets Curve hypothesis and the theory concerning the decomposition method and Kaya identity. In addition, a review of the existing literature on these topics will be provided. Then, chapter 3 reveals where the data that compose the decomposition model come from. Subsequently, chapter 4 illustrates the detailed formulas that compose the adaptation of the Kaya identity. The data used in the model are described in chapter 5, together with the analysis of the decomposition results. These results are discussed in chapter 6, and lastly, the conclusions in chapter 7 summaries the whole research.

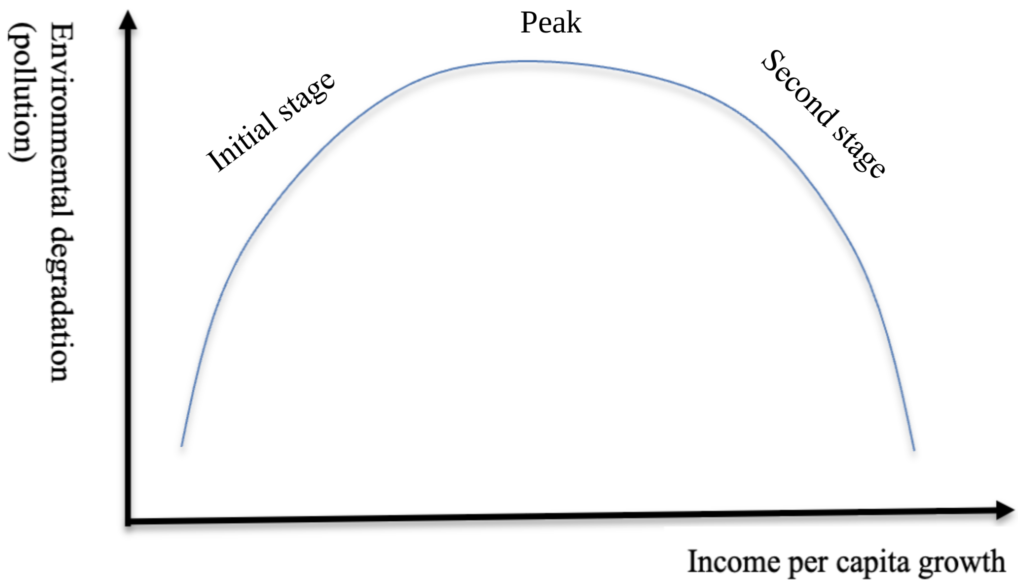
2 Theoretical framework

This thesis lies its foundation on the Environmental Kuznets Curve (EKC) hypothesis. It argues that the relationship between the economic development of a country and the environmental damage produced is not linear, but it follows an inverted-U shape. A methodology to quantify the key drivers of environmental harm is the Logarithmic Mean Divisia Index (LMDI) decomposition analysis. In particular, the Kaya identity is LMDI equation that identifies four variables as determinants of a change in carbon emissions. These variables are (i) demographic trends, (ii) income per capita, (iii) energy and (iv) carbon intensity. This section presents the theory behind the EKC and LMDI studies, together with the main findings of previous research.

2.1 The Environmental Kuznets Curve

The Environmental Kuznets Curve (EKC) theory studies the relationship between economic development and environmental damage (Grossman & Kreuger, 1995). As Figure 1 illustrates, the reverse U-shape relation between economic growth, on the x-axis, and environmental degradation, on the y- axis, is divided into two stages. At an initial time, societies experience economic growth at the expense of environmental degradation. This is the time when economies face their structural change towards industrialization. During this time, income per capita grows rapidly together with carbon emissions. However, after the peak, this trend changes. According to the EKC theory, the developed economy continues to increase its income per capita but emitting less carbon dioxide. Improvements in energy efficiency, thanks to the adoption of more powerful technology and greener type of fuels, are considered the major contributors to decreases in CO_2 emissions.

Figure 1. The Environmental Kuznets Curve



Source: Author elaboration on Grossman and Kreuger (1995)

There are exhaustive literature reviews that describe the theory proposed by Grossman and Kreuger (1995) (Dinda, 2004; Copeland & Taylor, 2004; Kijima, Nishide & Ohyama, 2010; Stern, 2004). According to these reviews, the main determinants of the EKC are technological change, environmental regulation, and international trade. The technological effect happens when an economy develops, and the structural change leads to the adoption of cleaner technologies (Grossman & Krueger, 1991). Particularly relevant to this topic is the research by Stokley (1998), according to whom before the peak of the EKC, developing countries adopted just the most pollutant technologies. On the contrary, after that peak, the use of cleaner technologies was responsible for decreases in pollution.

Environmental regulations have been considered also a determinant of the EKC. In low-income countries, it has been proven that political rights, literacy, and civil liberties influence environmental harm (Torras & Boyce, 1998). Likewise, Panayotou (1997) argues that the role of institutions is paramount in flattering the environmental degradation of the EKC of low-income countries.

Also, international trade has been an important determinant in the EKC hypothesis. There are two schools of thought. One claims that international trade increases the competition between nations, and this would permit them to use scarce resources more efficiently and to develop or even import new and cleaner technologies (Stevens, 1995; Helpman, 1998). The other one, argues that international trade increases the depletion of natural resources. Indeed, numerous studies confirm the positive relationship between open trade and environmental degradation (Copeland & Taylor 2001; Schmalensee, Stoker & Judson, 1998). Particularly interesting is the fining of the research by Kander et al. (2017) according to whom the industrialization of Britain and Germany between 1970 and 1935 followed a flat or even declining trend in the EKC, if energy for international trade was not counted.

The main critique of the EKC is that it presents numerous econometric gaps (Jaunky, 2011; Omri et al. 2015; Stern et al. 1996). These authors have criticized the unidirectional causality between income and environmental degradation. They claim that the EKC is econometrically weak because income should not be considered an exogenous variable. According to these critics, there should be endogeneity and simultaneity assumptions between the two variables of the EKC. The absence of these assumptions could bring biased and inconsistency results. Fortunately, authors have developed new methodologies to solve these econometric issues (Cole et al. 1997; De Bruyn, 1998).

2.2 LMDI decomposition

One of the main methodologies to measure the factors that influence a change in energy consumption or carbon emission is the Logarithmic Mean Divisia Index (LMDI) decomposition. It is an analytical method used to decompose an aggregate variable into different factors (Ang, 2004). Decomposition studies were historically introduced after the oil crisis of 1973. During this time there was a necessity to quantify the impact of fuel changes in the industrial sector. Decomposition studies persist still today, and their focus has shifted towards sustainability. Their main attempt is to quantify the key driver of energy consumption and carbon emissions.

There are many types of decomposition methodologies. They could be classified between structural decomposition analysis (SDA) and Index Decomposition Analysis (IDA). Su and Ang (2012) provide a literature review of both methods. According to the authors, the IDA methodology has some advantages compared to the SDA. First, it requires easier mathematical calculations and fewer data. Then, the IDA methodology is particularly useful when using energy intensity as a key variable. Energy intensity is the ratio between the energy used to produce economic output, and it is therefore paramount for EKC studies.

The LMDI methodology belongs to the IDA decomposition group. It has been used in this research because it allows a perfect decomposition without residuals (Ang, 2004). What is more, it provides great flexibility in choosing the period of research. To clarify, it permits finding the key drivers of a variable between specific times. In addition, LMDI decomposition studies permit to quantify the structural change between sectors or within sectors. However, this thesis is not going to capture the sectoral structural change, but the variation in the energy-mix. The LMDI decomposition permits to quantify to what extent a change in the energy mix, for example from coal to oil or renewables, influences carbon emissions.

I would like to clarify with an example the process of this methodology because it is central to this thesis. The LMDI method permits quantifying to what extent some key variables could explain a change in an aggregate variable between flexible periods. Let's have an example. We want to investigate an aggregate variable, such as the total energy consumption of a nation, between two periods, 2000 and 2010. The aggregate variable is decomposed into key variables, which could be for example (i) the demographic trends, (ii) the type of fuels used, (iii) the economic development and (iv) the technological improvement. Thanks to the LMDI methodology we know to what extent these four key variables influenced energy consumption between 2000 and 2010.

In a mathematical term, the change in the aggregate variable between two periods, T1 and T0, is the sum of the change of the key variables. More specifically, the formula (2) by Ang (2004) used in this research is the following:

$$\begin{aligned} \Delta\, AV_{tot} = \; & AV_{T1} - AV_{T0} \\ = \; & \Delta KV_{X_1} + \Delta KV_{X_2} + \ldots + \Delta KV_{X_n}. \end{aligned} \tag{2}$$

Where the change in the aggregate variable (AV) between a final time T1 and an initial one T0 is equal to the sum of the changes of the key variables at the same time. The formula (3) used for obtaining the changes of the key variables, such as $\Delta KV_{X_1},\ \Delta KV_{X_2},\ and\ \Delta KV_{X_n}$ is the following:

$$\Delta KV_{X_n} = \sum_i \frac{AV_i^T - AV_i^0}{\ln AV_i^T - \ln AV_i^0} \cdot \ln \frac{KV_i^T}{KV_i^0} \tag{3}$$

Where *i* represent a sub-category of the aggregate variable. Using the previous example of the energy consumption, *i* could represent the type of fuel consumed. In this way, the total energy consumed would be the sum of the single fuels consumed. The aggregate variable and the key variables that I am going to use come from a noted identity in energy studies, called the Kaya identity.

2.3 The Kaya indentity

The Kaya identity is a LMDI decomposition formula. As equation 4 illustrates, the Kaya identity decompose the aggregate variable CO_2 emissions into demographic, economic and energetic key factors (Kaya, 1995) .

$$CO_2 = Populat \cdot \frac{GDP}{Populat} \cdot \frac{Energy}{GDP} \cdot \frac{CO2}{Energy} \quad (4)$$

More specifically, CO_2 represents the carbon emission rate, $\frac{GDP}{Population}$ the per capita gross domestic product, $\frac{Energy}{GDP}$ the energy intensity, and $\frac{CO_2}{Energy}$ the carbon intensity. The Kaya identity was presented in 1989 by the Japanese professor Yoichy Kaya during a Intergovermental Panel on Climate Change (IPCC) conference. It has been used as the official parameter of the IPCC IS92 (Alcamo et al. 1995) and SRES (Nakicenovic et al. 2000) scenario reports.

Climate change policies tend to focus more on carbon and energy intensity compared to population and economic growth (Hoffert & Caldeira, 2004). This is because few governments have historically tried to reduce their population growth and GDP per capita. Even the notorious one-child policy adopted by China was relatively short in historical perspective, from 1980 to 2016. What is more, no single society wishes to stop its economic growth. For these reasons, the reductions in CO_2 emissions are handled by the other two variables of the Kayan equation, such as energy and carbon intensity. At this point, let us dwell on each one of these four key variables, giving a definition and investigating what previous research has to say.

2.3.1 *Population*

There is a clear causality relationship between demographic variations and carbon emissions. Indeed, as population increases, it leads to an increment in the energy demand and therefore to a rise in fossil fuel consumption and CO_2 emissions. For this reason, it is necessary to give particular attention to the population variable and to the internal factors that could modify it, i.e., ageing, fertility rates and urbanization rates (Tavakoli, 2018).

The scientific revolution, together with the progress of technology and medicine has dramatically improved the living standard condition of societies, leading to a demographic transition (Boserup, 1983). This transition is characterized by a shift from high mortality and natality rates, typical of low-income economies, towards low mortality and natality rates, typical of the high-income ones (Lutz, 2009). What is more, within this demographic transition there is an intermediate state characterized by high natality rates and low mortality rates. It is in this stage that the demographic boom occurs (Mason, 2007).

Previous literature shares different opinions regarding the relationship between population growth and carbon emissions. According to T. Dietz & E. A. Rosa (1997), there is a unitary elasticity between population growth and CO_2 emissions, meaning that a population change has proportionally the same effect on carbon emissions. A different view is argued by A. Shi (2003), according to whom the global elasticity is higher. Particularly, she illustrates that a change of 1% in population provokes a change of 1,42% in CO_2 emissions. The author argues that this higher value is driven by the dramatic difference between developed and developing nations. Indeed, lower-middle-income countries have an elasticity of 2, meaning that an increase in population causes a double effect on carbon emissions. On the contrary, high-income countries have an elasticity of less than one. Therefore, the research by A. Shi (2003) provides support for the theory by E. Boserup (1983), according to whom technological progress of high-income societies could lead to population growth with just modest environmental damage.

What is more, it must be mentioned that the relationship between population and environmental damage should consider the per capita emissions of the areas in consideration. Indeed, although some countries are among the larger carbon emitters, their emissions per capita could be very low. This is the case of India, the third greater emitter of greenhouse gas. The Indian rate of CO_2 emissions per capita was just 2.0 tCO_2/person, ranking globally as the 130th emitter (GPC, 2015).

2.3.2 *Income*

Together with population, economic growth is one of the greatest driving forces of carbon emissions. Economic growth is measured as Gross Domestic Product (GDP) per capita, which is the total economic output of a society divided by its inhabitants. To clarify, GDP is the value of all the domestic production of finished goods and services of a country in a specific time.

