Master Thesis

M.Sc. Management of Technology

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The Effectiveness of Climate Change Policies for Decarbonization; a Comparison Between India and the UK

Amritasree Menon

(4717201)

(A.P.Menon@student.tudelft.nl)

Chairperson: Dr. Cees van Beers

First Supervisor: Dr. Servaas Storm

Second Supervisor: Dr. Udo Pesch

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Executive Summary

The idea that the world has been going towards climatic catastrophe is not new and should not be the cause of much surprise within academic circles. Climate change has been largely attributed to global temperatures rising over the years. This has been further mitigated by the increased usage of fossil fuels, deforestation, increased livestock farming, and chemical emissions, as a result of the large-scale industrialization of developing nations, combined with the increased consumption of goods and services all across the world (Steffen et. al., 2018). While separate research can be conducted in individual fields, it has become increasingly apparent that interdisciplinary research is imperative. The Kaya Identity was formulated by Yoichi Kaya to form a relationship between carbon emissions and economic and technological factors. The Kaya Identity has since been a mainstay of analyzing carbon emissions by internationally acclaimed bodies like the United Nations.

The Kaya Identity is: $C \equiv \frac{C}{E} \times \frac{E}{Y} \times Y$, where, C = CO_2 emissions (in million tonnes); E = total primary energy supply or TPES (in kg Oil Equivalent); and Y = GDP (Gross Domestic Product in US dollars at a constant prices). The identity was transformed to; $C = y \times c \times e \times p$. The carbon intensity of output, the amount of carbon emitted per unit energy is denoted by $'c'$. The energy intensity of output, the amount of energy consumed per dollar of GDP output, is denoted by $'e'$. Together $'c'$ and $'e'$ form the 'technological factors' for the study. The scale factors, influenced directly by economic and population growth, are denoted by $'y'$, which is GDP per capita, and $'p'$ which is population.

To specify the research objectives a few research questions were asked: What form have policies to curb carbon emissions taken until now and what are the main points of differentiation between developed and developing countries? Using the Kaya Identity framework, what have been the main trends in energy efficiency and carbon intensity, thus identifying the main factors that policies have been aimed at correcting? What are the trends in energy efficiency and carbon emissions in each of the main sectors of the economy: transport, industry and manufacture, energy and heat, and buildings? What are the main deep decarbonization pathways which can be implemented by a developing economy (India) and a developed economy (the United Kingdom)? Some sub-questions are further posed in the main body of the document to further direct the line of questioning.

In the research methodology of this thesis, the growth in carbon emissions was decomposed over the time period from 1970 to 2014, again using a variation of the Kaya Identity which accounts for growth; $\hat{C} = \hat{y} \times \hat{p} \times \hat{e} \times \hat{c}$. The years also split into three time periods to account for major economic changes, like the 1991 liberalization of the Indian economy, and the 2008 economic crisis. The time periods thus were 1971-1991, 1991-2008, and, 2008-2014. Chapters

three to seven of this document decompose the metadata taken from the World Bank database. Chapter three does a total carbon decomposition across all sectors of the economy, and the following do a sector-wise decomposition across the major sectors; transport, industry and manufacture, energy and heat, and buildings.

The results of the decomposition showed that while the United Kingdom showed a decreasing trend in carbon emissions over time, India has shown an opposite trend. Also, the results showed that technological factors have had a sufficient impact in offsetting carbon emissions in the United Kingdom, shown by negative growth percentages. Similar trends are observed in most individual sectors in the UK, except for the building sector, where the technology factor has not sufficient to offset the scale factor, showing us that it is a sector which needs particular focus. In India it is evident that the effect of technological factors needs to be enhanced, since the scale factors will. In each of the chapters, policies which were implemented for corresponding sectors looked at as well. We see that while the United Kingdom has actively implemented policies, and are thus bearing the fruits of improved air quality, India has not done so with the same vigour.

After the decomposition, a regression analysis was done till the year 2050 to predict the future trends of carbon emissions, followed by a stakeholder analysis of a possible technology in each sector. While the United Kingdom aims for zero carbon by that time, and seems to be well on its way to achieving it, India is on quite a different path and shows no sign of slowing down. From the second law of thermodynamics which states that the entropy of a system only *increases*, we can infer that energy efficiency can never be perfect, or 100%, so we focus on solutions based on clean technologies and decarbonizing existing industrial processes. A two-phase solution is suggested; first by integrating carbon capture technologies into existing industrial methods, followed by large-scale investments into the research and development of technologies with a much higher efficiency which have a greater chance of mass acceptance into society and industry without discounting important stakeholder values. Since it is clear that immediate action also needs to be taken, a two phase program will reduce the rate of carbon emissions released into the environment till truly sustainable result can be achieved, considering that CCS technologies also have their flaws. Cleaner energy sources and cleaner methods of processing energy would be the focus of these long-term changes.

There is no question that this research is important to understanding the emission data of the largest democracy in the world. From the decomposition and the subsequent analysis of technologies and policies, the implementation of decarbonization pathways which have impacted the United Kingdom can thus be calibrated for the Indian context can now be considered by policymakers.

Chapter 1 - Introduction

1.1 The Earth is Warming.

In 2013, the Intergovernmental Panel on Climate Change (IPCC) concluded in its authoritative fifth assessment report that "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased". The IPCC experts also concluded that “Human influence on the climate system is clear.” Global warming has been building up to such an extent that there is a considerable risk that it is becoming ‘dangerous’ and unmanageable. Such ‘dangerous warming’ will be extremely damaging. For instance, it would massively disrupt crucial weather patterns like the monsoons, causing water shortages affecting millions of people, and this might be too much to cope with. It also risks becoming unstoppable and irreversible, once we cross certain climate thresholds (Steffen et. al., 2018).

Global temperatures have been found to have increased over the years (fig. 1.), a process which is further accelerated by the increased usage of fossil fuels, deforestation, increased livestock farming, and chemical emissions, particularly caused by the industrial revolution. Since the industrial revolution, the manufacturing sector has transformed completely from small-scale cottage industries to large-scale fossil-fuel-intensive mechanical production. As of 2019, it has been reported by the National Aeronautics and Space Administration (NASA) that the global average temperature has increased by 0.85 degrees (compared to pre-industrial temperature) – (Sanchez-Lugo, 2019). It must also be registered that the temperature increase has not been uniform across the Earth, and important ecosystems are heating up or cooling down disproportionately, resulting in calamitous damage to flora and fauna. The resulting changes in weather patterns affect agriculture too, further fueling the world hunger pandemic too.

The seemingly small change in global average temperature has resulted in the loss of biodiversity from delicate regions across the world, and more droughts and heat waves are predicted to affect the general human population as well. This can be attributed mostly to anthropogenic activities, most importantly the use of carbon-intensive fossil fuels as our energy sources in production, transportation, construction, refrigeration, agriculture, farming practices, deforestation, and urbanization (Khetrapal, 2018). Of these factors, urbanization has caused the most perceptible changes, as is especially visible in cities in countries of higher population densities, like New Delhi, in India. This is especially so because of the replace of trees, and green foliage, which cool the environment through evapotranspiration, with steel and concrete buildings built with technology which have not yet advanced into self-cooling systems. Environmental disasters are also guaranteed to result in major financial damage. It is clear that the world we know today may cease to exist within a matter of three or four decades if a concerted effort is not put into averting or mitigating further damage.

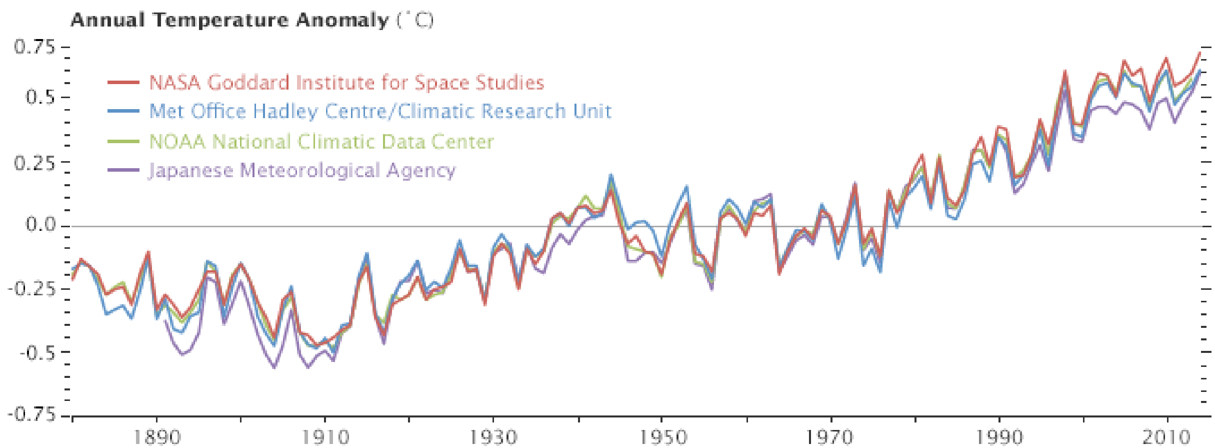

Figure 1: Increase in global average temperature since the 19th century (Source: https://earthobservatory.nasa.gov/world-of-change/DecadalTemp)

'Annual temperature anomaly' refers to the variation in global temperature per year with respect to the average global temperature across a period of three decades. As is clear in figure 1, various environmental agencies of repute have consistently recorded increasing average global temperatures since the 1940s.

The worldwide environmental movement is marked by the inception of official studies to understand and analyze the (accelerating) process of global warming and accompanying occurrence of catastrophic environmental events around the world by scientists, engineers, economists, and policymakers alike. Starting with the focus on reducing global CO2 emissions, in November 1998, the United Nations, specifically, the UN Environment Program (UNEP), and the World Meteorological Organization (WMO), formed the 'Intergovernmental Panel on Climate Change' (IPCC) to begin formal talks to address the management of extreme climate events and disasters (Dowson & United Nations, 2019). The 'Intergovernmental Negotiating Committee' (INC) was established in December 1990 to begin forming binding targets and timetables to reach emission reduction goals, involving 'financial mechanisms' and 'technology transfer', focusing on the 'common but differentiated' responsibilities of countries.

1.2 Carbon emissions are still rising, but have to be reduced.

Notwithstanding the growing awareness that global warming is happening and potentially dangerous, global carbon emissions continue to rise. With the advent of the internet, the exponentially larger-scale outsourcing of global manufacturing practices to countries like India and China, the smoother movement of goods and services across the world has been facilitated in a phenomenon which economist Thomas Friedman refers to as the ‘flattening of the world’, there seems to be no foreseeable reduction to the sources of carbon emissions. Along with the increase in economic growth, through increase in productivity and access, the impact that this change has brought on the environment is unmistakable. Since a distinct relationship between emissions and economic growth can be identified, international leaders set themselves to developing climate change policies and agreements. Beginning with the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 which aimed to “stabilize the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (United Nations Framework, 1992). Upon entering into force in 1995, the UNFCCC was further bolstered by the Kyoto Protocol, in 1998, which aimed at recognizing that individual countries should have different obligations based on their activities, both historically and at present, and was more absolute and legally binding (Dowson & United Nations, 2019). In December 2015, the Paris Agreement was signed by 195 UNFCCC members with the ultimate goal of limiting the increase in global overall temperature to 2^{o} centigrade, and all measures are to be taken to reduce temperature change to 1.5^{o} centigrade.

The IPCC (2018) has defined targets for the reduction in global CO2 emissions, which are consistent with pathways in which global average temperatures rise by less than 1.5 or 2 degrees Celsius (with a 66% probability). To attain these desired results in the coming decades, the global carbon emission levels have to reach net ‘zero’, by the year 2050, where the anthropogenic emissions are equal to its removal by carbon sinks; natural ‘reservoirs’ containing chemicals which have a tendency to store carbon, or carbon sequestration. Accepting the conclusion that carbon emissions are the main cause of the temperature rise, governments have started implementing policies which are aimed at reducing industrial, agricultural, waste, and domestic emissions (Meckling, Sterner, & Wagner, 2018). Such policies fall under the umbrella-term of ‘Decarbonization policy’. They are usually implemented in a two-pronged manner: by promoting higher energy 'efficiency' clauses in policy by encouraging cleaner technologies possibly through increased funding or subsidies, or ‘reduced consumption’ policy aimed at lowering emission through minimizing lifestyle habits in the population and reducing inputs into industry. Reduction of consumption is largely done through ‘carbon pricing’ where emissions are priced either through a ‘carbon tax’ or a ‘cap-and-trade’ mechanism (Meckling, Sterner, & Wagner, 2018). Together with research and development subsidies, these policies have been held by economists to be the most cost-effective decarbonization pathway.

1.3 The need for (deep) decarbonization

Historically, economic growth and higher (material) standards of living are associated with and based on higher per capita energy use and higher per capita CO2 emissions. The relationship is illustrated in Figure 2. While high-income (developed) countries have the resources to reduce CO2 emissions and aim at a zero percent growth in emissions, the challenges facing the low-income (developing) countries are bigger: these countries want to grow their economies and raise living standards, but at the same time find themselves having to aim at lower rates of emission growth by the year 2050.

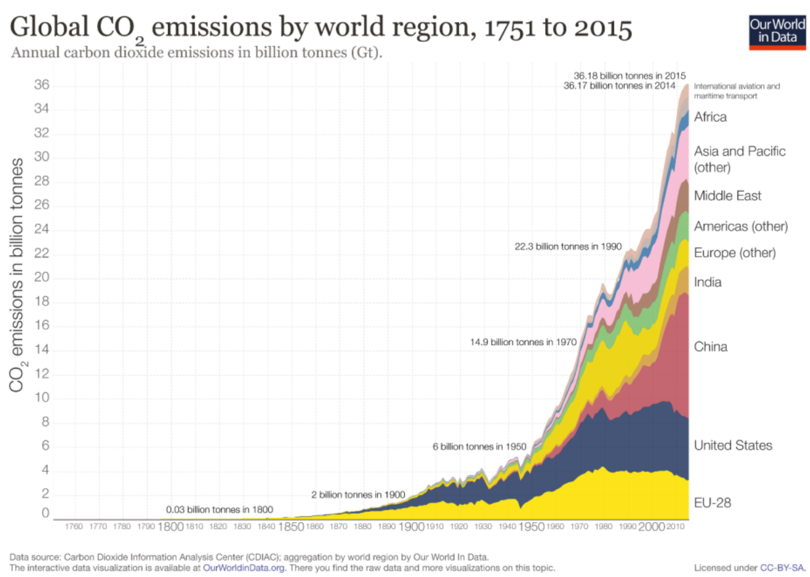

Figure 2: Global Carbon Dioxide Emissions, 1791-2015 (Source: ourworldindata.org)

Developing countries thus have to solve the double-edged problem of ensuring economic development with the tightening carbon constraint. To do this, they have to reduce the carbon intensity of Gross Domestic Product (GDP) which is the amount of carbon emitted per dollar of output in each country. Certain economists (Campagnolo & Davide, 2017; Rovere, Grottera, & Wills, 2018) argue that this increased pressure on developing countries is unfair, since developed countries were able to increase production efficiency manifold without any limitations. The Deep Decarbonization Pathways Project (DDPP) was formed as a global collaborative to research and develop appropriate solutions tailored to the national requirements of each country, developing and developed. Liobikiene and Butkus (2018) in their paper on 'Climate Change Policy on Different Stages of Economic Development' begin with the assumption that increased economic development immediately prompts increasing rates of greenhouse gas (GHG) emissions. They also find that outsourcing production to low-income countries was a common by-way that high-income countries took to overcome the emission problem, while low-income countries suffered both the heightened carbon constraints on them and the ecological damage, with the related economic damage.

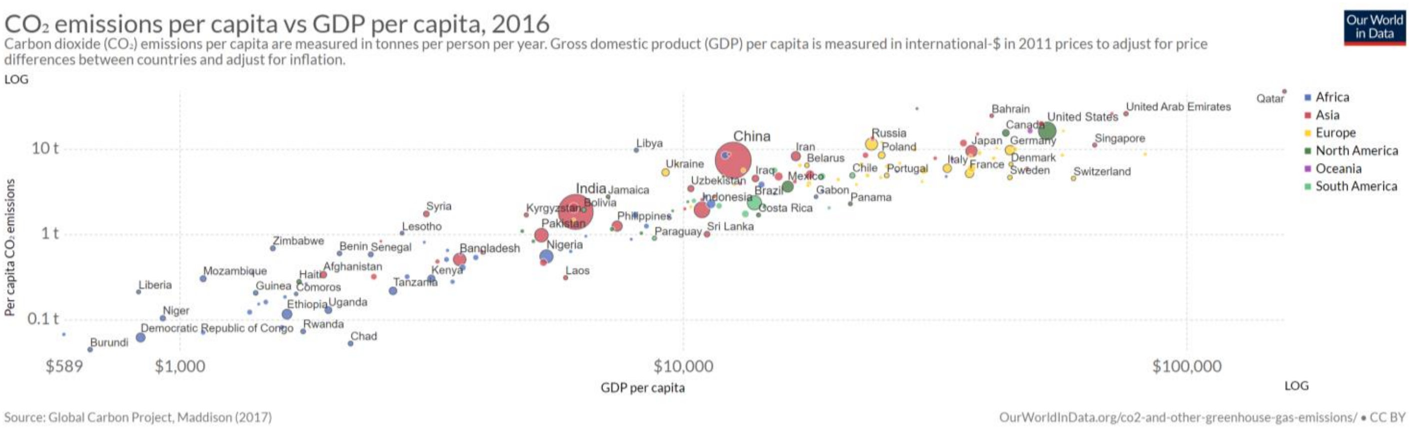

Figure 3: Carbon Emissions of some countries, showing a relationship between GDP and Carbon Emission (source: ourworldindata.org)

We also see in figure 3 that CO2 emissions per capita vs GDP per capita in the year of 2016 also shows a lot of variation between countries. India and China display the largest ratios possibly taking into consideration the massive populations of the countries in contrast with the emission rates of the middle and upper classes. While the poorer margins of society get almost nothing to live on, the rich upper class can afford to live extravagant lifestyles, consequently producing emissions at rates which overpower the per capita income rate of the country. The United Kingdom on the other hand does not even feature on this graph due to its relatively low emission rate per capita. An anomalous result on this figure is also the larger circle representing the United States. It may thus be interesting to note that Americans, whilst living in a developed country, seem to still be producing carbon emissions at higher rates than other developed contries. While this may be a genuine social problem which exists in developing countries of such scale, it is not tackled in this thesis report. Instead, this thesis focuses on economic productivity, assuming mostly utilitarian economics, and the correlating behavioural patterns in both developing and developed countries.

Many studies (Burke & Csereklyei, 2016; Shanker & Stern, 2018; Vale, 2015) have been carried out to identify possible relationships between the productivity and economic growth of countries, and their emission rates in an attempt to identify solutions, the most famous of which is the 2015 Paris Agreement. The Paris Agreement attempted to provide a common framework to recognize key sectors which could benefit from decarbonization within a country, using unique domestic dimensional analysis, and to open a forum for international cooperation.

Decarbonization also affects growth by altering market efficiency. In the real world, markets do not always work according to theory. Many market imperfections plague the system and the predictive capabilities of economists and market scientists can be severely limited, so, policy changes may not have the effects that are anticipated. For example, the carbon tax implemented by some countries may act to increase economic efficiency, but it may only be to the extent of any fuel subsidy that has also been implemented. Occasionally, a policy instrument which reduces fossil-fuel consumption may also act to increase the fiscal revenue of governments, which can be taken advantage of to lower existing taxes in the country.

Through the Kyoto Protocol's 'flexible mechanisms', a global carbon emission market was created where countries could trade emission 'levels' to grant some room for economic development. A direct result of developed countries trying to reduce carbon emissions to remain in line with the clauses of the Kyoto Protocol, was the birth of the European Union Emissions Trading System (EU ETS), which exists solely to buy and sell permits to emit carbon dioxide. Governments soon realized that the protocol allowed certain flexibility which they used to their advantage, without providing a 'real' change to emission levels.

This system has been diagnosed to be fraught with problems including corruption, and is yet used extensively by Brazil and China to tackle their emission levels (ICAP, 2017). By buying credits from other countries, they were able to maintain higher emission levels. Although this may seem to 'fudge' the emission numbers of the world sufficiently to provide a final report which could indicate controlled levels of emissions, the truth remains that this is a shallow arrangement since developed countries actually have to take more effort to reduce emissions by large amounts to avoid climate catastrophe, and yet in the official documents, it may seem like their methods have 'worked' (Böhm, 2013). Scientists believe that encouraging carbon trading is a 'distraction' from the main requirement to end the burning of fossil fuels.

The economic resilience of a country is also highly affected by its decision to shift to alternate energy sources. Apart from increased resilience to environmental shocks, they are also less affected by changes in centralized sources of fuel. This would also protect countries from decisions made by coalitions like the Organization of the Petroleum Exporting Countries.

Modelling the uncertainty of these risks also poses extremely serious fundamental challenges, including but not limited to; the actual amount of 'warming' that a particular concentration of GHGs cause, and the particular ecological resilience threshold for each country beyond which the original ecological state can never be reverted to, also known as the ecological 'tipping point' (Ostrom, 2010). As mentioned in the introduction, it is clear that low-income countries are most affected by these changes, and thus have the least resilience, putting them at risk of poverty traps due to chain effects (Hallegatte et. al, 2015). Poverty traps are incredibly difficult to escape from for countries, due to their self-reinforcing nature, and can affect every single aspect of its functioning, preventing the country from ever improving its situation. The analysis of probable poverty gaps that a country may fall into is of extreme importance to decision-makers, and is at the forefront of the debate on climate change policy for developing countries.

1.4 Research questions

In this thesis, the aim is to identify the potential of and the challenges to the implementation of 'deep-decarbonization' policies in low-income (developing) and high-income (developed) countries. India is taken to be the example for a major developing country, considering both its potential for economic growth, its rapid industrialization, and its large geographic and demographic scale. The United Kingdom is taken as the case for the developed country since it provides considerable parallels to India as a region that has already undergone massive industrialization, without any environmental constraints, and has since focused on implementing deep-decarbonization policy over many years now. The main sectors of the economy, viz. agriculture, industry, waste, and domestic use, are compared for their GHG emissions in order to answer the following research question(s):

1) **What form have policies to curb carbon emissions taken until now and what are the main points of differentiation between developed and developing countries?**
2) **Using the Kaya Identity framework, what have been the main trends in energy efficiency and carbon intensity, thus identifying the main factors that policies have been aimed at correcting?**
3) **What are the trends in energy efficiency and carbon emissions in each of the main sectors of the economy: transport, industry and manufacture, energy and heat, and buildings?**
    a. **What have been the goals of the regulations implemented in each sector, and have they had any real impact for the reduction of emissions?**

4) What are the main deep decarbonization pathways which can be implemented by a developing economy (India) and a developed economy (the United Kingdom)?

a. What comparisons can be made between the technologies that can be implemented in a developed country versus in a developing country?

While considering the main deep decarbonization pathways, it is important to analyze the fundamental differences between encouraging energy efficiency, and introducing funding for newer low-carbon and/or zero-carbon technologies. Countries have to pick and choose the exact form the policies that they implement will take, taking into account major factors like the size of the population and the main industrial activities of the country. Across the world, only 2% ($ 6 Billion) of the publicly funded research and development programs are committed to renewables, while $101 billion is spent on subsidizing renewables (King et.al, n.d.). Improving energy efficiency and reducing carbon intensity requires investment into research and development. Investment (both private and public) of these kinds of R&D, while of critical importance to the success of deep decarbonization, is still inadequate. Therefore, this thesis will focus on the financing of these investments, comparing the (institutional) ways in which the U.K. and India have been trying to mobilize (financial) resources for research in low-carbon (zero-carbon) technologies and their implementation/adoption. While the British government has implemented the 'Green Initiative Bank' aimed at encouraging normal citizens to invest in cleaner, more sustainable, innovations, the Indian government has started the 'Make in India Movement' which although not directly aimed at cleaner technologies, does have it as a main function. Secondly, in countries like India which have consistently faced problems with accessibility and funding, there is always a natural tendency towards frugal innovations which are usually much cheaper to build and maintain, with locally sourced materials. While universities in the country are usually encouraged to develop more frugal innovations aimed at improving the lives of people below the 'poverty line' (earning less than $1.90 per day), with 'Make in India' international firms are encouraged to provide funding to Indian engineers and scientists to develop and mass-produce technologies within the country.

On the other hand, in a developed country such as the U.K., it is harder to implement clean technologies for the 'zero-emission' goal, because the 'low-hanging fruit' (such as solar-cells or wind energy) have already been implemented (during the past two decades or so). Instead, developed countries have to aim at 'deep-decarbonization' pathways which usually require complete policy reform, the large-scale employment of highly-engineered technologies, and considerably extensive lifestyle changes on the part of the population (Nabernegg et.al, 2017).

While it may seem like developing countries have been handed the short-end of the metaphorical climate-change mitigation policy 'stick', it is important to note that developed countries have their own set of policy implementation problems. To achieve a win-win situation without loss or too much investment requirement from developed countries would be ideal. International media also serves to continuously remind us that in today's highly volatile political environment, a satisfactory global consensus may well never be reached, and a coordinated international effort pertaining ecological matters may never materialize. Countries would benefit more from shifting from a 'universalistic' approach towards one that's more individualistic, in what political scientists' term as 'building blocks', through the implementation of multiple policies which each aim to align a particular individual goal, much like the various protocols and committees formed under the IPCC over decades. This is considered to be a 'polycentric approach', implying that decision-makers aim at attaining objectives that are formally detached from one another, with multiple guiding authorities, even if they are interconnected down the line (Ostrom, 2010). This sentiment seems to be reflected in the major studies on this front, and also largely imitated by international governing agencies; Gilley (2017), Teng & Jotzo (2014). To this end, it is possible to identify if the polycentric approach has been considered at all by the Indian and UK policy-makers, and their decision-making process in parliament could be traced. However, this line of questioning is beyond the scope of this study. Thus, the effectiveness of the different approaches, which could also vary with scale, can be acknowledged in the relevant impacts on the climate.

It has also been made clear from existing literature that decarbonization policies have to be implemented all through the supply chain for maximum efficiency. The emission of the final product, whichever country it is sold in, is dependent on the embodied emission of all raw materials and processes at every point in production, especially now that materials are transported across the globe for most products and services, as in the case of the chain effects from the electricity sector (Nabernegg, et al., 2017). There is almost always an inherent carbon footprint to even the sourcing of raw materials to form a product, transparency and the tracing of materials to the root source become much harder as the product becomes more engineered. The perspective of the market structure, and the particular focus on the industries which form the sectors of countries studied will make a difference in the way the policies are implemented, and it would be interesting to know if the economic paradigm makes a difference in the way the policies have been developed in the countries, and their effectiveness in each situation.

