LUND UNIVERSITY
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Identifying the key drivers of CO2 emissions in China 1990 - 2015: An approach using the LMDI approach.

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Abstract

This study examines China’s CO_2 emissions from 1990 – 2015. Using the LMDI decomposition analysis to calculate energy factors, in order to identify the key sectors contributing to CO_2 emissions. While the paper will also take forecasted scenarios from other research alongside consideration of China’s policy implementations in effect in order to reduce CO_2 emissions. This paper also uses the Environmental Kuznets Curve (EKC) to examine the relation of economic growth, energy consumption and CO_2 emissions, and provide an explanation where China currently stands along this path.

Keywords: *Economic growth, CO_2 emissions, LMDI decomposition, Environmental Kuznets Curve, Energy Consumption*, *Sectoral emissions.*

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Acknowledgments

This thesis is my final work from my first and last year as a master student at Lund University School of Economics and Management, from the Economic History faculty.

I have been through many things in my life, however, this has undeniably been one of the toughest years I have ever experienced. I moved to Sweden on August 15, 2017 and from the following day I went searching for a part time job in order to support myself during my studies. By November, after countless emails and CVs given out and completely exhausted my savings I had no other choice but to drop out of the programme. I gave my landlord my 1 month notice and told her my situation, which she sadly accepted. The next day she told me I can stay, and she will help me with my accommodation until I find a job. The following week I found a job in a coffee shop, however, I worked 5 to 6 days a week.

After all this stress and not to mention handling deadlines, I fell into a light depression and experienced panic attacks throughout December to April. I received help from a psychologist at the student health centre and I can happily say she helped me get better. However, in May I received news that my grandmother was at advanced stage of lung cancer and also had a brain tumour. My grandmother meant the world to me and at one point in my life took the role of my mother. I flew back and forth to Hungary in order to spend time with my grandmother in her last moments. She later passed in July.

First and foremost, I would like to thank my landlord Karin Lonn. I would also like to thank the student health centre and some of the professors in the Economic History department for their patience and understanding.

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1.INTRODUCTION

Climate change has been an ever-increasing problem and one of the most important environmental issues of our age. Over the past 50 years, global sea level rose an average of 1.5 millimetres per year. If CO2 emissions and other greenhouse gases (GHGs) continue at the current rate, average sea level would rise 20-60 centimetres by end of the century. In order to improve global conditions, improved energy efficiency has been studied and confirmed to reduce total energy consumption and emissions of GHGs and other pollutants, while supporting economic growth.

The importance of producing renewable energy (RE) from renewable sources has been an ever-increasing challenge and regarded with high importance in order to preserve our environment. RE sources are naturally replenished such as sunlight, wind, rain, tides, waves and geothermal heat. These sources can be used to produce electricity with fewer environmental impacts, although many countries regard energy efficiency improvement and the development of RE as two of the most effective measures for addressing environmental and climate challenges, the sector faces challenges in expanding. Lund, H (2005) confirms that although RE is considered an important resource, on a global scale it holds less than 15% of primary energy consumption. Challenges that the RE sector face is the cost of infrastructure and the transition from moving away from fossil fuels to renewable energy in the long term.

As the largest developing country and the second biggest economy worldwide, China is used in this study, due to its well-known rapid economic growth within the last three decades. Along with the extraordinary growth rates, China has produced large amounts of energy consumption and emits considerable amounts of CO2, have surpassed those of the US, becoming the highest in the world in 2006 (United Nations, 2011). High levels of energy consumption have been the result of rapid economic growth which has led to negative environmental impact in China. According to Cepal, N (2016) China's activities also have had direct consequences for the global environment as a result of its growth. A dangerous fact is that it has been projected that China’s CO2 emission will continue to rise and is expected to continue exceeding that of the US during 2020-30.

CO2 emissions are both dependent on the levels of energy consumption and also on the make-up of the energy mix. In order to reduce emissions, it must be done by either lowering the level of energy consumption or by transferring the composition of the energy mix to sources with a lower emission content, such as the sources of renewable energy (Henriques & Borowiecki, 2017). China's carbon emissions have become a crucial subject for many previous empirical studies, which explore the driving forces behind both long-term and short-term variations (Ang and Pandiyan, 1997; Zhang, 2000, Dhakal et al.,2003; Wu et al.,2005; Lee and Wankeun, 2006; Wu et al., 2006). These studies highlight the various contributions of economic, technological, legislative, and social factors as driving forces behind China's energy-related CO2 emissions.

The Logarithmic Mean Divisia Decomposition (LMDI) derived from the index decomposition analysis (IDA) is used to examine the driving forces behind the changes in CO2 emissions in China over the time period of 1990 to 2015. Decomposition techniques have been used to explore the driving forces of China's carbon emissions in previous work but have not followed this exact timeline or included other countries in the analysis. The LMDI method enables to decompose total changes in CO_2 emissions into four components: activity, energy intensity changes, structural changes, and CO_2 emission intensity. This method enables to quantify the contribution of various sectors such as; agriculture, industry, services, transportation and household, for the total change in emissions for 2015.

This study will conduct an analysis on sectors from 1990-2015 for a recent understanding the contribution of CO_2 emissions from sectors. The structure of this study will be outlined in the following order. Section 2 will provide the background of China's emissions, importance of renewable energy development, a brief of scenarios provided by other researchers and policies that have been implemented from the Chinese government. Section 3 will continue to with the literature review of other studies using the methodology similar to this study, along with Environmental Kuznets Curve. Section 4 will explain the methodology used in this paper. Section 5 will explain the data used for the methodology and this study. Section 6 will discuss the results and discussion. Section 7 will be the conclusion to our conducted research.

1.1 Purpose

The purpose of this thesis is to conduct an analysis on China's key sectors of agriculture, industry, household, transportation and services from 1990 to 2015, in order to gain an understanding of the contribution of CO_2 emissions from these sectors. It provides the area of research with an up to date study of recent levels. Furthermore, we attempt to provide an assessment of where China rests along the Environmental Kuznets Curve and if their continued growth or decline of GDP mean less economic growth and therefore a decrease in energy consumption?