There are numerous studies that consider economic growth as the main driver of an increase in carbon emissions (Andreoni & Galmarini, 2016; Fan et al., 2006; Guan et al., 2009; Zhang et al., 2009; Ze-yuan & Jiang, 2006). Between them, Fan et al. (2006) argue that there is a distinction between countries that share different incomes. The authors illustrate that, between 1975 and 2000, the income variable has been much more relevant for the low-income countries than for the high ones. A possible explanation is that their economic structural chance is at an initial phase compared to developed nations (Ze-yuan & Jiang, 2006). On the other side, the developed nation has indeed learned how to reach economic growth with less environmental damage (Tavakoli 2018).

What is more, decomposition analysis shows that the manufacturing and export sectors are the main drivers of emissions in the last three decades (Guan et al., 2009). Emerging economies are at the initial stage of the structural transition and their industrial expansion is a paramount step for their development. On the contrary, developed countries are experiencing a structural transition from the industrial to the service economy. This transition has played an important role in the carbon emission drop (Okamoto, 2013), and it has influenced the improvements in energy intensity, that is considered the main driver of a decrease in carbon emissions (Voigt et al. 2014; Wang, Li & Zhang, 2017; York, Rosa & Dietz, 2003; Zhang et al. 2009).

2.3.3 *Energy intensity*

Energy intensity is a variable that measures the energy efficiency of a society. It indicates the amount of energy required to produce monetary output. The desired goal would be to have small values in this variable because it would indicate an efficient allocation of energy to generate wealth (Martínez, Ebenhack & Wagner 2019).

Energy intensity is strictly related to the two stages of the Environmental Kuznets Curve, i.e., before and after the peak of the inverted U-curve (Tavakoli 2018). Indeed, in the first phase of the curve, where GDP grows fast together with carbon emissions, energy intensity is high. The earlier phase of industrialization requires an abundant amount of energy to produce cement for infrastructures, steel for transportation, and the development of the industrial sector, just to name a few.

Fortunately, in the second stage of the EKC, energy intensity is a great contributor of CO_2 reductions. Two factors, a positive and a negative one, could be the reasons to that (Martínez, Ebenhack & Wagner 2019). The first one is the fact that (i) technological progress, (ii) the use of more advanced techniques of energy conversion, and (iii) the efficiency of material production have a dramatic impact on CO_2 reduction. However, according to the authors, a decrease in energy intensity could be the result of the exportation of industrial activity towards another zone. The outsourcing of the production of manufacturing products to emerging economies is the negative side of the decrease in energy intensity variable (Peter et al. 2011). Indeed, there is broad research confirming the use of dirty technologies by low-income countries (Stokley, 1998).

LMDI studies confirm that energy intensity is a key variable in mitigating carbon emissions (Voigt et al. 2014; Wang, Li & Zhang, 2017; York, Rosa & Dietz, 2003; Zhang et al. 2009). What is more, the effect of the energy intensity varies among countries that share different income (Dong et al. 2019; Henriques & Kander, 2010; Lima et al. 2017; Marcucci & Fragkos, 2015). Upper-middle countries have the greatest potential to reduce their carbon emissions thanks to improvements in energy intensity. Nevertheless, also in emerging economies, the energy intensity variable has been proved to be essential (Lima et al. 2017; Marcucci & Fragkos, 2015). In a comparison of emerging and developed economies' energy efficiency between 1971 and 2008, it has been proved that only improvements in energy intensity can compensate for the economic and carbon emissions growth (Lima et al. 2017). What is more, in a future perspective, the authors Marcucci and Fragkos (2015) argue that energy intensity will be the key variable to moderate carbon emissions in China, India, Europe and the US until 2100.

Focusing on economic sectors it has been illustrated that the manufacturing sector is the main driver of improvements in the energy intensity variable, and therefore in CO_2 emissions (Henriques & Kander, 2010). The authors compared 10 high-income countries and 3 emerging economies between 1971 and 2005 and they concluded that the service sector had just a marginal effect on changes in energy intensity in 7 of the developed countries.

2.3.4 *Carbon intensity*

Carbon intensity is the ratio between the carbon emissions and the energy or fuels consumed. It is a variable that depends on the energy mix used by a society. The energy mix constantly changes because of the availability, economic situation, and environmental rules that a country needs to adapt and follow (Tevakoli, 2018). Coal is the protagonist of the carbon intensity because of its high carbon content per unit of energy liberated. Coal represented 25 per cent of the global energy supply in 2019 and it was responsible for 42 per cent of CO_2 emissions (IEA, 2019). An alarming factor is that these values have not decreased since 1990.

There are two ways to reduce the carbon intensity variable (Tevakoli, 2018). These are a change in the energy mix and a decrease in the energy intensity. Within fossil fuels, a shift from carbon to other fuels like oil and gas has been proved to improve the carbon intensity of a country (Tevakoli, 2018). What is more, the use of low or even zero-carbon sources like solar, hydro, and nuclear power has been proved to provide enormous environmental benefits (Xiaowei & Gallagher, 2014).

Focusing on the comparison between emerging and developed economies, Tevakoli (2018) provides a clear picture of the trends of the carbon intensity variable of the 10 top emitters between 1971 and 2011. According to the author, emerging economies, such as India, China and Brazil are the countries with the highest value in carbon intensity. On the other hand, developed nations like the US, or European countries like Germany, experienced a slight and constant decrease in the carbon intensity variable.

At this point, it is time to introduce the data that compose the variables of our Kaya decomposition.

3 Data

Four variables are composing the decomposition dataset. These are (i) the total energy consumption, (ii) the CO_2 emissions from the energy source, (iii) the Gross Domestic Product (GDP) per capita, and (iv) the population growth. It is a historical dataset collected from different sources. The first variable, total energy consumption, consists of just primary sources of energy. Primary sources are types of energy that come from the extraction of natural sources and that are not yet converted or transported (Bhattacharyya, 2010). They are the input of a natural source that is inserted into engines. As an example, electricity is not a primary source of energy. On the contrary, the coal, oil, or renewables, that produced electricity, are considered the primary source. In this research energy consumption from coal, oil, gas, renewables, and nuclear power is measured in Mtoe (million tonnes of oil equivalent).

The source where data on energy consumption come from is the historical database gathered by Malanima (2020). In this database, North America and Western Europe are composed by many nations. North America includes the United States and Canada. While Western Europe consists of 16 nations, namely Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. When other variables in this thesis refer to North America and Western Europe, they include the countries mentioned here above. What is more, data on primary energy consumption could be divided before and after 1965. Indeed, before 1965 there is no availability of data on China and India. In addition, data after 1965 are more accurate in a national prospect because they include indirect energy spent to produce traded products sold and consumed abroad. Data after 1965 are sourced from the BP Statistical Review of World Energy (2021).

Then, the CO_2 emissions by the fossil-fuel variable is obtained by the database of the Global Carbon Project (Le Quéré et al. 2015). Data from this source are perfect for this research since they offer the carbon emissions divided by nations and by single fuels. The Global Carbon Project data start in 1959. Prior to this date, this thesis uses data by Andrews and Peters (2021), which combined a dataset by Marland & Gilfillan and the BR Statistical Review of World Energy (2021). CO_2 emissions are measured in Mt (million tonnes).

The third variable used, GDP per capita, comes from a combination of four sources. It is measured in the international dollar at the price of 2017, and it is adjusted for inflation and the cost of living according to different countries, such as according to purchasing power parity (PPP). The four sources are the following. After 1990 data are obtained from the World Bank (2021). Before 1990 data come from a combination of two databases, such as the Maddison Project Database (Bolt & van Zanden, 2013), and the Penn World Table (Heston, Summers & Aten, 1998).

Lastly, the population variable comes from two sources. Before 1950, data are obtained from the Maddison Project Database (Bolt & van Zanden, 2013). After 1950 they come from the World Population Prospects (Heilig, 1996). At this point, table 1 reassumes the variables used, their units of measure, sources, and where to access them.

Table 1. Variables names, units, periods, and sources

Variable	**Unit**	**Period**	**Source**
Energy Consumption	Mtoe	1870-1965	Malanima (2020)
		1965-2019	BP Statistical Review of World Energy
CO_2 emission	Million Tons	1870-1959	Andrews & Peters (2021)
		1959-2019	Global Carbon Project
GDP per capita	US$ PPP 2017	1870-1990	Maddison Project Database Penn World Table
		1990-2018	The World Bank
Population		1870-1950	Maddison Project Database
		1950-2019	World Population Prospects

4 Methods

The Kaya identity consisted of the four variables described in the previous chapter, here illustrated in equation 5.

$$CO_2 = Populat \cdot \underbrace{\frac{GDP}{Populat}}_{\text{Income}} \cdot \underbrace{\frac{Energy\,Tot}{GDP}}_{\text{Energy Intensity}} \cdot \underbrace{\frac{CO2}{Energy}}_{\text{Carbon Intensity}} \tag{5}$$

This formula could also be written as equation 6 displays. The aggregate variable CO_2 was the sum of the carbon emissions released by three fuels *f*, such as coal, oil, and natural gas. This sum consisted of the product of four relations. These were the population P, the GDP (GDP/P), the energy intensity EI (Etot/GDP), and the carbon intensity CI (CO_2f/Etot).

$$CO_2 = \sum_f CO_2^f = \sum_f P \cdot \frac{GDP}{P} \cdot \frac{Etot}{GDP} \cdot \frac{CO_2 f}{Etot} = \sum_f P \cdot GDP \cdot EI \cdot CI \tag{6}$$

At this point, what we what is to quantify the change in carbon emissions from a time *t0* to a time *t1*. As has been pointed out in previous chapters, the periods that this model was going to use are the most significant years for the history of North America, Western Europe, China, and India. These were considered to be the end of the two World Wars (1918 and 1945), the oil crisis (1973), the entrance into the WTO of China (2001), and the financial crisis of 2008. The results of the equation 7-10 revealed the changes in the four key variables from year *t0* to *t.*

$$\Delta P = \sum_f \left[\frac{\left(CO_{2_f}^{t1} - CO_{2_f}^{t0} \right)}{lnCO_{2_f}^{t1} - lnCO_{2_f}^{t0}} \right] \cdot ln\left(\frac{P^{t1}}{P^{t0}} \right) \tag{7}$$

$$\Delta GDP = \sum_f \left[\frac{\left(CO_{2_f}^{t1} - CO_{2_f}^{t0} \right)}{lnCO_{2_f}^{t1} - lnCO_{2_f}^{t0}} \right] \cdot ln \left(\frac{\frac{GDP^{t1}}{P^{t1}}}{\frac{GDP^{t0}}{P^{t0}}} \right) \quad (8)$$

$$\Delta EI = \sum_f \left[\frac{\left(CO_{2_f}^{t1} - CO_{2_f}^{t0} \right)}{lnCO_{2_f}^{t1} - lnCO_{2_f}^{t0}} \right] \cdot ln \left(\frac{\frac{Etot^{t1}}{GDP^{t1}}}{\frac{Etot^{t0}}{GDP^{t0}}} \right) \quad (9)$$

$$\Delta CI = \sum_f \left[\frac{\left(CO_{2_f}^{t1} - CO_{2_f}^{t0} \right)}{lnCO_{2_f}^{t1} - lnCO_{2_f}^{t0}} \right] \cdot ln \left(\frac{\frac{CO_{2_f}^{t1}}{Etot^{t1}}}{\frac{CO_{2_f}^{t0}}{Etot^{t0}}} \right) \quad (10)$$

As equation 11 illustrates, the change in CO_2 emissions from the period *t1* to *t0* was equal to the sum of the changes of the four key drivers. Table 2 provides a schema with all the abbreviations of the variables used in this thesis.

$$\Delta\, CO_2 = CO_2^{t1} - CO_2^{t0} = \Delta P + \Delta GDP + \Delta EI + \Delta CI \quad (11)$$

Table 2. Variables description

Name	Description	Unit
CO₂	Carbon emissions from the consumption of coal, oil, and natural gas	Million Tons
P	Population	
Etot	Energy consumption of primary sources as coal, oil, gas, renewables, and nuclear	Mtoe
Ef	Energy consumption of a single fuel at a time	Mtoe
EI	The relation between the amount of energy used to produce monetary output	Mtoe/US$(2017, PPP)