1.5 The structure of the thesis

During the course of this thesis, I will aim to answer the main research questions first by describing the basis of policy decisions that have been made to set the current state of affairs as a means of introduction.

The **second chapter** will present and explain the theoretical framework for the current policies and the economic basis along with the literature review to validate the thought process by which this research methodology was formed. My review of the literature suggests that most of the existing research on developing countries deals with the cases of China and Brazil. There is a dearth of analyses for India and this provides a sufficient literature gap for this thesis to be relevant. The decomposition analysis followed in this thesis is validated by the existing literature.

In the **third chapter**, an analysis (based on the Kaya identity) of the overall GDP- Energy Intensity- Carbon Intensity relationship and trends is done for the United Kingdom and India. This provides information on the overall factors that interact within the Kaya relationship, and narrow down the exact areas to look at in the decomposition analysis. Variation, if any, in trends between the UK and India should also help focus the direction of the study in a more appropriate manner in case of a large difference. To understand the focus of policy it is helpful to use the Kaya Identity, formulated by Yoichi Kaya, to identify the main determinants in emissions:

(1) $$C \equiv \frac{C}{E} \times \frac{E}{Y} \times Y$$

In this equation, C = CO2 emissions (in million tonnes); E = total primary energy supply or TPES (in PJ); and Y = GDP (at constant prices). C/E is the carbon intensity of energy, E/Y is the energy intensity of economic output (GDP).. Initially, the identity can be used in discerning if the countries have been carbon intensive or energy intensive with respective to their GDPs.

In **chapter four** a decomposition analysis is conducted on the transportation sector for both the United Kingdom, and India. analysis will decompose emission rates with respect to the energy intensity and activity share of the sector. The ‘intensity effect’ of each sector will be found using the growth rates from the decomposition study. A comparison of the results over time with the policy implementation will then provide some answers to the main research questions. The trends should be indicative of the effectiveness of the policy, and provide some key insight into the impact of ‘energy efficiency’ policy vs. ‘deep decarbonization’ policy.

In **chapter five**, a decomposition analysis is conducted on the industry and manufacturing sector for both the United Kingdom, and India. analysis will decompose emission rates with respect to the energy intensity and activity share of the sector. The ‘intensity effect’ of each sector will be found using the growth rates from the decomposition study. A comparison of the results over time with the policy implementation will then provide some answers to the main research questions

In **chapter six,** the decomposition analysis is conducted on the energy and heat ssector for both the United Kingdom, and India. analysis will decompose emission rates with respect to the energy intensity and activity share of the sector. The 'intensity effect' of each sector will be found using the growth rates from the decomposition study. A comparison of the results over time with the policy implementation will then provide some answers to the main research questions.

In **chapter seven,** the decomposition analysis is conducted on the building sector for both the United Kingdom, and India. analysis will decompose emission rates with respect to the energy intensity and activity share of the sector. The 'intensity effect' of each sector will be found using the growth rates from the decomposition study. A comparison of the results over time with the policy implementation will then provide some answers to the main research questions.

The **eight chapter** will present the results of a simple regression analysis which considers the energy intensity, and carbon emission trends over time. The purpose of the analysis is to enable the prediction of future emission trajectories, assuming that no major policy changes occur to alter this. Differences in the curves of the United Kingdom, and India considering the time gap between the implementation of policy, and the fundamental differences in size of the countries, and their industries are studied.

From the results of the decomposition study and the aggregate study using the Kaya Identity, the **ninth chapter** will identify the main pathways which provide effective decarbonization, in developing and developed countries, with respect to the goals of the UNFCCC. A stakeholder analysis is conducted on one technology or policy for each sector. The effectiveness of the financing initiatives, via the Green Initiative Bank and the 'Make in India' movement, can also be attempted to be explained. The rebound effect, and the possibility novel ideas such as f 'De-growth' and the 'Green New Deal' are considered in the context of each country.

In **chapter ten**, the results of the whole thesis is rounded off to form a conclusion, the main policies which are effective in each sector are reiterated. A reflection is also done for a hypothetical situation in which this research is conducted again from the beginning with unlimited time and resources.

The benefits of decarbonization may go beyond reduced climate change, in terms of improved human health through co-benefits like mitigated air pollution. This would also reduce consumption in the medical sector and by default, less expense in the sector. It is absolutely clear that it is not enough for individuals to engage in environmentally friendly behavior, since a majority of the decisions which cause damage, in this context, are to be made by politicians; presidents, prime ministers, ambassadors in the United Nations, and other forums. If this problem is not solved within the next decade, the future climatic predictions are alarming to say the least, and future generations will have to live in a world riddled with severe weather marked by extremely hot and extremely cold days, glacial retreat which will also increase the water level across the planet, bushfires which will put public and residential properties at risk, and an increase in the acidity of ocean water which puts majority of sensitive marine life at risk (N. Khetrapal, 2018).

Chapter 2: Theoretical Framework and Research Methodology

2.1 Background and context: Energy and economic growth

Global warming is caused by the rising concentrations of greenhouse gases in the atmosphere. This growing concentration, from a level of around 300 ppm in 1900 to more than 450 ppm in 2017 (see the famous "hockey stick" graph, figure 4 below), is caused mostly by the carbon emissions coming from energy use in the human economy. As of May 2019, we are at unprecedented levels; at a 48% increase of CO2 (in ppm) from the pre-industrial level of 280 ppm ("Earth's CO2 Homepage, 2019). The "hockey stick" character indicates that CO2 emissions started to grow especially with industrialization, i.e. after 1800. What the Graph illustrates is that economic growth and rising material standards of living in general is associated with more energy use and growing CO2 emissions.

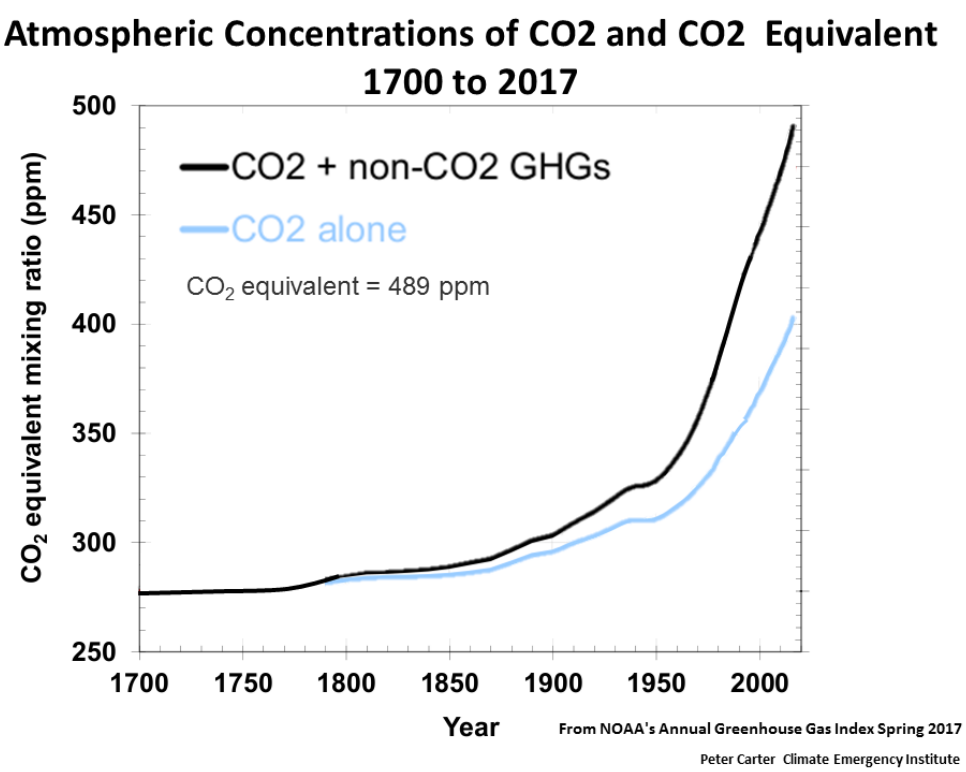

Figure 4: Atmospheric Concentrations of CO2 and CO2 Equivalent, (source: http://www.onlyzerocarbon.org/co2_levels.html)

It has been noted that limited energy supply constrains economic growth, while a surplus of energy seems to have a much reduced effect (Stern, 2011). Stern in his 2011 paper, identifies a few key factors which link energy use to economic activity over time; the substitution between energy inputs within an existing technology, changes in technological development, changes in the share in sources of energy, and changes in the 'composition' of economic output. Stern is clear to mention that according to the mass-balance law of physics, to produce a material output, an equal or greater amount of material input is required. In addition, the second law of thermodynamics, states that the total entropy of an isolated system can only increase with, meaning that a minimum amount of energy will always be required to produce any change in materials or material properties; which is the basic function of most production lines.

Energy intensity, joules of energy per unit of GDP, has continuously reduced around the world even as carbon emission rates have increased (Shanker & Stern, 2018). According to the main findings of Shanker and Stern in their 2018 paper, this can be attributed to a *structural* change in the economy. Main comparisons are derived between the impact of energy-augmenting technologies and labor-augmenting technologies. Findings imply that energy-augmenting technologies have a greater effect even though the growth rate of the former is less than the latter, and almost ceases under extreme state dependence. Research into the aforementioned energy-augmenting technologies is also encouraged, and sustained, by the consistently growing market size even when prices remain constant (Shanker & Stern, 2018).

Studies have shown that with the relationship is particularly inelastic in regions with low income households, as is common in the developing countries, if solid biofuels are primarily used. People in low income households tend to have fewer alternatives for fuels, and usually do not even have the option of taking into account less carbon emitting alternatives. For many such households, the alternative lies between using firewood, or coal. Low income households normally are very much dependent on the local terrain and their energy usage models cannot be scaled to larger societies. The elasticity is also higher, as indicated in the graph above by a positive slope, for higher-income countries, again most probably because of their lack of traditional energy sources (Burke & Csereklyei, 2016).

High income families in developing countries, and the general population of developed countries on the other hand, have many more options, and the means of accessing them too. We thus get the result that the aggregate energy-GDP elasticity is higher in regions with high-income households, as in developed countries (Burke & Csereklyei, 2016). Burke and Csereklyei (2016) empirically estimated these energy-GDP elasticities in a cross-sectional study of energy-GDP elasticity, and electricity-GDP elasticity, using five main sectors in their research methodology; residences, agriculture, transport, industry, and services. According to their findings, the energy-GDP elasticity of the residential sector is low, especially for low-income households, and even negative at points as indicated by the negative slope in the graph (figure 5) below.

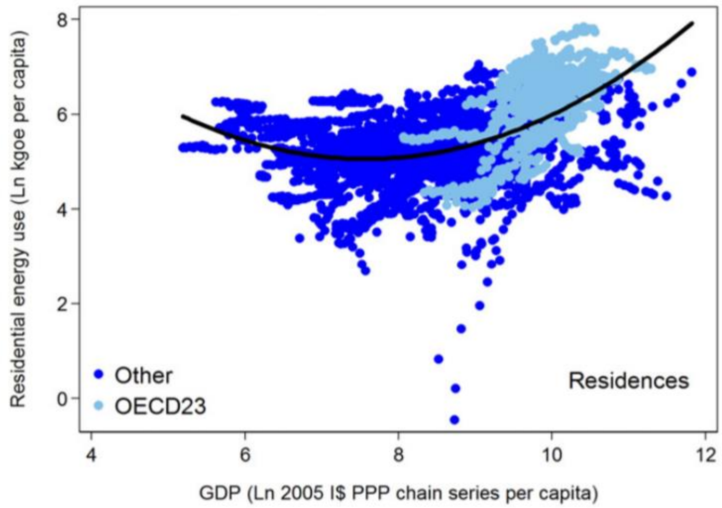

Figure 5: Residential Energy Use - GDP relationship in OECD vs. the Rest of The World (Burke & Csereklyei, 2016)

It has been observed that countries tend to move from solid biofuels to fossil fuels, and then to nuclear or renewable energy sources as they develop depending on the natural potential for particular renewables for example, wind for windmills (Stern, 2011). The transition is further strengthened as consumers become more aware and are capable of making environmentally friendly decisions. While short-term energy elasticity has been studied, it must be noted that long-term studies have not been conducted, and information is very scarce on that front.

Developing countries can aim to achieve lower energy intensities by either systemically altering their policies, or by investing in technological advances, but are actually 'carbonizing' the energy supply by depending more on coal. The main problem here remains discord between the optimism of engineers, and their belief that newer innovations have the capacity to achieve the level of decarbonization required, and the inherent pessimism of economists. In the private sector, 'Voluntary Carbon Offsetting' (VCOs) began developing as a parallel market especially in countries, where government policies were perceived to be ineffective, in the UK alone, more than 61 such organizations have been identified (Bumpus & Liverman, 2008). Governance and geographical differences between countries; access to wind, and solar, power sources, are also factors which affect individual carbon-offsetting requirements.

To accurately understand the impact of the implementation of the climate change mitigation policies in the global north and south, an appropriate comparison has to be made between a developing country that is currently a large emitter of carbon, and is undergoing industrialization with the goal of becoming 'developed' and a country has already undergone industrialization, without any climate change related constraints. The countries selected for this are India (developing) and the United Kingdom (developed). Of the developing countries, India shares many similarities, socio-economically and environmentally with Brazil and China, so literature on these countries are used as a basis for the development of this study. Some literature already exists about China and Brazil's decarbonization policies. A study has also been done on a specific state in India, Gujarat; but nothing exists analyzing the country as a whole, holistically studying the major sectors of its economy. The literature gap ties back to the fact that long term studies haven't been conducted till date, but with the currently available data spanning about five decades in both the UK, and India, a longer-spanning analysis can be done, with the possibility of projecting future emissions within logical restrictions. Such a study will be able to contribute to literature by forming a basis for the further analysis of the implementation and impact of decarbonization policies in India, through a few different moderate and strong decarbonization policies.

2.2. Decarbonization in developing countries: the cases of Brazil and China

China and Brazil share many similarities with India which can play into making them effective comparison basis for India. Brazil and China are not subjects of this study, but the method by which researchers have studied their decarbonization trajectories is used to develop and validate the methodology of my thesis due to their similarities with India. With all three continuously attracting investors and promises of exponential development, in combination with their large geographical sizes and populations, and historically complicated politics and governance issues, they form a unique group of countries; both forces to be reckoned with, and to be dealt with carefully. Investments required towards the transition into deep-decarbonized societies are projected to reach upward of 3-5 billion US dollars per year in the coming decades, which may not be feasible for the countries without international money flow.

2.2.1 The Case of Brazil

Brazil in particular has a low per-capita GHG emission (2.4 tons CO_2 in 2014), and mostly clean energy sources. Deforestation has also fallen down enough to make 'land-use change' no longer the major emitter, and causing a 50% reduction of CO_2 equivalent in 2010 to 1.25 Gigaton CO_2

Equivalent ($GtCO_2e$). Similar to India, there is large income inequality, and reducing the inequality is a major focus of political parties in the country, which would also play into consumption patterns that are observed, and the future predictions. The main difference in the modelling between Brazil and India is that, in Brazil population is projected to decline, while in India, it is projected to increase. In 1975, the 'Brazil Ethanol Program' was launched in which the gasoline used in the country is mixed with ethanol, a biofuel, up to 22—25%, and this has been a success. The country has taken up ambitious macroeconomic strategies, targeting a 43% reduction in GHG emissions by 2030, and in keeping with the Paris Agreement to global warming levels below 1.5^{o}c, and aiming to reach 8 $GtCO_2e$ in 2050. However, with the anticipated growth of GDP and GDP per capita, extensive measures towards deep decarbonization must be introduced to meet the Paris pledges. The financing of these investments is a major challenge. Financing currently happens through carbon taxation, as in most other countries, but only energy related emissions are taxed in Brazil (Rovere, Grottera, & Wills, 2018).

Rovere, Grottera, & Wills (2018) assess the implications of adopting a new financial device for the funding of low-carbon investments, another form of decarbonization policy in Brazil. The biggest deterrent for investors is the high capital cost and risk involved in new technologies. The paper goes on to suggest 'de-risking' the investments by giving partial guarantees from the state towards large capital flows from the global north to the south for the most capital-efficient approach. The guarantee would act as an insurance covering the global value of carbon saved of the projects. Since developing countries form the low-cost, large-opportunity market, they are bound to gain the most from 'de-risking'.

2.2.2. The Case of China

Apart from the fact that mitigation is seen as costly by most countries, historically, there have been significant differences in the emission levels of countries that are now considered developed and developing. When the case of China is analyzed, it is suggested that the principle of 'equity' is followed rather than that of 'equality' to accommodate for the aforementioned disparities while allowing for development, which would also require large financial transfers between the countries in the global north and south as in the case of Brazil (Teng & Jotzo, 2014). Much like India, there is a directly relationship between China's exponential economic growth and its increased energy use, especially since it now produces a large fraction of the products used in most major developed countries and has thus effectively absorbed their emissions as well. China's real GDP growth from 2005 to 2013 averaged 10% while CO_2 emissions grew by 5.4% per year (Teng & Jotzo, 2014).

The main decarbonization pathways for China have been identified to be:

1) Improving energy productivity, and reducing the carbon emission per unit of energy consumed. Increasing the technical efficiency of factories and large-scale manufacturing methods should change the 'composition' of the economy from mass-production to higher-value manufacturing, and service-based industries.
2) China has large coal-reserves which have acted as its main source of energy for its activities. A concentrated effort has to be put into new-energy infrastructure for cleaner sources of energy (Teng & Jotzo, 2014).

In a situation similar to India, a fast-growing economy like China has the scope for quick reductions in carbon intensity since new technologies are available which were not available to the developed economies during their growth trajectories. The new energy infrastructure is more efficient, and has been developed with more foresight than their previous versions. The arguments surrounding this development mode has come under much criticism over the years because of the conflicting goals of economic growth, environmental protection, and climate change mitigation. In China, the central government has increasingly started placing emphasis on the 'quality' and sustainability of the economic growth, including more economic and social dimensions. Climate change mitigation is thus increasingly being considered as a 'risk-management' strategy for sustained growth. Teng & Jotzo (2014) also suggests that decarbonization through fiscal policy reforms would have a positive impact keeping in line with the central government's goals.

Gilley (2017) compares economic growth, GHG emissions and decarbonization in China and India. Gilley begins by considering the fact that the countries produced roughly 33% of the global GHG emissions in 2015, and account for 66% of the increase in energy use between 2000 and 2012. Previous research did not consider challenges faced by local governance in gaining traction for international policies, and the lack of integrated governance solutions. Gilley (2017) focuses mainly on the city of Guangzhou in China, and the state of Gujarat in India. The paper emphasizes the importance of integrated policies which are closely linked to political and administrative support. In China, an initiative to create a single national market by 2016 was constrained by disagreements between politicians. In India, a government subsidy for installing solar panels on rooftops had to be dropped in 2015 since vague budgets and staffing costs meant that companies installing panels with a subsidy were indeed charging *more* than those not registered with the subsidy program. Both of these cases are examples of poor public management and worse, corruption in the implementation of decarbonization policies (Gilley, 2017).

Both China and India currently use “state signaling” and “market plus” approaches which incentivizes users to increase their energy efficiency by using a high price of energy to encourage savings (Gilley, 2017). In the process of state signaling, the central government provides guidelines and targets, with particular incentives, which the state governments are expected to follow and achieve. In the market plus approach, the governments use high energy prices to encourage users to increase efficiency to reduce their expenses. Nevertheless, neither can produce sustainable reduction in GHG emissions. Particularly in the case of Gujarat, India, a state with a population of 60 million and emitting about 150 million tCO_2e, and 120 million tons of actual CO_2, in 2012. Although these numbers seem very large, the city of Ahmedabad in Gujarat, one of its major industrial hotspots, boasts having one of the lowest emission rates of all the major cities in India (Gilley, 2017). This can be attributed to state government policies which don’t seem to have been effective when translated to the national scale. For example, the failed rooftop solar panel case was actually effective when implemented in the state in 2009, prior to the national policy, but was not effective when it was upscaled to the national level. The concept of a poly-centric systems, defined as system with multiple formally independent committees that are capable of decision making, even capable of considering each other to be competition to their own ends (Ostrom et. Al., 1961). This seems to be effective here since polycentric systems also bypass the criteria of all parties having aligned values for an agreement, and act as an important bridge between the paradigms of economists and engineers (Ostrom, 2010). Although only considered in the context of a universal carbon tax till now, a polycentric approach along with a few uniform policies may be the overarching remedy that is needed. Insurance against catastrophes is also to be modelled, by appropriately considering all the risks involved (Vale, 2016). A polycentric approach in combination with regulative policies, such as requiring manufacturing plants to buy “green credits” by purchasing land for non-polluting endeavor before building a factory, and by increasing the interest rate for loans to build chemical and manufacturing plants, as implemented by China in 2007, have proven to be effective (Wang, Yang, Reisner, & Liu, 2019). On the other hand, India’s national government committed to focusing on climate change policy only in 2015, which promises to change emission levels largely which hasn’t been able to be considered in literature till now (Gilley, 2017).

A rebound effect, specifically the “Jevons effect” is also noticed; defined as the phenomenon by which the implementation of a new technology or policy aimed at increasing resource efficiency suffers an unexpected offset in the reduction of benefits because it stimulates the consumption of more energy (Amado & Sauer, 2012). In the context of climate change mitigation policies, it has also been observed in India and China. Considering the growing demand in both countries in juxtaposition with the global requirement for decarbonization, these countries have to implement strong policies which most probably won't realize the extent of change that the governments hope for.

As in the case of most countries, the majority of reduction emissions can only come from the decarbonization of the energy and electricity sector. The decarbonization of energy intensive industries, such as steel or aviation, can happen by substituting fossil fuels with renewables and cleaner technologies, which again requires large investments (Nabernegg, et al., 2017). Decarbonization also affects growth by altering market efficiency, which then requires an energy efficiency policy to fix. In the real world, markets do not always act according to theory. Many market imperfections plague the system and the predictive capabilities of economists and market scientists can be severely limited, so, policy changes may not have the effects that are anticipated. For example, the carbon tax implemented by some countries may act to increase economic efficiency, but it may only be to the extent of any fuel subsidy that has also been implemented. Occasionally, an energy efficiency policy instrument which reduces fossil-fuel consumption may also act to increase the fiscal revenue of governments, which can be taken advantage of to lower existing taxes in the country. The savings from using fossil fuels are much higher than the investment into alternatives, resulting in the much lower unit cost for energy. Further, since electricity is a major input to most other sectors, the decarbonization of this sector promises to set off a chain reaction which would be beneficial to all aspects of the economy (Nabernegg, et al., 2017). Multiple channels to ensure that the domestic market is kept secure have been identified; particularly, more efficient technology, an increase in output to generate a scale effect, and structural changes to shift from energy intensive to less energy-intensive sectors. All of these pathways promise to have a social impact which also have to be considered before their implementation, tying in with the requirement of integrated, polycentric, governance.

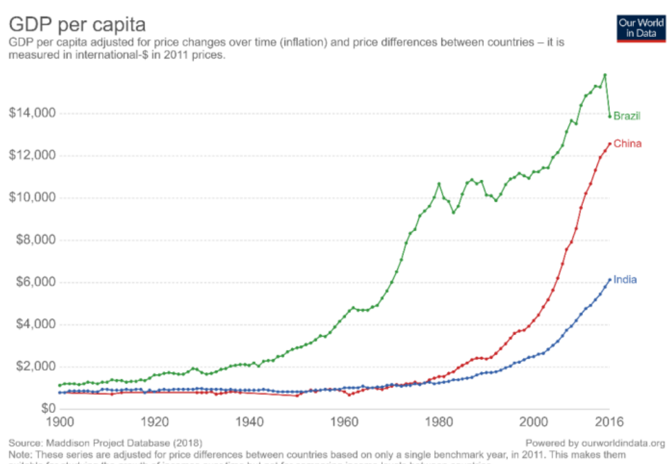

Figure 6: GDP per Capita; India, China, and Brazil (source: ourworldindata.org)

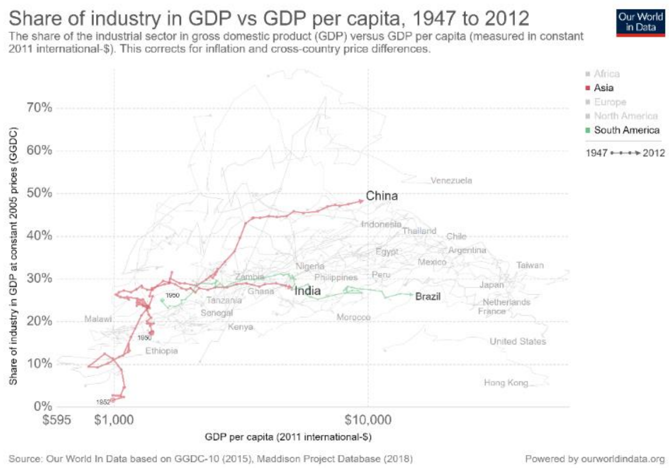

Figure 7: Share of Industry in GDP w.r.t GDP per Capita (1947-2012); India, China, and Brazil (source: ourworldindata.org)

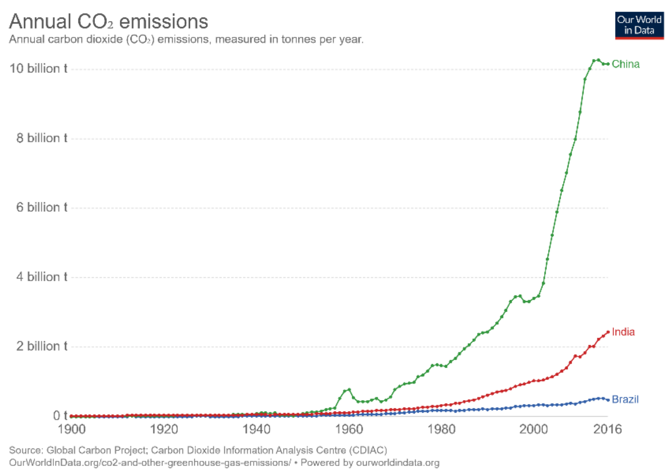

Figure 8: Annual CO2 Emissions; India, China, and Brazil (source: ourworldindata.org)

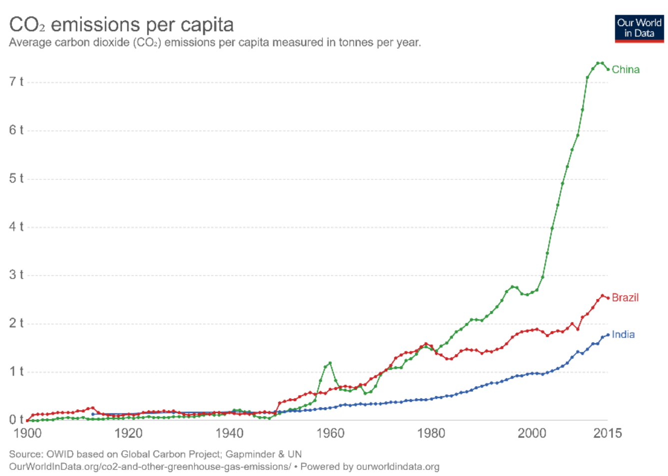

Figure 9: CO2 Emissions Per Capita; India, China, and Brazil (source: ourworldindata.org)

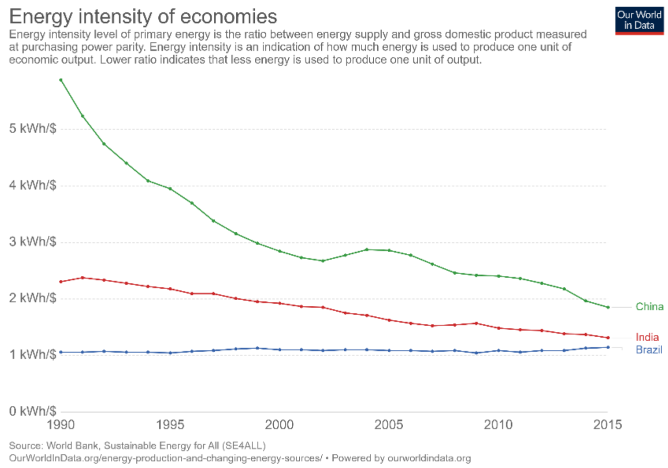

Figure 10: Energy Intensity; India, China, and Brazil (source: ourworldindata.org)

2.2.3. The case of the U.K.

Developed (high-income) countries on the other hand also suffer a particular set of political and economic hurdles when it comes to the implementation of decarbonization policies. Although per capita emissions are currently lower in some of these countries, there is a constant drive towards further reduction which has to be done in an economically efficient and socially acceptable manner. The implementation of an "almost mature" technology, if released before all the sufficient testing, could largely fracture the validity of studies on their effectiveness. In the UK in particular, which aims an 80% reduction in emissions by 2050, it is implied that policies that are not rigorously tested for their impacts through various models may reduce the energy return on investment (EROI) which could result in an energy crisis (Roberts, Foran, Axon, Warr, & Goddard, 2018) . Roberts et. Al (2018) also notes that there are certain thermodynamic limits to the rate of change of infrastructure, and that it gets progressively harder to develop technologies which require less energy to function.