1.2 Outlook

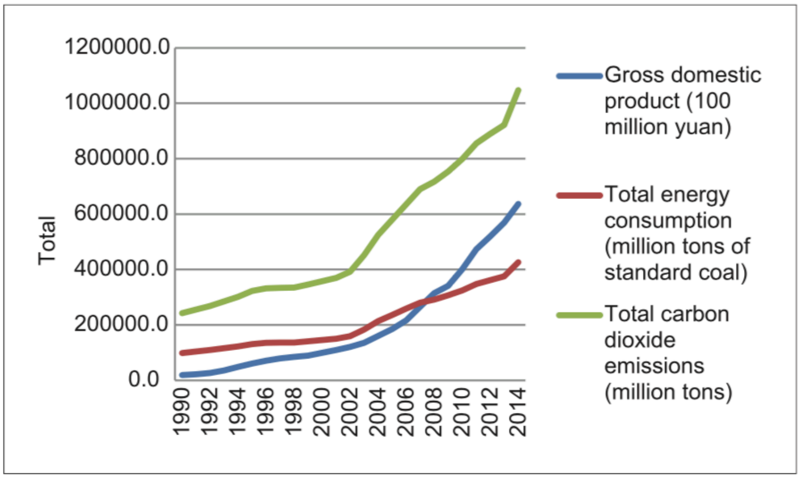
What we expect to find throughout this study is whether or not there is any relevance of China's policies and whether or not there has been any decrease in CO_2 emissions. Naturally, this study would hope to find some decreasing trend as the development of renewable energy, policies and initiatives offer a rather optimistic possibility of its impact in China. Although after reviewing previous research it is rather expected that China's CO_2 emissions should continue rising and be seen at unprecedented levels than ever experienced before.

2. BACKGROUND

2.1 China's Sectoral Emission Factors

China's widely known historic transformations, from rural, agricultural society to an urban, then industrial, and then to a market-based have led to great results for the economy. China has experienced that the overall energy consumption and carbon intensities are strongly affected by the scale and nature of the industrial sector, driven particularly by manufacturing and construction for urbanisation (Grubb et al., 2015). Between 1980 – 2002, China experienced doubling figures of total energy consumption from 603 million tons of coal equivalent (tce) to about 1,200 million tce and continued to increase (Guan, D et al 2008). In 2006 China's energy intensity was ranked more than 9 times higher than Japan and 3.4 times higher than the USA measured in market exchange rates (MER) (Guan, D et al 2008). Due to China's manufacturing sector being a vital aspect of their economic growth and a vital driver of energy consumption, it is not a feasible solution for China to cut energy consumption for the cost of continuous growth, neither if it is to reduce carbon emissions. China's energy situation is characterised by the oversupply of coal, although it has been declining it is still one of the largest in the world. Energy produced primarily from coal accounting for nearly 70% of the total primary energy consumption, has been a key driver to China's economic growth (Wang, 2009). Figure 1, displays the relationship between GDP, total energy consumption and CO_2 emissions in China for the time period of 1990 – 2014.

Figure 1. The relationship between GDP, total energy consumption, and CO_2 emissions 1990-2014



Source: Cui, (2016)

China faces many barriers in the process of developing renewable energy, thus the need of policy support and market cultivation to overcome barriers, all of which will be discussed in the next sections. Other external factors that will inhibit the development of renewable energy are poor market acceptance, imperfect capital markets, technology prejudice, and the increasing cost of capital and transactional (Wang, 2009). This paper will go into further detail of policies in Section 2.3 and 2.4.

2.2 The importance of Renewable Energy (RE) in China

The growing importance of renewable energy in China has reflected on its rapid development, however, it is claimed that it is still a small proportion in the whole energy consumption (Ming, et al, 2013). However, in figures the total energy supply from renewable energy has shown an average annual growth rate of approximately 12% from 2000 – 2010, meaning it has substituted 293 million tonnes of coal equivalents (tce) by the end of the decade (Ming, et al, 2013). Thus, increasing the share of renewable energies is becoming an increasingly important element of China's energy system transition. Yet, energy consumption continued to increase at an annual growth rate of 14.7%, which meant an increase of 51% from 2005 to 2008 (Chai & Zhang, 2010). In 2008 the total renewable energy consumption reached 250 million tce, which is approximately 9% of China's primary energy supply, roughly the amount of energy supply from renewable energy in the span of 10 years.

Although China’s total renewable energy consumption has seen and continues to experience large increases, renewable energy consumption is increasing in parallel. The potential for renewable energy in China is immense and can greatly impact the environment and reduce CO2 emissions, however, renewable energy sources have yet been largely unexploited. Liu et al, (2011) studies explain that renewable energy supply in comparison to the potential of renewable energy sources in China still shows a large gap in addition to the energy demand and efficiency. China has abundant RE resources and is especially rich in hydropower, solar energy, wind energy, and great potential for biomass. The hydropower potential which ranks in as the largest in the world and is expected to continue doubling, as the estimated exploitation rate by the end of 2008 was only 29.9%, much lower than the average level of 60% in the advanced countries (Zhang, N et al, 2011). Furthermore, the growth of hydropower, solar energy, wind power, and biomass has been developing quite effectively and China has set great targets up to 2020.

Although China has great potential to continue developing and using RE sources, the uneven distribution of energy sources and economic development across regions in China such as the social and economic differences between the highly developed coastal eastern regions compared to the central and other rural regions, inhibits the full potential of RE sources providing difficulties in reducing overall emission factors. The uneven distribution of development approximately affects 27 million low-income earners living in rural, mountainous areas of China did not have access to electricity by the end of 2004. The supply and demand of electricity plays a very important role in promoting social and economic development in all underdeveloped areas in China, thus making renewable energy power generating a solution to improving economic development from RE sources such as small hydro system, small-sized wind generating systems, and solar photovoltaic systems which are often more cost-effective than the extension of conventional power grids (Zhang et al, 2010). Renewable energy technologies also have the potential to increase the productivity of agriculture. In approximately 30 million rural households, biogas is used for cooking and lighting and farmers in the rural areas can benefit from these sources in order to increase their income. Furthermore, other renewable technologies such as geothermal and solar greenhouses can all play a role in increasing the output quality and productivity levels.

2.3. China's scenarios (past, present, and future policies)

China is in a historic era of industrialisation and urbanisation, that saw decades of high levels of growth and GDP, the rise in energy demand and consumption levels.

The Chinese government has implemented a sequence of policies and key programs, specifically targeting energy efficiency levels for power generation, key energy intensive sectors, appliances and transportation (Xu, et al., 2014). Improving energy efficiency through policy initiatives became a focal point in 2005 – 2010, where several policies and measures were set in place for key energy intensive industries and in order to promote and replace any outdated production capacity and promote energy saving technology (NDRC, 2006). Furthermore, the state council also introduced policies in order to transform the manner of attracting and securing economic growth that yet allowed industrial structural adjustment and to reduce the development of energy-intensive sectors (Xu, et al., 2014). Naturally, smaller and inefficient power plants were shut down in order to improve the energy conversion and optimisation of energy supply structure along with the augmenting the proportion of renewable energy (NDRC, 2008).