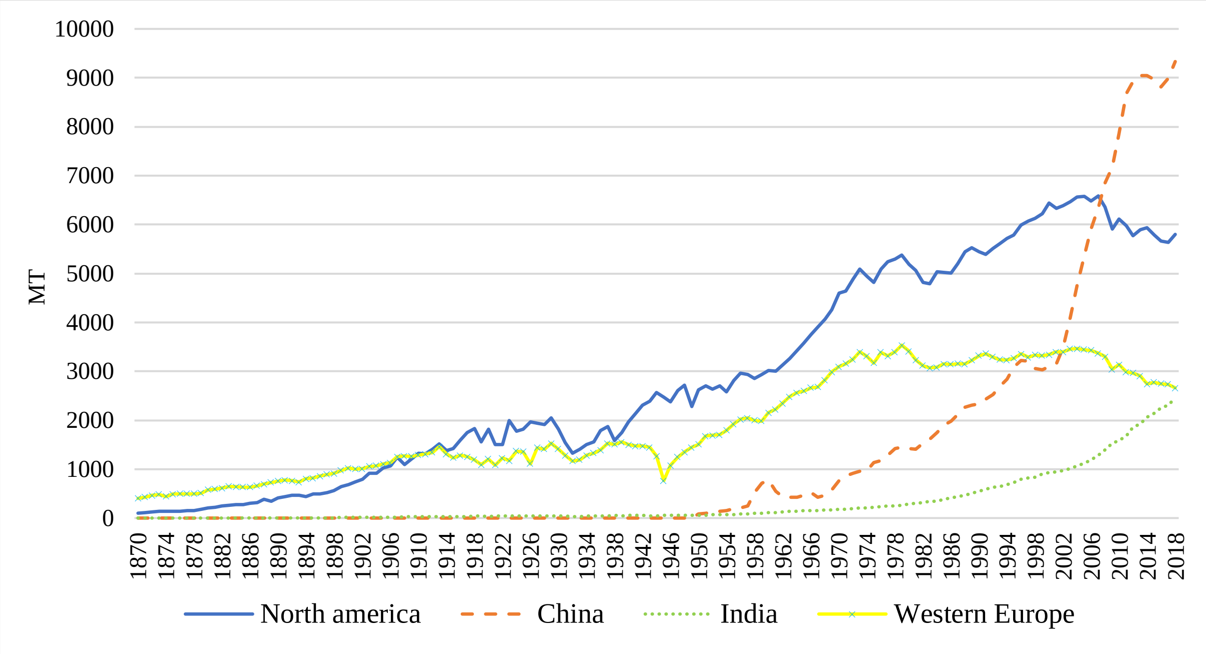
CI	The relation between the CO_2 emitted by a single fuel, and the consumption of total energy	Mt/Mtoe

5 Empirical Analysis

5.1 Data description

The starting point of the data analysis is the aggregate variable of the decomposition model, such as the amounts of CO_2 emitted by the consumption of fossil fuels. As Figure 2 illustrates, there are interesting facts concerning the historical evolution of CO_2 emissions in the four zones (Our World in Data, 2021). The most evident aspect is the exponential rise of the Chinese CO_2 emissions from the beginning of the 21st century. Just in a short period of 10 years, China tripled its carbon dioxide emissions, abruptly becoming the global emitter leader. The leadership position has historically been held by North America during the entire 20th century. The North American trend followed a rapid increase after War World II until the oil crisis in 1973. After that, the North American emissions had an initial slowdown and then increased again until the beginning of the 2000s, and then decreased. The Western European trend was like the North American one. However, after the oil crisis of the 1970s, European emissions did not increase, but remained constant until the 2000s, and then decreased. The Western European CO_2 are today at the same level as the Indian ones. The South-Asian country has increased its emission at a constant rate, during the last four decades.

Figure 2. Total CO_2 emissions, tonnes. North America, Western Europe, China, and India, 1820-2018

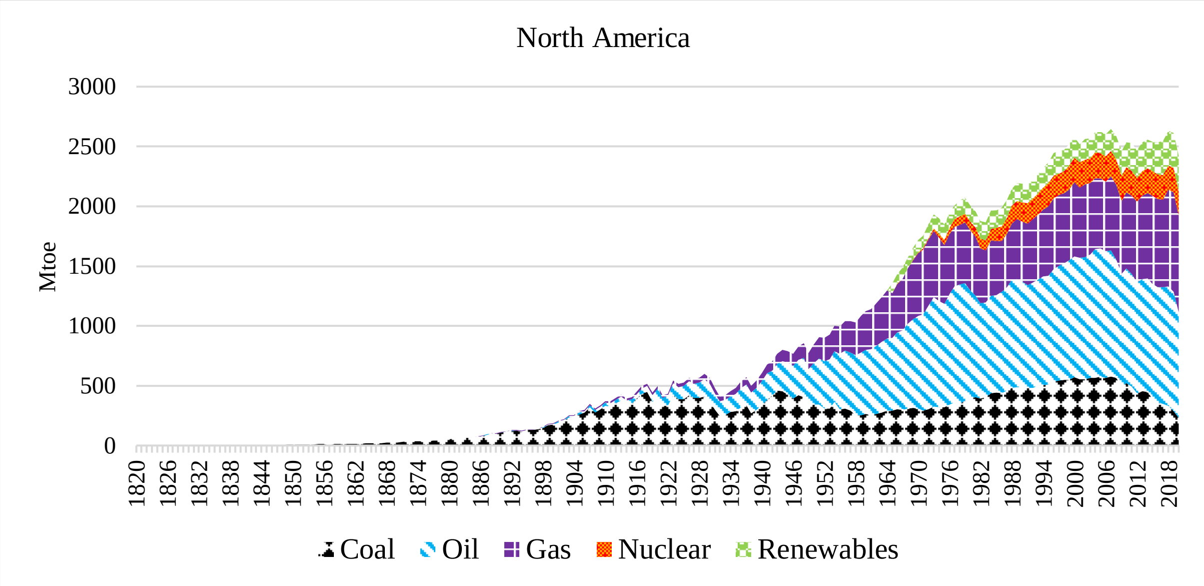


Source: Our World in Data (2021)

The trends in the production of CO_2 represented in Figure 2 are similar to the total energy consumption represented in Figures 3,4,5 and 6 (Malanima, 2020; BP Satistical , 2021). This is because fossil fuels have represented the vast majority of the share of energy consumption. The share of zero-carbon fuels, that is renewables and nuclear power, has been marginal. However, the trends between CO_2 emissions in Figure 2 and the total energy consumption, that is the edges of the graphs here below, are not specular. This is because different fuels emit different amounts of carbon dioxide. As Table 3 illustrates, coal emits a greater amount of CO_2 in comparison to oil and natural gas. The exponential rise in CO_2 emissions of China could be attributable to this since this country has been the greatest consumer of coal since 1987. On the contrary, the reduction of coal usage by Western Europe since the 1950s in favour of other fuels could be one of the reasons behind the reduction of CO_2 emissions in the last four decades. In order to explain changes in CO_2 emissions the decomposition analysis in this thesis will describe the role of fuel substitutions in a more precise way.

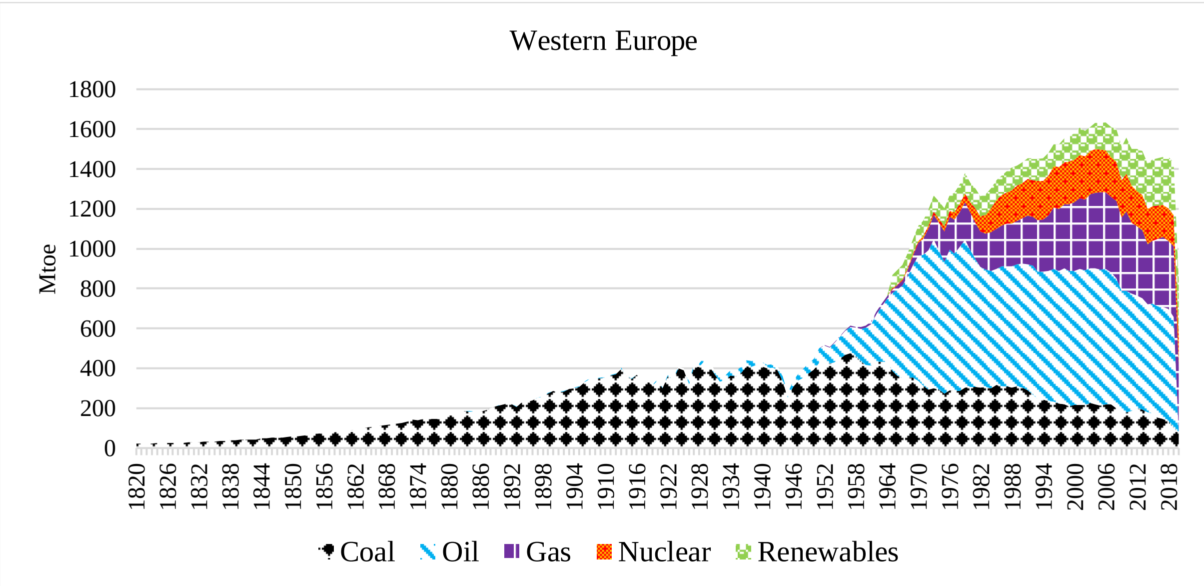
It is important to note that Figure 5 and Figure 6 illustrate the energy consumption by source in China and India after 1965, because of lack of data for a previews period. For this reason, the two figures have been slightly moved to the right of the paper.

Figure 3. North American fuel composition, 1820-2018



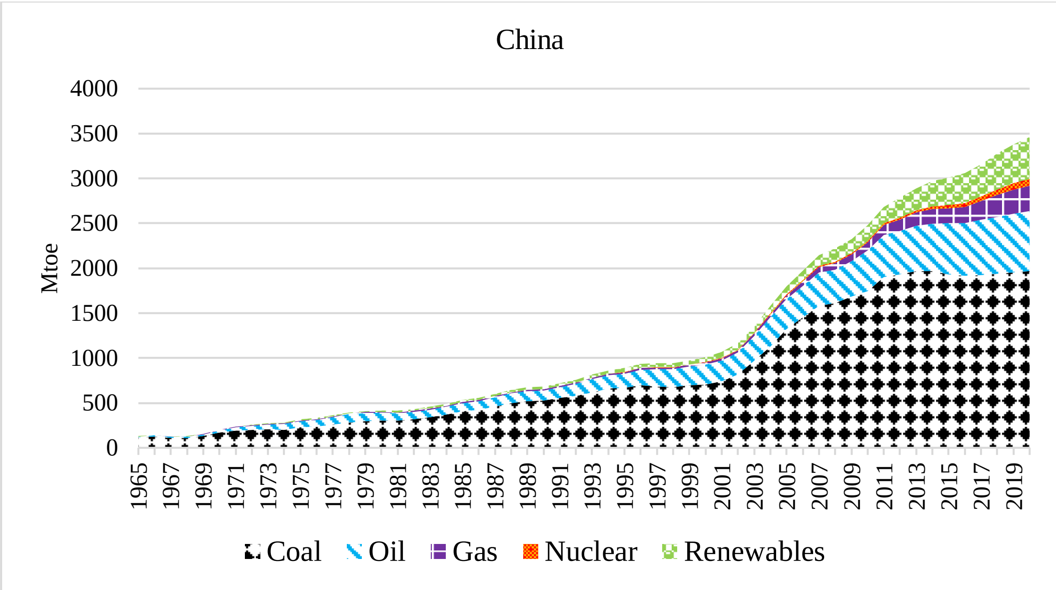
Source: Malanima (2020), BP Statistical (2021)

Figure 4. Western European fuel composition, 1820-2018



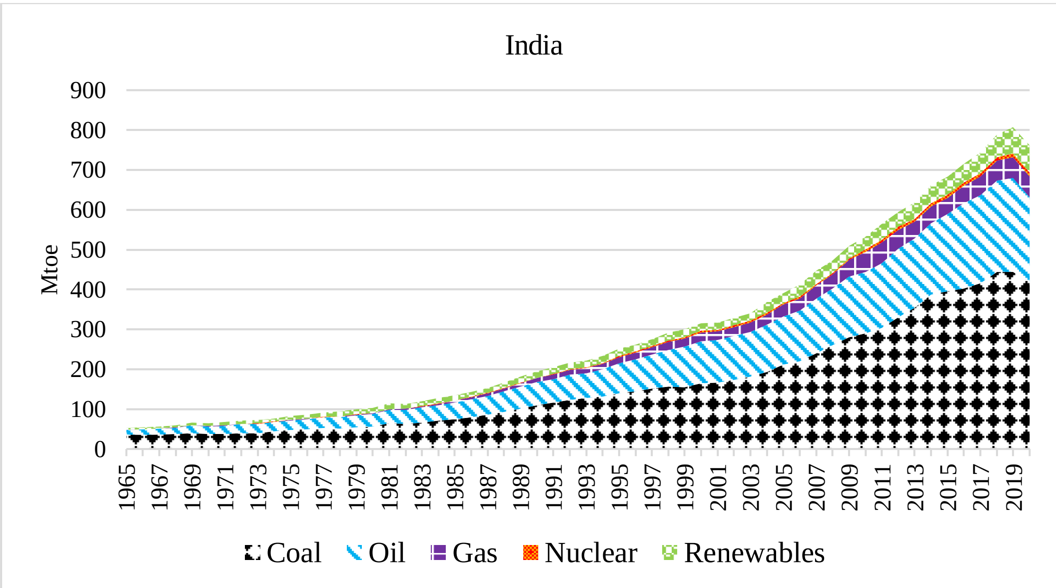
Source: Malanima (2020), BP Statistical (2021)

Figure 5. Chinese fuel composition, 1965-2019



Source: BP statistical review (2021)

Figure 6. Indian fuel composition, 1965-2019



Source: BP statistical review (2021).