The UK government has implemented an ambitious target of an 80% reduction in GHG emissions from the 1980 level by 2050, but it is not certain that the country will achieve it. The upcoming Brexit may not only hurt economic growth, but could also negatively affect the country's decarbonization strategy. The UK climate change act, implemented in 2008, has been one of the most pivotal in propelling British climate change policy forward over the past decade. Fankhauser et. al (2018) suggests that the following characteristics to the legislature have contributed to its success: a scientific long-term emissions target and a prescribed path to reach the goal, a continuously adapting contingency plan aimed at increasing climate change resilience, an unbiased and independent advisory body to ensure up-to date decision making, and regular monitoring. The fact that the UK has been implementing nation-wide climate change policies since the beginning of the century, along with-it previous industrialization trajectory, makes it a good comparison basis for a developing country with sufficient data to go upon for modelling.

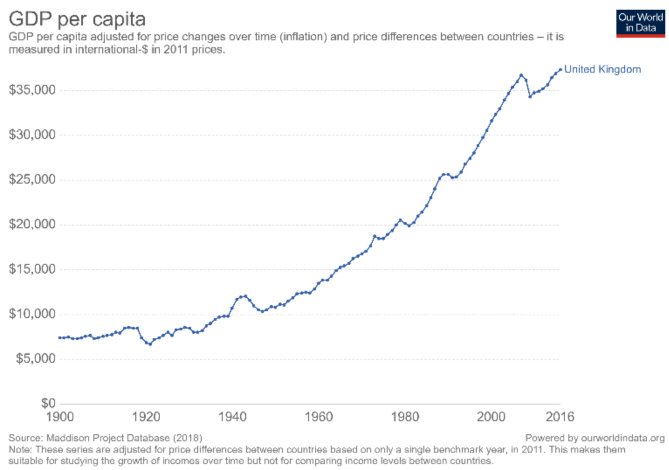

Figure 11: GDP per Capita; UK (source: ourworldindata.org)

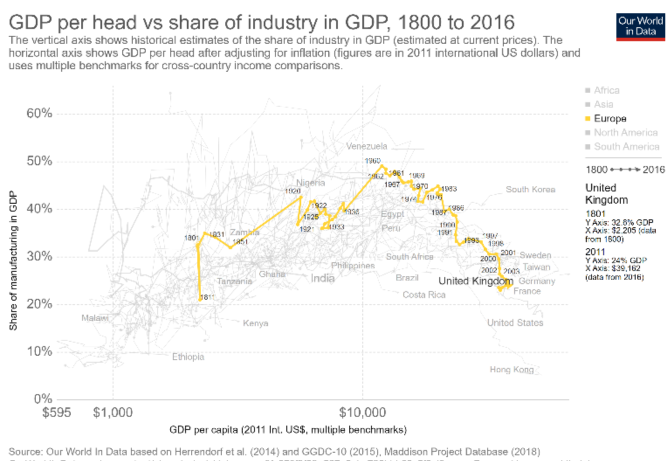

Figure 12: GDP per head w.r.t share of industry in GDP; UK (source: ourworldindata.org)

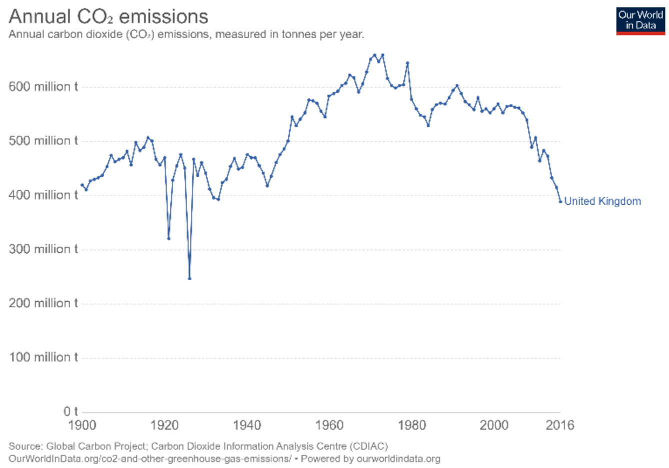

Figure 13: Annual CO2 Emissions; UK (source: ourworldindata.org)

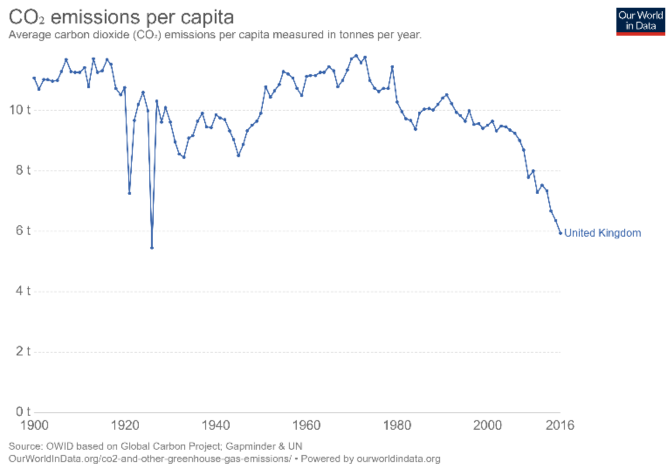

Figure 14: CO2 Emissions per Capita; UK (source: ourworldindata.org)

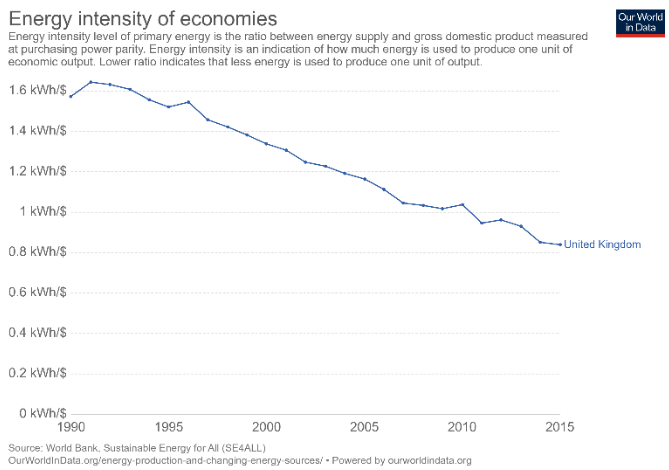

Figure 15: Energu Intensity; UK (source: ourworldindata.org)

2.3. Methodology

The thesis will use the 'Kaya Identity' to identify major determinants in emission reduction; portraying the energy-GDP relationship with the emission levels of a country in the identity developed by Yoichi Kaya (Fankhauser & Jotzo, 2018):

$$C \equiv \frac{C}{E} \cdot \frac{E}{Y} \cdot Y$$

Where C is total global carbon emissions (Tonnes), C/E is the carbon intensity of energy (tonnes/ joules), E/Y is the energy intensity of economic output (Joules), and Y is the economic output (in US$ at a constant 2014 price).

Two decomposition methodologies were used; index analysis, and the log-mean Divisia Index (LMDI). Index analysis allows for direct interpretation of values, while the LMDI allows for a comprehensive analysis of the scenarios of different stringency levels. Most of the models showed that for optimal results, global emissions required immediate attention, and additionally should fall to negative emissions in the long term. To prevent atmospheric concentrations of CO2 to go beyond 450 ppm CO_2 by 2100, a coordinated global effort at climate change mitigation and decarbonization will be required.

Liobikiene and Butkus (2018) begin with the assumption that increased economic development immediately prompts increasing rates of greenhouse gas (GHG) emissions. They also identify that outsourcing production to low-income countries was a common by-way that governments of high-income countries took to overcome the emission problem, while low-income countries suffered both the heightened carbon constraints on them and the ecological damage. Data specifications and descriptive statistics about GDP, imports, exports, energy efficiency, and renewable energy consumption, from the World Development Indicators between 1990 to 2013 were used. The empirical data thus obtained were modelled into the 'Dynamic Peel Model' with an appropriate formula and assumptions based on the existing research, which also acts a variation of decomposition analysis, by breaking down the data into the statistical factors. Theoretically there is possibility for bias in the 'dynamic peel model' because endogeneity in the dynamic framework has not been addressed in the more classical estimation models, like OLS, or panel regression.

While the focus of this literature review is on decarbonization policies, which may involve the implementation of a clean technology, or just be a financial incentive towards lower carbon emissions, another common method of controlling emissions is through energy efficiency policies. By aiming at increasing the efficiency of each tCO_2e, countries can effectively limit emissions in keeping with the UNFCCC targets. Developing countries have a higher scope towards energy efficiency policies analogous to the case of 'low hanging fruit', and are capable of 'leap-frogging' over technological developments without going through every single substage of development. Developed countries tend to have already implemented many energy efficiency policies, and have effectively reached a plateau of efficiency making it harder to improve on their emission levels (Roberts, Foran, Axon, Warr, & Goddard, 2018; Bloom et. Al. 2017).

In multi-modal comparison studies, the factors can only be broken-down into three categories; activity measured in terms of GDP, the effect of structural changes on energy intensity, and the effect of carbon intensity per unit of final energy demand, lending to some very general results (Mathy, Menanteau, and Criqui, 2018). To overcome this problem, an Index Decomposition Analysis (IDA) was used which provides much more flexibility to the study. The evolution of socio-economic and macro-economic trends was studied. Other options for modelling the impact of economic policy for climate change mitigation include the Dynamic Integrated model of Climate and the Economy - Regional (DICE-R) (Ortiz, Golub, Lugovoy, Markandya, & Wang, 2011), and the Refined Model of Investment and Technological Development- Regional (ReMIND-R) (Luderer, Pietzcker, Kriegler, Haller, & Bauer, 2012). While the latter focuses mostly on investments into the region, the former is a possible consideration for implementation into this study, although substantially more complex than a decomposition analysis, as it helps understand the dynamics between the environmental changes and the economic policies executed, and is designed to accommodate for uncertainties.

2.4. Policy implementation: the U.K. versus India

2.4.1. The UK

In the United Kingdom, there has been implementation of decarbonization policy since the late 1980s. The main pathways of policymaking have been through: pricing GHG emissions to increase costs, stimulating the research on and development and employment of cleaner technologies, and improving the energy efficiency of existing technologies. These measures tie together to form a complex network involving many actors, and multiple levels of cross-party commitment to climate change mitigation coherent with the UNFCCC. The UK's monetary commitment to decarbonization policy implementation has ranged from 0.5 to 1.5% of its GDP

(Evans, 2016). It also provides funds to other countries through The Foreign and Commonwealth Office. To control the behavior of domestic users, some 'market friendly' were designed which use pricing signals to encourage cost-effective usage of energy. The Climate Change Act of 2008, proposed by the "Secretary of State for Energy" Ed Milliband, gives power to the law to *force* domestic 'carbon-reduction' budgets. It also added responsibility towards proposing carbon budgets, assessing the progress towards the long-term targets, and giving advice to the respective government agencies involved. Pricing carbon emissions also forms a 'signal' which then points path dependent technological development and investment.

Another initiative which was undertaken was that of the Green Investment Bank (GIB), launched in 2012, to encourage public to invest in green infrastructure. While this can simplify the path towards the development and implementation of cleaner technologies, it is still highly debated if such an initiative can work as a 'real' bank (Bowen & Rydge, 2011). It is also doubted if financial markets are capable of taking the risks involved because of the very large time horizons before payback. As is clear, the UK has taken two main routes towards decarbonization policy; namely, the price instruments, and the quantity instruments. Further investment into these, are also found to happen when policymakers make public commitments, increasing accountability. Although there are a few overarching 'umbrella policies', there are also a few sector-specific policies which mainly focus on; domestic use, transportation, and agriculture.

Timeline of Major Policy Milestones in the UK (Bowen & Rydge, 2011):

1989: **The Non- Fossil Fuel Obligation (NFFO)** – which places a tax levy on the industrial purchase of fossil fuels.

2000: **Climate Change Programme** – a set of policies updated in 2006 which aims to reduce CO_2 emissions and GHG levels by 15% and 23% respectively by 2010.

2001: **The Climate Change Levy (CCL)** – a downstream tax on non-domestic energy use.

2002: **The Renewables Obligation (RO)** – requires suppliers to purchase a fraction of their energy from renewable sources.

2002: **The Energy Efficiency Commitment (EEC)** – committing energy suppliers to achieve 62TWh of energy savings by 2005.

2005: **European Union Emissions Trading System (EU ETS)** – offsetting of carbon emissions in accordance to the flexible clauses of the Kyoto Protocol.

2007: **The Code for Sustainable Homes** – from 2008 all homes were required to comply with improved efficiency regulations.

2008: **Climate Change Act** – set an aim of reducing emissions by 80% from 1990 levels by 2050

2008: **Carbon Emission Reduction Target (CERT)** – replaced the “Energy Efficiency Commitment” to have more focus on sustainable energy saving measures.

2008: **Renewable Transport Fuel Obligation (RTFO)** – requires suppliers of fossil fuels to ensure a percentage of their fuel is from renewable sources.

2008: **Energy Performance Certificates (EPS)** – an energy certification required whenever a building is sold, or to be sold.

2009: **Community Energy Saving Programme (CESP)** – aims to reduce carbon emissions and fuel poverty by requirining energy savings from suppliers in the ‘most deprived’ areas of England.

2010: **Carbon Reduction Commitment Energy Efficiency Scheme (CRC EES)** – reduces emissions of firms not already subject to EU regulations.

2010: **Feed-In Tariffs (FITs)** – Payments for energy that is added to the grid by electricity generated by households, businesses and communities.

2010: **Carbon Capture and Storage (CCS) Demonstration Project** – 1 billion pounds of capital funding for CSS systems for coal-fired and gas- plants.

2011: **Carbon Plan** – a plan for reducing the UK’s emissions by 2020

2012: **Green Investment Bank (GIB)** – committed 3 billion euros in funding from lenders to encourage investments into green technologies.

2012: **Renewable Heat Incentive (RHI)** – financial support for households and businesses which install renewable heating systems.

2012: **The Energy Bill** – encourages greater security for energy supplies, and higher supply of low-carbon energy sources.

2014: **Smart meter roll-out** – replacement of older gas and electricity meters.

2.4.2. India

Increasing ‘environmental’ awareness, and increasingly entrepreneurial nature of young graduates results in an added focus on decarbonized effects in newer technologies (Chipman, 2016). Being a developing country, any policy that is proposed at in the houses of parliament have to always be framed in the context of social development, poverty alleviation, or the Sustainable Development Goals (SDGs) of the United Nations (Shukla & Chaturvedi, 2011). They also have to align with other priorities such as the ‘Make in India’ campaign which have also announced projects particularly for solar energy technologies in the states of Uttar Pradesh, Maharashtra, and Odisha. While social development goals, such as the electrification of villages have been largely achieved over the past few years, it could negatively impact its decarbonization goals (Shukla & Chaturvedi, 2011). Shukla & Chaturvedi (2011) developed a “CEEW Synergies and Trade-Off Matrix” to better understand the mitigation pathways and their sustainability. According to their matrix, the increase in per capita energy consumption caused by electrification would have no impact on limiting carbon dioxide emissions levels by 2030. In fact, counter-intuitively, the marginal cost of electricity generation is found to fall with a more restrictive climate change policy (Shukla & Chaturvedi, 2011).

The policies in India are aimed in two directions; tackling the supply side, and the demand side. For supply, while coal is projected to remain the dominant source of energy till 2030, ‘policy-hybrid’ scenarios allow for a combination of a cleaner technology along with the coal (Dubash, Khosla, Rao, & Bhardwaj, 2018). Policy changes have also indicated a shift towards electric vehicles, and there has been a steep decline in the cost of renewable energies with the country consciously bidding at lower ranges to increase competitiveness with the price of coal, acting as in a manner to the UK approach at price-management, but instead reducing the cost of renewables rather than increasing the cost of carbon emission.

Climate change polices in developing countries like India can also have a major impact on the availability of jobs as well. It is found that the number of jobs required in the wind and solar sectors than in the coal, gas and nuclear sectors, enhancing the employment rate, but this would shift the economic strength of different states which are heavily dependent on coals (Shukla & Chaturvedi, 2011). The paper also notes that land use will increase drastically for setting up electricity plants, especially in the case of solar panels which take up a large area. This would possibly cut into ‘livable’ areas for poverty-stricken families, and the locations of plants have to be decided keeping many factors in mind. The reduction of air-pollution is also seen as a co-benefit to climate change policy (Shukla & Chaturvedi, 2011).

2.5 Methods (and Data)

2.5.1. Aggregate Study

To answer the particular questions asked in this study, it makes sense to begin the analysis of the aggregate factors using the Kaya Identity. Following which, the details of identifying sector-specific trends can be done using the appropriate form of index decomposition analysis. The Kaya identity is based on a very simple premise; that four factors can express the total GHG emission level of a region. The four factors being; the human population, the gross domestic product (GDP) per capita, the energy intensity, and the carbon intensity of the region; $F = P \times \left(\frac{G}{P}\right) \times \left(\frac{E}{G}\right) \times \left(\frac{F}{E}\right)$. Where, ‘F’ is the total emission, ‘P’ is the human population, ‘G’ is the GDP, and ‘E’ is the energy consumption.

The CO_2 emission information (*F*) for this analysis can be extracted from the World Resources Institute (WRI), and World Bank databases for both countries, and the GDP (*G*) and population (*P*) data can be extracted from their respective government sites (data.gov.in, and data.gov.uk). By using the aforementioned statistical data available into the Kaya Identity, the energy consumption (*E*), carbon intensity, and energy intensity of each country can be calculated.

This information can be compiled over a period of about forty years; which is about the time over which reliable information can be gathered covering periods before, during, and after implementation of decarbonization policy. From this, the major trends can be identified and by calibrating the chronological points at which decarbonization policies are implemented, the specific impacts can be identified. This information can also indicate whether countries have specifically aimed their decision-making at controlling either energy intensity, carbon intensity, or both.

2.5.2. Decomposition Analysis

To get policy insights for each sector over time, from the literature review, it is clear that from previous research into the topic the main method of identifying trends in carbon emissions, with respect to economic movement, is through some form of decomposition study. As mentioned in the literature review (section 3), multi-model decomposition analysis was used to “quantify the relative contribution of the pre-determined factors” using data from 1990 to 2010 (Marcucci & Fragkos, 2015). There are a few basic forms of decomposition analyses, starting with the Index Decomposition analysis and the Log Mean Divisia Index analysis I and II, of which there is an additive and multiplicative form. The LMDI method with its sound theoretical basis, and adaptability gives results that are easily interpreted, making it suitable for this study as well. The factors of the Kaya Identity can be used in the analysis as well, which will provide continuity between the aggregate and sector-wise study. From the aggregate study, as done previously, the main factor, energy consumption (*E*), with which the decomposition study can be done with will also be known.

While deciding exactly which form, additive or multiplicative, is to be used, it is important to understand that the additive study will identify the change in 'quantity' over time while the multiplicative study will identify changes in 'intensity', as a ratio, over time.

We know that net emission (*F*); $F = F_{Industry} + F_{Energy} + F_{Agriculture} + F_{Waste}$

and thus Emission Intensity per GDP is; $\frac{F}{G} = \frac{F_{Industry}}{G} + \frac{F_{Energy}}{G} + \frac{F_{Agriculture}}{G} + \frac{F_{Waste}}{G}$

The total change over a period from time '0' to time '*T*';

$$\Delta F_{tot} = \Delta\, F_{Industry} + \Delta\, F_{Energy} + \Delta\, F_{Agriculture} + \Delta\, F_{Waste}$$

Where, in an additive study, the 'intensity effect' for each sector can be found.

For example, $\Delta F_{Industry} = \sum_i L(F^T_{industry}, F^0_{industry})\ \ln(\frac{E_T}{E_0})$

Where $L\left(F^T_{industry}, F^0_{industry}\right) = \frac{F^T_{industry} - F^0_{industry}}{\ln F^T_{industry} - \ln F^0_{industry}}$

For the multiplicative decomposition, for example in the case of industry, the formula is;

$$D_{industry} = \exp(\sum_{ij} \widetilde{w}_{ij} \ln(\frac{E_T}{E_0}))$$

Where, $\widetilde{w}_{ij} = \frac{(E^T_{ij} - E^0_{ij})/(\ln E^T_{ij} - \ln E^0_{ij})}{(E^T - E^0)/(\ln E^T - \ln E^0)}$

For this particular study, the multiplicative and additive studies should both show similar upward trending results, while the LMDI I and II should both show similar results numerically too. There is no need to accommodate for alternative methods since there is no possibility of a 'zero' value or a negative value for population, GDP, or emissions for either India or the United Kingdom. A basic growth decomposition using final and initial values is used to produce a rate. The results of this analysis provide the platform, when compared with the chronological points at which decarbonization policies have been implemented, to spot their exact impacts.

2.5.3. Regression Analysis

A simple regression analysis considering the energy intensity, and carbon emission trends over time, will enable the prediction of future emission trajectories, assuming that no major policy changes occur to alter this. There is bound to be some difference in the curves of the United Kingdom, and India considering the time gap between the implementation of policy, and the fundamental differences in size of the countries, and their industries. This is also done with the assumption that no major political activities, for example a war, happens in the foreseeable future. The regression can be done once a causal relationship is established, between policy implementation and carbon emissions, which can be done with the previous chapters of this study. The aim is naturally to get a regression with minimum error, and a maximum fit.

2.6. Reliability and Validity

The reliability of this study depends most of all on the reliability of the data-sets which are put into the models. This can be done by ensuring that the sources of information are from the particular government agencies involved and internationally accountable sources like the World Bank databases.

Due to the statistical nature of this study, and the fact that a decomposition study is the most commonly used method for analyzing decarbonization policy effects on carbon emissions, it currently seems to be the most externally valid method. The criterion validity of the predictions in this study can although be jeopardized in case of large political shifts which aren't impossible in the current climate.

Chapter 3: The Kaya Identity

3.1 Introduction to the Kaya Identity

It has already been established in the introduction chapter that multiple research papers show that there is a direct connection between economic growth and carbon emissions. It is also known that the IPCCC considers the emissions which cause global warming, to largely come from the burning of fossil fuels, which has a direct relation to the economic status of the country being studied. The Kaya Identity thus acts as an attempt to 'decouple' the emission variable from the economic one, and is one of the key indicators used by the UNFCCC for tracking the progress of the Paris Agreement. The decoupling of the variables is done to remove the relationship between the variables to allow for an individual analysis of the physical quantities (Wang, Kuang, Huang, & Zhao, 2014). It allows for researchers to not only identify the expected relationships, but also the unexpected relationships between the variables involved for most research into economic growth, environmental resource shortage, and emissions. The OECD in its proposal for 'decoupling' in the theoretical research bifurcates it into two major types; absolute decoupling, and relative decoupling.

The Kaya identity, named after its proponent, the Japanese scholar Yoichi Kaya, managed to establish a relationship between population, value per capita, energy per capita, and carbon dioxide emissions in 1993.

The Kaya Identity is repeated below:

(1) $$C \equiv \frac{C}{E} \times \frac{E}{Y} \times Y$$

In this equation, C = CO2 emissions (in million tonnes); E = total primary energy supply or TPES (in kg Oil Equivalent); and Y = GDP (in US dollars at a constant prices).

For this particular study, initially, the identity can be used in discerning if the countries have been carbon- intensive or energy- intensive with respective to their GDPs. The relevant data was taken from the world bank database for the United Kingdom, and for India. The data collection starts in the year 1960 for the United Kingdom, but doesn't start till 1971 for India possibly due to the lack of availability of data-collection measures in the country. To maintain the continuity of the results, all the data collected is from the same world bank database. The energy intensity for each country is the energy used per capita (in kg oil equivalent) per thousand dollars of GDP. And the carbon intensity is calculated as the carbon emissions (in metric tons per capita) divided by the energy used per capita.

For the purpose of this study, the Kaya identity is further decomposed into a scale factor and a technology factor as follows. From the original Kaya identity, we find an equivalent;

(2) $C \equiv \frac{C}{E} \times \frac{E}{Y} \times \frac{Y}{P} \times P$

Where, 'P' is the total population of the country.