Many of the Chinese government's efforts and policy implementation played and still plays a strong role in yielding the growth of energy consumption and greenhouse gas emissions, during the 10th Five Year Plan (FYP). Moreover, the continuation of the 11th and 12th FYP holds the same values with different methods of approaching the solution to cut CO_2 emissions. The next section will explain the policies China have implemented in hopes to tackle these challenges.

2.4 Policy implementation

The Chinese government has enforced policies, which have been a key driving factor in the implementation and development of renewable energy. Although renewable energy development programs existed in the 1990s, it did not become a policy issue until 2005.

In 2005, the National People's Congress passed the Renewable Energy Law (REL), marking a new stage of renewable energy development in China. The introduction of the REL supported a number of regulations and guidelines have been put in place to implement the law (Wang, F et al 2010). In 2007, China's National Development and Reform Commission (NDRC) issued the Medium and Long-term Plan of Renewable Energy Source Development to meet the growing demand and improve the energy structure.

The REL took effect on January 1, 2006 and according to Zhang et al (2010) among the comprehensive RE policy framework, and institutionalisation of a number of policies and instruments for further development and utilisation of China's renewable energy, the major policies and/or institutions covered by the REL include; (1) Directives on setting indicative renewable energy targets, (2) Directives on renewable energy planning, (3) Directives on functions and responsibilities of the relevant government agencies in renewable energy management, (4) Directives on removal of barriers of renewable energy products to entry energy market, (5) Directives on grid connection of renewable power generation project, (6) Directives on feed-in tariff of renewable power generation, (7) Directives on taxation measures, (7) Directives on special fiscal fund of renewable energy development, (8) Directives on renewable energy technology standards and certification. Further to this initiative the renewable energy and energy efficiency (REEE) policies belong to five significant issues in China; (1) energy security, (2) climate change, (3) economic competitiveness, (4) pollution, and, (5) human livelihood (Zhang et al., 2010).

Overall, government initiatives have been highly analysed, such as China's FYP. The 10th FYP, according to the study of Xu, et al., (2014) experienced a decrease of energy consumption per unit of GDP by 19.1%, along with sulfur dioxide emissions by 14.29% and chemical oxygen demand by 12.45%, all by 2010. Which saw an immense result in the savings of cumulative energy by 630 million tonnes of standard coal equivalent (Mtce), and a reduction of 1.46 billion tonnes of CO2 emissions (Xu, et al., 2014).

However, promoting energy conservation and carbon emission reduction would always be a difficult task, especially to a large economy such as China's. The economic restructuring has progressed slowly, and the fuel mix adjustment remains below expected levels. Although China has set many policies and overall initiatives, China still faces many barriers to overcome. Briefly explained at the end of Section 2.1, additional to those factors there are macroeconomic perspective, energy conservation and emission reduction performance. All of which the 11th Five Year Plan seeks to reflect on the comprehensive effects of all measures and policies. For the years 2006-2010, the 11th (FYP) was placed in order to increase consumption of renewable energy sources. The outcome of this plan was a 15% annual increase regarding investments in treating environmental pollution and environmental investment reached 1.33% of GDP by 2009 (OECD, 2018). Although, it is rather difficult to reliably measure the performance of the policies China has implemented and pinpoint which has played a major role in the projected improvements of the FYP.

The 12th Five-Year Plan is built on top of the previous plan with the concept and objectives to continue developing renewable energy and a concentration on green growth by focussing on the development of wind power, hydropower, solar, biomass and other renewable sources (Ming, et al, 2013). To highlight the recognised importance of RE sources as explained in section 2.2, Table 1 displays the development of renewable sources in 12th Five-Year Plan to meet their objective from the previous plan of reducing energy intensity by an additional 16% by 2015. As of January 2016, China has submitted their Intended Nationally Determined Contributions (INDCs), which aims of reducing carbon intensity by between 60% and 65% by 2030 in comparison with the 2005 level (Cepal, N., 2016).

Table 1: China's 12th Five Year Plan for the development and use of renewable energy.

Content	Exploit scale quantity (million kW)	Annual output of energy (billion kW)	Standard coal (million t/yr)
Generation	394	1203	390
Hydropower (excluding pumped storage)	260	910	295.8
Wind power into the grid	100	190	61.8
Solar power	21	25	8.1
Biomass power	13	78	24.3
Agriculture and forestry biomass power generation	8	48	15.0
Biogas power generation	2	12	37.0
Garbage power generation	3	18	5.6

Source: (Ming, et al, 2013).

Additionally, the most recent FYP is the 13th Five Year Plan that has been set for 2016 – 2020. This plan sets to comfort the "new normal" of growth rates, which are set to accommodate the predicted deceleration growth rates to an average of 5% in the decade of the 2020s. The policy brief explained by Aglietta, & Bai, (2016), the six objectives in the plan which are the shift from capital accumulation-led growth to innovation-led growth; integrated urban-rural development; green development; inclusive development; finance and State-Owned Enterprises (SOEs) reform.

Many of these objectives will have either a direct or indirect effect in reducing China's CO_2 emissions. However, by examining the first objective which noticeably works in favour of tackling the challenges that face RE. The shift from capital accumulation-led growth to innovation-led growth, will see reforms in the supply side in the industry and services in order to apply certain types of innovation that will target energy efficiency and overall production, which in hopes to accelerate the development of new models in manufacturing (Aglietta, & Bai., 2016).
Through the main types of innovation; customer focused, efficiency driven, engineering-based innovations, science-based technologies, China has shown overall great potential. Although a key area for innovation is efficiency driven industries, where high value segments such as construction machinery and electrical equipment have seen a rise in Chinese entrepreneurs. Using their wide network of firms in manufacturing, several platforms can support start-ups and small and medium sized enterprises (SMEs) in order to develop new models based on innovation and automation (Aglietta, & Bai., 2016).