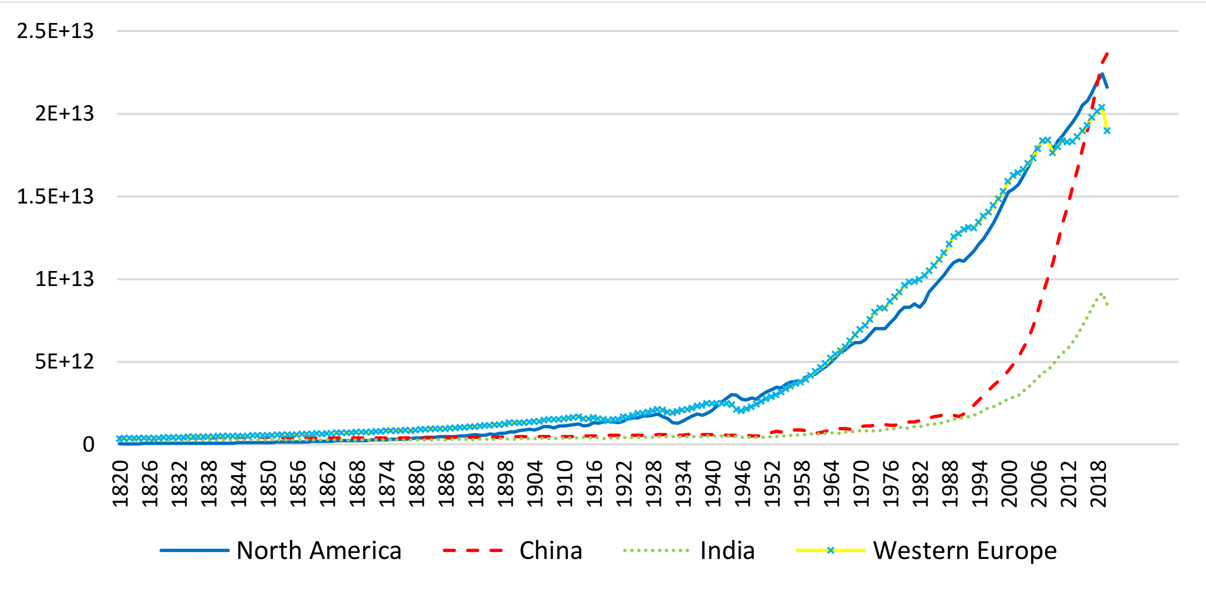
Table 3. Different fuels' CO_2 emission factor, CO_2/Mj

Coal	92
Oil	74
Natural Gas	56

Source: Levander (1991)

The consumption of energy is strictly correlated to economic growth. Figure 7 shows the total GDP trends of our four areas (The Maddison Project Database, 2021). North America and Western Europe develop in a similar way. The GDP trends of the two developed regions and the two emerging economies diverged during the beginning of the 19th century, and the discrepancy grew rapidly by the end of War World II. However, the GDP accumulated by North America and Western Europe in a century has been recovered by China in little more than a decade. By 2019, China has become the global leader in total GDP (PPP). The situation is different for India, which has developed rapidly economically by the end of the 20th century, but with a slower growth rate than China.

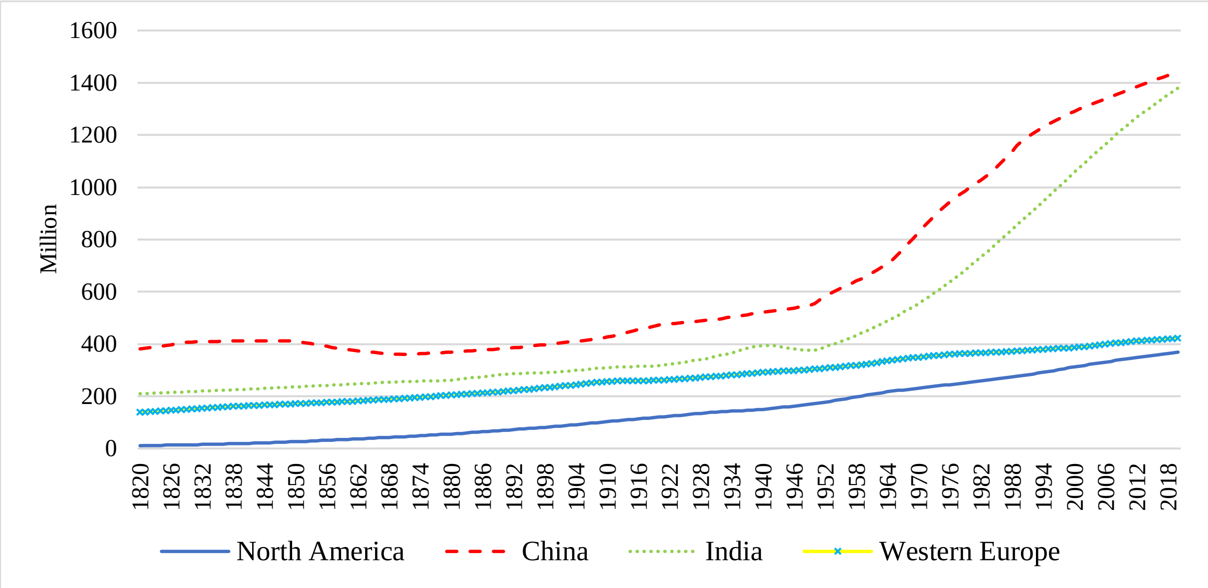
Figure 7. Total GDP, constant PPP $



Source: The Maddison Project Database (2021)

The circumstances are different regarding the demographic history of the four zones. As Figure 8 depicts, the two emerging economies have always shared a greater population compared to North America and Western Europe, especially after the half of the 20th century. China has always had greatest population. However, there is a forecast that the Indian population will overtake the Chinese one by the end of the current decade (The Maddison Project Database, 2021). It is worth noting that the demographic gap between the two emerging economies and the two developed areas is enormous today, with more than 2 billion inhabitants.

Figure 8. Population. North America, Western Europe, China, and India, 1820-2019



Source: Our World in Data (2021)

5.2 Results analysis

The result analysis deserves major attention because it is the most valuable part of this thesis. It describes the results obtained by the decomposition analysis. Firstly, Table 4 is going to show an overview of all the results obtained. Then, there will be a graphic comparison of the four key variables –Population (P), GDP, Energy Intensity (EI), and Carbon Intensity (CI) – of North America, Western Europe, China, and India.

At this point, how to read the results in Table 4? Table 4 schematises to what extent the four key variables have driven a change in CO_2 emission (Mt) from two different periods. This can be explained with an example, taking North America in the second period, from 1918 to 1945. The item "TOTAL" represents the sum of the four key variables. In 1945 North America produced 641 Mt CO_2 more compared to in 1918. This value is the sum of the four key variables. Looking at the table, it is arguable that GDP (+932 Mt) was the main key variable enhancing CO_2 emissions in the period 1918-1945, while improvement in energy intensity (-

719 Mt) and coal substitutions (-782 Mt) in the energy structure were the main drivers of a reduction in carbon emissions.

The results of the amount of 1000 Mt of carbon emissions have been underlined in bold in Table 4. They signify the greatest effects that need special attention. Regarding North America, it is the economic expansion together with a demographic increase that has been the main driver of carbon emissions throughout the 20th century. However, North America has decreased its total CO_2 emissions in the two periods after 2001, and energy efficiency has been the main driver. Similarly, Western Europe in the last three periods has decreased its carbon emissions thanks to improvements in energy efficiency and coal and gas substitutions. Regarding China, after 2001 the East Asian country has had high values in carbon emissions. Economic production has been the main driver. The difference in GDP per capita between 2019 and 2008 has been responsible for the emissions of the dramatic value of 6252 million tonnes of CO_2. However, during this period, energy intensity and coal switching mitigated the total carbon emission. However, the balance of China’s last decade is seriously negative. Nevertheless, India shared a lower value compared to China and the two other developed areas. However, it is worth noticing that in the last period between 2008 and 2019, the GDP variable had an alarming role in an increase in the Indian carbon emissions. What is more, India was the only country in which coal substitution increased the amount of CO_2 emissions in the last period.

Table 4. Complete Kaya decomposition results

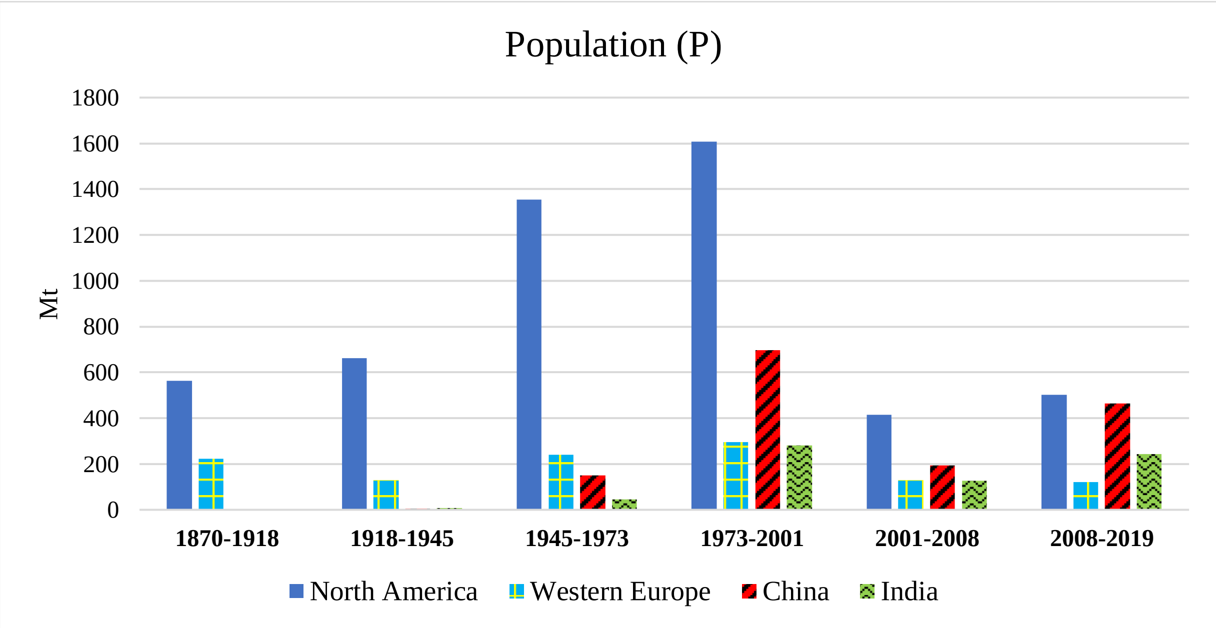
		1870-1918	1918-1945	1945-1973	1973-2001	2001-2008	2008-2019
North America							
Δ CI							
	Coal	-73	-782	**-1501**	526	-14	**-1146**
	Oil	52	427	539	-628	-172	-63
	Gas	31	123	490	-155	44	457
Δ EI		699	-719	120	**-2970**	-924	**-1138**
Δ GDP		464	932	**1612**	**2862**	673	694
Δ P		562	661	**1355**	**1607**	415	501
TOTAL		1735	641	2617	1243	23	-695
Western Europe							
Δ CI							
	Coal	22	-219	**-1022**	-473	-62	-339
	Oil	11	-4	**1379**	-749	-120	-96
	Gas	0	1	208	434	93	0
Δ EI		241	-542	246	**-1574**	-428	-614
Δ GDP		295	201	**1584**	**2070**	287	174
Δ P		222	129	241	294	131	122
TOTAL		792	-434	2636	1	-99	-753
China							
Δ CI							
	Coal	16	-1	-53	-337	473	**-1079**
	Oil	0	1	76	21	-281	57
	Gas	0	0	10	13	7	284
Δ EI		4	29	647	-121	12	**-3342**
Δ GDP		0	-4	74	**1929**	**3287**	**6252**
Δ P		0	5	150	696	195	464
TOTAL		21	29	904	2201	3694	2637
India							
Δ CI							
	Coal	27	2	-52	-11	36	95
	Oil	2	-3	37	24	-48	-23
	Gas	0	0	1	25	-2	17
Δ EI		9	0	104	117	-56	-349
Δ GDP		0	4	14	305	387	**1110**
Δ P		0	9	45	282	127	243
TOTAL		39	12	149	742	445	1093

After this brief presentation of the results, it is time to graphically show a detailed comparison of the four key variables.

5.2.1 *The population (P) effect*

Variations in the demography have always caused an increase in carbon emissions, as Figure 9 illustrates. The most important aspect is the role played by demographic growth in North America. During the 20th century, it was one of the major drivers of carbon emissions. In the third and fourth periods, it contributed to more than a billion tonnes of CO_2 emissions. It is interesting to notice that although China and India share higher demographic values, as Figure 8 illustrates, their demographic change did not provoke great shocks in carbon emissions. This could signify that a change in their demography was not the major driver of carbon emissions. The high values of North America could be attributable to demographic shocks, caused by imbalances between fertility, mortality, and immigration rates. What is more, the high North American values could be the results of the carbon intensive lifestyle of its population. Canada and the United States are ranked between the highest CO_2 emitters per capita (Tiwari, 2011). For this reason, a significant change in their population would provoke a greater carbon emission effect.