Further, we can simplify this into another set of variables where; $\frac{C}{E}$ is the carbon intensity of energy 'c', $\frac{E}{Y}$ is the energy intensity of economic output (GDP), 'e', and $\frac{Y}{P}$ is the GDP per capita, 'y'. The exact units are of little relevance as long as there is continuity between them, following the rules of an 'identity'.

(3) $C = y \times c \times e \times p$

We can split the factors $y \times p$ to define the scale factor of the kaya identity, and $c \times e$. By studying their growth rates over time, we can thus successfully compare the growth of the scale and technology factors over time in each of the countries.

(4) $\hat{C} = \hat{y} \times \hat{p} \times \hat{e} \times \hat{c}$

As there are continued changes in the policies and technologies involving emission rates, with many countries, it is important to consider the rate of growth of the technology factor along with the scale factor to identify if the impacts caused by technology change have had enough of an effect to offset the impact of economic growth.

The decoupling of the variables is done to remove the relationship between the variables to allow for an individual analysis of the physical quantities (Wang, Kuang, Huang, & Zhao, 2014). It allows for researchers to not only identify the expected relationships, but also the unexpected relationships between the variables involved for most research into economic growth, environmental resource shortage, and emissions. The rate for India has been much larger than that of the United Kingdom, possibly because the data-set for the United Kingdom starts much after the country's industrial revolution, and that for India starts at a time of exponential growth in the Indian economy. The rate of increase of the Indian population has also been much larger than that of the British. It is also interesting to note that, in the United Kingdom, even though carbon emissions have increased over the years, the number of trips taken per person has reduced by 16% in comparison to 20 years ago showing that the change is almost solely because of the volume increase in population (Stark, 2018).

3.2. Kaya Identity in UK – results

According to the data, the energy intensity reduces quite drastically as the population increases. This could be due to the increased efficiency of use, and increased population density in certain areas, meaning that families and localities are sharing more resources, resulting in more sharing of energy sources and thus reducing the emission rate per capita.

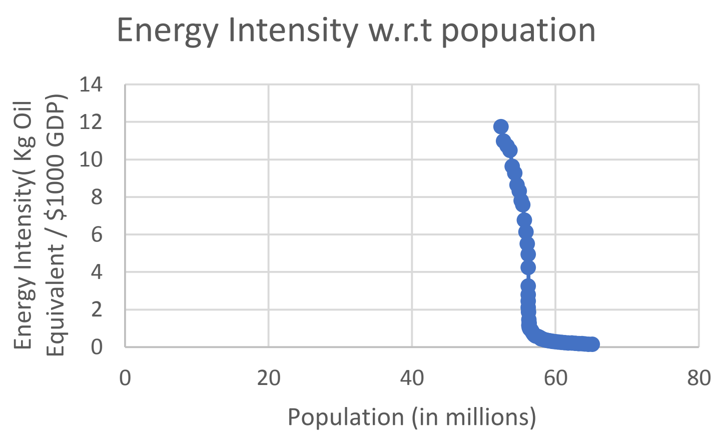

Figure 16: UK; Energy Intensity vs Population (author's calculations)

The energy intensity has been noticed to reduce quite drastically over the past few decades as the GDP has increased. This could possibly be attributed to countries shifting towards more service- based industries, and larger portions of the population moving towards technological and programming related tasks which produce lower emission levels than working machinery, and in factories. There can also be some correlation with the growth in the sizes of factories and offices which would contribute to a larger GDP, as a result of being able to produce more goods and services, while also demonstrating increased energy efficiency with a larger number of people working in a single location. Shanker and Stern (2018) already attributed this effect to a *structural* change in the economy, and implied the importance of energy-augmenting technologies. An example of this is the fact that the sales of electric cars in the UK has increased by 1.9% from the 2017 value (Stark et. al., 2018). Developed countries like the United Kingdom would find it easier to raise the capital required for this change.

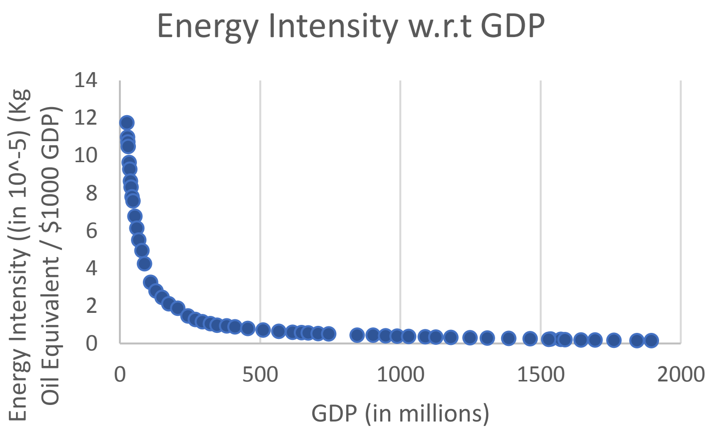

Figure 17: UK; Energy Intensity w.r.t GDP (author's calculations)

The carbon intensity has been noticed to reduce with an increase in the population size. Although it is easy to understand that this could again be contributed to more people moving to areas of larger concentration and sharing resources, this result is in stark contrast with the observation for India. The difference could be attributed to the fact that the British government had started implementing varieties of carbon intensity laws over the years studied, directly impacting the emission rates. This could also be because of the 'developed' status of the country, and the fact that industries in the United Kingdom had also been selling some of their carbon credits; i.e. the British steel industry (Pooler, 2019).

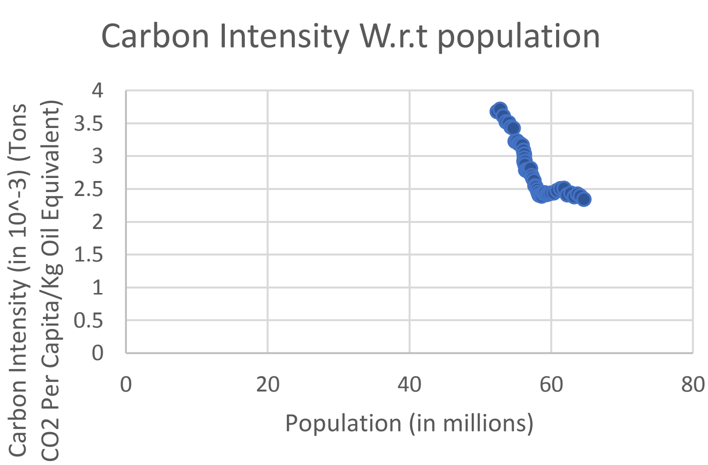

Figure 18: UK; Carbon Intensity vs Population (author's calculations)

Correlating with the population increase in most countries, is an increase in GDP. Similar to the above, the carbon intensity has been observed to reduce with a rise in GDP. The reasoning behind this could be quite comparable to that for population increase, while also taking into consideration the 'developed' status of the region, and that the British government had also started implementing decarbonization measures by this time.

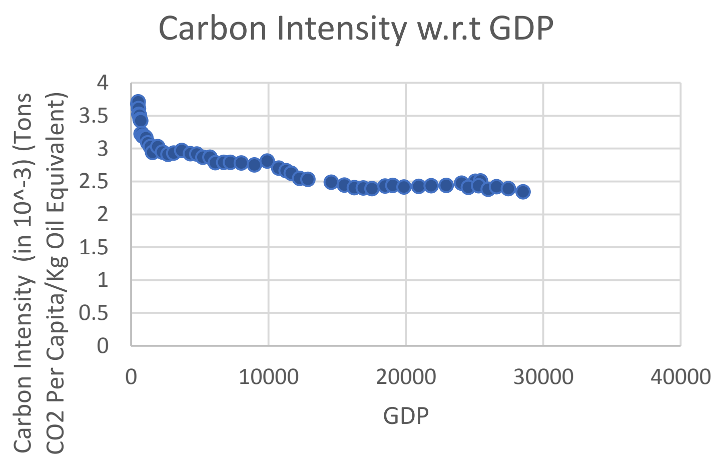

Figure 19: UK; Carbon Intensity w.r.t GDP (author's calculations)

3.3. Kaya Identity in India – results

In a situation similar to that of the United Kingdom, the energy intensity reduces quite drastically as the population increases. This could be due to the increased efficiency of use, and increased population density in certain areas, meaning that families and localities are sharing more resources, resulting in more sharing of energy sources and thus reducing the emission rate per capita. In India in particular, an increased migration of the population from villages and towns to denser, more urban areas has been noticed (World Economic Forum, 2017). According to the 2017 report by the World Economic Forum, rural-to-urban migration has a negative impact, particularly because the population growth also results in lower estimations than accurate. This could also be a major contributing factor to the reduction in energy intensity.

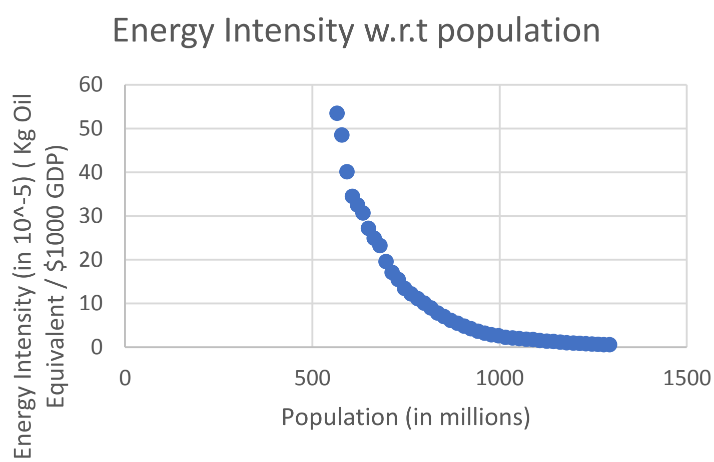

Figure 20: India; Energy Intensity w.r.t Population (author's calculations)

Again, in a pattern similar to that noticed in the United Kingdom, the energy intensity has been noticed to reduce quite drastically over the past few decades as the GDP has increased. This could possibly be attributed to countries shifting towards more service- based industries, and larger portions of the population moving towards technological and programming related tasks which produce lower emission levels than working machinery, and in factories. There can also be some correlation with the growth in the sizes of factories and offices which would contribute to a larger GDP, as a result of being able to produce more goods and services, while also demonstrating increased energy efficiency with a larger number of people working in a single location (Stark, 2018). The rate for India has been much larger than that of the United Kingdom, possibly because the data-set for the United Kingdom starts much after the country's industrial revolution, and that for India starts at a time of exponential growth in the Indian economy. The rate of increase of the Indian population has also been much larger than that of the British. It is also interesting to note that, in the United Kingdom, even though carbon emissions have increased over the years, the number of trips taken per person has reduced by 16% in comparison to 20 years ago showing that the change is almost solely because of the volume increase in population (Stark, 2018). Younger people are also travelling less than 20 years ago by 20%.

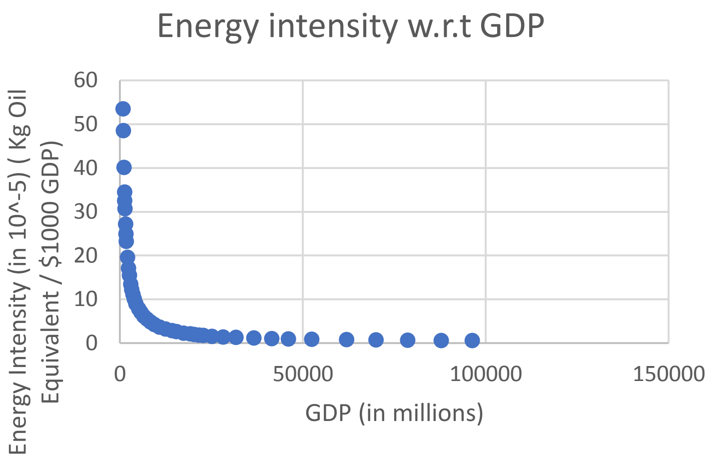

Figure 21: India; Energy Intensity w.r.t GDP (author's calculations)

In a stark contrast with the situation in the United Kingdom, the carbon intensity has been noticed to increase with an increase in the population size. The difference could be attributed to the fact that the British government had started implementing varieties of carbon intensity laws over the years studied, directly impacting the emission rates while the Indian government has not. The 'developing' status of the country could also have contributed since it would have been able to buy some carbon 'credits' from other developed countries and justify its increased emission rate.

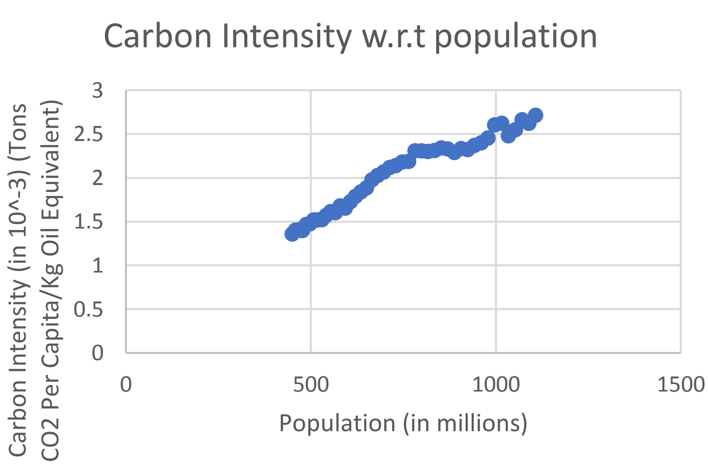

Figure 22: India; Carbon Intensity w.r.t Population (author's calculations)

Similar to the above, the carbon intensity has been observed to increase with a rise in GDP. The reasoning behind this could be quite comparable to that for population increase, while also taking into consideration the 'developing' status of the region, and that the Indian government had not started implementing any decarbonization measures at this time, and was in fact more focused on building factories which would also have contributed to carbon emissions (Kashyap, 1988).

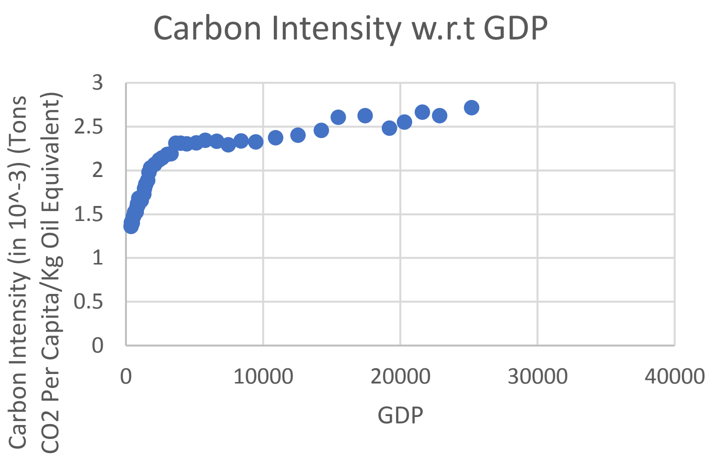

Figure 23: India; Carbon Intensity w.r.t GDP (author's calculations)

3.4. Comparing the Energy Intensity and Carbon Intensity over the years

The observations are not clear because of the scaling, but both show a decrease over time probably due to the standard development indicators; population migration to denser areas, more sharing of resources by larger groups of people, and growth in industry size (Kashyap, 1988).

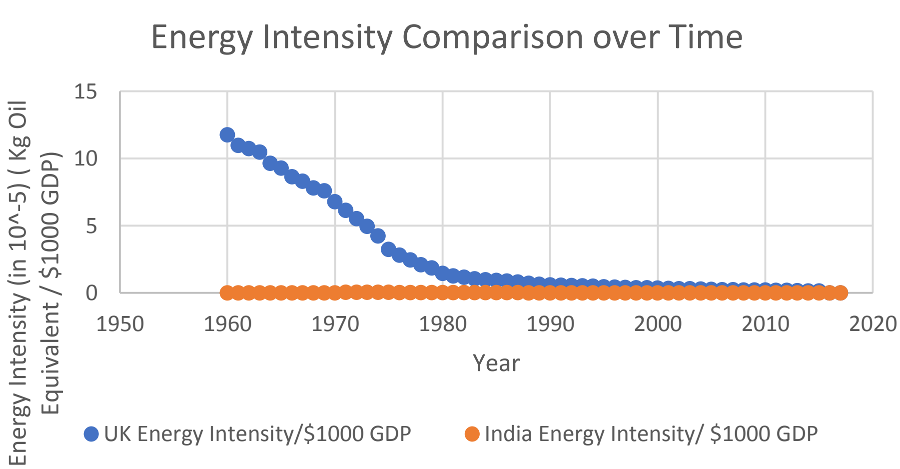

Figure 24: Comparison of Energy Intensity over Time (author's calculations)

The carbon intensity is where the two countries have been clearly found to differ. This could again be due to the developed state of the United Kingdom vs. the developing status of India. It is interesting to note that the cross-over, the point at which India has a higher carbon intensity, happens around 2007, almost a decade after the implementation of the first climate control policies, such as the Kyoto Protocol in 1998. The Kyoto Protocol is also the one which allows for a carbon trade, and it is fitting that it would take about ten years after its implementation for the carbon emission levels to actually invert. This could act as proof of the fact that these measures, while initially meant to bridge the development gap, and ensure an overall reduction in emissions, actually resulted in quite the opposite, which not actually changing the already existing trends of the countries.

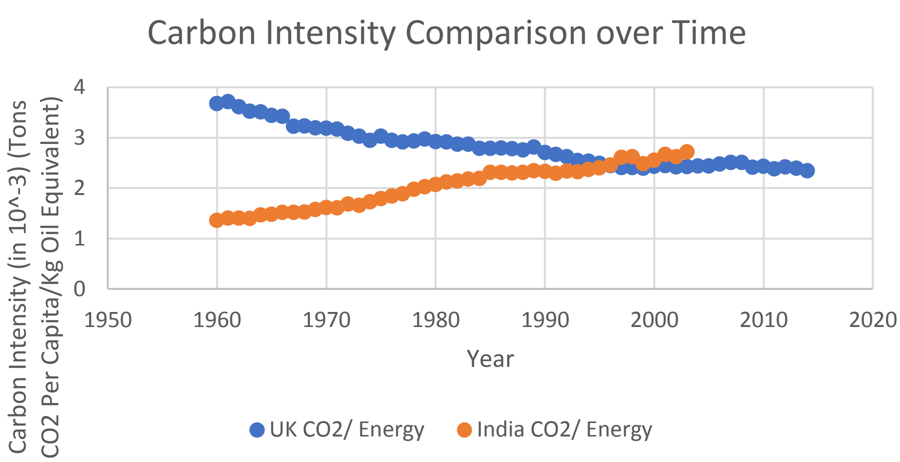

Figure 25: Comparison of Carbon Intensity over Time (author's calculations)

3.5. Growth Rates in the Kaya Decomposition

Using the version of the Kaya Identity which is decomposed into the growth rates of the scale and technology factors, $C = \hat{y} \times \hat{p} \times \hat{e} \times \hat{c}$, we can quantify these changes over specific periods of time. Throughout this thesis, the time periods used are those between 1971 to 1991 to accommodate for the growth in India up to the point of economic liberalization, 1991-2008, to accommodate for the changes in the world economy which affected the UK up to the financial crisis of 2008, and from 2008-2014 to account for the changes which have occurred since. The values represent the average percentage *change* in carbon emissions per year.

Growth rates (UK)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum (TC)	check
		ŷ	p̂		ĉ	ê			
1971-1991	20	2.23	0.14	2.36	-0.55	-2.21	-2.76	-0.40	-0.050
1991-2008	17	2.71	0.47	3.18	-0.55	-3.20	-3.74	-0.56	-0.089
2008-2014	6	0.41	0.77	1.18	-1.24	-3.53	-4.77	-3.59	-0.009

Table 1: Kaya Decomposition for Total Carbon, The United Kingdom; Author's Calculations

In the case of the UK, we can see that over the time periods under consideration. As is clear in the table, the total scale effect has grown but not as exponentially. The total technology effect in 1971-1991 just slightly offsets the scale effect to produce a negative final figure. For example, in the time range between 2008 to 2014, the 1.18% increase in scale effect is completely negated by the -4.77% decrease in carbon emissions as a result of the technology effect. This thus justifies the overall decrease in the carbon emissions.

Growth rates (India)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum (TC)	check
		ŷ	p̂		ĉ	ê			
1971-1991	20	0.04	2.28	2.31	2.13	1.43	3.56	5.87	0.114
1991-2008	17	6.29	1.77	8.06	1.37	-4.03	-2.66	5.41	-0.165
2008-2014	6	6.77	1.30	8.07	0.69	-2.57	-1.88	6.19	-0.084

Table 2: Kaya Decomposition for Total Carbon for India, Author's Calculations

On the other hand, India shows exponential growth in its scale factors, with the total scale effect increasing by about 8% per year from 1991 onwards as a result of its economic and population growth. Simultaneously, we can see that its carbon intensity has reduced in 1991, and has since shown an increase, which is visible in the 2008-2014 range which is much shorter (only 6 years) but still shows a 0.69% increase over this period. Although energy intensity has shown an increase, resulting in a decrease in carbon emissions per year by 2.57%, the sum total of this impact is not enough to offset the growth in carbon emissions as a result of the scale factors. These numbers thus justify the unyielding growth in carbon emissions that India is facing.

3.6. Conclusions

Here, we see that the total carbon emissions of the United Kingdom have shown a general decreasing trend over the years studied, while India has demonstrated the diametric opposite with increasing levels of carbon emissions. This result is not a surprise, and is as expected. Especially since the Kyoto Protocol’s flexible mechanisms allows for carbon emissions to be ‘transferred’ from one country to another. The protocol allows some flexibility which governments can use to their advantage, without providing a ‘real’ change to emission levels. The United Kingdom in particular has taken advantage of this by selling carbon credits to other countries (Sheppard, 2019). It is also important to note that although domestic carbon emissions in the United Kingdom show reduced values, the actual emissions are embodied in the goods that the country imports (Evans, 2019). Since an analysis of the carbon market and embodied carbon emissions is out of the scope of this thesis, we focus on individual sectors in each country to identify trends and to come up with policy and technology suggestions.

Chapter 4: Kaya Decomposition of Transportation Emissions in India and UK

4.1. Emissions in the Transportation Sector

Transportation has accounted for an average of around 20% of the world's emissions since the 1960's. This value has consistently remained nearly similar to that of the manufacturing industries and construction sector. This shows that although the world's total carbon emissions has increased exponentially every year as a result of increased industrialization, the usage of vehicles for private transport, public transport, and transportation of goods and services and has also increased at a similar scale. Apart from the increased use of vehicles, modes of transport have also developed to allow for faster movement over longer distances, which also contribute more carbon emissions. For example, in 2010, the aviation industry accounted for about 12% of the world's transportation emission, while 74% was from road transport (ATAG, 2018).

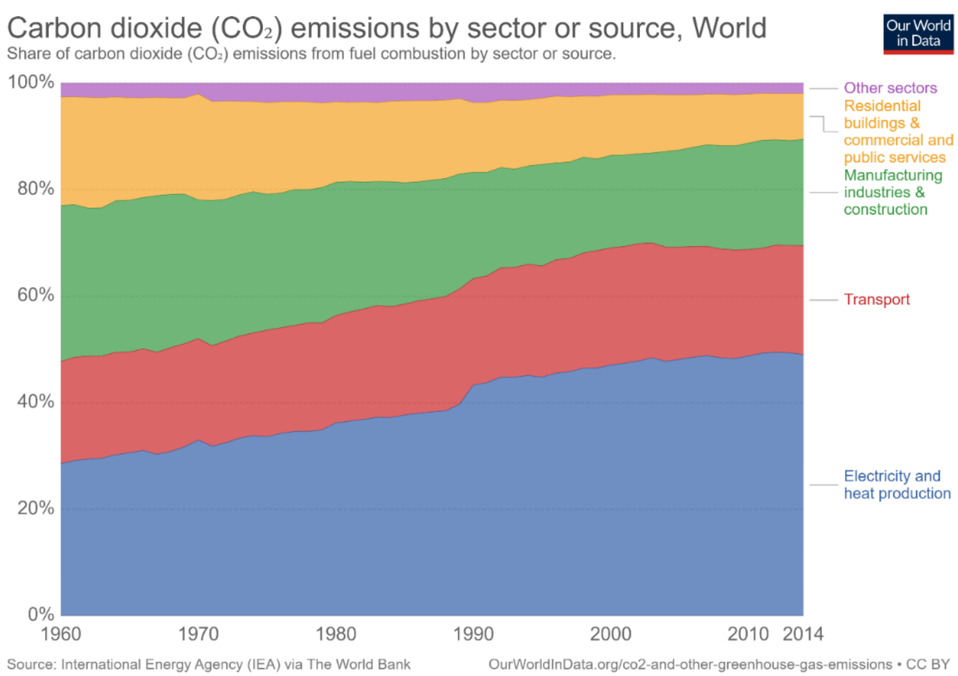

Figure 26: Carbon Dioxide Emissions by Sector; Source: 'ourworldindata.org'

In developed countries, there is a movement towards private transportation and more and more families and individuals have the means to travel for vacations. In these countries, the increased quality of life also results in the purchase of imported goods and services, especially due to the presence of fewer manufacturing industries. These trends are clearly visible in the increased thickness of the transportation band (red) in *figure 2*, which describes sector-wise emission percentages in the United Kingdom, below. In 2018, in the UK, the 33% of all emissions were found to be from the transport sector but, this showed a 2.4% decrease from the 2017 value (A. Penistone, 2019). According to the 2019 Provisional Report on Carbon Emissions by the UK government, the aforementioned reduction can be attributed to reduced traffic volumes and improvements in fuel efficiency. These numbers only include domestic aviation and shipping. The report also mentions that transport emissions peaked in 2007, and then suffered a sharp decline, possibly as a direct result of the financial crisis of 2008 and 2009 (A. Penistone, 2019).

It is also valuable to note that the rate of increase of transportation emission percentages have reduced since 1990 because of the increased implementation of decarbonization and carbon-control policies. To do so, the European Commission developed a strategy prescribing three main courses of action; increasing the energy efficiency of the transport system by taking advantage of modern technological innovations, encouraging the fast deployment of low-emission alternatives by removing as many barriers to entry as possible, and making a conscious effort to move towards zero-emission vehicles (European Commission, 2016). The funding for the strategy relies largely on the Commission's President Juncker's 'Investment Plan for Europe' which focuses on bridging the investment gap for transportation technologies. In addition to this, 70 billion euros was also available under the 'Structural and Investment Fund', apart from other various smaller amounts from other funds. Since at the time of writing this paper, Britain is still in the European Union, majority of these polices are still applicable to the United Kingdom as well.