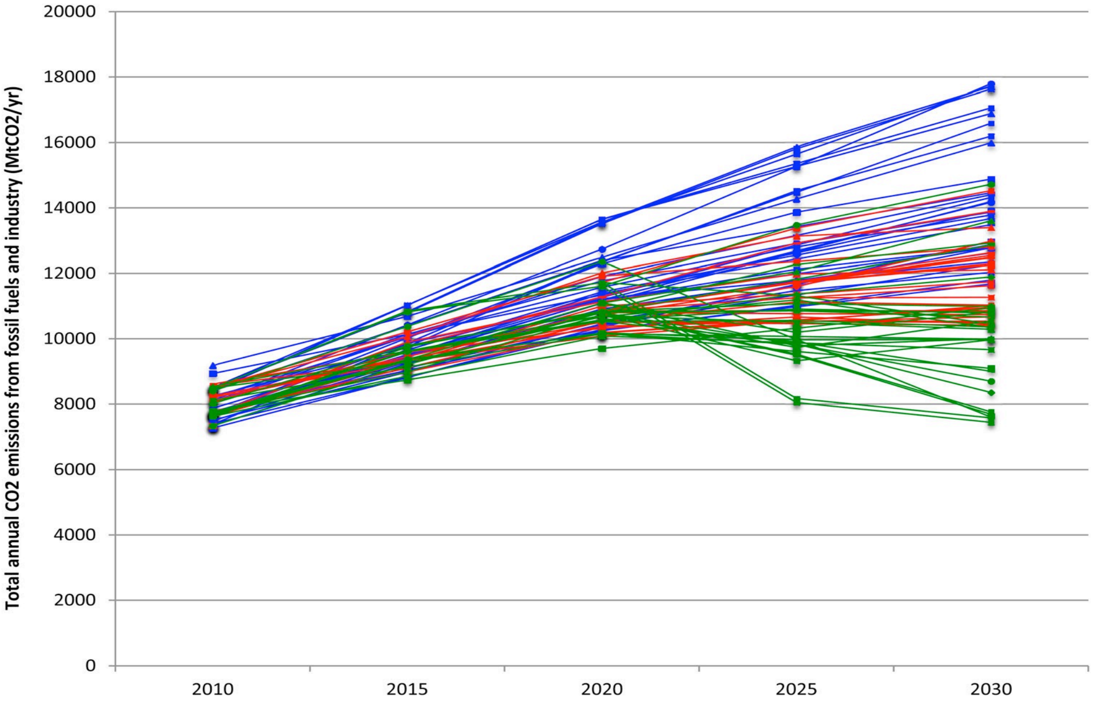
The plans third objective which is green development, will seek out the reduction of GHG emission and clean energy development targets that will accommodate a decrease in the energy intensity of economic growth from 40% – 45% by 2020, although they could reach their final goal by 2030, see Table 3 (Aglietta, & Bai., 2016). The brief continues to explain that China is in an advantageous position, due to strong leadership in providing the ability to understand and take charge of their climate challenges. Furthermore, the contribution of developments from new tech industries will strengthen and support the country's objective in innovation-led growth pattern. It is well known that economic growth has been slowing, and thus at a faster rate has China seen their total energy demand falling since 2012. According to Aglietta, & Bai., (2016) explains the decline from around an 8% annual growth in 2001-2011, to -3.9% in 2013, and -2.5% in 2014. Aglietta, & Bai., (2016) continues to explain that this slowdown was based on a shift in the production structure from industry to services and is estimated at 3% in 2013 and 2% in 2014.

2.5 Forecasted Scenarios to 2030

This study will take forecasted scenarios in order to use against our analysis, in hopes to further understand in which direction China is currently heading towards and whether or not it can be explained where they can be placed amongst the EKC, which will be explained later on in this paper. Forecasts are important to understand and should be continuously examined and reworked in order to build a trend and understanding of CO_2 emissions.

Firstly, we use the study of Grubb, et al., (2015) due to the fact that this paper takes into consideration a forecast to 2030 and also analysis the involvement and contribution of policies and their potential to decrease emissions. Figure 2, a scenario created by Grubb, et al., (2015) projects the total CO_2 emissions from energy related fossil fuel use in China from 2010 – 2030. The scenarios are categorised into three different parts; (1) Blue - is on the basis of no additional climate policies, (2) Red – the implementation of additional climate-related policies (3) Green - projections of strong climate policies that are coherent with a global effort to achieve stabilisation of atmospheric CO_2 (Grubb et al, 2015).

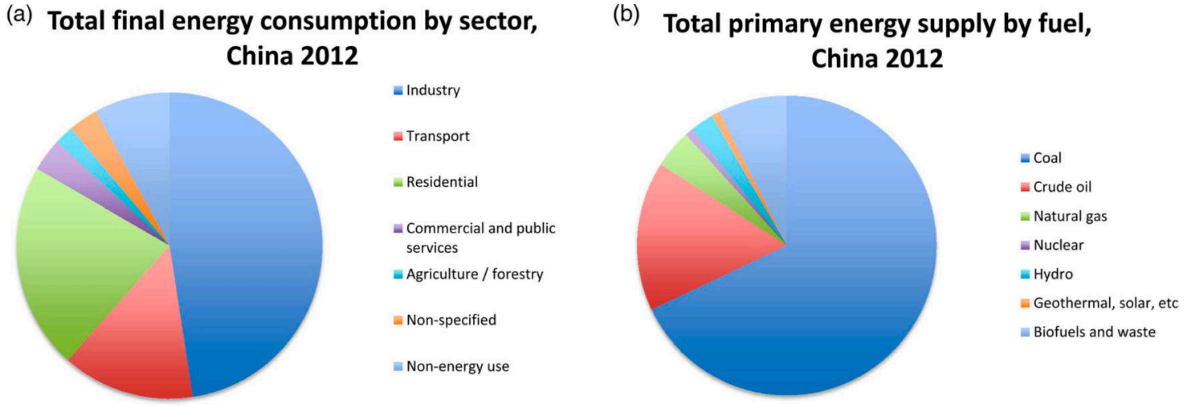
Figure 2. Total impact of energy related CO_2 emissions scenarios from 2010 to 2030.



Source: *Grubb, et al., (2015)*

Additionally, Grubb, et al., (2015) explains that industrial emissions are controlled by three combined factors which are; the economy dominated by industry, high energy intensity and high carbon intensity of industrial energy and power production. All of which in the matter of China is mostly based on coal. Figure 3a below displays that by 2012 industry had already accounted for nearly half of the total final energy consumption, while Figure 3b shows that coal has still dominated the total primary energy supply by fuel, regardless of their efforts and initiatives to promote RE.

Figure 3. Total final energy consumption by sector and primary energy supply by fuel



Source: *Grubb, et al., (2015)*

China's efforts to reduce emissions by 2030 are critical to the global effort to limit climate change. China announced at the UN climate talks held in 2015 that its contribution to the climate initiatives which will attempt to undertake a target of achieving the peaking of CO_2 emissions around 2030 and making efforts to peak early (NDRC, 2015). According to Grubb et al., (2015) between the decade 2000 – 2010, Chinese energy use and their resulting CO_2 emissions provided both local and international institutions China a viewpoint of underestimated growth as China's energy development plans that are part of China's 11th Five Year Plan (2006 – 2010) and China's National Development and Reform Commission (NDRC, 2007) projected coal use of 2.5 billion tonnes by 2010, where in fact in 2010 it was well over 3 billion tonnes, higher than the initial estimate for 2020.