Figure 9. The population effect, Kaya decomposition results

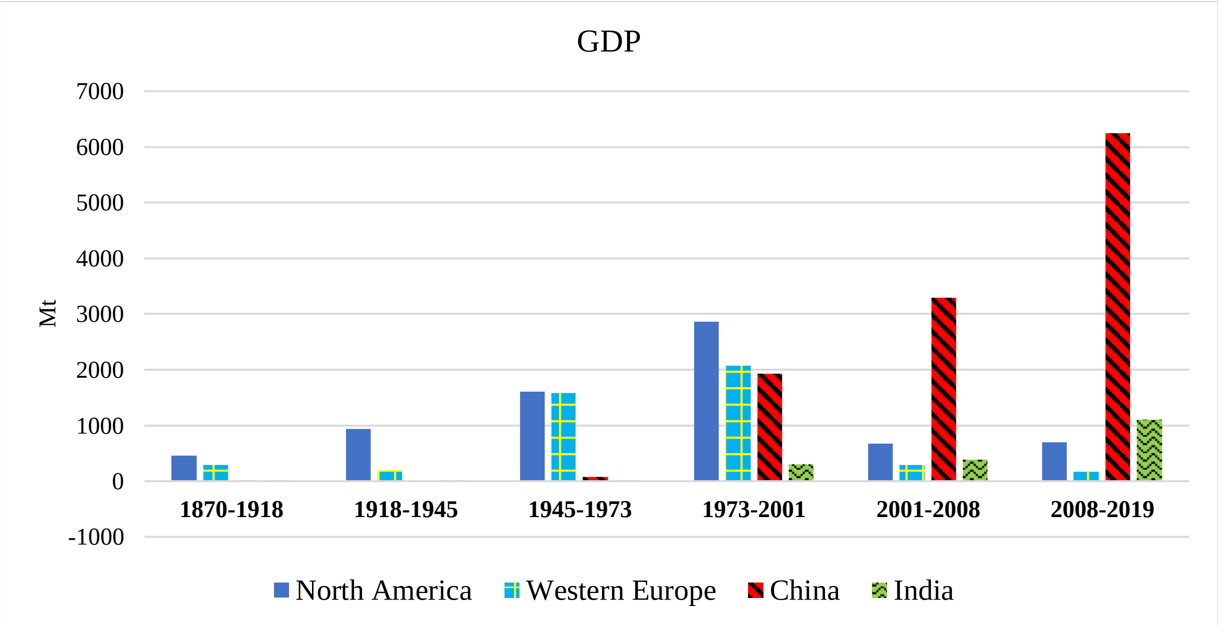


5.2.2 *The income (GDP) effect*

Together with the population variable, the GDP per capita effect was a key variable for an increase in CO_2 emissions, as Figure 10 shows. On the y-axis there are high values, and it is worth remembering that values over the 1000 Mt of carbon emissions are elevated. For this reason, the values of China in the two last periods merit a lot of attention. There is a vast literature confirming that the economic expansion of China after the 2000s has been too fast and disproportionate concerning the environmental degradation that it has caused (Zhang et al., 2009; Ze-yuan & Jiang, 2006). Figure 10 reveals that the comparison between China and developed areas such as Northern America and Western Europe was unequal during the last two periods. China's economic development has been way more of a cause of environmental degradation compared to developed areas. The main finding of the decomposition analysis is that the emissions provoked by the Chinese economic growth of the last two decades, and in particular between 2008 and 2019, cannot be comparable with any other region.

On the contrary, a positive aspect is the strong decrease of the impact of the Northern America and Western Europe GDP variable after the 2000s. Although in these areas there is still constant economic growth, GDP per capita growth has not accounted for significant carbon emissions in recent times. It could be argued that North America and Western Europe are following the EKC, such as a decoupling between environmental degradation and economic growth. However, this is not the case for India. The South-East Asian developing country has scored a significant value of over 1000 Mt carbon emissions during the last period. This value could explain the great attention towards India in recent times and its economic development. There is a great concern about the trends of this key variable for India (Tiwari, Shahbaz, & Hye, 2013). The pathway taken by China could not be a sustainable option for India.

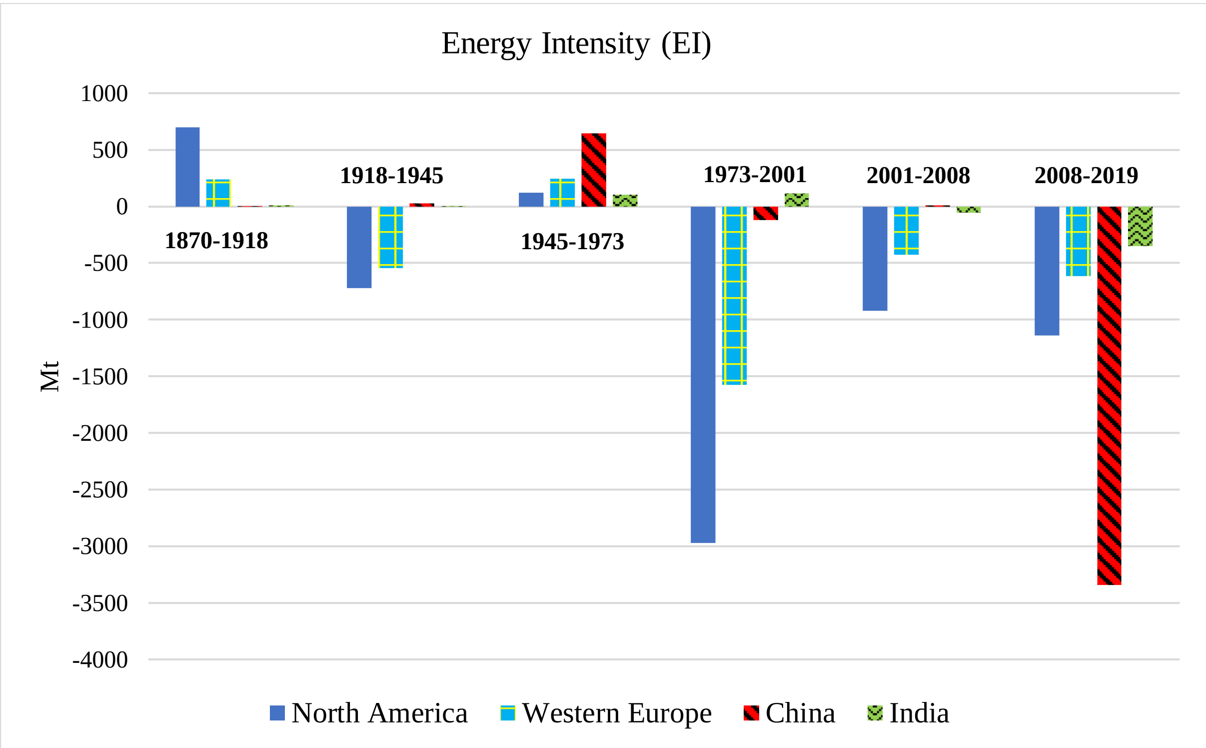
Figure 10. The income effect, Kaya decomposition results



5.2.3 *The energy intensity (EI) effect*

Energy intensity has been the major driver of a decrease in carbon emissions. The most significant results have been reached after 1973, as Figure 11 illustrates. Indeed, during the last three periods developed areas, particularly North America, have reached decreases in carbon emissions due to constant improvement in energy intensity. In contrast, the Chinese situation is different. China had low results in energy intensity in the period between 2001 and 2008. It is worth keeping in mind that the Asian country had high emissions during this time, and improvements in energy intensity could have compensated for such values. Comparing the results in the period 2008-2019 with the previous one, 2001-2008, shows that China learned how to consume energy in a more efficient way in the latter period. The transition from carbon to other fuels is expected to be essential for improvement in energy emissions efficiency.

Figure 11. The energy intensity effect, Kaya decomposition results



5.2.4 *The carbon intensity (CI) effect*

The main point of the carbon intensity variable is the decrease of carbon emissions caused by the switching from coal to other fuels. North America and Western Europe have reached the best results, as Table 5 illustrates. The two developed regions have cut their carbon emissions as result of the transition from coal almost constantly during all the period considered. They reached the best results between 1945 and 1973.

Regarding China, coal transition has recently started to provoke a significant decrease in carbon emissions. On the contrary, India has increased its carbon emission provoked by coal consumption since 2001. Nevertheless, the Indian values are much lower than the ones of the other regions.

Also the other two fuels, oil and gas, play an important role. Oil was the main driver of carbon emissions for the two developed countries before 1973. However, it is important to underline that the values reached by the oil variable during this time were still relatively low, that is lower than 1000 Mt. The highest values were still represented by the coal substitutions. Similarly, the difference in the share of gas of the developed nations has provoked minor shocks compared to the coal variable in carbon emission.

However, the values of the developed areas and the ones of the emerging economies differ greatly. The former ones are much higher. This could signify that a change in the energy mix has played a major role in North America and Western Europe. In developing nations, other variables have played a major role in explaining their carbon emissions.

It is worth remembering that it is not possible to quantify the impact of the shift towards renewable energies and nuclear power. This is because the decompositions aim to decompose CO_2 emissions as the sum of the four key variables. The carbon intensity variable is one of these four. Renewables and nuclear power cannot be part of this variable because they do not produce CO_2. For this reason, although they have a great impact on CO_2 reduction, their effect cannot be captured in this model.

Table 5. The carbon intensity effect, Kaya decomposition results

		1870-1918	**1918-1945**	**1945-1973**	**1973-2001**	**2001-2008**	**2008-2019**
North America	*Coal*	-73	-782	**-1501**	526	-14	**-1146**
	Oil	52	427	539	-628	-172	-63
	Gas	31	123	490	-155	44	457
Western Europe	*Coal*	22	-219	**-1022**	-473	-62	-339
	Oil	11	-4	**1379**	-749	-120	-96
	Gas	0	1	208	434	93	0
China	*Coal*	16	-1	-53	-337	473	**-1079**
	Oil	0	1	76	21	-281	57
	Gas	0	0	10	13	7	284
India	*Coal*	27	2	-52	-11	36	95
	Oil	2	-3	37	24	-48	-23
	Gas	0	0	1	25	-2	17

6 Discussion

In this section the reasons that could explain the results of the decomposition analysis are discussed. It is important to better understand the dynamics behind significant changes in carbon emissions, for the purpose of learning from the unsustainable pathways taken by developed and emerging economies in the past to prevent taking them again. On the other side, this section has the aim to identify the major sustainable policies taken by the four zones. At this point, the main findings of the decomposition analysis, that this section is going to discuss, are the following:

- *The Chinese income (2001-2019)*
  China's economic growth during the periods 2001-2008 and 2008-2019 causes a dramatic increase in carbon emissions.

- *The North American and European energy intensity (1973-2001)*
  Energy intensity in North America and Europe was the main driver of CO_2 reduction during the period 1973-2001.

- *The Chinese energy intensity (2008-2019)*
  Also in China, energy intensity has been the major driver of a drop in carbon emissions, during the period 2009 and 2019.

- *The North American population (1945-2001)*
  In North America, population growth has been a considerable driver of carbon emissions, during the period 1945 and 2001.

- *The Indian income (2008-2019)*
  The recent economic growth of India during the last period, 2008-2019, was responsible of a significant increase in carbon emissions.

The Chinese income (2001-2019)

During the last two decades, the Chinese economy has increased five times and foreign trade has expanded twelve times (Garnaut, 2018). According to Garnaut (2018), the origin of this economic miracle could be attributable to reforms that started in 1978, two years after the death of Mao Zedong. During this time, reformist leaders were conscious of the Chinese economical, technological, and military backwardness. The new political strategy after 1978 adopted foreign trade and foreign direct investment (FDI) as the main instruments to reach rapid economic growth.

The foundations of the rapid development of the Chinese foreign trade lie on export-promotion policies, specialization according to competitive advantage, and admissions into new markets (Drysdale & Hardwick, 2018; Li & Jiang, 2018). The manufacturing industry has been essential for the growth of Chinese export. The development of this sector was the result of the competitive advantage that China had in labor-intensive activities. The industrial sector developed through a process that started with the specializing in resource-based products, and further on in textile, chemical, mechanical, and electronics exports.

Export-promotion policies encouraged the creation of an abundant cheap labor force that permitted China to have a comparative advantage over the rest of the world. Among the main reforms that permitted such development, Garnaut (2018) identifies the organization of the household responsibility system (HRS) and the township and village enterprises (TVEs). Both reforms boosted the productivity of the Chinese economy.

The export-promotion policies started in 1978 paved the way for the event that boosted the Chinese economy enormously, that is the entrance of China into the World Trade Organization (WTO) in 2001 (Li & Jiang, 2018). The WTO membership significantly improved the access to FDI (Chen, 2011). Indeed, the Chinese market has historically been seen as a risky investment, but the WTO accession increased investors' confidence (Armstrong, 2009). What is more, the entrance into the WTO and the access to FDI improved the Chinese economic development in two ways. Firstly, it created employment. In 2014, almost 30 million inhabitants were hired by FDI companies. Secondly, FDI attracted new technology and human capital (Rodik, 2006).