In developing countries, such as India, social and economic growth have historically taken a priority over environmental concerns. The energy efficiency effect has been found to be one of the most influential factors in emission reduction, and thus, is highly relevant for the decomposition (Wang, et al., 2014). While a majority of the population does not have access to private transport, the sheer volume of the population results in increased carbon emissions. For those with limited means, it is easier to gain personal mobility than in other countries, termed 'rapid motorization'. As of 2015 there are 167 motor vehicles registered per thousand people in India (Sperling & Salon, 2002) while the Gross National Income per capita is a mere $1600 (worldbank.org, n.d.). It is also noticed that one people gain access to a private vehicle, they prefer to use it even if alternative modes of transport are available, possibly as it provides greater comfort. This increased number of vehicles in combination with the limited existing infrastructure leads to more congestion on the road, and traffic also contributes to large increases in emissions (Sperling & Salon, 2002).

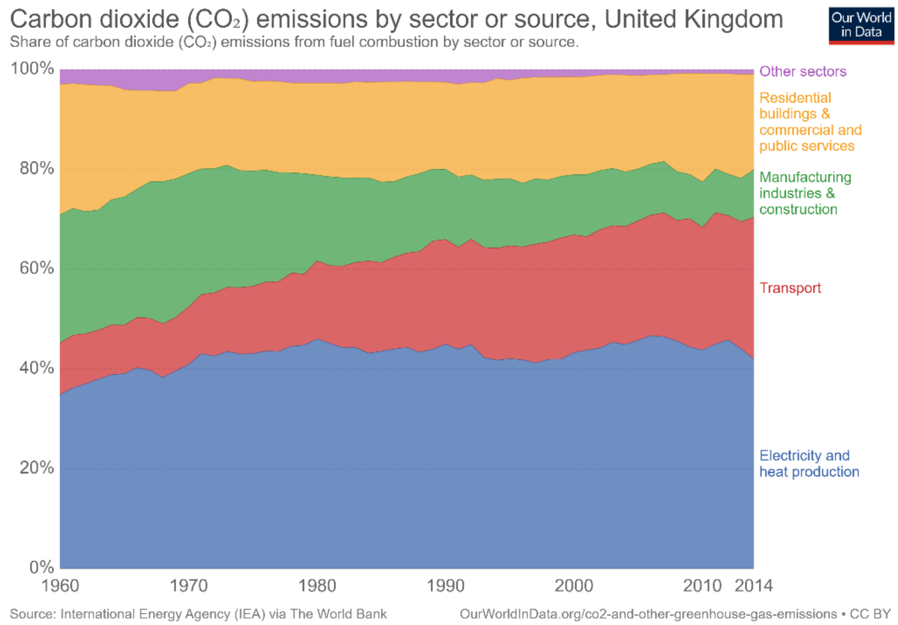

Figure 27: Carbon Dioxide Emissions by Sector, The United Kingdom; Source: 'ourworldindata.org'

The trend in developing countries of people moving towards cities, with more facilities, also accounts for an increase in the transportation carbon emission per capita. While the enhanced mobility provides ease of access to most of the upper-middle and higher classes of society, a good majority of funds have to be diverted to developing infrastructure, increasing fuel efficiency, and implementing decarbonization policy. While developed countries were able to implement these in smaller, gradual steps, developing countries have to effectively overhaul all the current practices in one go, and thus needing more initial investment (Sperling & Salon, 2002).

The Kaya Decomposition was done with information from the ‘Our World in Data’ which takes its information from the International Energy Agency. The decomposition was done over four main ranges of time to accurately identify the changes over the specific time period. First, all the years were decomposed with respect to the first year in which the data was collected, 1971, to account for the entire dataset holistically. Then from 1971-1991 to take into account the ‘Indian Economic Crisis’ which ended up in the economic liberalization of the country. The next sector is from 1991-2008, to account for the major global financial recession of 2008/2009 and finally, from 2008-2014 since most datasets don’t have complete information between 2014-now.

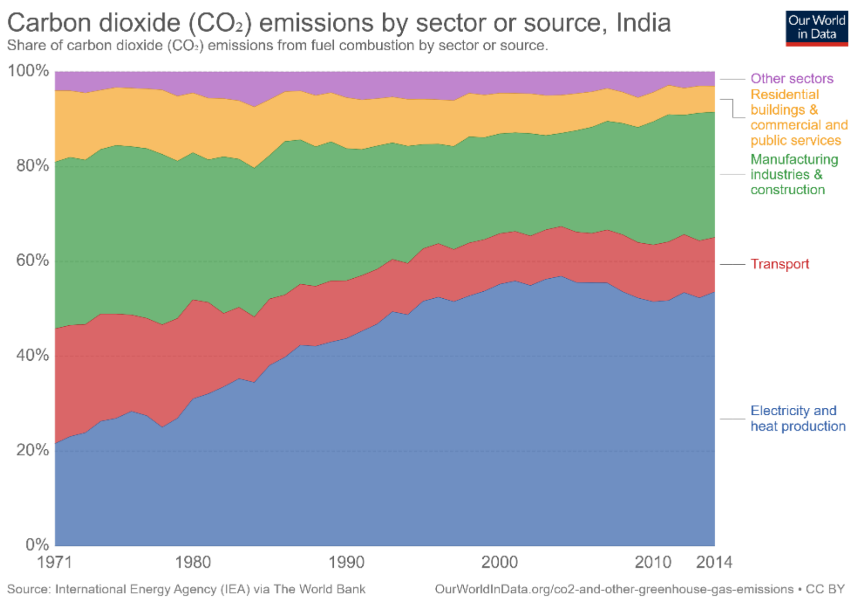

Figure 28: Carbon Dioxide Emissions by Sector, India; Source: 'ourworldindata.org'

Again, the Kaya Identity is further decomposed into the scale factors and technology factors specifically in the transportation sector, using $C = \hat{y} + \hat{p} + \hat{e} + \hat{c}$. Where, $\hat{y} + \hat{p}$ defines the growth in the scale factor and, $\hat{e} + \hat{c}$ defines growth in the technology factor.

4.2 Kaya Decomposition Results and Analysis

According to the results, we see that in the case of the UK there is a continuous increase in the impact of the technology in reducing the carbon emissions over the time periods studied. The absolute values of carbon emissions based on the total scale effect is 2.36 MT over 1971-1991 followed by 3.18 MT in 1991-2008 and 1.18 MT in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 0.03 MT over 1971-1991 followed by 2.76 MT in 1991-2008 and 2.03 MT in the short time period of 2008-2014.

Although from 1971 to 1991, it has a very minimal impact in reducing the scale factor, only a 0.03 reduction on the 2.36 of the scale factors. There is a clear increase in the technology factor over the period from 1991 to 2008, directly correlating with the begin in carbon emission reduction policy implementation by the United Nations. This also corresponds with the policies implemented by the British government, beginning with the 1989 National Fossil Fuel Obligation (NFFO) (Bowen & Rydge, 2011). It is also largely interesting to note that the technology effect from 1991 to 2008 were large enough to significantly offset the scale effect even through the booming economy of the time period, where consumers were largely using more and more private transportation in the UK.

Even with the increase in the technology effect there is a profound decrease in both the scale factors and the impact of the technology effect soon after the 2008 financial crisis. This could be attributed to the sudden reduction in the use of private, more carbon emitting, transport. It is easy to see that the carbon intensity faced a steep drop from 1991 to 2008, followed by a spike, while the energy intensity only continuously increased in intensity, albeit all being negative values. Companies were also largely less capable of investing in emission reduction technologies rather than increasing efficiency.

Growth rates (UK)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	2.23	0.14	2.36	2.19	-2.21	-0.03	2.34	2.29	-0.047
1991-2008	17	2.71	0.47	3.18	0.44	-3.20	-2.76	0.42	0.33	-0.090
2008-2014	6	0.41	0.77	1.18	1.50	-3.53	-2.03	-0.85	-0.93	-0.074

Table 3: Kaya Decomposition for Transport Carbon in the United Kingdom, Author's Calculations

In India, the exponential growth of the scale effect is again clearly visible after the liberalization of the economy but, the technology effect has consistently been minimal in offsetting the scale effect. The absolute values of carbon emissions based on the total scale effect is 2.31 MT over 1971-1991 followed by 8.06 MT in 1991-2008 and 8.07 MT in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 0.08 MT over 1971-1991 followed by 2.51 MT in 1991-2008 and 2.67 MT in the short time period of 2008-2014.

Growth rates (India)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	0.04	2.28	2.31	-1.51	1.43	-0.08	2.23	2.21	-0.023
1991-2008	17	6.29	1.77	8.06	1.51	-4.03	-2.51	5.55	5.39	-0.160
2008-2014	6	6.77	1.30	8.07	-0.10	-2.57	-2.67	5.40	5.28	-0.127

Table 4: Kaya Decomposition for Transport Carbon in India, Author's Calculations

Again, as in the case of the UK, there is a sudden increase between 1991 to 2008 in the technology effect too. Instead of facing a reduction in the next time period though, there is a slight increase in the technology effect. It is interesting to note the extreme increase in the carbon intensity of India, post its 1991 liberalization, and the proceeding drop soon after, while energy intensity also increased also, probably because of the accessibility Indians had to already existing, more energy efficient technologies developed in other countries.

While in the UK there has been an increase in the percentage of transport fuels supplied from low carbon sources in 2018, by 0.2% from the 2017 figure of 0.5%, it is nowhere near enough to result in lasting change (Department for Business, Energy and Industrial Strategy, 2019). There also has been next to no real reduction in the Greenhouse Gas Emission (in terms of carbon dioxide equivalent) between 2016 and 2017, remaining at a constant value of 125.9 million tonnes of carbon dioxide equivalent. Also, While the UK decreased in its energy intensity, India increased in energy intensity drastically as well. This could be because of the intense degradation of the Indian economy between 1971-1991, and its subsequent liberalization in 1991, which strongly stimulated the economy afterward.

4.3. Conclusion

The results of this chapter show that the energy intensity in the UK reduced at a faster rate in the UK than in India, as the Indian economy also had large growth rates, as is in correspondence with the results of the 2018 paper written by Akshay Shanker and David Stern (2010). According to the United Kingdom Carbon brief, transportation emissions has reduced by 7% in 2018 (Evans, 2018).

Since the decomposition was done relative to the energy intensity, it is clear that the energy efficiency of the countries was extremely low, but is increasing over time showing the increased absolute value of decomposition.

It is clear that for the transportation sector the energy intensity of India and the UK have increased dramatically over the past few decades. Although more policies have to be implemented, it is clear that some efforts have been made in the past; increasing the energy efficiency, encouraging fast deployment of low-emission alternatives, deliberately moving towards zero-emission vehicles (European Commission, 2016). Since they do seem to be reducing the emissions in the UK, it makes sense for India to implement them too, although, their implementation would face a completely different set of barriers in India in comparison.

Chapter 5: Kaya Decomposition of Electricity Emissions in India and UK

5.1. Emissions in the Electricity Sector

Electricity and heat production have historically been one of the largest emitters of carbon emissions. Since the industrial revolution, and the proceeding speed of international economic growth, the fraction of emissions from this source has only increased, and now makes up almost half of the total emissions. The worldwide energy demand has only increased consistently to reach its latest peak 2018, at 2.8% above previous levels, prompting increased production of heat and electricity (yearbook.enerdata.net, 2019).

In developed countries, the energy consumption for many years between the industrial revolution to the middle of the 1980s was increasing drastically because of the higher buying power of people. Increased expenditure and consumerism further encouraged increased production of goods and services until the large scale of outsourcing of the manufacture of goods and providing of services began in the 1990s. The corresponding increase in the energy consumption and resulting emissions in China and India can also thus be expected. While energy intensive factories reduce in number over the years in developed countries, they become more prominent in the economies of developing countries.

These trends are clearly visible in the massive increase in the thickness of the 'Electricity and Heat Production' band (blue) in *figure 27*, which describes sector-wise emission percentages in the United Kingdom, below. In 2018 the energy supply sector faced the largest reduction in emission from 2017 according to the Provisional Report on Carbon Emissions by the UK government. It accounted for only 27% of the total emissions. This could be a direct result of the change in the fuel mix used, along with the focus on moving away from coal-based energy to alternate, renewable energy sources (Penistone, 2018). The document also mentions that there is a decrease in the demand for electricity due to enhancements in technology resulting in much higher efficiency.

It is interesting to note that since the late 1990s, about a quarter of all electricity production in the United Kingdom was from nuclear power plants, a number which has reduced to a fifth in the 2010s. Although a much cleaner source of energy, nuclear energy requires a large upfront investment, and has a long start-up time, and has hence largely been out of scope of developing nations. In India, nuclear energy is the fifth largest source of energy, ironically starting the program at a time when the country's industrial infrastructure was barely existent (Banerjee & Gupta, 2017).

In developing countries, such as India, as social and economic growth have historically taken a priority over environmental concerns, it is understandable that as in the case of the transportations sector, there is minimised effort in reducing emissions. The distinct plateau that is visible in the graph for the United Kingdom is very much missing in that of India. While it is clear that the vast majority of the Indian population does not even have access to electricity, offices and industries consume enough to balance any differences.

The Indian government has announced a goal of '24-hour electricity by 2022' and investments have focused 'grid-connected' projects which aim at connecting distant villages to the national electricity grid. Even so, it is suggested that off-grid techniques are to be invested in as well if the goal is to be attained (The Economist, 2018). Energy consumption is anticipated to continue increasing by at least 3% per year. There is also much to be said about the state of political affairs in developing countries such as India. It can be safely assumed that portions of the investments made into extracting energy may not even reach the projects, and may be waylaid into the pockets of politicians resulting in major inefficiencies in policy implementation (Adam & McCulloh, 2019).

The decomposition was done over four main ranges of time to accurately identify the changes over the specific time period. First, all the years were decomposed with respect to the first year in which the data was collected, 1971, to account for the entire dataset holistically. Then from 1971-1991 to take into account the 'Indian Economic Crisis' which ended up in the economic liberalization of the country. The next sector is from 1991-2008, to account for the major global financial recession of 2008/2009 and finally, from 2008-2014 since most datasets don't have complete information between 2014-now.

5.2. Kaya Decomposition Results and Analysis

From the results we can see that the technology effect in the United Kingdom has increased in strength over the period of time studied, with the largest change being in the time region between 2008 to 2014 even though it accounts for a shorter period of time. The absolute values of carbon emissions based on the total scale effect is 2.36 MT over 1971-1991 followed by 3.18 MT in 1991-2008 and 1.18 in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 5.09 MT over 1971-1991 followed by 0.35 MT in 1991-2008 and 4.97 in the short time period of 2008-2014.

Growth rates (UK)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	2.23	0.14	2.36	4.94	-2.21	2.72	5.09	-0.35	-5.433
1991-2008	17	2.71	0.47	3.18	-0.33	-3.20	-3.53	-0.35	-0.44	-0.089
2008-2014	6	0.41	0.77	1.18	-2.62	-3.53	-6.15	-4.97	-4.94	0.024

Table 5: Kaya Decomposition for Energy and Heat Carbon in the United Kingdom, Author's Calculations

The carbon efficiency and energy efficiency have also shown consistently decreasing values, showing a fall in the carbon emission and energy consumption per dollar of GDP. Even though the population effect increased exponentially over the years, again albeit the shorter time gap between 2008 to 2014. The overall decrease in the total scale effect can thus be attributed to the massive decrease in the scale factor due to economic growth. Like most of the rest of the world, the United Kingdom seems to have more policies aimed at the energy and heat production sector than the others.

Growth rates (India)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	0.04	2.28	2.31	5.99	1.43	7.42	9.73	9.99	0.260
1991-2008	17	6.29	1.77	8.06	2.38	-4.03	-1.64	6.42	6.29	-0.127
2008-2014	6	6.77	1.30	8.07	0.68	-2.57	-1.88	6.19	6.10	-0.084

Table 6: Kaya Decomposition for Energy and Heat Carbon in India, Author's Calculations

We also can see that the impact of the total technology effect increases in India over the years in question, even when a smaller time period is under consideration. The absolute values of carbon emissions based on the total scale effect is 2.31 MT over 1971-1991 followed by 8.06 MT in 1991-2008 and 8.07 in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 7.42 MT over 1971-1991 followed by 1.64 MT in 1991-2008 and 1.88 MT in the short time period of 2008-2014. The carbon intensity decreases over the years, with the total carbon levels falling as well, although the drop in 2008 to 2014 could be a result of studying a shorter time period over which time the effects would be less minimal. The corresponding economic and population growth show a similar pattern of growth with the shorter time period probably showing a higher level if extrapolated to a longer time. It is thus clear that technology effect is nowhere near enough to offset the economic and population impact, even in such a time of environmental crisis as today.

5.3. Conclusion

The Energy Efficiency Commitment (EEC) of 2002 required energy suppliers to produce 62 TWh of energy savings within three years. This was followed by the 2008 Climate Change Act which set a goal of reducing emissions by 80% from 1990 levels by 2050. Also, in 2008, the Carbon Emission Reduction Target (CERT) was implemented which focused more on sustainable energy saving measures. Further technological development is encouraged by the British government through the 2010 Carbon Capture and Storage (CCS) Demonstration Project in which 1 billion pounds of capital funding for CSS systems for coal-fired and gas- plants, aiming at ensuring that the existing fossil- fuel based energy plants would effectively release less carbon into the atmosphere. This is further reinforced by the 2011 Carbon Plan which aims at reducing the UK's emissions by 2020. The Energy Bill of 2012 additionally encourages greater security for energy supplies, and higher supply of low-carbon energy sources. Further, at the level of the European Union, the 'National Energy Efficiency Action Plan' is a series of consumption and "planned energy efficiency measures" which all individual EU countries are expected to achieve, and reconfigure every three years (European Parliament, 2012). A Heat Network Investment Project was also announced in 2016, investing 320 million pounds into supporting 200 projects (Department for Business, Energy and Industrial Strategy, 2019). A target has also been set; the "Renewable Energy Directive Target", requiring 15% of energy in the United Kingdom to be from renewables.

The energy industry also accounts for about 9.8% of total investment in the country, a number which has increased since the 2004 figure. As of 2017, 60% of all investment in energy was in electricity, 30% was put into oil and gas, while 7.5% was into natural gas with the rest going into renewables (Department for Business, Energy and Industrial Strategy, 2019). Even so, the generation of energy from renewables has been on the increase; by 19% in 2017. This can be attributed to the 13.6% increase in storage capacity and the increase in wind speed registered that year (Department for Business, Energy and Industrial Strategy, 2019). The increase in storage capacity is largely possible only by increase in investment into the research and development of renewables storage.

Chapter 6: Kaya Decomposition of Manufacturing Industry Emissions in India and UK

6.1. Emissions in the Manufacturing Industry sector

The manufacturing sector has long been one of the most recognized carbon emitters in most countries. Since the industrial revolution, as humans have started consuming more, directly culminating in the emission patterns we see across the world today. Predictably, the amount emitted globally has fallen since the international implementation of various climate accords. India on the other hand seems to show an increase post its 1990 economic liberalization. According to the World Bank database, India has faced an average reduction in emission growth, from 1970 to now, rate by 0.55% while the United Kingdom has reduced its emissions by 2.12% (International Energy Agency, 2019).

The manufacturing industry in India has grown largely in correlation with a massive growth in the domestic market since the liberalization of the Indian economy in 1991. The combination of the exponential growth in the population along with the increased investment in Indian industries from foreign and domestic firms. In this particular chapter it is helpful to introduce the concept of 'Gross Fixed Capital Formation' a term which describes the net investment into all the fixed assets in the country, without including stocks of inventories, depreciation, and operational costs. This calculation doesn't take into account land sales and purchases due to the complication involving the ownership of land and its value upon sale. According to the 'India Brand Equity Foundation', India's Gross Fixed Capital Formation has increased by about 10% every year between 2016 and 2018 (IBEF, 2019). The increase in investment can also be connected to some policy changes which have been implemented with the specific aim of encouraging expenditure into research and development behind green technologies.

In developing countries, such as India, as social and economic growth have historically taken a priority over environmental concerns, it is understandable that as in the case of the transportations sector, there is minimised effort in reducing emissions. The distinct plateau that is visible in the graph for the United Kingdom is very much missing in that of India. While it is clear that the vast majority of the Indian population does not even have access to electricity, offices and industries consume enough to balance any differences. The Indian government has announced a goal of '24-hour electricity by 2022' and investments have focused 'grid-connected' projects which aim at connecting distant villages to the national electricity grid.

Even so, it is suggested that off-grid techniques are to be invested in as well if the goal is to be attained (The Economist, 2018). Energy consumption is anticipated to continue increasing by at least 3% per year. There is also much to be said about the state of political affairs in developing countries such as India. It can be safely assumed that portions of the investments made into extracting energy may not even reach the projects, and may be waylaid into the pockets of politicians resulting in major inefficiencies in policy implementation (Adam & McCulloh, 2019).

The decomposition was done over four main ranges of time to accurately identify the changes over the specific time period. First, all the years were decomposed with respect to the first year in which the data was collected, 1971, to account for the entire dataset holistically. Then from 1971-1991 to take into account the 'Indian Economic Crisis' which ended up in the economic liberalization of the country. The next sector is from 1991-2008, to account for the major global financial recession of 2008/2009 and finally, from 2008-2014 since most datasets don't have complete information between 2014-now.

6.2. Kaya Decomposition Results and Analysis

From the results we can see that the technology effect in the United Kingdom has increased in strength over the period of time studied, with the largest change being in the time region between 2008 to 2014 even though it accounts for a shorter period of time. The absolute values of carbon emissions based on the total scale effect is 2.36 MT over 1971-1991 followed by 3.18 MT in 1991-2008 and 1.18 in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 2.72MT over 1971-1991 followed by 3.53 MT in 1991-2008 and 6.15 in the short time period of 2008-2014.

The carbon efficiency and energy efficiency have also shown consistently decreasing values, showing a fall in the carbon emission and energy consumption per dollar of GDP, by 2.62% and 3.53% on average each year. Even though the population effect increased exponentially over the years, by 0.77% on average, again albeit the shorter time gap between 2008 to 2014. The overall decrease in the total scale effect can thus be attributed to the massive decrease in the scale factor due to economic growth.

Growth rates (uk)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	2.23	0.14	2.36	4.94	-2.21	2.72	5.09	-0.35	-5.433
1991-2008	17	2.71	0.47	3.18	-0.33	-3.20	-3.53	-0.35	-0.44	-0.089
2008-2014	6	0.41	0.77	1.18	-2.62	-3.53	-6.15	-4.97	-4.94	0.024

Table 7: Kaya Decomposition for Manufacturing and Industry Carbon in the United Kingdom, Author's Calculations

We also can see that the impact of the total technology effect shows an apparent increase in India, in the table below, over the time period in study. There is an apparent growth of 7.42% carbon emissions from 1971-1991 followed by decreasing growth rates of -1.64% and -1.88% on average per year in the subsequent time periods.

The largest difference in impact is clocked from 2008 onwards with a value of -1.88% on average. This could be further influenced by the large- scale liberalization of the country in 1991 and the consequent focus on international investment into cleaner, and safer, manufacturing practices in the country.

The absolute values of carbon emissions based on the total scale effect is 2.31 MT over 1971-1991 followed by 8.06 MT in 1991-2008 and 8.07 in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 9.73 MT over 1971-1991 followed by 6.42 MT in 1991-2008 and 6.19 MT in the short time period of 2008-2014.

This in particular shows the large-scale of the influence that allowing technology, and investments, from foreign countries has on reducing carbon emission levels. This is specifically shown by the speedy reduction in carbon intensity over the years under consideration.

Growth rates (India)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		$\hat{y}$	$\hat{p}$		$\hat{c}$	$\hat{e}$				
1971-1991	20	0.04	2.28	2.31	5.99	1.43	7.42	9.73	9.99	0.260
1991-2008	17	6.29	1.77	8.06	2.38	-4.03	-1.64	6.42	6.29	-0.127
2008-2014	6	6.77	1.30	8.07	0.68	-2.57	-1.88	6.19	6.10	-0.084

Table 8: Kaya Decomposition for Manufacturing and Industry Carbon in India, Author's Calculations

6.3. Conclusion

Four main policies which have a direct effect on the manufacturing sector can be identified in the United Kingdom. The first is the ‘Non- Fossil Fuel Obligation’ (NFFO) implemented in 1989, which levies a tax on fossil fuel purchases by companies. This came as a result of the privatization of energy production in the country. Although the NFFO expired in 2018, the country had largely replaced its effect by the ‘Renewables Obligation’, implemented in 2002. The Renewables Obligation works in a similar fashion by encouraging electricity suppliers to source more electricity from renewables. Along with the ‘Renewables Obligation’, the ‘Climate Change Levy’ of 2001 also adds additional cost to the downstream, non-domestic, energy consumption. There also has been further encouragement to use ‘distributed’ sources of energy, like solar panels, through the enforcement of ‘Feed-In Tariffs’ in 2010. This policy allowed for houses and companies which produce their own electricity to earn payments by feeding any excess to the local and national electricity grids. For firms which did not already conform to the pre-requisite European Union standards, the ‘Carbon Reduction Commitment Energy Efficiency Scheme’ (CRC EES) of 2010 ensures a control in emissions too.

Chapter 7: Kaya Decomposition of Building Emissions in India and UK

7.1. Emissions from Buildings

Building emissions seem to have been largely overlooked by most literature using the kaya identity (insert literature citations). Although it does not contribute to a major portion of the carbon emissions, there is a clear difference in the way that the building sector grows in both developed and developing countries. As the graphs below show only the percent of emissions from the specific sources, it is hard to visualize the actual growth in building-emissions over the years. A particular consideration of the building sector is the division between 1) 'operational' energy consumption, which covers the daily functioning of the building, and 2) the 'embodied' energy consumption which encompasses its construction, renovation, maintenance, and the final demolition of the building after its lifetime (Huang et. al., 2018). Between the two forms of energy consumption, embodied energy is found to account for a much larger percentage. This shows that for a lasting impact, attention has to be paid from the very conception of the building.

In the United Kingdom, data shows that there has been a reduction in carbon emissions in most sectors from 1990 onwards. Especially in the 'building and commercial' sector, this drop has been by 1.45%, not a large margin in comparison to growth in emissions in other sectors. An especially small number when contrasted with the large increase in Indian levels. From literature, it is indicated that construction in a country reaches a certain level of stability, and doesn't grow by much, once it reaches a 'developed' status (Wells, 1989). So, the United Kingdom should have shown consistent levels of carbon emission since its Victorian industrial revolution.