As previously highlighted, China's emissions are the largest worldwide, although it was initially forecasted that China wouldn't catch up with the US until 2030. This was mainly down to China's energy doubling between 2000 – 2007 due to continued high rates of economic growth, making China the largest carbon emitter around 2007 instead of the predicted 2030. Furthermore, Zhang et al., (2016) claims that the Copenhagen negotiations held in 2009, saw the Chinese government promising to cut their carbon intensity to 40 – 45% below the 2005 levels by 2020 (Zhang et al, 2016). Further to the decreasing rates, Grubb et al, (2015) study's that in 2014, the statistics indicate that primary consumption of coal fell by 2.9%, while crude oil and natural gas consumption rose by 5.9 and 8.6%. Although in 2014 displays a change from earlier trends in China of near double-digit annual emissions growth. In section 3.2 we will further discuss whether or not Grubb et al (2015) study considers 2014 a year that broke this trend or not and will further discuss their examination of China's energy related.

China has taken intensive efforts to promote research, development, demonstration and commercialization of sustainable energy technologies over the past five years (Chai & Zhang 2010). Policy actions to cover binding energy conservation and environmental pollution control targets, economic incentives for sustainable energy, and public R&D supports. Other suggestions to cut carbon submission explained by Wang, F et al (2010) are by slowing economic growth, reducing energy intensity, and developing renewable energy. Evidently, Chinese energy policies face tremendous challenge of maintaining rapid economic growth while reducing energy consumption and developing high tech clean energy to also reduce pollution emissions. Of course, China are already experiencing a slowdown of growth rates and are predicted to continue decreasing as displayed in Table 2.

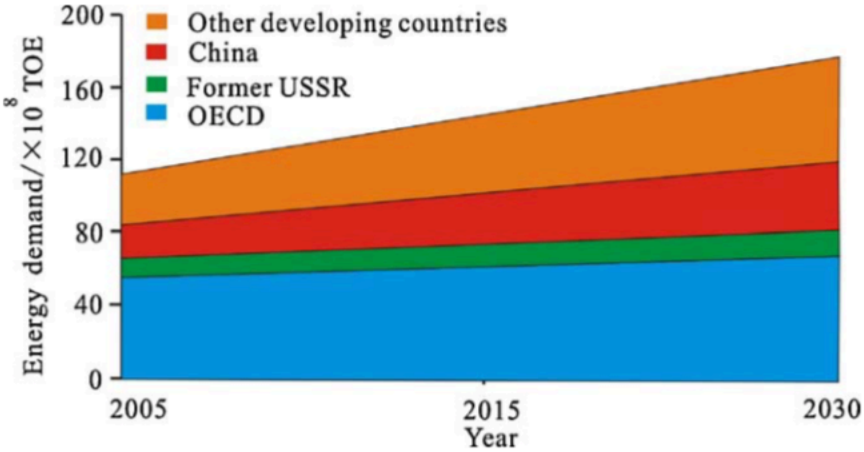
Table 2. Growth of GDP in China

	2000–2010	2010–2020	2020–2030
Annual GDP growth rate	7.8%	6.6%	5.6%

Source: Jiang, & Hu, (2006).

Although, Wang (2009) creates a hypothetical scenario in which carbon intensity keeps pace with GDP growth rate of 7% by 2030, which would result in China emitting as much as the world is currently emitting today of 8GtC7/year (Wang, 2009). As displayed in Figure 4, between 2005 and 2030 primary energy demand is projected to more than double (Wang, 2009). Another scenario according to Wang, (2009) suggests that China's agricultural output could be reduced by 5-10% by 2030.

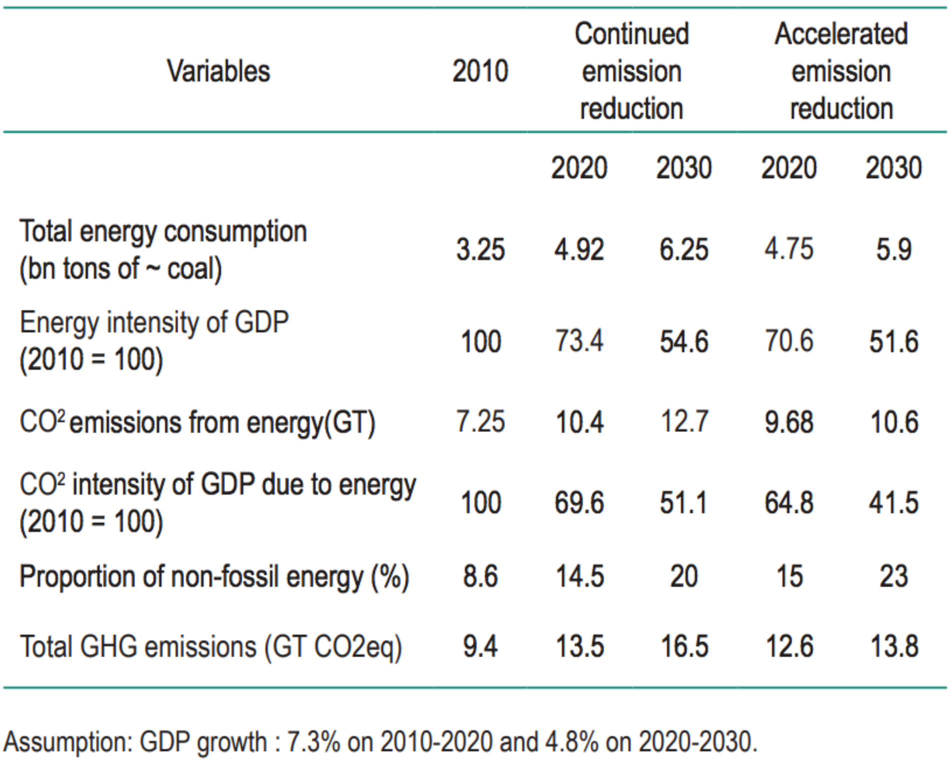
Figure 4. Projected energy demand in China and other regions



Source: *Wang (2009)*

However, as recently discussed from the 13th Five-Year Plan brief the expects a slower growth path and along with the changes in structure of production then emission reductions are to be achieved at lower levels by 2030 (Aglietta, & Bai., 2016). Table 3 is the scenario based on the projections from the 13th Five-Year Plan.