The North American and European energy intensity (1973-2001)

Doblin (1988) identifies three causes as the drivers of a decrease in energy intensity after the oil crisis of 1973. These are the rise of fuel prices, structural change, and technological development. According to the author, changes in the industrial sector had significantly decreased the energy intensity of Western Europe and the United States after 1973. With the oil crisis, the price per barrel more than quadrupled in just one year (Hamilton, 1996), and the industrial sector was deeply influenced by this shock because of the relatively high percentage of oil used. The empirical analysis by Doublin (1988) reveals that the energy intensity decline of Europe and the United States therefore was driven by a decrease in energy use in the industrial sector. The decrease in energy intensity was further enhanced by the fact that industrial production continued to grow, because of technological change and fuel switching strategies (Doublin, 1988).

Similarly, Gales et al. (2007) identify that after 1973 the prices of energy and the structural change within the industrial sector improved the energy efficiency of Western Europe. The utilization of information technology and the advent of the Information and Communication Technology (ICT) revolution played an important role. Although the importance of structural change, technological change has been historically the main driver of change in the long run.

Improvement in energy intensity due to price fluctuations, and structural and technological changes are the positive side of improvements in energy efficiency. However, there is also a negative one, that is the outsourcing of carbon emissions. According to Peters et al. (2011), the decrease in energy intensity of developed countries could be attributable to the outsourcing of carbon emissions to emerging economies countries. Outsourcing of emissions happens when a country involved in foreign trade, reduces its emission domestically but increases the ones abroad (Baumert et al. 2018). It has been estimated that almost one quarter of the global carbon emissions were attributable to international trade in 2004 (Davis & Caldeira, 2010). Peters et al. (2011) find evidence from the fact that developed countries are net importers of emissions while developing are net exporters. In particular, the authors claim that the United States faced a rapid growth in imported emissions from China and others emerging economies, between 1990 and 2008. On the other hand, China's exports accounted for 18 % of the global emissions. The main reason could be that developed countries already have experienced their structural change from the industrial to the service sector and are therefore outsourcing heavy industrial production to developing countries (Castells, 2009).

The Chinese energy intensity (2008-2019)

Energy-saving policies have fortunately permitted China to decrease its energy consumption recently. After the introduction of the Energy Conservation and Emission Reduction (ECER) policy in 2006, China's energy intensity has seen a significant decline. According to Wu et al. (2018), environmental policies could help decrease the Chinese energy intensity by switching from coal to cleaner energy. Many scholars have found evidence that the recent decline in the Chinese energy intensity had to deal with energy price adjustment (Hang and Tu, 2007). According to Hang and Tu (2007), the elasticity of the price of coal increased enormously from 1995 to 2005. What is more, it has been proved that energy price rises stimulate the development of low energy demanding industries and investment in research and development (R&D).

The fuel switch from coal to other fuels after 2010 provoked a decrease in the Chinese energy intensity (Li et al. 2018). From 2010 to 2015, the share of coal as primary energy decreased from 75 % to 69 %. However, the negative side of this result is that coal coal has been replaced by other fossil fuels. What is more, according to the research by Li et al. (2018), the decrease in coal demand could have been just temporary. The authors claim that the use of coal still has not reached its peak. The author's pessimism comes from the fact that China's electricity demand is growing, and it could not be satisfied by other types of fossil and non-fossil fuels than coal. The main sectors demanding this huge amount of electricity from coal are light manufacturing, agriculture, building and construction (IMF, 2019). This is to say that the improvement in the energy efficiency of the last decade could be attributable to changes in the energy mix due to changes in the energy prices. However, this could be just a temporary trend.

The North American population (1945-2001)

The population of the United States faced an incredible population growth during the decades between 1950 and 2000. Demographic factors, that are fertility rates, age-adjusted death rates, and immigration, were the contributors to such an increase. According to Heisler and Shrestha (2011), fertility rates faced a peak in the "baby boom" of the late 1950s, and then they had a decline in the 1960s and 1970s and have remained constant since then. On the contrary, age-adjusted death rates faced a dramatic decline since the 1950s, meaning that the risk of mortality has been falling constantly. Regarding immigration ratios, the trend is the opposite. Immigration has always been an important component of the US population growth. By 1950, the US net immigration rate has always been positive. For this reason, the combination of constant fertility rates, decreasing age-adjusted death rates, and increasing immigration rates led the US population to almost double from 1950 to 2000.

However, population growth di per se is not the only cause of the high values of the population variable in the decomposition studies. What is so special about the population of the United States is the fact that the emissions per capita of its inhabitants have been enormously high (Bhoyar et al. 2014). Other developing countries are experiencing high population growth rates, but the carbon emissions per capita are fortunately still lower than the US ones. Comparing the United States and India today, the developed country's inhabitants emit more than 8 times that compared to the South Asian one (Tiwari, 2011). It is worth noticing that the CO_2 emissions per capita of the United States have remained at a constant and high rate since the beginning of the 20th century. In sum, population growth, together with unsustainable living standards has been the main cause of the results obtained in the decomposition's population variable.

The Indian income (2008-2019)

Between 2013 and 2018 India experienced the greatest global economic growth rates (IMF, 2019). The roots of such an economic success could be attributable to the economic liberalization policies started in 1991. The characteristics of these policies were to make India open to the global market and the service economy. For this purpose, it has been claimed that the inflow of FDI has been paramount. It is sufficient to say that from 1991 to 2019 the inflow of investment from abroad has shifted from 277 million to 50 billion US$ (IMF, 2019). The service sector has attracted the maximum number of investments, and it has been followed by the manufacturing one. Regarding these two sectors, it is interesting to note the position taken by Singh (2019), according to whom the future of FDI in the service sector could be prosperous, but this is not being the case for the manufacturing one. The author claims that the comparative advantage of the Indian manufacturing sector based on low labor cost will not be sustainable in the future. This sector is at present based on low skilled technology and low labor cost, and if this will not change the inflow of FDI is at risk.

Political implications

The main political theme is the concentration of decision-making power (Smil, 2015, p.430). It has been argued that as soon as a society increases its energy consumption, the concentration of these energy resources is disproportionally held in the hands of a few people (Adams, 1975). A good example are the political and economic consequences caused by the decision-making power of a few individuals in Saudi Arabia in 1973. Their decisional power had tremendous consequences for the members of the Organization of Petroleum Exporting Countries (OPEC). The quintuplicating of the price of the oil barrel in 1973-1974 caused macroeconomic shocks, such as high inflation and strong economic degrowth (Yergin, 2008).

In addition, an extreme situation could be represented by the concentration of political power held in the hand of only one person, that could use this power in an aggressive and irresponsible way. This was the case of the decisions without appeal of the communist dictator Stalin. In 1953, the year of the death of Stalin, the URSS energy consumption was 25 times higher than in 1921 (Clarke & Dubravko, 1983). What is more, the dictator's leadership led to the death of millions of people and to an economic disaster. This shows that great energy consumption does not always benefit the society or the economy

7 Conclusions

This thesis makes a historical comparison of the drivers of carbon emissions of two developed areas, North America and Western Europe, and two emerging economies, China and India, between 1870 and 2019. Thanks to the Kaya identity, a particular LMDI decomposition model, it has been established to what extent changes in population, fuel transitions, income per capita, and energy intensity have influenced a change in carbon emissions. To evaluate these changes, the whole period was subdivided into six sub-periods. These sub-periods start with dates that are significant for the economic and energetic development of the four areas. These are the end of the two World Wars (1918 and 1945), the oil crisis (1973), the admission of China into the WTO (2001), and the financial crisis of 2008.

The results depict an overall picture that the four areas follow the Environmental Kuznets Curve. In the decomposition model, North America has started to be carbon negative by the 2000, while Western Europe started to be carbon negative already after the oil crisis. On the contrary the two emerging economies have greatly increased their carbon emissions in the past two decades, mainly because of their economic development. The main drivers of the decreasing trend in carbon emissions in North America and Western Europe are improvements in energy intensity and a switch from coal to other fuels. Particularly relevant are the North American improvements in energy intensity in the period 1973-2001 (-2970 Mt CO_2) and transition from coal between 1945-1973 (-1501 Mt CO_2). The economic development of North America and Western Europe has contributed to increases in carbon emissions. North America and Western Europe reached their peak in the 2001 (+2862 and +2070 Mt CO_2). However, although these values are high, they are not comparable with the enormous results obtained by the Chinese economic growth variable after 2001.

This leads to the main finding of this thesis. The Chinese carbon emissions caused by economic growth after 2001 are not comparable with the development that North America and Western Europe have experienced, and not even with the Indian one. The Chinese economic variable is significantly higher. It was responsible for 3608 Mt CO_2 during the period 2001-2008, and of the incredible value of 6252 Mt CO_2 after 2008. The rapid economic development in China, based on heavy-industrial export and with coal as the main fuel utilized, has been responsible of an environmental disaster, not comparable with other areas.

India is often put side by side with China, but their results are completely different. The impact of the four Indian key drivers on carbon emissions in the last decades has been much smaller in China. The economic development variable in the period 2008-2019 could explain the recent attention to India (+1110 Mt CO_2). Indeed, this high value could justify the worry that India could undertake the same unsustainable pathway taken by China. Fortunately, this seems not to be the case, since the economic structure in India is based mainly on the service sector, as the inflow of FDI confirms.

Regarding the energy structure, the transition from coal had the greatest impact on the decrease of CO_2 emissions in developed countries during the whole period that was studied. Also, for China, the transition from coal had an optimistic impact during the period 2008-2019 (-1079 Mt CO_2). The transition from coal to other types of fuels has become one of the greatest challenges for environmental policies today. In order to maintain the global temperature rise below 2°, as recommended by the IPCC, a substantial reduction of fossil fuels and a transition towards renewable energy is required. This challenge is not impossible, but highly improbable because of the actual dominance of fossil fuels and because of the high demand of energy sources to sustain the economic development of emerging economies. Renewable energy is a key to such a challenge; however, an alternative and accessible pathway on a large scale does not exist yet, apart from the use of fossil fuels. The only solution could be a global international cooperation, a challenge that has yet to occur. The proposal by Professor Harari (2022) is interesting; according to him a global investment of 2 % of single nations' GDP would ensure carbon neutrality in thirty years.

References

Alcamo, J., Bouwman, A., Edmonds, J., Grubler, A., Morita, T., & Sugandhy, A. (1995). An evaluation of the IPCC IS92 emission scenarios. *Climate Change 1994*, Available online http://pure.iiasa.ac.at/id/eprint/4465/ [Accessed 4 May 2022]

Andreoni, V., & Galmarini, S. (2016). Drivers in CO_2 emissions variation: A decomposition analysis for 33 world countries. *Energy*, *103*, 27-37, Available online https://www.sciencedirect.com/science/article/pii/S036054421630158X?casa_token=SLjLf2RF5qcAAAAA:ZZkYrGl70sOollAFpk-s88Ja8Xbgna_Ir9aWobP5KD_qy30EuqMoprKm_PzPDgzDvqGc_uLe1wRh [Accessed 25 April 2022]

Andrew, Robbie M., & Peters, Glen P. (2021). The Global Carbon Project's fossil CO2 emissions dataset, Available online https://www.nature.com/articles/s41558-021-01001-0?__ac_lkid=3298-563f-12b0-cda1789a2ddcc6 [Accessed 25 April 2022]

Ang, B. W. (2004). Decomposition analysis for policymaking in energy:: which is the preferred method?. *Energy policy*, *32*(9), 1131-1139, Available online https://www.sciencedirect.com/science/article/pii/S0301421503000764?casa_token=a77RZtAlbaEAAAAA:svCZpynTs41g0vVKnjQrLIZqmOp1qil5tIQ0qSTTIjzQT3541_M880aibjc85w84JyP6ivUlFTtI [Accessed 4 May 2022]

Armstrong, S. (2009). The Japan-China economic relationship: distance, institutions and politics, Available online https://openresearch-repository.anu.edu.au/handle/1885/109329 [Accessed 4 May 2022]

Baumert, N., Kander, A., Jiborn, M., Kulionis, V., & Nielsen, T. (2019). Global outsourcing of carbon emissions 1995–2009: A reassessment. *Environmental science & policy*, *92*, 228-236, Available online https://www.sciencedirect.com/science/article/pii/S1462901118307536 [Accessed 4 May 2022]

Bhoyar, S. P., Dusad, S., Shrivastava, R., Mishra, S., Gupta, N., & Rao, A. B. (2014). Understanding the impact of lifestyle on individual carbon-footprint. *Procedia-Social and Behavioral Sciences*, *133*, 47-60, Available online https://www.sciencedirect.com/science/article/pii/S187704281403078X [Accessed 25 April 2022]

Bolt, J., & van Zanden, J. L. (2013). The maddison project. *Retrieved October*, *14*, 2019, Available online https://www.rug.nl/ggdc/historicaldevelopment/maddison/publications/wp15.pdf [Accessed 25 April 2022]

Boserup, E. (1983). The impact of scarcity and plenty on development. *The Journal of Interdisciplinary History*, *14*(2), 383-407, Available online https://www.jstor.org/stable/203712?casa_token=w5PP05clh_QAAAAA:crQF5XVp5WsZRiCf-

Y80gJAa0o7JkLehwhMYAcXJ1Km2ieKjk7fnhMe84XaFxOxN_pxzAbLjOUbeldyCbHF009y_qY1hW7j84njicoiM9_HmJZ2PPWiBxw [Accessed 25 April 2022]

BP Statistical Review of World Energy (2021), Primary energy consumption by source. Available online https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html [Accessed 25 April 2022]

Castells, M. (2009). The Rise of the network society Volume 1 With a new preface. *Book The Rise of the network society, Volume 1, With a new preface*), Available online https://onlinelibrary.wiley.com/doi/abs/10.1002/9781444319514 [Accessed 25 April 2022]

Chen, C. (2011). Foreign direct investment in China. *Cheltenham: Elgar*), Available online https://library.oapen.org/bitstream/handle/20.500.12657/33799/458870.pdf?sequence=1#page=213 [Accessed 25 April 2022]

Cole, M. A., Rayner, A. J., & Bates, J. M. (1997). The environmental Kuznets curve: an empirical analysis. *Environment and development economics*, *2*(4), 401-416, Available online https://www.cambridge.org/core/journals/environment-and-development-economics/article/environmental-kuznets-curve-an-empirical-analysis/B58C62C4A38CA2ADA8C20571342E11CD [Accessed 25 April 2022]

Coondoo, D., & Dinda, S. (2008). Carbon dioxide emission and income: A temporal analysis of cross-country distributional patterns. *Ecological Economics*, *65*(2), 375-385.