Data from the world-bank shows a 107% increase in the carbon emissions for the 'residential and commercial sectors' from 1990 onwards (ourworldindata.org). Its already well understood that developing countries, especially one with the booming population of India has enough potential, by contributing to the scale factor in the kaya identity, for increase in carbon emission. In this chapter we look to see if there has been any impact caused by technological developments in reducing the carbon levels. In a country as complicated as India, caught up in multiple issues of socio-economic value there has been next to no development in construction technology and building efficiency since.

Like the other sectors, the decomposition was done over four main ranges of time to accurately identify the changes over the specific time period. First, all the years were decomposed with respect to the first year in which the data was collected, 1971, to account for the entire dataset holistically. Then from 1971-1991 to take into account the 'Indian Economic Crisis' which ended up in the economic liberalization of the country. The next sector is from 1991-2008, to account for the major global financial recession of 2008/2009 and finally, from 2008-2014 since most datasets don't have complete information between 2014-now.

7.2 Kaya Decomposition Results and Analysis

As is expected from the United Kingdom, the total scale effect shows an increase over the time period in question, especially when taking into consideration the shorter time period from 2008-2014. The absolute values of carbon emissions based on the total scale effect is 2.36 MT over 1971-1991 followed by 3.18 MT in 1991-2008 and 1.18 in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 2.39MT over 1971-1991 followed by 3.42 MT in 1991-2008 and 5.24 in the short time period of 2008-2014.

This in combination with the clear increase in the population over the years adds to the impact of the scale effect. In a direct contrast, we see that the total technology effect increases in absolute value over the years, even when a shorter time period is studied. This proves that the United Kingdom has had developments in building technology that have reduced the impact of the economic and population growth have had on the environmental factors.

Growth rates (UK)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	2.23	0.14	2.36	-0.18	-2.21	-2.39	-0.03	-0.08	-0.050
1991-2008	17	2.71	0.47	3.18	-0.22	-3.20	-3.42	-0.24	-0.33	-0.089
2008-2014	6	0.41	0.77	1.18	-1.71	-3.53	-5.24	-4.06	-4.05	0.002

Table 9: Kaya Decomposition for Building Carbon in the United Kingdom, Author's Calculations

India on the other hand is a country that has shown large increases in economic growth and population over the years, resulting in an understandably massive growth in the total scale effect. The carbon emissions due to scale effect have increased by 2.31%, 8.06% and, 8.07% on average per year in all the major time periods studied. The absolute values of carbon emissions based on the total scale effect is 2.28 MT over 1971-1991 followed by 8.06 MT in 1991-2008 and a whopping 8.07 in the short time period of 2008-2014. While the absolute values of the reduction in carbon emissions based on the total technology effect is 4.04MT over 1971-1991 followed by 2.67 MT in 1991-2008 and 3.16 in the short time period of 2008-2014.

Growth rates (UK)	Time gap	scale factors		total scale effect	technology drivers:		total technology effect	Kaya-sum	TC	check
		ŷ	p̂		ĉ	ê				
1971-1991	20	0.04	2.28	2.31	0.30	1.43	1.72	4.04	4.08	0.045
1991-2008	17	6.29	1.77	8.06	-1.36	-4.03	-5.39	2.67	2.40	-0.270
2008-2014	6	6.77	1.30	8.07	-2.35	-2.57	-4.91	3.16	2.91	-0.248

Table 10: Kaya Decomposition for Building Carbon in India, Author's Calculations

The major difference with the United Kingdom lies with the dismal rate of increase in the total technology effect which has next to no impact on the carbon level of the country. This could be a result of the fact that no major 'clean and green' breakthrough has happened in the sector which can be implemented widely in any country across the world. Although it can be argued that the density of the Indian population in cities is much higher, with more people living in a single construction. The fact remains that the number of construction sites, with shoddy technologies has only increased. This is particularly shown in the kaya-sum of the country, proving that the carbon emission rates have increased dramatically, while that of the United Kingdom remains in negative values.

7.3. Conclusions

While India seems to have only growth in its future, which would increase emissions, the United Kingdom has already set some policies in place to combat emissions. The Indian construction sector accounts for 55% of the steel, 15% of the paint, and 30% of the glass produced in the country, adding to its embodied carbon. Projections also show that the industry is only set to grow, and the country would spend about 454 billion dollars on upcoming infrastructure development (investindia.gov, 2019). The main drivers for growth are identified to be; the development of smart cities, industrial corridors which would also further the consumption of goods and services, more railway lines and stations, the construction of six new mega ports, and even more commercial space.

In 2007, the Code for Sustainable Homes was implemented, requiring homes across the region to comply with improved efficiency regulations. The following year saw the enforcement of Energy Performance Certificates (EPS), which were required whenever a building is sold, or to be sold. In 2012, the Renewable Heat Incentive (RHI) was implemented to allow for financial support for households and businesses which install heating systems which source renewable energy. As in the case of manufacturing and industry, the 2010 Feed-In Tariffs (FITs) encouraged the installation of distributed energy sources by paying for excess energy that is put back into the grid. Another effective measure was the 2014 Smart meter roll-out which replaced older gas and electricity meters.

8. Forecasts for Carbon Emissions

8.1. The United Kingdom

Using the information gleaned from the results of the decomposition of carbon emissions using the Kaya identity, a regression analysis was done. In this regression method, previous data is used to anticipate future values. For the sake of accuracy, only the data in the time range from 2008 to 2014 was used since no major events, such as the 2008 economic crisis, have happened since which largely affect emissions, and wold further affect the validity of the results in consideration. It is also assumed that no majorly disruptive changes occur since 2014, as they would be out of the scope of this research document to predict. This is considered a basic research methodology to help predict the future emission trends up to 2050, the year by which both countries aim to drastically reduce their emissions. The United Kingdom in particular has set the goal of attaining zero-carbon emissions by 2050 (Bowen & Rydge, 2011).

To be realistic, the situations where the carbon emission somehow increases, or where technologies improve faster than expected and cause further reduction in emissions should also be considered. For example, in the kaya decomposition for total carbon, we see that the technology effect has an overall -4.77% impact in reducing carbon emissions in the time range from 2008 to 2014. The results of the Kaya identity, the value of the 'kaya sum', are used to form the 'confidence bounds' of the prediction to create the 'best-case' and 'worst-case' scenarios, by subtracting and adding the 'kaya sum' value from the existing total carbon emission of the year.

Since the Kaya Identity calculations are already based on a 'growth factor' which forms a ratio, this would thus legitimately account for the percentage of change which happens per year, to cover all the possible values of the unknown future parameter. In the graph showing the predictions for transport carbon, it is clear that the curves are not parallel as a result of taking the Kaya value to decide the confidence bound. The further deviation for the directly predicted values are a result of assuming that technologies will worsen or improve at a rate which is a percentage of the previous year, and thus result in further compounded values in the future.

The Kaya sum values which were taken into account for the United Kingdom are recorded in the following table (11):

	Year	Absolute Value
Total Carbon	1971-1991	5.87
	1991-2008	5.41
	2008-2014	5.19
Transportation	1971-1991	2.34
	1991-2008	0.42
	2008-2014	0.85
Energy and Heat	1971-1991	5.09
	1991-2008	0.35
	2008-2014	4.97
Manufacturing and Industry	1971-1991	5.09
	1991-2008	0.35
	2008-2014	4.97
Buildings	1971-1991	0.08
	1991-2008	0.33
	2008-2014	4.05

Table 11: Kaya Decomposition Sums for Carbon in the United Kingdom, Author's Calculations

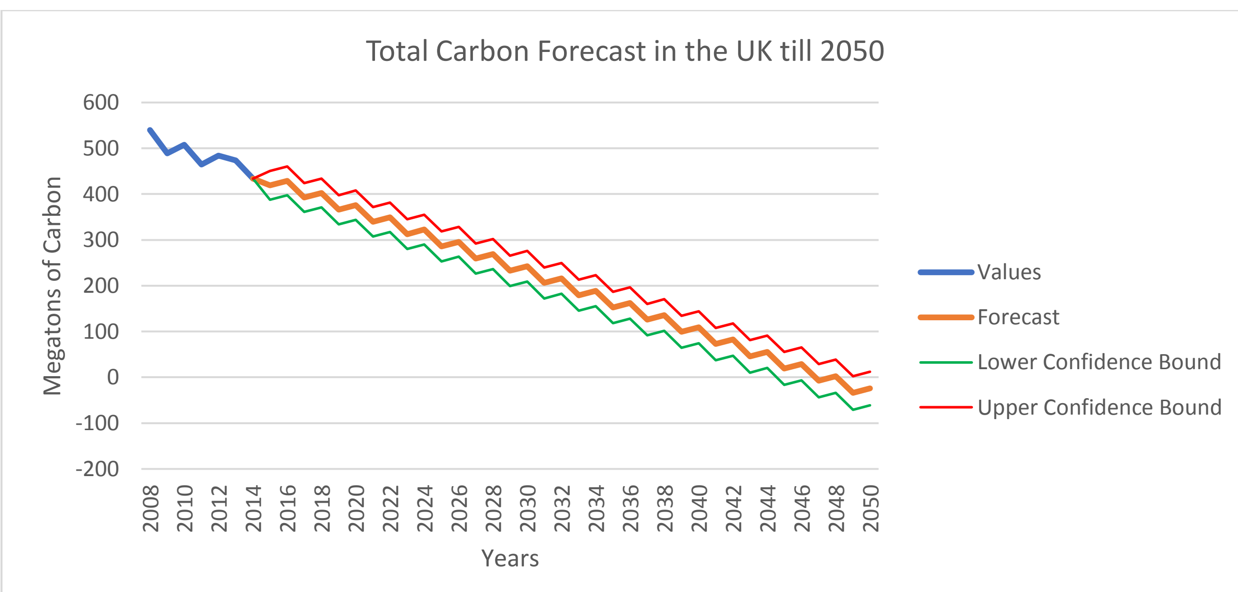

Figure 29: Total Carbon Forecast in the UK till 2050; Author's Calculations

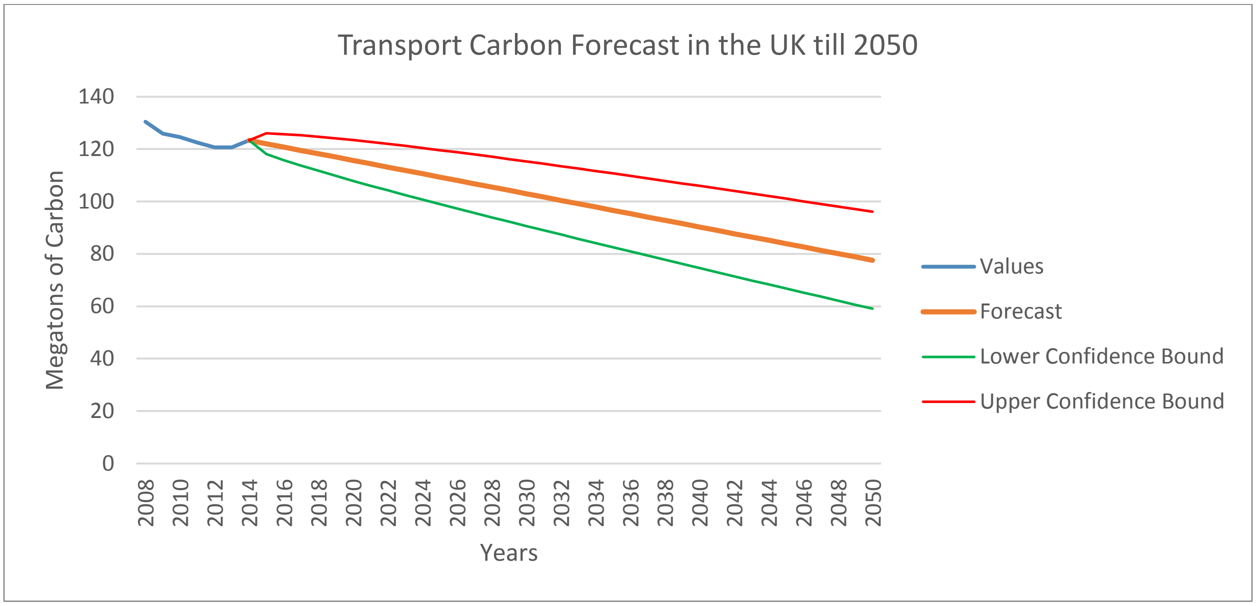

Figure 30: Transport Carbon Forecast in the UK till 2050; Author's Calculations

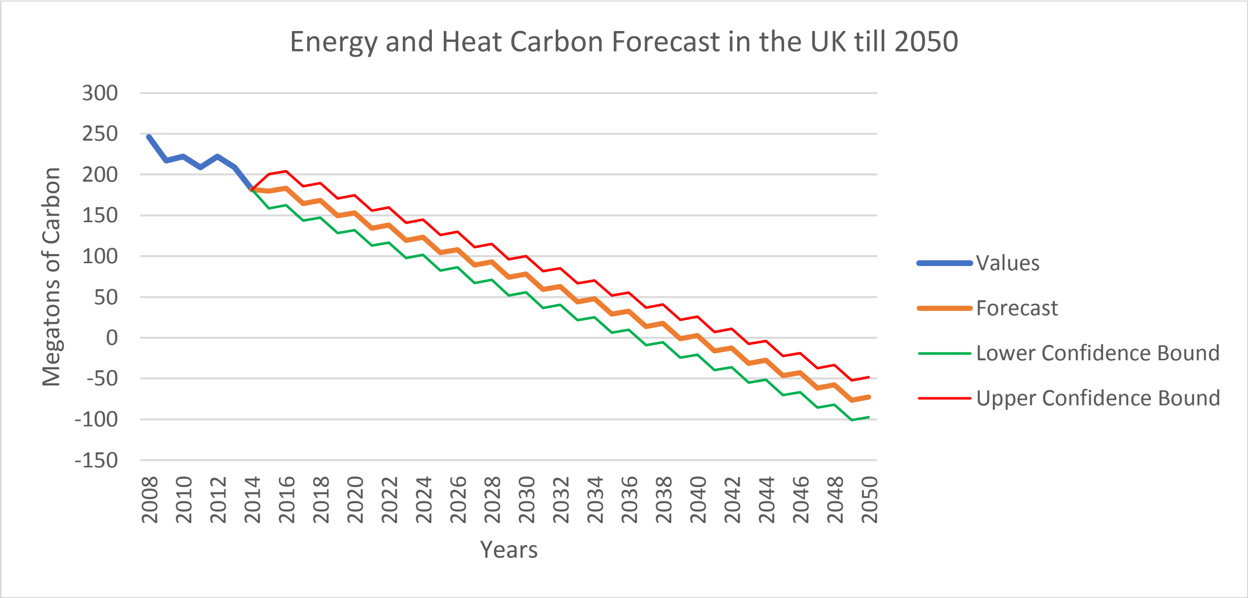

Figure 31: Energy and Heat Carbon Forecast in the UK till 2050; Author's Calculations

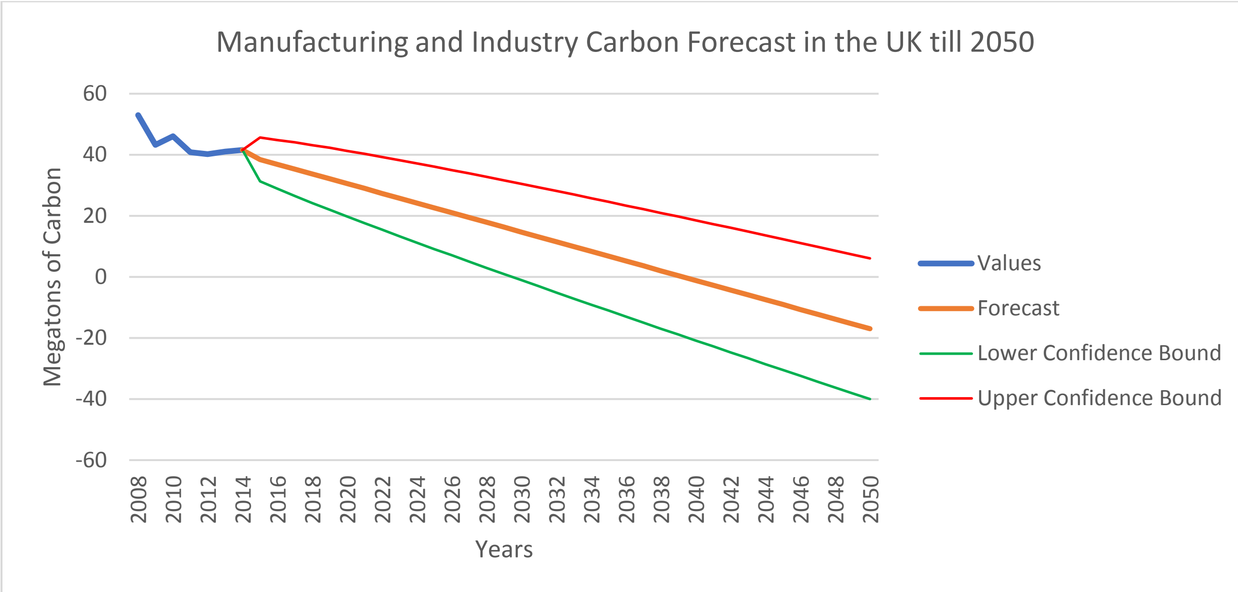

Figure 32: Manufacturing and Industry Carbon Forecast in the UK till 2050; Author's Calculations

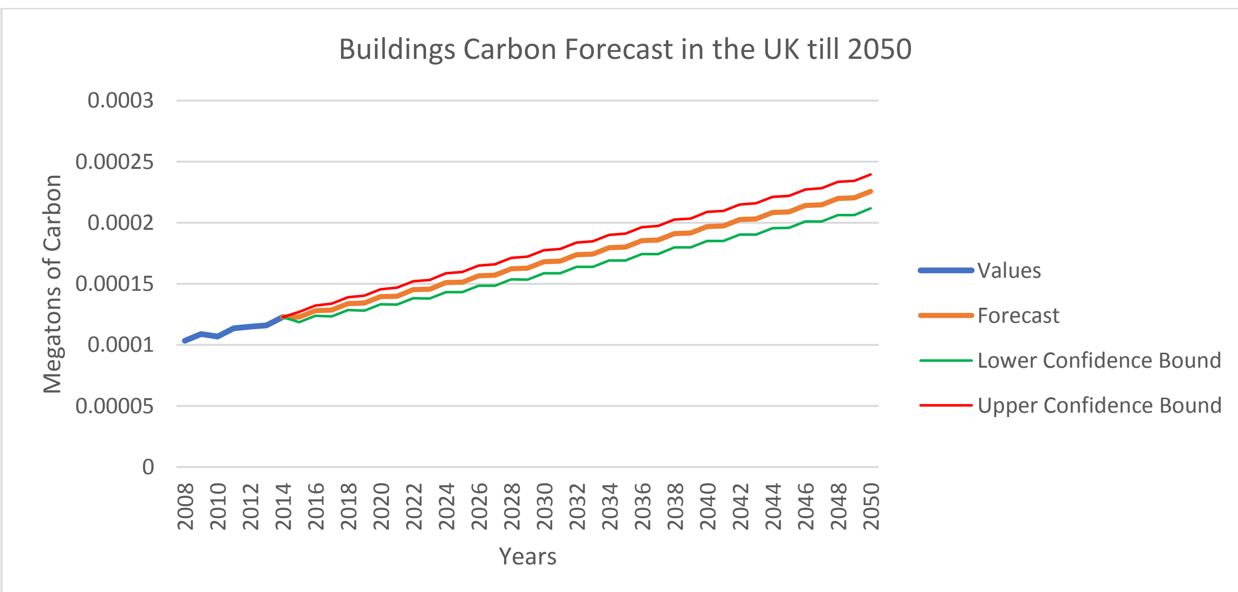

Figure 33: Buildings Carbon Forecast in the UK till 2050; Author's Calculations

From the projections, we see that the carbon forecast is showing an upward slope only for the building sector, indicating that the sector needs particular attention paid to it if carbon values are to reduce. Although in contrast to the carbon emission decomposition done in the previous chapter, where the rate of growth of carbon emissions show a slight decrease in the United

Kingdom, we still see that the total carbon emitted per year on averages still is on the rise. This is an understandable result since building technologies have not seen the sort of improvements which cause significant decarbonization in the construction and demolition phases which are most carbon intensive, and instead the focus has been on policy implementation during the running of the structure. However, these figures are offset by the clear decrease in carbon emissions in all of the other sectors studied.

8.2. India

Similar to the case of the United Kingdom a regression analysis was done using the information gleaned from the results of the decomposition of carbon emissions from Kaya identity. In this method, previous data is used to anticipate future values. For the sake of accuracy, only the data in the time range from 2008 to 2014 was used since no major events, such as the 2008 economic crisis, have happened since which largely affect emissions. It is also assumed that no majorly disruptive changes occur since 2014, as they would be out of the scope of this research document to predict. This is considered a basic research methodology to help predict the future emission trends up to 2050, the year by which both countries aim to drastically reduce their emissions. India had officially announced a goal of carbon reduction by 20-25% from the 2005 value by 2030, and no longer-term goal. Since the current overall trend does not show any signs of reduction, it is clear that none of the prospective goals can be attained without some major overhauling of the overall system.

The Kaya sum values which were taken into account for India are recorded in the following table:

	Year	**Absolute Value**
Total Carbon	1971-1991	0.40
	1991-2008	0.56
	2008-2014	3.59
Transportation	1971-1991	2.23
	1991-2008	5.55
	2008-2014	5.40
Energy and Heat	1971-1991	9.73
	1991-2008	6.42
	2008-2014	6.19
Manufacturing and Industry	1971-1991	9.73

	1991-2008	6.42
	2008-2014	6.19
Buildings	1971-1991	4.08
	1991-2008	2.40
	2008-2014	2.91

Table 12: Kaya Decomposition Sums for Carbon in India, Author's Calculations

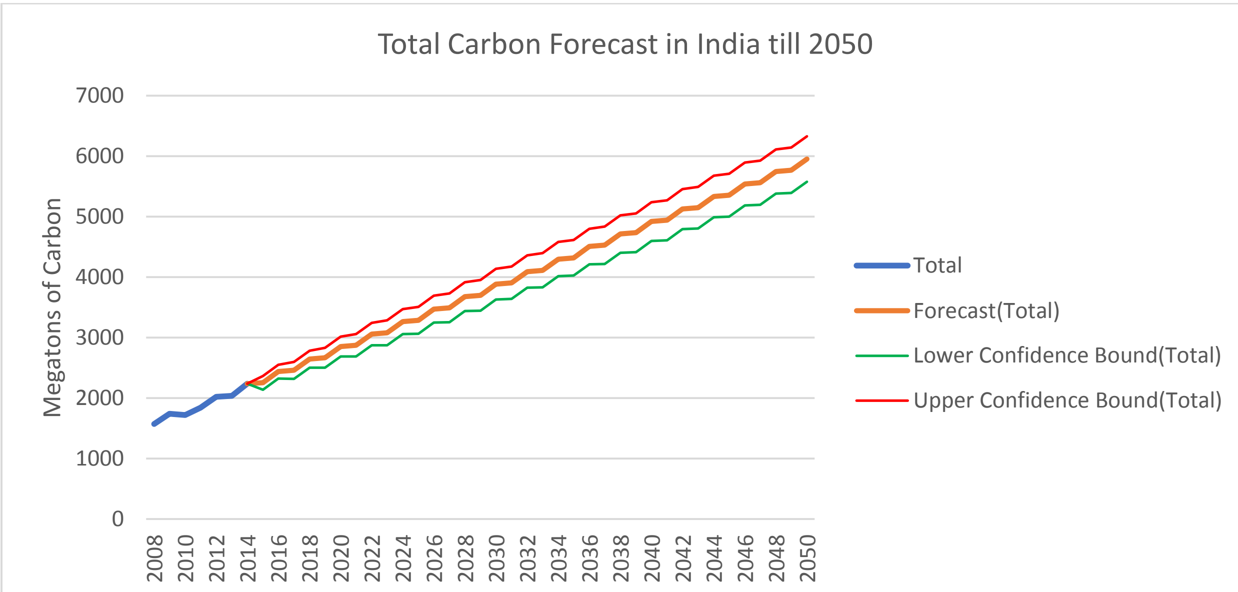

Figure 34: Total Carbon Forecast in India till 2050; Author's Calculations

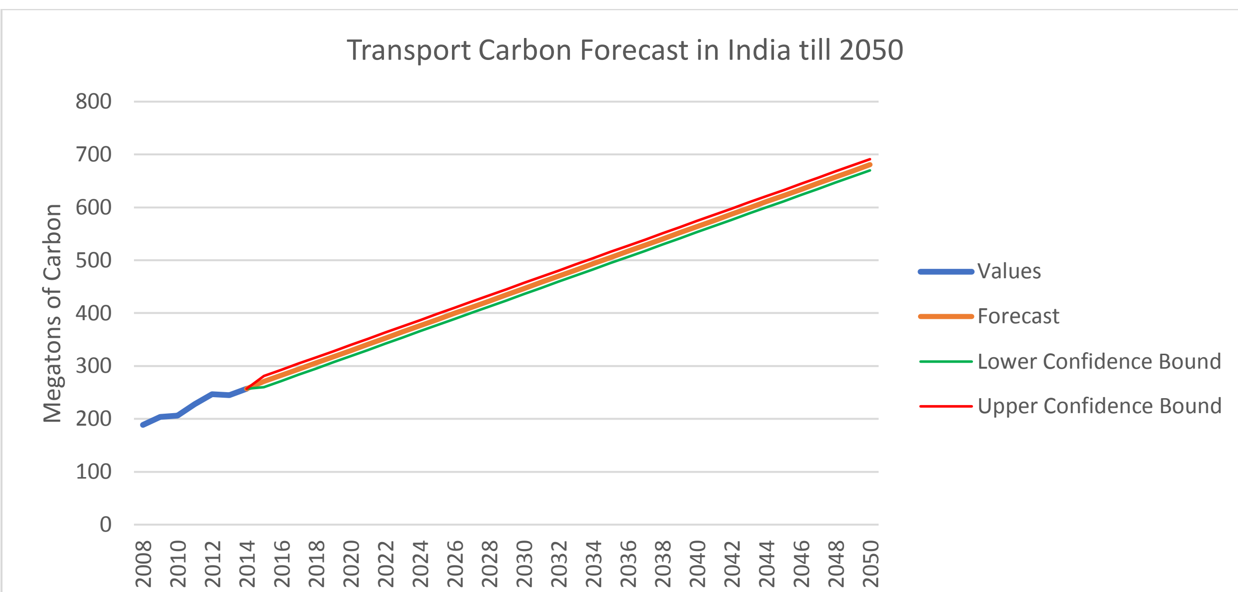

Figure 35: Transport Carbon Forecast in India till 2050; Author's Calculations

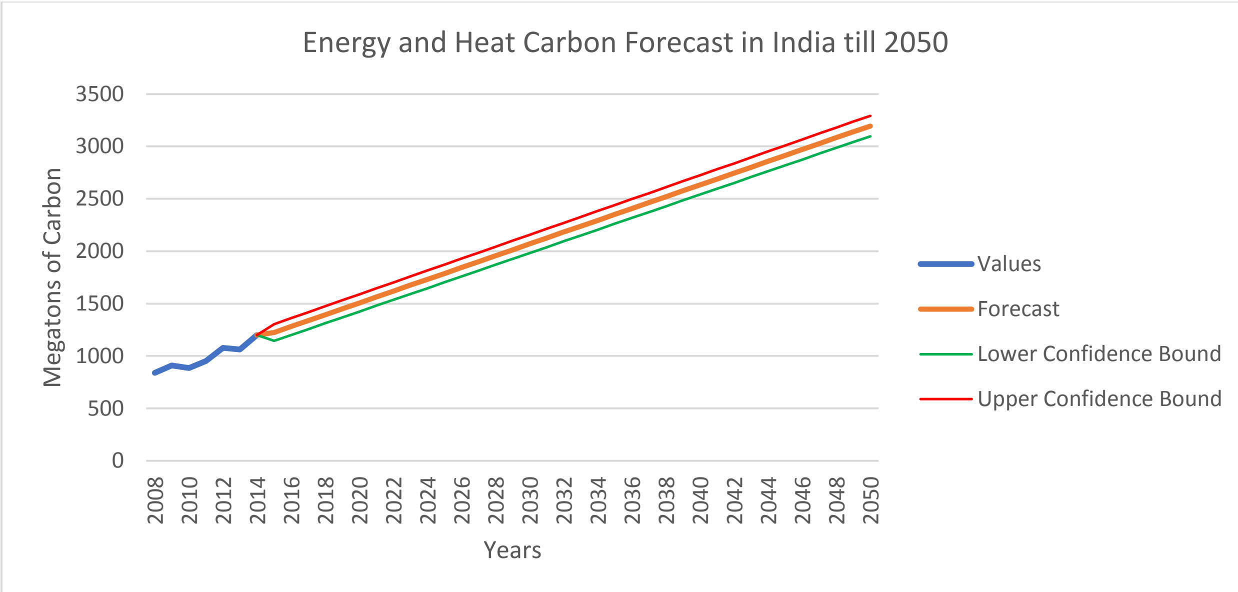

Figure 36: Energy and Heat Carbon Forecast in India till 2050; Author's Calculations