Table 3. Continued and Accelerated emission reduction scenarios



Variables	2010	Continued emission reduction		Accelerated emission reduction	
		2020	2030	2020	2030
Total energy consumption (bn tons of ~ coal)	3.25	4.92	6.25	4.75	5.9
Energy intensity of GDP (2010 = 100)	100	73.4	54.6	70.6	51.6
CO^2 emissions from energy(GT)	7.25	10.4	12.7	9.68	10.6
CO^2 intensity of GDP due to energy (2010 = 100)	100	69.6	51.1	64.8	41.5
Proportion of non-fossil energy (%)	8.6	14.5	20	15	23
Total GHG emissions (GT CO2eq)	9.4	13.5	16.5	12.6	13.8

Assumption: GDP growth : 7.3% on 2010-2020 and 4.8% on 2020-2030.

Source: Aglietta, & Bai (2016)

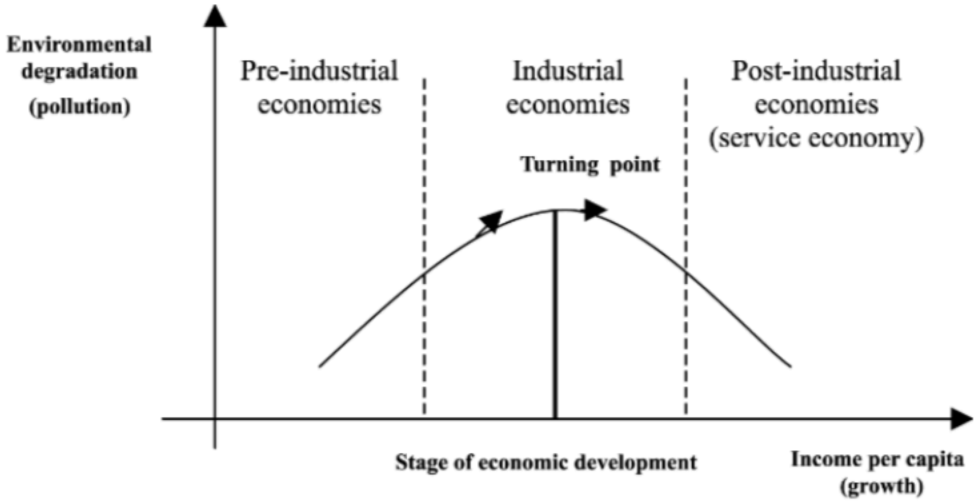
3. LITERATURE REVIEW

3.1 The Environmental Kuznets Curve

Understanding the impact of economic growth on the environmental quality is becoming increasingly important as general environmental concerns are making their way into main public policy agenda, which we have noted from China's future targets. Further, the relationship between environmental quality and economic growth has remained a widely debated issue and empirically modelled through the influence of emissions and income by many authors. Many questions have risen given this debate and whether or not the world can sustain economic growth open-endedly without losing resources or destroying the environment? Or are there any trade-offs for achieving high and sustainable rates of economic growth while obtaining a well-preserved environment? (Panayotou, 2003). It is believed that economic growth and rates of productivity will increase larger input of energy, materials, extraction of natural resources, which will inevitably harm and result in the degradation through the accumulation of waste, and concentration of pollutants. According to Panayotou, (2003) in order to save the environment, economic growth must cease to accommodate into a transitioning phase of a steady-state economy. Further to this argument, another perspective is that the relationship between economic growth and environmental quality, is not set by the country's development path whether the results are positive or negative. Although, many studies can prove that if the results are positive if income reach a certain point where it has an impact on society and allows an affluent society to become more conscious and have the opportunity to afford and demand efficient infrastructure and a cleaner environment. The outcome or testing the relationship as of economic growth and environmental quality has led to the formulating the hypothesis of the Environmental Kuznets Curve (EKC).

The EKC hypothesis is based on an inverted U-shaped relation between environmental quality and income per capita. Many studies have argued that the level of environmental degradation and economic growth follows an inverted U-shaped relationship, as seen on Figure 5. According to Panayotou, (2003) in the pursuit of economic growth and the process of structural transformation, as agriculture and resource extraction intensify then industrialisation occurs, therefore the depletion of resources and the acceleration of waste generation are one of the symptoms an economy would experience. Later experiencing that throughout increasing stages of development, structural change continues towards information-based industries and services, thus allowing innovation and more efficient technologies. All of which leads toward an increasing demand for environmental quality levelling-off and a steady decline of environmental degradation (Panayotou, 2003). This can be seen in Figure 5, below where the EKC is divided into three parts, (1) pre-industrial economies, (2) industrial economies, (3) post-industrial economics (service economy).

Figure 5. The developmental-environment relationship: Environmental Kuznets Curve



(EKC)

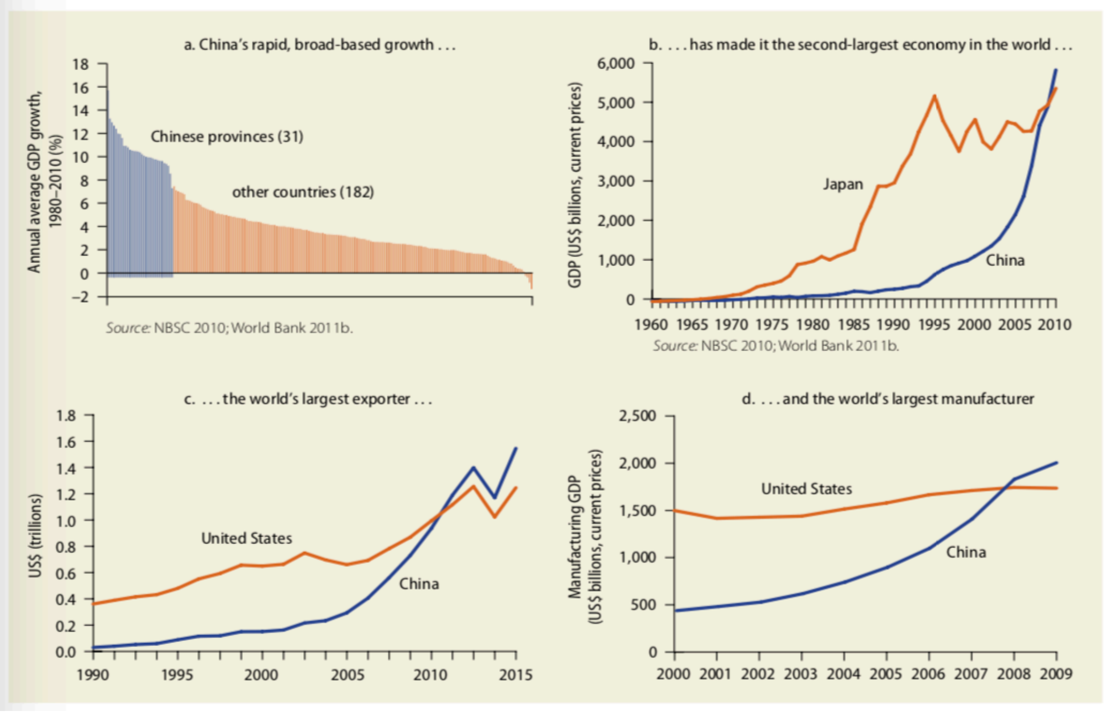
Source: Panayotou (1993)