Copeland, B., & Taylor, M. S. (2001). International trade and the environment: a framework for analysis, Available online https://www.nber.org [Accessed 25 April 2022]

Copeland, B. R., & Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic literature*, *42*(1), 7-71, Available online https://www.nber.org/papers/w8540 [Accessed 25 April 2022]

Davis, S. J., & Caldeira, K. (2010). Consumption-based accounting of CO2 emissions. *Proceedings of the national academy of sciences*, *107*(12), 5687-5692, Available online https://www.pnas.org/doi/abs/10.1073/pnas.0906974107 [Accessed 25 April 2022]

De Bruyn, S. M. (1997). Explaining the environmental Kuznets curve: structural change and international agreements in reducing sulphur emissions. *Environment and development economics*, *2*(4), 485-503, Available online https://www.cambridge.org/core/journals/environment-and-development-economics/article/explaining-the-environmental-kuznets-curve-structural-change-and-international-agreements-in-reducing-sulphur-emissions/3BFA884D433B3BBED01A5EEB25E01BC2 [Accessed 25 April 2022]

Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO2 emissions. *Proceedings of the National Academy of Sciences*, *94*(1), 175-179, Available online https://www.pnas.org/doi/abs/10.1073/pnas.94.1.175 [Accessed 25 April 2022]

Dinda, S., 2004, Environmental Kuznets curve hypothesis: a survey, Ecological Economics 49, 431–455, Available online https://www.sciencedirect.com/science/article/pii/S0921800904001570 [Accessed 25 April 2022]

Doblin, C. P. (1988). Declining energy intensity in the US manufacturing sector. *The Energy Journal*, *9*(2) , Available online https://www.iaee.org/en/publications/ejarticle.aspx?id=1888 [Accessed 2 May 2022]

Dong, K., Jiang, H., Sun, R., & Dong, X. (2019). Driving forces and mitigation potential of global CO2 emissions from 1980 through 2030: Evidence from countries with different income levels. *Science of the Total Environment*, *649*, 335-343, Available online https://www.sciencedirect.com/science/article/pii/S0048969718332972?casa_token=yWxFiF2pqUIAAAAA:GUVgHqBGxLcloUlBmO1_FEzjLIJLdVyGV9vvtiTUBnDrU45XB_ncbGH65A-MsArOla5Ap6VY-qId [Accessed 2 May 2022]

Drysdale, P., & Hardwick, S. (2018). 27. China and the global trading system: Then and now. *CHINA'S 40 YEARS OF REFORM AND DEVELOPMENT*, 545, Available online https://library.oapen.org/bitstream/handle/20.500.12657/29458/book(5).pdf?sequence=1#page=573 [Accessed 2 May 2022]

Fan, Y., Liu, L. C., Wu, G., & Wei, Y. M. (2006). Analyzing impact factors of CO2 emissions using the STIRPAT model. *Environmental Impact Assessment Review*, *26*(4), 377-395, Available online: https://www.sciencedirect.com/science/article/pii/S0195925506000059?casa_token=TFPBmoFqU6oAAAAA:BCUNESC10lUaqX4F39GzDJYvRg4bNt0-pXUNI8MKjegH_xmXqP9Kxo49Qt5aAZS9HXlROCYoYQN3 [Accessed 25 April 2022]

Gales, B., Kander, A., Malanima, P., & Rubio, M. (2007). North versus South: Energy transition and energy intensity in Europe over 200 years. *European Review of Economic History*, *11*(2), 219-253, Available online https://www.cambridge.org/core/journals/european-review-of-economic-history/article/north-versus-south-energy-transition-and-energy-intensity-in-europe-over-200-years/7709FEB12FA28435201256E3C25607EE [Accessed 2 May 2022]

Garnaut, R. (2018). 2. 40 years of Chinese economic reform and development and the challenge of 50. *CHINA'S 40 YEARS OF REFORM AND DEVELOPMENT*, 29, Available online: https://library.oapen.org/bitstream/handle/20.500.12657/29458/book(5).pdf?sequence=1#page=57 [Accessed 5 May 2022]

GCP (2015). Global carbon atlas, Available online: http://www.globalcarbonatlas.org/en/content/welcome-carbon-atlas. [Accessed 25 April 2022]

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement, Available online https://www.nber.org/papers/w3914 [Accessed 2 May 2022]

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, *110*(2), 353-377 Available online https://academic.oup.com/qje/article-abstract/110/2/353/1826336 [Accessed 2 May 2022]

Guan, D., Peters, G. P., Weber, C. L., & Hubacek, K. (2009). Journey to world top emitter: An analysis of the driving forces of China's recent CO2 emissions surge. *Geophysical Research Letters*, *36*(4) , Available online: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2008gl036540 [Accessed 25 April 2022]

Hamilton, J. D. (1996). This is what happened to the oil price-macroeconomy relationship. *Journal of monetary economics*, *38*(2), 215-220, Available online https://www.sciencedirect.com/science/article/pii/S0304393296012822 [Accessed 2 May 2022]

Hang, L., & Tu, M. (2007). The impacts of energy prices on energy intensity: evidence from China. *Energy policy*, *35*(5), 2978-2988, Available online https://www.sciencedirect.com/science/article/pii/S0301421506004137?casa_token=5vl3YZa4C_0AAAAA:AuHsLI2ohfsPS9gXilOzd3fRYvJfpgNLXGefdhNwXVd90Ybh2zqcT5zs5Iu_mAw0AAdQLRinIIx5 [Accessed 2 May 2022]

Harari, Y. N. (2022). Scenari. Per salvare il pianeta basterebbe il 2% del Pil globale, La Repubblica, 22 Januari, p. 46

Heilig, G. K. (1996). World population prospects: analyzing the 1996 UN Population Projections, Available online http://pure.iiasa.ac.at/id/eprint/4882/ [Accessed 2 May 2022]

Heisler, E., & Shrestha, L. (2011). The changing demographic profile of the United States. *Congressional Research Service*, *7,* 5700.

Helpman, E. (1998). Explaining the structure of foreign trade: where do we stand?. *Weltwirtschaftliches Archiv*, *134*(4), 573-589, Available online https://idp.springer.com/authorize/casa?redirect_uri=https://link.springer.com/article/10.1007/BF02773288&casa_token=QG6wfzsjs30AAAAA:beLOXNos0RakK4Xoi9zFQgkE92KPbBaI1VBtcObIt1zY4skcFjwxHmZK3zE4583e0IdOwg8iG3K6gl4gDC8 [Accessed 2 May 2022]

Henriques, S. T., & Kander, A. (2010). The modest environmental relief resulting from the transition to a service economy. *Ecological Economics*, *70*(2), 271-282, Available online https://www.sciencedirect.com/science/article/pii/S0921800910003344?casa_token=itkbKVeHwn4AAAAA:CZOeZn9b2SA9CwHHIRbFTXKbb_abzL95_BmnIToQ37MJ8piKu6BTPXcIbfVovIizemqDWaxzNQx5 [Accessed 2 May 2022]

Heston, A., Summers, R., & Aten, B. (1998). *Penn World Tables*... Computing in the Humanities and social sciences, University of Toronto, Available online https://www.academia.edu/download/30268047/pwt.pdf [Accessed 2 May 2022]

Hoffert, M. I., & Caldeira, K. (2004). Climate change and energy, overview, Available online: https://www.sciencedirect.com [Accessed 25 April 2022]

IEA (2019). International energy agency. CO2 emissions from fuel. IEA statistics, Available online https://www.iea.org/data-and-stati… [Accessed 2 May 2022]

International Monetary Fund, (2019). World Economic Outlook Database. (October 2019). , Available online: https://www.imf.org/external [Accessed 2 May 2022]

Jaunky, V. C. (2011). The CO2 emissions-income nexus: evidence from rich countries. *Energy policy*, *39*(3), 1228-1240, Available online https://www.sciencedirect.com/science/article/pii/S0301421510008748?casa_token=U310CRzM8wwAAAAA:dH0lZLB1q7cQQwAuHyWr1OgxbDxNQ4HxS0wAeRBEDyprowgYWFqJU6pa3f-aJgYw1g2gfOmFNw9 [Accessed 2 May 2022]

Kander, A., Warde, P., Henriques, S. T., Nielsen, H., Kulionis, V., & Hagen, S. (2017). International trade and energy intensity during European industrialization, 1870–1935. *Ecological Economics*, *139*, 33-44, Available online https://www.sciencedirect.com/science/article/pii/S0921800916307765 [Accessed 2 May 2022]

Kaya, Y. (1995). The role of CO2 removal and disposal. *Energy Conversion and Management*, *36*(6-9), 375-380, Available online https://www.sciencedirect.com/science/article/pii/0196890495000259 [Accessed 2 May 2022]

Kijima, M., Nishide, K., & Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey. *Journal of Economic Dynamics and Control*, *34*(7), 1187-1201, Available online https://www.sciencedirect.com/science/article/pii/S0165188910000680?casa_token=WOdj5XzgRSsAAAAA:X60nzOqjcpXUy8dDxHnnMdyUy1nS5q45blqdYjOI6V46Wq3Kqbm7L79iRJ8fKIGcP61sdjD_Kg_5 [Accessed 2 May 2022]

Levander, T. (1991). Koldioxid-Utsläpp och beräkningsmetodik. *Nutek Rapport*, *12*.

Li, K., & Jiang, W. (2018). 28. China's foreign trade: Reform, performance and contribution to economic growth. *CHINA'S 40 YEARS OF REFORM AND DEVELOPMENT*, 575, Available online https://library.oapen.org/bitstream/handle/20.500.12657/29458/book(5).pdf?sequence=1#page=603 [Accessed 2 May 2022]

Lima, F., Nunes, M. L., Cunha, J., & Lucena, A. F. (2017). Driving forces for aggregate energy consumption: A cross-country approach. *Renewable and Sustainable Energy Reviews*, *68*, 1033-1050343, Available online https://www.sciencedirect.com/science/article/pii/S1364032116304178?casa_token=qJeeRxPeSNgAAAAA:XVAl8RupHdEkBu1fIIpZ0hcUwjQiLO4qY9PF2x-Rop-LL5b3Oyj5v33ul8-T1yysj-EdwsXlDqlJ [Accessed 2 May 2022]

Lin, J., Fridley, D., Lu, H., Price, L., & Zhou, N. (2018). Has coal use peaked in China: Near-term trends in China's coal consumption. *Energy policy*, *123*, 208-214, Available online https://www.sciencedirect.com/science/article/pii/S0301421518305871?casa_token=uWYGRkL0Mp0AAAAA:1aCPb6xqvdevSd8kWhnNXjJuxMu4BkzlHHF2Bro-y1Q12a4Np16yv21PHPqYW7wmC41AjeJ_UgpN [Accessed 2 May 2022]

Lutz, W. (2009). The demography of future global population aging: Indicators, uncertainty, and educational composition. *Population and development review*, *35*(2), 357-365, Available online https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1728-4457.2009.00282.x?casa_token=3EdLsGhAegoAAAAA:7-o6aFG8ybDJbGq2E0xLGM3Vj7SCdGyD6Gc0bjXg15PIiL9Hnjf0m3RB9yQBbOUM2ED6wFMA7Ds49clP [Accessed 2 May 2022]

Maddison Project Database. (2018). Population. Available online https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020?lang=en , [Accessed 25 April 2022]

Malanima, P. (2020). World Energy Consumption A Database 1820-2018, Available online https://histecon.fas.harvard.edu/energyhistory/DATABASE%20World%20Energy%20Consumption.pdf [Accessed 2 May 2022]

Marcucci, A., & Fragkos, P. (2015). Drivers of regional decarbonization through 2100: A multi-model decomposition analysis. *Energy Economics*, *51*, 111-124, Available online https://www.sciencedirect.com/science/article/pii/S0140988315001838?casa_token=BDqFqxliVtMAAAAA:CS4aHzPEN43ewOoxjXldwESOC7NSBa_F_qYciEppJ-yO5zYKl77vk0Y5mgZzedGm0rAfnYcVKUaz [Accessed 25 April 2022]

Martínez, D.M., Ebenhack, B.W. and Wagner, T.P. (2019) 'Chapter 1 - Introductory concepts', in Martínez, D.M., Ebenhack, B.W., and Wagner, T.P. (eds) *Energy Efficiency*. Elsevier, pp. 1–33.