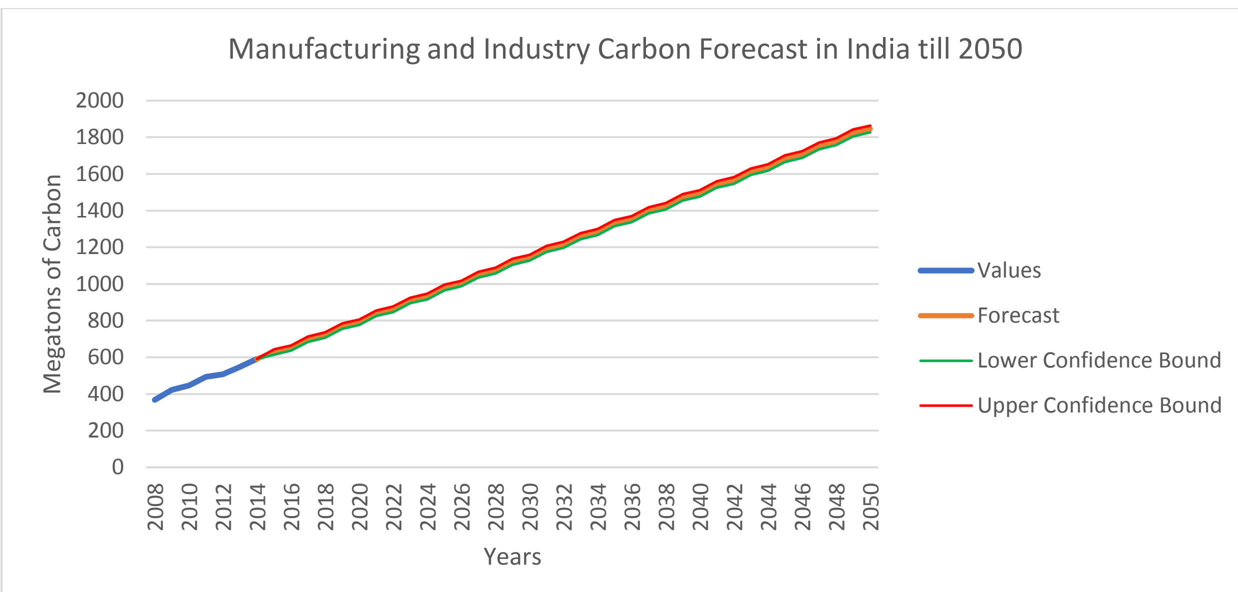

Figure 37: Manufacturing and Industry Carbon Forecast in India till 2050; Author's Calculations

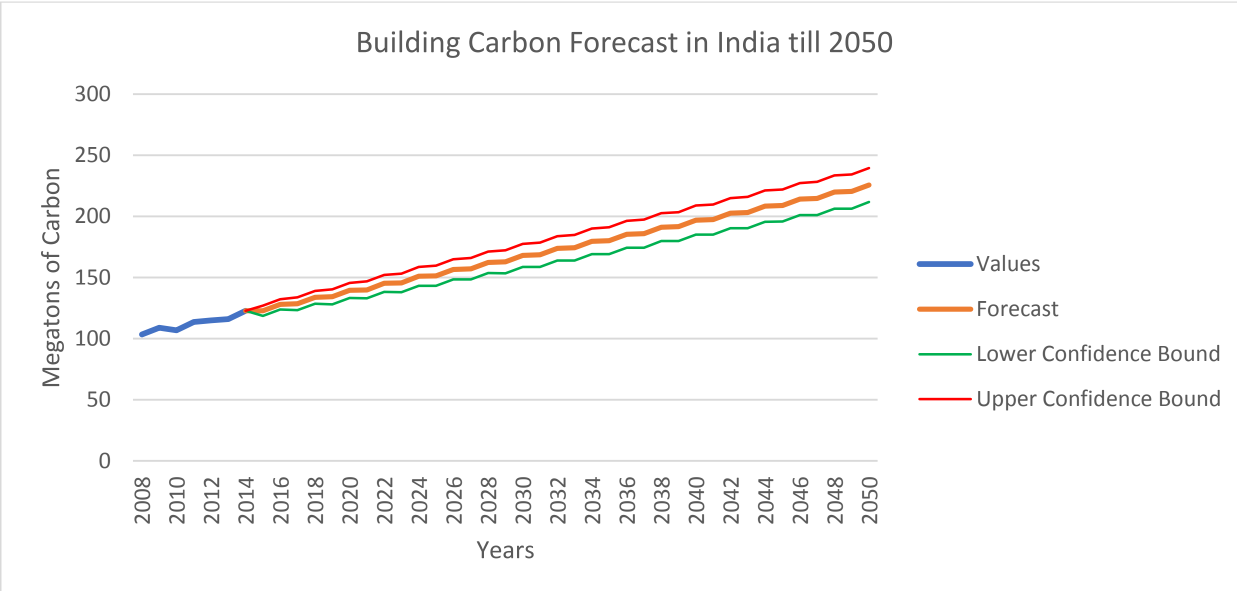

Figure 38: Building Carbon Forecast in India till 2050; Author's Calculations

Of all the industries forecasted, it is interesting to note that transport, and manufacturing and industry sectors show the least variance in decrease in carbon with both the best-case and worst-case scenarios. Since both sectors have technologies which should help reduce the carbon emissions over the long-term, it is clear from these results that these industries have to be focused on particularly to achieve slightly better results.

8.3. Conclusion

From the results of the overall carbon prediction, it is interesting to note that the United Kingdom shows promising which indicate that it would be able to achieve the goal of 80% reduction in overall carbon emissions by the year 2050. On the other hand, India does not seem to be showing any such trend, and the country has to work hard on increasing efforts into the development and implementation of technologies and policies which would help the country to get closer to its goal of reducing its emission intensity by 20-25% by 2030. From these results, the goal which will clearly not be reached, but the country would do well to commit to a decarbonization pathway by the year 2050. Some possible technology and policy solutions are discussed in the next chapter, although their implementation is a quite different between the countries studied.

9. Analysis of Solutions

9.1. Our findings so far

From the analysis in the preceding chapters, it is clear that there is an immediate requirement for the implementation of technologies and policies which further encourage improvements in energy efficiency and reductions in carbon emissions in both countries, the U.K. and India. Major general policies have already been in the corresponding previous chapters, along with the Kaya Decomposition to explain some of the patterns. More specific examples of 'clean' technology policy are considered in this chapter, within the specific (and different) institutional and socio-economic contexts of the two countries. To get an accurate comparison of effectiveness, it was helpful to start by identifying the areas in which the policies already implemented in the United Kingdom work, and to recognize them in the context of each sector, in their respective chapters. The policies which were identified to work in each sector are then analyzed in the context of India, a country at a different stage of economic development, featuring complex socio-economic institutions, and having a large population. While emphasizing that a direct 'translation' of these policies (which arguably have worked in the U.K.) to the Indian situation will not be effective, this chapter will attempt to contextualize these policies by considering the various stakeholders and their powers in India.

9.2. Policies affecting the Technology Effect

The two main factors which are considered in the technology effect are the growth rate of the 'carbon intensity' ($\hat{c}$) of technologies, and the growth rate of their 'energy efficiency' ($\hat{e}$). While it was mentioned in the introduction that both factors are of importance in the policy-making decisions of countries, both have different impacts, and different extent of effectiveness in the various sectors. From the second law of thermodynamics which states that the entropy of a system only increases, we can infer that energy efficiency can never be perfect, or 100%. Since it cannot be done, in this chapter we focus on solutions based on clean technologies and decarbonizing existing technologies rather than those that focus on energy efficiency. The implementation of policies which affect carbon intensity is mostly enforced by limiting the use of existing technologies, either through regulation changes or by levying a tax. As it is not within the scope of this thesis to study every single policy we focus on the implementation of one major particular technology or policy intended to increase decarbonization in each of the four sectors (analyzed in the preceding chapters). (We focus on decarbonization, because this is the dimension where the long-run potential for CO2 emission reductions is largest.)

8.2.1. Transportation

In the Transportation Sector of the UK, we see from the Kaya Identity that there has been an overall decrease in carbon intensity, especially since the 2008 economic crisis, the corresponding energy intensity has been found to increase consistently. This results in steady increase in the impact of the total technology effect. Even though these numbers are visible from the Kaya decomposition, the total transport CO_2 in the UK has barely changed with respect to the other sectors, as is proved by the fact that between 2016 and 2017, the transport carbon remained at a constant value of 125.9 million tonnes of carbon dioxide equivalent (Department for Business, Energy and Industrial Strategy, 2019). This could be because any reduction in carbon intensity measured is immediately offset by an increase in the usage of the goods and services provided (the scale effect). Reduction in carbon intensity in the UK can be attributed to a few factors: a change in the fuel mix at the energy production stage, rail electrification, and increase in regulations encouraging the British Population to purchase less carbon intensive vehicles; like electric vehicles (Evans, 2019). In India, electric vehicles are a blossoming trend, but largely without the infrastructure to back it up.

Worldwide, we see that low-carbon alternatives which are cost-effective are only recently beginning to emerge. These alternatives need to have higher energy efficiency, in the form of a higher mileage, and need to use improved fuel mixes, biofuels, or have to be electric. According to the Bloomberg Electric Vehicle outlook, 2018 saw the sales of over 2 million electric vehicles with an expected rise to about 10 million by 2025, and 56 million by 2040 (BloombergNEF, 2019). To encourage the uptake of electric vehicles, a cross-departmental 'Office for Low Emission Vehicles' was founded by the British Government, with over 900 Million pounds as its budget (Department for Business, Energy and Industrial Strategy, 2019). Along with this, programs like the 'Plug-in' Car Grant which provides a subsidy of up to 5000 pounds towards the purchase of green vehicles, was also implemented (Department for Business, Energy and Industrial Strategy, 2019).

Apart from the environmental concerns pushing the shift to electric vehicles, countries can benefit from certain political and economic advantages too. The growth of electric vehicles reduces the dependency of a country on fossil fuel imports, which would then result in less involvement in various other geo-political problems as well (Talantsev, 2016). The effective monopoly held by oil-producing countries can thus be disintegrated, adding to the political strength of non-oil producing countries. An economic impact of this shift can also be seen through the creation of new jobs, and new factories in the country, albeit with the simultaneous social threat of job-losses in the fossil-fuelled car industry. These losses can be offset by improvements in the energy efficiency of the country by the implementation of a smart-grid system (Talantsev, 2016). Further, there are innumerable social advantages to this shift, improved air quality resulting in better health, and fewer medical bills to name a few. The extra funding in this direction can also result in other cleaner technologies to create a self-propagating cycle.

The main stakeholders who have been identified in the Electric Vehicle industry in the United Kingdom by Talantsev (2016) are as follows;

1) Electric car manufacturers, whose main aim is to earn profits and gain market share,
2) Petrol producers, who want to maintain their exiting profits and market share,
3) Internal Combustion Engine (fossil-fuel based) car manufacturers, who want to maintain their profits and market share,
4) Renewable energy producers, who want to gain profits and market share,
5) Citizens who want cheap, accessible transport, possibly with advantages to the environment and their health,
6) Fossil Fuel based energy producers who want to maintain profits and market share,
7) Electricity Suppliers who want to maintain profits and maintain or increase market share,
8) The Government which wants to attain zero-carbon emissions by 2050, while improving the environment and preserve the health of citizens, while still maintain a healthy economy.

While the implementation of these policies would benefit Electric car manufacturers, renewable energy producers, and electricity suppliers for sure, it also will threaten the petrol producers, and the Internal Combustion Engine (fossil-fuel based) car manufacturers. Alternatively, it can be argued that the insurgence of electric vehicles would result in an increase in electricity prices, which would then make fuel-based options more attractive to potential customers again (Talantsev, 2016). This can also be considered a ‘rebound effect’, in the form of ‘Jevons effect’ (Amado & Sauer, 2012). Also, electricity suppliers who should ideally be benefited from such a policy, can also temporarily compromise their profits because of the instability that a sudden increase of renewables can add to their grids. Also, the advantages of buying an electric vehicle may not be sufficient for every consumer, even though they would benefit from cleaner air, and the long-term effects of overall reduced greenhouse gas emissions, although they would also have to suffer the brunt of increased electricity prices (Talantsev, 2016).

In the case of India, these factors are unlikely to operate in a similar way, with similar stakeholders, just at a much earlier stage in the product lifecycle. First of all, major electric car manufacturers have not yet set deep roots in the Indian market, and have not really penetrated their products into the minds of the Indian masses. There is also a clear bureaucracy problem given that the country has had many instances of corruption at various levels, although it seems to be changing for the better in recent years (Bhardwaj, 2019). India also does not have many renewable energy providers, and the existing fossil fuel and electricity providers are large companies which have immense control over many sectors in the country. For example, ‘Reliance Power’ is the sole distributor of energy in Mumbai, and runs power generation, transmission, and distribution in Maharashtra, Goa, and Andhra Pradesh. These companies thus also have a strong blocking power, even bribing politicians when necessary, to stop the passing of policies which would affect their profits.

It must also be stated that although the Gross National Income (GNI) per capita of the country is increasing, reaching 2020 US dollars per year in 2018, a large portion of the country still lives below the poverty line (data.worldbank.org, 2019). So, the main concerns of the Indian citizens are social development and basic living requirements, with environmental issues being well on the backburner (Jasanof, 1993). The boost of electric vehicles would also require investment into the infrastructure behind installing multiple charging ports at convenient locations across the entire country.

The Indian government on the other hand seems to have taken a strong stance on the promotion of electric vehicles. The Ministry of Heavy Industries and Public Enterprises announced a goal of ensuring that 30% of new vehicles purchased in the country will be electric by 2030, an announcement which was made with no follow-up, or implementation plan. The Ministry of Road Transport and Highways announced in 2018 that it also aims at completely electrifying all of India’s extensive railway system, and the introduction of electric buses for both private and public transport. Apart from moving towards electric vehicles, the country has plans to encourage the use of biodiesel, to encourage the widespread use of a 5% blend of biodiesel by 2030 (Gupta, Ghersi, Vishwanathan, & Garg, 2019).

9.2.2. Energy and Heat

In this sector, having its carbon emissions somehow embodied in all the other sectors and several downstream effects, there have been multiple large-scale plans set in motion in the U.K. and in India with the aim of reducing the carbon emission intensity of energy production.

Nuclear energy is produced through the process of nuclear fission; by which uranium atoms are split. The heat released from the reaction is used to produce steam from water, which then turns turbines to produce electricity (Evans, 2013).

A first such initiative is the plan to increase nuclear energy. Of all the sources of energy commonly used in both the United Kingdom and India, nuclear energy is a clean source that is a large provider for both countries, and is independent of geographical variations like solar and wind energy, making it a good basis of comparison.

National governments of both developed and undeveloped countries would want to invest in a source of low-carbon, reliable, and cost-effective source of energy (Moses, 2018). The United Kingdom has about 15 reactors, providing 21% of the country's 2017 requirement, while India has 22 reactors which supplied 3.22% of its 2017 requirement. While India has a larger number of reactors, their outputs are severely limited due to lack of funding into increasing their capacity, and due to lack of nuclear resources to use as fuel (Mohan, 2016). Ironically, the Indian nuclear program was initiated almost sixty years ago in the 1950s, with its first reactor 'Apsara' inaugurated on 20th January 1957, and still hasn't grown to a stage of being able to support a larger portion of the energy requirement of the country (Banerjee & Gupta, 2017). In the United Kingdom, funding and infrastructure have been developed and have existed since the 1940s, with the country being one of the leading developers of the technology (Moses, 2018).

To allow for the commissioning, running, and decommissioning of nuclear power plants, multiple stakeholders and their values must be considered.

The major stakeholders that can be identified are (Harris, Heptonstall, Gross, & Handley, 2013);

1) The Government, which wants a sustainable and powerful source of energy while maintaining the safety of the citizens,
2) Environmental departments, which want to ensure there is no negative impact on the environment as a result of nuclear activity,
3) Institutions governing nuclear proliferation, which want to ensure that nuclear countries do not threaten the safety of other nuclear and non-nuclear countries
4) Citizens, want safety and higher quality of life
5) Academics and Research Institutions, who want to encourage research and development into even safer, and even higher energy storage capacities

So, while it is understandable why governments would like to invest in nuclear energy, there are very high capital costs involved, a number which reduces with every additional plant built. The 'pre-construction' period is also estimated to be around 3-7 years, a number which is longer than a single political term in most countries (Harris, Heptonstall, Gross, & Handley, 2013). The long start-up time may contribute to politicians and policymakers not being willing to start a nuclear program which may not bear fruit until their successor comes in power. This factor is of particular importance in the Indian context where, trust in politicians had disintegrated heavily.

It is also common for environmental departments and citizens to begin protesting the development of a new plan for fears of large-scale accidents, and mismanagement of nuclear waste resulting in larger nuclear fall-out. Although the chances of these things happening are extremely low, with only three, albeit major, incidents in the past fifty years (world-nuclear.org, 2019).

Although aware of the benefits of strengthening national nuclear energy programs, it normally is a cause of concern to neighboring countries, for fear of their weaponization. The International Atomic Energy Agency is as an inter-governmental panel which was formed by the United Nations with the aim of limiting the use of any nuclear technology solely for the production of energy. So, although it is also surprisingly easy to weaponize nuclear sources, once an energy plant has been built, accountability for materials, physical security and, containment and surveillance is placed on the governing countries (world-nuclear.org, 2019). Member countries are also expected to have signed onto the Nuclear Proliferation Treaty, which safeguards from countries weaponizing their technology.

9.2.3. Manufacturing and Industry

A suggestion for a technology which can be implemented in both India and the United Kingdom to minimize the amount of carbon emission in the countries is 'Carbon Capture and Storage' (CCS). Developing countries have a much lower per capita income and the average material standards of living than developed countries. Thus, India needs the economic growth and improvements in standards of living, which are usually the result of growing GDP, and GDP growth is usually the result of manufacturing enterprises. The production of goods indicates higher total energy use for at least a few more years to come and without a transition period, carbon emissions also promise to remain high. This, in turn, points to the need to invest in carbon capture and storage technologies (CCS), because this could help to remove emissions, which are bound to happen, and keep them away from the environment.

CCS technology refers to a wide number of specific technologies which have various results. Most technology which can capture about 90% of the carbon dioxide that is passed through it qualify as 'Carbon Capture Technology', and those with the added capacity to store the carbon is known as 'Carbon Capture and Storage Technology'. CCS technology follows three main steps; the separation of carbon-based emission from other gases, transporting the stored carbon, and finally securely storing it, usually in depleted oil and gas fields (ccsassociation.org, n.d.).

Carbon emissions are a common by-product of most industrial manufacturing sectors, and the usage of energy, and this technology aims at reducing the impact of the activities rather than just minimizing it. This potentially reduces any negative economic impact that could occur as the result of some policies which are more 'austerity'-based. Once captured, this technology can also transform the carbon into other commercially productive products, such as 'feed' into some chemical plants (Mander & Miller, 2018). Since attaining the goal of 'zero-carbon emissions' does not have any particular clauses considering the depletion of fossil fuels, and only the byproducts of their use, this is generally considered an 'end-of-the-pipe' technology (Swinkels, 2013).

Although no real developments have happened on this front in India, the British government has outlined plans to invest in these technologies in 'The Clean Growth Strategy' presented in 2017 (Department for Business, Energy and Industrial Strategy, 2019). About 100 million British pounds were invested in various projects to help reduce costs and encourage further industrial innovation on this front, starting with about 20 million British pounds in a demonstration program. This would act as an important integrating step in the process of shifting to a completely zero-carbon economy.

The major stakeholders identified are;

1) The Government, which wants to reduce overall carbon emissions to attain its carbon budget without affecting the strength of its economy overall
2) Manufacturing firms which want to maintain profits and market share
3) Residents, who want clean air and protection from environmental damage

Since CCS technologies are relatively new, there are no large-scale examples of its usage (Terwel, Harinck, Ellemers, & Daamen, 2011). An important factor which has to be considered in its implementation is the trust that the general public has in the other stakeholders of CCS technologies; the government and other manufacturers. A concern that has been voiced by multiple focus groups is the unknown future impacts of CCS technologies, and potential harm it can cause to groundwater, plants, and animals (Terwel, Harinck, Ellemers, & Daamen, 2011). Considering these factors, the British Government has still announced ambitions plans to lead the world's move into CCS technologies. The country has since announced 24 million pounds into the extensive roll-out of carbon capture technologies in its 'CCUS Innovation Program' to encourage novel technologies (Department for Business, Energy and Industrial Strategy, 2019).

While it clearly is not a sustainable technology as it still relies on the idea that industries will continue to use fossil fuels and emit carbon, this is a viable option in countries like India as well. Provided that bureaucracy allows for subsidies which will encourage CCS technologies to actually reach the industries, and positive developments aren't stalled by protests by civilians caused by information asymmetry.

9.2.4. Buildings

While in the other sectors it is much easier to identify an example of a technological development which can help reduce carbon emissions, it is not as easy in the building sector. Instead, it is possible to compare policies which have been implemented which regulate the various appliances and systems within most residential and commercial buildings. The changes implemented also vary largely between buildings which already exist, and those that are under construction.

According to 'designingbuildings.co.uk', the energy efficiency of buildings which have already been constructed can be improved by doing the following things;

1) Setting heating systems at lower temperatures
2) Minimizing the use of air conditioning, lights, and other appliances.
3) Ensuring wind and thermal insulation of buildings are installed correctly, and of high quality.
4) Ensuring that appliances in the buildings are highly energy efficient.

Of all of the above, controlling the heating of the building would have the biggest impact in the carbon emissions, and is thus the focus of most policies in the United Kingdom. The Renewable Heat Incentive was implemented in 2011 for the non-domestic sector and in 2014 in the domestic sector, replacing the previous 'Low Carbon Building Program' which expired in 2010. With this program, the government placed a financial incentive on the off-grid production of renewable heat for about seven years, depending on the amount produced (ofgem.gov.uk, 2019). The aim of this was to reduce the cost-gap between conventional and renewable energy, and thus incentivize the shift to renewable energy use.

Stakeholders who have been identified are;

4) The Government, which wants to reduce overall carbon emissions to attain its carbon budget without affecting the lives of citizens too much
5) Renewable energy companies, which wants to maintain profits and grow their market share

6) Residents, who want to avoid getting fined for out-of-date appliances
7) Appliance and meter-companies, who want to maintain profits and grow market share

The two facets of the renewable heat incentive cover the 'domestic' and 'non-domestic' fronts, with different payback amounts and different criteria. Another aspect of the renewable heat incentive is providing support throughout the supply chain for renewable energy, to encourage the propagation of renewable energy appliances. The cost for the implementation of this was estimated to be around 2,830 million British pounds (assets.publishing.service.gov.uk, 2018). Even considering the cost to the government, there are many advantages to its implementation, improved air quality being a major one cited (assets.publishing.service.gov.uk, 2018). The renewable energy companies are expected to also benefit from this, as their costs fall further and the supply chain is extended in capacity. This also would minimize all the other factors which would act as a barrier to using greener technologies that consumers face.

While all of these processes make sense in the United Kingdom, it is very interesting to note that in India, heating is not used as much due to its largely tropical weather. Along similar lines to the Renewable Heat Incentive of the United Kingdom, is the 'Energy Conservation Building Code' in India. It aims to "further reduce building energy consumption and promote low-carbon growth" (Ministry of Power and Bureau of Energy Efficiency, 2017). It encourages renewable energy sources to be integrated into the construction of future buildings, with the expectation of reducing energy consumption by at least 25%. This move is anticipated to reduce overall energy consumption by 30% by the year 2030. Stakeholders in this move are largely similar to that of the Renewable Heat Incentive by the United Kingdom, although with the standard differences in implementation which have been detailed for the previous sectors, like corruption in the bureaucracy which does not always see that money which is put into projects really translates into positive effects at the ground level, instead ending up lining the pockets of various politicians (Adam & McCulloh, 2019).