The reason for the three classifications according to the EKC, is placed in order to clearly define the stages and understand the characteristics of an economy according to the hypothesis. Along with economic growth, energy consumption is an important determinant of CO_2 emissions. In the study of Jalil & Mahmud (2009) the estimation of the EKC for CO_2 emissions for the ever rapidly growing country of China for the period between 1971 – 2005, which will be later on in the paper.

Furthermore, Jalil & Mahmud (2009) test the EKC hypothesis under their chosen time-series analysis framework and using CO_2 emissions as an indicator of environmental conditions. The studies empirical results suggest the existence of a robust long-run relationship of a positive sign with income and negative sign with the quadratic term of income, which confirms the presence of EKC for CO_2 emissions in China. The long run findings imply that 1% increase in per capita consumption of energy will lead to 0.57% increase in the per capita CO_2 emission in the long run. This positive correlation is also consistent with previous studies of Liu (2005) and Ang (2007, 2008, 2009). Additionally, a 1% increase in real per capita capital will lead to 4.1001% increase in the per capita CO_2 emissions (Jalil & Mahmud, 2009). Ultimately, their results supporting the EKC hypothesis that the level of CO_2 emission will initially increase with income until reaching a point of stability, leading to a period of decline. An interesting conclusion worth noting from the empirical results of Jalil & Mahmud (2009) study, is that it shows that China's 11th Five Year aimed at reducing CO_2 emissions may have had some impact in controlling environmental degradation. Although, the results are based on aggregate data and the significant differences in the growth patterns of the eastern, central and western provinces of China, should be reasons to take caution for these results.

Understanding the EKC in the lens of China has seen historical transformations from a rural, agricultural society to an urban, industrial economy and market based, since 1978. Figure 6 displays that China has been exceeding at an incredible pace, overtaking the United States as the world largest exporter and largest manufacturer during the millennium.

Figure 6. China's overall economic performance.



a. China's rapid, broad-based growth . . .

Source: NBSC 2010; World Bank 2011b.

b. . . . has made it the second-largest economy in the world . . .

Source: NBSC 2010; World Bank 2011b.

c. . . . the world's largest exporter . . .

d. . . . and the world's largest manufacturer

Source: Jalil & Mahmud (2009)

Prior to their industrial surge, approximately 60% of China's labour force was employed in agriculture, which would be the pre-industrial stage referring back to the EKC curve. From the late 1970s onwards, China experienced rapid growth as viewed on graph 2b. China's large labour force saw growth in the industrial sector around the 1990s, leading to a reduction of labour within the agriculture sector. And for the next three decades China experienced an annual average of 8-10% levels of GDP, as an industrial economy.

On the other hand, China is now forecasted to experience a downfall in GDP, due to much of the growth contribution from shifting resources from agriculture to industry has already occurred (World Bank and the Development Research Centre of the State Council, PR China (DRC), 2013). which would mean China is now facing a turning point, which referring to Fig 1, could mean that economic degradation and in this case CO_2 emissions should start to see a declining rate.

3.2. Previous Research

In this section, we review literature that used IDA and LMDI decomposition analysis in their studies.

There are a number of studies concerning the correlation between economic growth, energy consumption and CO_2 emissions in China, along with the use of the EKC. However, there are limited LMDI decomposition analysis studies focusing on China. The studies that do exist mainly focus only on CO_2 emissions in the manufacturing industry or are also conducted for other countries. With the right to do so, considering the manufacturing industry is a main focus in the analysis for CO_2 emissions. Studies such as Xu & Ang (2013) have conducted an intensive literature review in analysing over 80 existing papers that adopt the IDA analysis to study the drivers of CO_2 emissions from 1991 to 2012. The conclusion to this review is that the applicability of using the IDA is recognised by researchers and analysts as a useful analytical tool for studying the drivers of changes in CO_2 emissions. Furthermore, to the analysis on China, Qi et al, (2016) conducts a review of existing papers by also adopting the LMDI approach to analyse China's economy-wide CO_2 emission. Although using an extension of the IDA, the LMDI-I a popular approach adopted in the analysis. The study provides a very detailed analysis of contributing factors on China's emission from 2005 to 2013. In this study of Qi, et al., (2016) analysed the driving factors of energy-related CO2 emission reduction in China from 2005 to 2013. The analysis found that the primary contribution of emission reduction in previous years has been predominantly from the reduction of energy intensity per output in the industrial sectors (Qi, et al., 2016). Qi, et al., (2016) confirms the improvement of energy productivity in those sectors play a relatively important role to achieve a reduction in emissions.

The rationale of decomposition analysis is to decompose the change in a variable of interest, such as total CO_2 emission, into a sum of changes in each of a number of key driver variables in the likes of total energy use, the share of renewables, and the composition of fossil fuel energy use. What is known for this approach is the ability to identify the effects in an IDA in order to draw conclusions regarding the impacts of improved energy efficiency (activity intensity effect), adjusting economy structure (structure effect) and decarbonising energy mix (energy mix effect). In a study done by Feng et al. (2015) and Steenhof and Weber (2011) the energy mix is introduced as one of the explanatory factors without an explicit consideration or separation of renewables and nuclear energy. Mohlin et al. (2018) decomposes the changes in the energy mix in three components: changes in the energy supply from renewables, nuclear energy, and changes in the fossil fuel mix, which allowed to ability to quantify the rise of renewables and the recent share decrease in their costs have meant for the U.S. CO_2 emissions, while also considering to separately quantify the contribution from changes in the fossil fuel mix. Although the study of Mohlin et al, (2018) did not analyse emissions in China but rather the U.S. their study was supported by the usage of the index decomposition analysis (IDA) and structural decomposition analysis (SDA) provides an opportunity to analyse the role of renewables in CO_2 emission trends. Mohlin et al, (2018) decomposition analysis was able to show how to assess the contribution from renewables to CO_2 emissions reductions between 2007 – 2013, and also consider the structural shifts, which resulted in a contribution to the 10% decrease in CO_2 emissions. It then supports the importance of analysing the role of renewables due to their influence on CO_2 emissions and their expected continued cost decrease.