Mason, A. (2007). *Demographic dividesnds: the past, the present, and the future*. na, Available online http://www2.hawaii.edu/~amason/Research/Demographic%20Dividends[1].Kobe.2005.pdf [Accessed 25 April 2022]

Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., ... & Waterfield, T. (2018). Global warming of 1.5 C. *An IPCC Special Report on the impacts of global warming of*, *1*(5) , Available online https://apps.ipcc.ch/outreach/documents/451/1551801374.pdf [Accessed 25 April 2022]

Nakicenovic, N., Alcamo, J., Davis, G., Vries, B. D., Fenhann, J., Gaffin, S., ... & Zhou, D. (2000). Special report on emissions scenarios, Available online https://escholarship.org/content/qt9sz5p22f/qt9sz5p22f.pdf [Accessed 4 May 2022]

Okamoto, S. (2013). Impacts of growth of a service economy on CO2 emissions: Japan's case. *Journal of Economic Structures*, *2*(1), 1-21, Available online https://link.springer.com/article/10.1186/2193-2409-2-8 / [Accessed 25 April 2022]

Omri, A., Daly, S., Rault, C., & Chaibi, A. (2015). Financial development, environmental quality, trade and economic growth: What causes what in MENA countries. *Energy economics*, *48*, 242-252, Available online https://www.sciencedirect.com/science/article/pii/S0140988315000225?casa_token=TeIt3RcaQdwAAAAA:eoxxsiL0QFzXy-U-ffSJpdG8bE5vYT1RPw7w3lSKwJKPrltyyWdI8fwlISkzsfoBsOrst8PBL1tR [Accessed 25 April 2022]

Our World in Data. (2021). CO_2 emissions by fuel. Available online https://ourworldindata.org/emissions-by-fuel [Accessed 25 April 2022]

Our World in Data. (2021). World population growth. Available online https://ourworldindata.org/world-population-growth [Accessed 25 April 2022]

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: turning a black box into a policy tool. *Environment and development economics*, *2*(4), 465-484, Available online https://www.cambridge.org/core/journals/environment-and-development-economics/article/demystifying-the-environmental-kuznets-curve-turning-a-black-box-into-a-policy-tool/3410AAB71BDA7A3D6C819B8E1F3ACE14 [Accessed 25 April 2022]

Peters, G. P., Minx, J. C., Weber, C. L., & Edenhofer, O. (2011). Growth in emission transfers via international trade from 1990 to 2008. *Proceedings of the national academy of sciences*, *108*(21), 8903-8908, Available online https://www.pnas.org/doi/abs/10.1073/pnas.1006388108 [Accessed 4 May 2022]

Pincheira, R., & Zuniga, F. (2021). Environmental Kuznets curve bibliographic map: a systematic literature review. *Accounting & Finance*, *61*, 1931-1956, Available online https://onlinelibrary.wiley.com/doi/abs/10.1111/acfi.12648?casa_token=y5k0inSykBwAAAAA:c1mb8skqOWJNHJMtgL2ZwvaDJ3RkW6GZTUNCmHWCBzAVeRcjFxBNQvUli5igAi7IvTsKA3It-5KK71Rz [Accessed 25 April 2022]

Le Quéré, C., Moriarty, R., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., ... & Zeng, N. (2015). Global carbon budget 2015. *Earth System Science Data*, *7*(2), 349-396, Available online https://agris.fao.org/agris-search/search.do?recordID=NL2020065419 [Accessed 25 April 2022]

Rodrik, D. (2006). What's so special about China's exports?. *China & World Economy*, *14*(5), 1-19, Available online https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1749-124X.2006.00038.x?casa_token=w0WTBPSwI9EAAAAA:rStORY0Qt42aXRXUXW57grbuVKDOcet6LQyhrLt59jAXynSdOcyF4C2nTOj40O8ri9Vc2JGUJMYamEA5 [Accessed 25 April 2022]

Schmalensee, R., Stoker, T. M., & Judson, R. A. (1998). World carbon dioxide emissions: 1950–2050. *Review of Economics and Statistics*, *80*(1), 15-27, Available online https://direct.mit.edu/rest/article-abstract/80/1/15/57053 [Accessed 25 April 2022]

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data. *Ecological economics*, *44*(1), 29-42, Available online https://www.sciencedirect.com/science/article/pii/S0921800902002239 [Accessed 25 April 2022]

Singh, S. (2019). Foreign direct investment (FDI) inflows in India. *Journal of General Management Research*, *6*(1), 41-53, Available online https://www.researchgate.net/profile/Shikha-Singh-70/publication/333561209_Foreign_Direct_Investment_FDIin_India_A_review/links/5cf4114e92851c4dd023ffdb/Foreign-Direct-Investment-FDIin-India-A-review.pdf [Accessed 25 April 2022]

Stern, D. I., Common, M. S., & Barbier, E. B. (1996). Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. *World development*, *24*(7), 1151-1160, Available online https://www.sciencedirect.com/science/article/pii/0305750X96000320 [Accessed 25 April 2022]

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World development*, *32*(8), 1419-1439, Available online https://www.sciencedirect.com/science/article/pii/S0305750X04000798?casa_token=ap3SbTrSJgcAAAAA:aB2KGM5QvPLiY8X78a8eVG1PRu3LKGXZIZiS2nf9_vuedcSHWQmOSuIztY_BnxsFsjJr-zRIOfRM [Accessed 25 April 2022]

Stevens, C. (1995). Freer Trade, Protected Environment: Balancing Trade Liberalization and Environmental Interests, Available online https://www.jstor.org/stable/3146721?casa_token=k-NHktB78e0AAAAA:QV1Y5itDKf-IERAv5s8NK5_JbAjl5wfvivDLE9Xe_F0cb0iZ-SQncS1_uGpZ7yWZvGnkD7EYPG1lhtb09u1nNXtY9_r9RetC_C5iXC6ntONEscSM8rfD-w [Accessed 25 April 2022]

Stocker, T. (Ed.). (2014). *Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge university press, Available online https://books.google.com/books?hl=it&lr=&id=o4gaBQAAQBAJ&oi=fnd&pg=PR1&dq=Stocker,+T.+(Ed.).+(2014).+Climate+change+2013:+the+physical+science+basis:+Working+Group+I+contribution+to+the+Fifth+assessment+report+of+the+Intergovernmental+Panel+on+Climate+Change.+Cambridge+university+press&ots=WhoA8MJsOi&sig=hUwBQJkFYUdtH6LajLU19U6Mskw [Accessed 25 April 2022]

Stokey, N. L. (1998). Are there limits to growth?. *International economic review*, 1-31, Available online https://www.jstor.org/stable/2527228?casa_token=mEqz_X5HDgkAAAAA:nYzkZzrWbGDNdlzS3yK9TZFYVeflF_5rUV1a6BtYZkYjnDg_2zD_uVcJHla3G3jiKOUH5PJMBEtz-S2Amq2TB9SgjRkcVltuIMHbBYVXm615vw2TU280gA [Accessed 25 April 2022]

Su, B., & Ang, B. W. (2012). Structural decomposition analysis applied to energy and emissions: some methodological developments. *Energy Economics*, *34*(1), 177-188, Available ‘online https://www.sciencedirect.com/science/article/pii/S0140988311002374?casa_token=1EdE8j2XmL8AAAAA:QZhkEclAhXDSLMfDg8qjggrtrE7ZJK7Z3JfYT0MR8L74vca_V9iNXBOG3_I4uciFV33TDJgsIewz [Accessed 25 April 2022]

Suri, V., & Chapman, D. (1998). Economic growth, trade and energy: implications for the environmental Kuznets curve. *Ecological economics*, *25*(2), 195-208, Available ‘online https://www.sciencedirect.com/science/article/pii/S0921800997001808 [Accessed 25 April 2022]

Tavakoli, A. (2018). A journey among top ten emitter country, decomposition of “Kaya Identity”. *Sustainable cities and society*, *38*, 254-264, Available online https://www.sciencedirect.com/science/article/pii/S221067071731291X?casa_token=R8fUjDXwBQQAAAAA:bhUsqcd7Y7zNn_k0jVwnme9iFtC8KpwC4gqhRj_Cr2HXO9PklnGNo_3ZiAhhHsHsBzAsAlWnqtaF [Accessed 25 April 2022]

Tiwari, A. K. (2011). Energy consumption, CO2 emissions and economic growth: Evidence from India. *Journal of International Business and Economy*, *12*(1), 85-122, Available online https://www.academia.edu/download/38066299/2011_121-5.pdf [Accessed 25 April 2022]

Tiwari, A. K., Shahbaz, M., & Hye, Q. M. A. (2013). The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. *Renewable and Sustainable Energy Reviews*, *18*, 519-527, Available online https://www.sciencedirect.com/science/article/pii/S1364032112005734?casa_token=bdkFHBcszgQAAAAA:0eeBkmSY2QEbFq-rUEpcoWFpbzTTpJew1SjX8anpq3nwdPq0gonDPzxR1tJ7lg530tBTd64Mok-I [Accessed 2 May 2022]

Torras, M., & Boyce, J. K. (1998). Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. *Ecological economics*, *25*(2), 147-160, Available online https://www.sciencedirect.com/science/article/pii/S0921800997001778 [Accessed 2 May 2022]

Voigt, S., De Cian, E., Schymura, M., & Verdolini, E. (2014). Energy intensity developments in 40 major economies: structural change or technology improvement?. *Energy Economics*, *41*, 47-62, Available online https://www.sciencedirect.com/science/article/pii/S0140988313002405?casa_token=6-KZmWvKKUYAAAAA:AuYyNKdi_ooRk6WjHtT-xa-nkGPtalpCcgBoVpGBcBFSnX-0fgtjFxd_peYBaEYllLItTJLP404W [Accessed 2 May 2022]

Wang, W., Li, M., & Zhang, M. (2017). Study on the changes of the decoupling indicator between energy-related CO2 emission and GDP in China. *Energy*, *128*, 11-18, Available online https://www.sciencedirect.com/science/article/pii/S0360544217305662?casa_token=0rkHQGHeUX4AAAAA:kXgdkALCmE5hkGz0kGIHggqAqNCbw7STK2QkUXTUzX5-XVwiJkKpUeJCSVuw8t0DgQU-wXXfwydw [Accessed 25 April 2022]

Xiaowei, X., & Gallagher, K. S. (2014). Prospects for reducing carbon intensity in China. *The Centre for International Environment and Resource Policy, Tufts University, Medford*, (008)

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. *Ecological economics*, *46*(3), 351-365, Available online https://www.sciencedirect.com/science/article/pii/S0921800903001885 [Accessed 25 April 2022]

Wing, I. S. (2008). Explaining the declining energy intensity of the US economy. *Resource and Energy Economics*, *30*(1), 21-49, Available online https://www.sciencedirect.com/science/article/pii/S0928765507000164?casa_token=ZTroGJJe5qoAAAAA:8nL-jf91dgi3YHLclfNnWypfCyXTi9sh-Cvf4cFJZc8kI7mkSlbam4Q0e8hHyfnNpa0L2HM3VsdS [Accessed 25 April 2022]

Wu, J., Wu, Y., Cheong, T. S., & Yu, Y. (2018). Distribution dynamics of energy intensity in Chinese cities. *Applied Energy*, *211*, 875-889, Available online https://www.sciencedirect.com/science/article/pii/S0306261917315416?casa_token=smSIbbCCc5MAAAAA:7Wp1-31SZjwb5LuGzcoFcJMsnNZkXJbGpSm9rVAfnLCkd6id_lX0gBjQNBS_ekrM7CwYy730ikMZ [Accessed 25 April 2022]

Zhang, M., Mu, H., Ning, Y., & Song, Y. (2009). Decomposition of energy-related CO2 emission over 1991–2006 in China. *Ecological Economics*, *68*(7), 2122-2128, Available online https://www.sciencedirect.com/science/article/pii/S0921800909000627?casa_token=XC3nV-

1GHB0AAAAA:eJTjwx5S81D3o0ZFSbZg4ouXsYLJBdjMtbjEASCeCZ4RIjykSrVng795q1xnshhAgW9a1vHVfGfA [Accessed 25 April 2022]

Ze-yuan, X., & Jiang, Z. H. (2006). Decomposition model and empirical study of carbon emissions for China, 1995-2004. *China Population Resources and Environment*, *6*, 029.