9.3. Affecting the Scale Effect: De-Growth versus a Green New Deal?

In the 2018 article by Pesch, three alternative storylines are brought together to explain the economic theory and sustainability; growth, innovation, and degrowth (Pesch, 2018). Another way to affect carbon emissions is by attacking the root cause which is economic and population growth. This is thus naturally found to be combated by developments in innovation. The repercussions of these scale factors are compounded by malpractices in technological factors, making the concept of 'decoupling' economic growth from its environmental impact almost impossible (Pesch, 2018). In keeping with the rational choice assumptions of neoclassical economics, we assume that individuals, firms, and governments attempt to maximise their utility within the limits of their income, and bringing us to the third storyline of 'degrowth'.

India's total expenditure on 'social public goods', like health and education, has increased over the years resulting in a matching increase in GDP per capita for most of the population. This fiscal expenditure has resulted in increased consumption by the masses in the population (Ahmed & Hong, 2009). Similar effects are also observed in the United Kingdom, although the expenditure is aimed at further improving the quality of life beyond basic human right requirements. In the United Kingdom alone, 31.1% of government expenditure in the 2016-2017 fiscal year was on 'social protection', like pensions, followed by healthcare (HM Treasury, 2016).

As a result of economic stability, carbon emissions are found to increase. One way to reduce emissions via the scale effect is by lowering economic growth in a process termed 'de-growth' (Kallis, et al., 2018). De-growth is usually an indicator of a radical political or economic overhauling process to get a desirable social change. In India, this has been implemented at a very basic level in villages which make economic decisions for themselves, usually also veering towards keeping ecological concerns in mind. This has had very little impact since majority of the individuals also want to move to cities and earn money to improve their lives (Kallis, et al., 2018).

While De-growth has minimum impact in a developing country like India, it could be a source of relief from carbon emissions in developed countries with established higher GDPs like the United Kingdom. Tying in with the shallow objectives of the flexible mechanisms of the Kyoto Protocol, in fact a focus on the systematic and well-planned reduction in GDP growth may be the solution which developed nations need. Without drastically cutting out the economic growth of the country, an intentional reduction in the 'material throughput' of the country may just work towards solving our carbon emission problems (Hickel, 2018). Reducing the rate of GDP growth and moving towards a more restrained and sustainable society may seem like a viable option for a rich country like the United Kingdom where standards of living are comparatively much higher than India already. Hickel effectively argues that poverty in the country is caused by an artificially developed 'scarcity' of resources as a result of capitalization. A more even distribution of capital would relieve poverty as well as maintain the GDP of the country at an even level which would maintain lower emissions. In India, as the scarcity is not artificially caused so there is very limited option to 'level-out' the playing field and implement a similar 'de-growth'.

For Indians, a legitimate alternative to de-growth is a 'Green New Deal', an option by which all the governments in the world commit to investing a small percentage, 1% or 2%, of their GDP every year into the development of clean, sustainable, technologies. Using this method, it is argued that high standards of living can be maintained while still eradicating carbon emissions within fifty years (Pollin, 2018). Proposed by the United Kingdom by the New Economics Foundation in 2008, this was also proposed by the United States in its legislature in 2019. Pollin further argues that the Green New Deal would solve multiple problems and be propagated by the small and medium sized enterprises, which is of particular effectiveness in the Indian context as its economy is largely driven by SMEs (Gupta, 2019). The country's central government's 'Make in India' initiative also aims to encourage the growth of SMEs, which may then further help attain the goals of the Green New Deal, by raising the country's GDP and thus adding to the reinvestment back into the country for green technologies (Rastogi, 2019).

In short, we see these novel solutions of 'de-growth' and the 'Green New Deal' are effective in two different contexts. We see that all three storylines listed by Pesch (2018), have to work in cohesion to form reliable solutions, one concept can barely stand without the support of the others. In that context, both 'de-growth' and the 'Green New Deal' can be implemented for effective decarbonization in the particular environments where they are most effective, while still keeping options open for alternative future orientations.

9.4. Encouraging Investors

We see that in all the sectors for both the countries, the factors affecting the scale effect have similar impacts. Economic growth is measured by increases in the Gross Domestic Product over time. GDP growth can also be attributed to changes in investment which result in the redeployment of labour, both capital and human (Anderson, 1990). In the case of GDP growth ($\hat{y}$), along with domestic product, changes in investment experienced by the country, specifically the investment into 'green technologies' are considered in this instance. Investment into green technologies would have an impact across all the sectors involved, both directly and indirectly. Directly, in certain sectors as a result of increased capital which encourages the use of low-carbon technologies, and indirectly, as a result of increased employment and spending power of the general population. While increased spending power would also result in more resource usage, a rebound effect which will be analysed further in the chapter, it can also result in 'greener' changes in consumer habits, particularly with millennials (Price, 2018).

While it is easy for laymen to question why politicians and policymakers do not just spend the required money to begin implementing highly effective cleaner technologies, it is not usually understood that high government expenditure would result in increased taxes, and other fiscal policy changes which would affect the masses at a grassroots level. To validate this scale of government spending, private investments have to be milked through domestic and international funding.

In an attempt to encourage further investment in Green Technologies, the British government founded the Green Investment Group limited (GIG). Established around 2012 as a public limited company, and now owned by the Macquarie Group, it effectively pools resources from the sale of public shares to build its capital, while providing returns to individual investors. GIG provides services across a wide range of financial requirements including development funding, project delivery and portfolio building services (greeninvestmentgroup.com, 2019). This company also provides trustworthy analysis of the green impact of technologies, and consultancy services from the 'Green Bank' also setup by the British Government. The Green Investment Group now invests in multiple projects spanning energy efficiency, waste and bioenergy, onshore renewables, and offshore wind (greeninvestmentgroup.com, 2019). By becoming a public limited company, it now has the capacity to engage in projects nationally and internationally, thus allowing for profits to be gained across the world which can also be put into domestic projects. According to their 'Green Finance Impact Report', of the 2100 million British pound loan 'facility' that the Macquarie Group currently has, 500 million pounds has gone into the 'green financing' (greeninvestmentgroup.com, 2019).

Although no such major setup has been founded by the Indian government, from the results of the Kaya Decomposition, it is clear that the liberalization of the Indian economy, and the authorization of Foreign Direct Investment has allowed for the growth of the economy. With the boost in the economy, came development, its consequent carbon emissions, and the requirement for green technologies. Particularly in countries like India, with a giant population, it is imperative to note that the marginal cost for the installation of green technologies at an initial stage is much lower than fitting them in retroactively (Harrison, Martin, & Nataraj, 2017).

9.5. Rebound effect

The rebound effect considers the counter-intuitive impact that the implementation of green policies can have at a macro-economic or meso-economic level. For example, in the case of the 'Renewable Heat Incentive' policy of the United Kingdom, the installation of a low carbon technology which reduces costs, would then result in increased consumption of energy (assets.publishing.service.gov.uk, 2018). Further the monetary savings would also result in other energy intensive expenditure.

The impact of the rebound effect is inferred as the compound outcome of three effects; the engineering effect (ΔH), the embodied effect (ΔM), and the income effect (ΔG).

The total rebound effect is thus; $\Delta Q = \Delta H + \Delta M + \Delta G$

Two types of rebound effects have been identified; direct effects, and indirect effects. As an example of indirect rebound effects, monetary savings from subsidies for renewable energy sources would increase macro-economic activity and result in an economy-wide rebound effect (Gillingham, 2014). Since economic stimulation is also a possible product, it is extremely hard to measure the full scale of the significance of the effect. The key then is to somehow filter out the policies which result in a complete annihilation of its positive environmental impact, from the ones which do not. But, given the scale of the uncertainty involved, the long-scale impacts are far from being empirically estimated correctly.

In the transportation sector, this is seen particularly as the result of hybrid vehicles, as the cost of the batteries of electric cars acts as a strong deterrent to rebounding. In the energy and heating sector, OECD countries see a 10-30% rebound effect while in the United Kingdom, this goes up to 60%. In this case we see that for fuels, a policy requiring a technology shift is much more effecting than an energy efficiency policy which would make the usage of fuels cheaper (Ghoddusi & Roy, 2017). And in the commercial building sector, this effect is seen through low-energy lighting.

9.6. Conclusions

From this chapter, we can see that there is no 'one' panacea that can solve all the issues faced in today's world of sustainable development. Energy consumption will never totally stop, due to the basic tenets of thermodynamics, and the only answer is to control consumption, and minimise the carbon that is released into the atmosphere as a result of this consumption. A two-phase solution would first be to install 'carbon capture' methods into existing large-, and medium- scale industries. This would help slow down the rate at which carbon is emitted into the world, a solution much like plugging a thumb into a leak in a dyke, like in the traditional Dutch tale. This would provide the time for major decision-makers to really involve themselves in the process of increasing investments in, and rolling out cleaner technologies like the examples explained in this chapter, at a mass-scale to provide a truly sustainable solution. While developing countries now have the opportunity to begin this process and leap-frog over various generations of technology, they must focus more on building investment. Developed countries on the other hand, will now find themselves overcoming the inertia of transferring to different types of technology. This is a process which will require intense stakeholder analysis to ensure that the needs of the population are reflected in the design of the technology (Pesch, 2018).

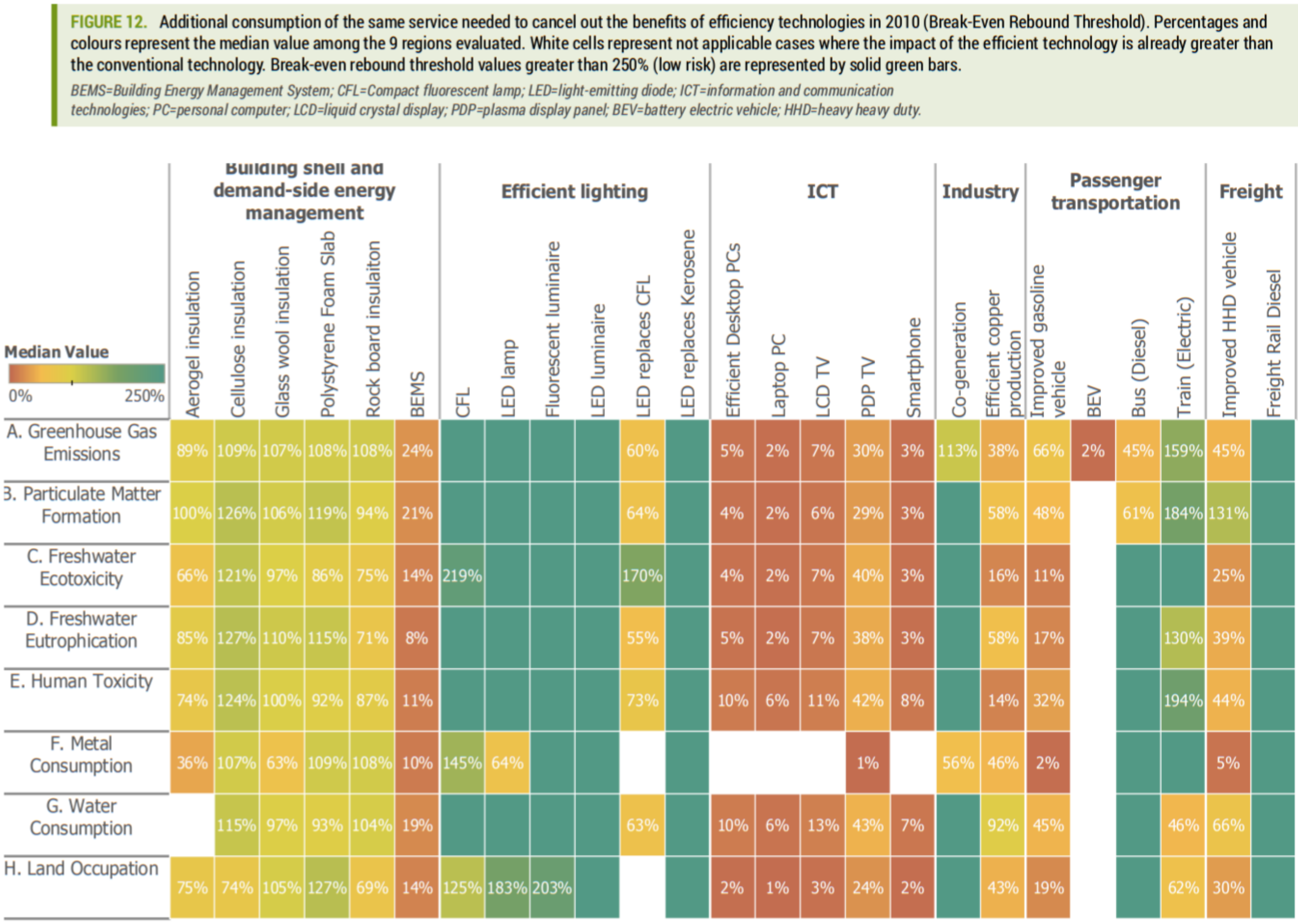

FIGURE 12. Additional consumption of the same service needed to cancel out the benefits of efficiency technologies in 2010 (Break-Even Rebound Threshold). Percentages and colours represent the median value among the 9 regions evaluated. White cells represent not applicable cases where the impact of the efficient technology is already greater than the conventional technology. Break-even rebound threshold values greater than 250% (low risk) are represented by solid green bars.

BEMS=Building Energy Management System; CFL=Compact fluorescent lamp; LED=light-emitting diode; ICT=information and communication technologies; PC=personal computer; LCD=liquid crystal display; PDP=plasma display panel; BEV=battery electric vehicle; HHD=heavy heavy duty.

Median Value (0% – 250%)	Building shell and demand-side energy management						Efficient lighting						ICT					Industry		Passenger transportation				Freight	
	Aerogel insulation	Cellulose insulation	Glass wool insulation	Polystyrene Foam Slab	Rock board insulaiton	BEMS	CFL	LED lamp	Fluorescent luminaire	LED luminaire	LED replaces CFL	LED replaces Kerosene	Efficient Desktop PCs	Laptop PC	LCD TV	PDP TV	Smartphone	Co-generation	Efficient copper production	Improved gasoline vehicle	BEV	Bus (Diesel)	Train (Electric)	Improved HHD vehicle	Freight Rail Diesel
A. Greenhouse Gas Emissions	89%	109%	107%	108%	108%	24%					60%		5%	2%	7%	30%	3%	113%	38%	66%	2%	45%	159%	45%	
B. Particulate Matter Formation	100%	126%	106%	119%	94%	21%					64%		4%	2%	6%	29%	3%		58%	48%		61%	184%	131%	
C. Freshwater Ecotoxicity	66%	121%	97%	86%	75%	14%	219%				170%		4%	2%	7%	40%	3%		16%	11%				25%	
D. Freshwater Eutrophication	85%	127%	110%	115%	71%	8%					55%		5%	2%	7%	38%	3%		58%	17%			130%	39%	
E. Human Toxicity	74%	124%	100%	92%	87%	11%					73%		10%	6%	11%	42%	8%		14%	32%			194%	44%	
F. Metal Consumption	36%	107%	63%	109%	108%	10%	145%	64%								1%		56%	46%	2%				5%	
G. Water Consumption		115%	97%	93%	104%	19%					63%		10%	6%	13%	43%	7%		92%	45%			46%	66%	
H. Land Occupation	75%	74%	105%	127%	69%	14%	125%	183%	203%				2%	1%	3%	24%	2%		43%	19%			62%	30%	

Figure 39: Additional Consumption as a Consequence of the Rebound Effect; Source: (Suh et. Al. 2017)

10. Conclusions and Reflections

10.1 Conclusions

As with any problem-solving methodology, the process starts with identifying the presence of a problem, followed by considering alternatives, and finally providing a range of solutions. This research was done with the aim of answering the research questions which were posed at the beginning of this thesis. Question one; 'what form have policies to curb carbon emissions taken until now and what are the main points of differentiation between developed and developing countries', was answered in the introduction chapter. Most countries tend to encourage decarbonization either through 'higher efficiency' or 'reduced consumption' policies. Due to the nature of the Management of Technology course, the focus was naturally on the higher efficiency policies which are implemented through improved technologies. The varied nature of developed and developing nations in terms of population sizes, bureaucracy, rates of economic and population growth, and the major barriers to the large-scale enforcement of decarbonization techniques were described.

Upon explaining the background of climate change, and the course towards decarbonization, the kaya identity was used in the following five chapters to answer the second research question; using the Kaya Identity framework, what have been the main trends in energy efficiency and carbon intensity, thus identifying the main factors that policies have been aimed at correcting?'. The Kaya Identity breaks down the total carbon emission into four factors; two scale factors and two technology factors. The scale factors are impacted by economic growth, as measured by GDP per capita, and population growth. The technology factors were split into carbon intensity and energy intensity. The growth in carbon emissions was decomposed over the time period from 1970 to 2014. For greater accuracy, these years were split into three sections to account for some major economic changes which would impact the factors which affect the carbon emissions. These chapters also attempted to answer the third research question that was posed; 'what are the trends in energy efficiency and carbon emissions in each of the main sectors of the economy: transport, industry and manufacture, energy and heat, and buildings'.

While the United Kingdom showed an overall decrease in carbon emissions, India has shown an opposite trend. Further, we saw that in the United Kingdom, technological factors have had a considerable impact on carbon emissions, shown by negative growth percentages, sufficient to offset the result of the scale factors in most sectors. Contrarily, in the building sector, the technology factor is not sufficient to offset the scale factor, showing us that it is a sector which needs particular focus. On the other hand, in India it is clear that the technological factors need to be worked on to increase its impact, since the scale factors do not show any signs of reducing in momentum. In each of the chapters, the corresponding policies which were implemented by each of the countries were also looked at to understand if they have had the impacts which they were initially meant to have. This goes on to answer the sub-question to the third question; ‘What have been the goals of the regulations implemented in each sector, and have they had any real impact for the reduction of emissions’.

In chapter eight, a regression analysis was performed to predict the future values of carbon emissions in each country for the various sectors, and the overall. From the analysis, it was observed again that in the United Kingdom, all the sectors apart from the building sector shows a downward curve in carbon emissions. India, however, shows a steadily upward accelerating curve in its carbon emissions, showing no evidence of retardation. This clearly demonstrates that the country will not reduce its emissions to attain any decarbonization goal in the foreseeable future. Knowing that this is not a surprising result, policies which could have been used to produce similar results in India were considered in chapter nine which outlines solutions.

From this dissertation, the main solution that can be identified is the implementation of policies which encourage the proliferation of greener technologies. Since an overall analysis of all the possible technologies and policies which result in decarbonization is beyond the scope of this study, one appropriate technology was focused on for each sector. For the transportation sector, it was ‘electric vehicles, for the energy and heat sector, it was ‘nuclear energy’, for the manufacturing and industry sector, it was ‘carbon capture and storage’ technologies. Since the building sector seems to show no widely accepted clean technology which can be studied for both countries, the policy to control the energy efficiency of buildings was studied. While an optimistic approach can be taken in which green technologies are assumed to be immediately adopted by the mass of the population, this is not possible.

A stakeholder analysis was done to find the repercussions this would have on various groups, and their power to block or encourage changes. This aims to answer the fourth research question; ‘What are the main deep decarbonization pathways which can be implemented by a developing economy (India) and a developed economy (the United Kingdom)’. Naturally, this analysis also compares the two countries in terms of their stakeholders, and attempts to explain the various barriers introduced in the first few chapters. This answers the sub-question to research question four; ‘what comparisons can be made between the technologies that can be implemented in a developed country versus in a developing country'. The major investments methods into these technologies, and possible rebound effects were also considered, to ensure that the research maintained a holistic view.

According to the laws of thermodynamics, every single human activity requires energy, whether produced by the individual, or from an external source. Considering that it has been established that most current sources of energy are carbon-heavy, a main solution that this dissertation can provide as a first step is the implementation of 'deep-decarbonization' technologies while making the shift to cleaner energy sources. Again to this end, a specific technology is 'Carbon Capture and Sequestration' which seems to have some opposition, but in the perspective of this document, it provides the most accessible and overarching solution.

The next phase would thus naturally be to permanently seal the leak by providing sustainable, self-serving, decarbonization pathways. While the world moves towards clean sources of energy, it has become painfully apparent that we do not have the efficiency levels required for a complete shift, and there just isn't enough investment into research and development into these either. For this, the global political and business leaders have to get together to form alliances which will result in perceived win-win situations for both sides. 'Crowdsourcing' resources, as in the case of the Green Investment Bank of the UK, where individuals gain returns on their investments into green technologies, is also found to be effective to a certain extent, but cannot earn money at the scale required by the world.

It is easy from an academic perspective to provide optimistic suggestions which seem relatively obvious, like 'new' green technologies, or more effective policies which are implemented sooner. In a utopian world, all of these solutions would work together in an ideal manner to provide an abundance of investment followed by the continuous roll-out of clean technologies which are implemented almost instantaneously to directly reduce carbon emissions. With all these solutions in theory, the question still remains to be answered in terms of their 'real' effectiveness in practise.

10.2. Reflections

During the period of writing this dissertation, I found myself applying many skills I had learnt in my study of the Management of Technology, starting with the basic research methodology in itself. Knowing that combining a qualitative and quantitative method into one document would be well out of the scope of the study at this time, I stuck to following a quantitative process using empirical data and variations of existing formulae. Post this stage, I also got the opportunity to study some technologies themselves, further using skills learnt in the M.Sc., and consider their proliferation and scope in the real world. For example, in this chapter, I used some of the concepts of technology dynamics, responsible innovation, and emerging and breakthrough technologies. In particular, this was useful in mapping stakeholder values and considering the priorities of each of the main stakeholder groups to reach mutually beneficial decisions. The fundamental concepts, and assumptions, of the economic modelling were from the courses of my ‘economics and finance’ specialization; ‘economic foundations’, ‘intermediate economics’, and ‘economics and finance’. One clearly visible aspect of this is the assumption of utilitarian economics wherein people make efficient financial decisions for themselves. This assumption made sense given the lack of comprehensive empirical data available about the behavioural aspects of the decisions that people make. It was much easier to find studies about certain parts of the population demographic and their behaviour with respect to individual technologies or particular environmental alternatives, which were not of particular use to this study.

Now at the end of this thesis project, although the modelling results attained were satisfactory, it is clear that this document is merely a basis for future research into producing lasting decarbonization solutions to developed and developing economies. The main empirical aspects were considered in this research, with a larger focus on numerical analysis. A major limitation of this study was the accessibility of information, and the lack of detailed information available on sector-wise carbon emission in each country. To ensure continuity and validity, all the data used was collected from the same World Bank source, and were from similar time ranges. The Kaya identity could also have been decomposed in various methods; additional and multiplicative, to know which version would have been the most appropriate in this situation, and result in increased accuracy of numerical results. This would not affect the overall trends observed, as they remain elemental, but the exact numerical values could be of some value to academic researchers.

As this study focused on technologies and numerical values, it represents a very academic perspective which may not translate directly into the real world. To allow for a further understanding of the grass-root realities which act as barriers to the enforcing of any technologies or policies, interviews of experts in each sector, for each country could be done. Given sufficient time and resources, I think that this dissertation would have been much more holistic with these changes in place. Interviews could thus be transcribed and coded to understand the practical aspect further too. For example, in the building sector, this academic paper recognizes that there is a result which varies from the other sectors and identifies policies which may help. Interviews of experts in the field of investing in building technologies, and policymakers would bolster the comprehensiveness of the stakeholder analysis and direct the course of this study as appropriate. Doing this for all of the sectors, with multiple interviews would provide an exhaustive analysis of this line of inquiry.

Through the course of this thesis, the main research questions were considered, and appropriate answers were produced to attain a better understanding of various aspects of decarbonization. First by introducing the importance of decarbonization for the environment, followed by potential pathways taken, the decomposition of emissions over time, a future prediction, and a study of promising technology solutions. I sincerely hope that these results are considered again for future studies and that the momentum that I have gained in the writing of this dissertation is not lost. As we learn more and more about the damage in the environment and the alternatives that humankind has, the time has come for concepts which have been formed in theory, as in the case of my thesis, to be put into practise for real-world results.

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Appendix A: Interview

Mr Matampath R P Kumar, Director, Arcadis India Pvt Ltd

1. *From your experience, do you think that there has been an upward or downward trend in investments in India?*

ANS: Certainly India is witnessing an upward trend in Foreign Investments in almost all the sectors over the past five years.

a. *Do you think this has an overall positive or negative impact?*
ANS: This has a positive impact as the general confidence levels in investing in India is growing exponentially, which was not the case earlier. These Foreign investments are creating thousands of employment opportunities and the related economic activity is beneficial for the country overall.

2. *What do you think are the main barriers for investment in India?*

ANS: Barriers in Investing in India are much less when compared to a decade ago. The key issue earlier was the uncertainties in the political stability of the elected Government. The situation has improved since the current Government took power for a second time with the proactive measures taken by them for ease of doing business in India.

India's infrastructure still often poses challenges for Industries to set up in India as the land transport infrastructure remains poor, and is imperative to encourage growth. Taxes and Tariffs are another challenge as India is on a higher bracket in corporate taxes and tariffs when compared to major global investment destinations, making other countries like China more attractive to investors. Slow judicial process and loopholes in the legal system also pose major challenges for investment in India. These barriers also mean that research and development into the building sector in India tends to be quite limited, as there is a drought in funding.

a. *Are there any specific stakeholders who pose a problem, or who you consider to be of particular importance?*
ANS: Some of the recent projects we were involved in indicate that acquiring land is a critical problem for anyone planning to invest in India. Unclear land documents and ownership rights often poses difficulties for Industries that require large tracts of Land. Land owners are important stakeholders since they might be from poorer backgrounds, and proper compensation is imperative. While there is usually a government body in place, like the Karnataka Industrial Area Development Board (KIADB) in

Bangalore, to ease this process for international investors, the differences in regulation between the states makes it hard to keep track of.

The situation has improved as several state Governments are proactive and their Industrial Development Authorities are vested with more power to deal with land acquisitions and the Governments are proactive in indemnifying anticipated risks associated with Land acquisitions.

In the context of your project, there is no real body involved with controlling the environmental impact of the results of land acquisition. This may inherently have an impact in terms of carbon emission since land which may have only held one house or had a farm would be transformed to hold a factory, residential apartments, or a retail mall. The upside to this is that these transformations, when handled correctly, would also bring more economic activity in the area, and increase the value of the surrounding areas. The social benefits may thus out-value the other impacts for a developing country.

3. *How is the scenario in India different from another country?*

ANS: India is a union of states and each state has its own investment norms so, states compete regularly to draw investments. Hence comparing with any other country is difficult as some states are very proactive in attracting investments by providing incentives and tax holidays etc., while others may not. As indicated earlier, India definitely has some barriers compared to other countries, developing or developed, in the south-east region, though those barriers are thinning down and more and more investments are flowing in with time.