Referring back to China, Wang, et al., (2005) extends current studies to quantify the contributions of several predefined factors to changes in total energy-related CO_2 emissions in China, through providing a historical analysis on how the contributing effects have transformed over the period between 1957 and 2000. This study uses the CO_2 emissions based on the climate change (IPCC) method along with the variations that contribute to the factors of inter-fuel switching, carbon-free renewable energy penetration, energy conservation, economic growth, and population expansion using LMDI (Wang, et al., 2005). The results from the study indicate that there has been significant contribution to reducing global CO_2 emissions in China, although none of the carbon savings resulted from conscious domestic climate mitigation policies. Which indicated that China has achieved a considerable decrease in its CO_2 emissions predominantly due to much improved energy intensity. Wang et al, (2005) also claim that fuel switching, and renewable energy penetration also made a positive impact, meaning, leading to a decrease in CO_2 emissions. The study was able to link the influence of China's economic growth in the past four decades to a theoretical total increase of CO_2 emissions of 4983.94 Mt for the entire period of 1957 – 2000, assuming that the production energy mix, energy efficiency and the structure of production remained unchanged (Wang et al., 2005). Other methods have been used in correspondence to China's energy related CO_2 emissions until 2030, which have been generated from energy system models. Energy models provides the ability to analyse the demand of numerous energy complex system that may be met through specific fuels and conversion technologies.

Furthermore, the study of Xu et al., (2014) analysed the factors that influenced carbon emissions due to fossil fuel energy consumption in China in order to identify key factors for policies promoting carbon emissions reductions, throughout the periods of 1995 – 2011. Although the study used the Kaya identity decomposition method for carbon emissions, it allowed to explain the results through five factors of energy structure, energy intensity, industry structure, economic output, and population scale effects. The study analysed factors that energy consumption per unit of GDP was showing and increasing trend, putting more pressure on carbon emissions (Xu et al., 2014). Thus, providing a confirmation of the relation between economic growth and environmental degradation in the viewpoint of the EKC.

The study of Grubb et al., (2015) and the scenarios, were based on 12 different models in order to review CO_2 emissions. Their study provided acknowledgment of the difficulties in assessing and predicting China's potential. No models projected the explosive growth of Chinese energy and CO_2 after 2000, moreover, there was also no prediction of the sudden halt in 2014 (Grubb et al., 2015). Which has amplified debates amongst research. Chinese macroeconomic reforms are poorly represented in models used in studies (Grubb et al., 2015). Grubb et al., (2015) continues to explain that projections and policy need to recognise the essential uncertainties in emission prospects, due to the fact of poor representation in models. The study highlights the interconnectivity between China's macroeconomic and climate prospects. The conclusion is that the 'new normal' could lead to a successful macroeconomic transition, with a controlled decrease of GDP levels in order to restructure the economy away from heavy industry and towards services.

In order to investigate the changes in CO_2 emissions, this study carry's out the decomposition method of LMDI-I, to investigate the changes in energy consumption and CO_2 emissions from China's Agriculture, Industry, Services, and Household sectors. The outcome would also provide insight as to where China's sectors are fitted alongside the EKC, and whether or not they are experiencing a turning point.

4. METHOD

4.1. Index Decomposition Analysis (IDA)

The decomposition analysis has become a widely accepted and the most applied approach for studies that breakdown the changes in emissions into explanatory factors (Ang et al. 2009). The advantages to this approach is due to the sound theoretical foundation, high degree of adaptability, ease of use, and understanding to the presentation of the results, the application of decomposition analysis has increased substantially in scope over the years since its development (Wang, et al.,2005). Furthermore, the decomposition analysis may be a period-wise or a time-series set up, which changes the way the data is used and alters from the question of the study. For this thesis we will use the additive period wise, which will be explained further in Section 4.2.

As previously mentioned, the decomposition method is a valid and useful tool in order to analyse the change of CO_2 emissions over time throughout different sectors. The two main that are used for decomposition of carbon emission factors are the SDA and IDA. Previous studies have used the SDA method which is based on input-output data and can capture more complex effects than IDA, however, due to timing and data this method has not been selected for this study. On the other hand, the IDA also has advantages as the data is much more accessible and can cover a wider time frame, and for that reason it has been chosen for this study.

4.2 The Logarithmic Mean Divisia Index LMDI

For this analysis we will be using an LMDI additive period-wise method, as viewed in Eq 1. LMDI is based on the IDA, which derives from many specific decomposition methods can be developed from this foundation. Although there are two versions of LMDI, the one selected in this study as its method is the most favorable method, which is the LMDI-I. As it is easier to understand, in the additive format as explained in Ang et al. (2009). In its additive form, the general formula of the decomposition is, Eq 1:

Equation 1.

$$V = \sum_i V_i = \sum_i x_{1,i}\, x_{2,i} \ldots .\, x_{n,i}$$

In Eq. 1, V is the energy related aggregate composed of x factors $x_{1,}$ $x_{2,}$ $x_{n,}$ which are impacting the changes in V over time. The aggregate changes from V_0 in period 0 to V_t in period T, and as written as follows in Eq. 2 and 3:

Equation 2. **Equation 3.**

$$V^0 = \sum_i x^0_{1,i}\, x^0_{2,i} \ldots x^0_{n,i} \qquad V^T = \sum_i x^T_{1,i}\, x^T_{2,i} \ldots x^T_{n,i}$$

Following the above, the complete additive decomposition is re-written as follows in Eq. 4, in order to include total energy aggregate for period 0 and T.

Equation 4.

$$\Delta V_{tot} = V^T - V^0 = \Delta V_{x1} + \Delta V_{x2} + \ldots + \Delta V_{xn}.$$

The next step in the methodology is then to calculate the changes in CO_2 emissions in each sector by calculating the changes in the four underlying driving factors. The five factors are the total industrial activity, industry activity mix, sectoral energy intensity, sectoral energy mix, and CO_2 emission intensity. Also known as the activity effect, structure effect, energy intensity effect, and emission-factor effect, where CO_2 emissions is the result of all these factors. It is important to investigate these factors within the sectors in order to analyse and evaluate the production of CO_2 emissions and how this will be impacted and in line with the scenarios in the previous section. Bearing this in mind the five explanatory effects, can be identified by the IDA as follows in Eq. 5:

Equation 5.

$$C = \sum_i C_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{C_i}{E_i} \sum_i Q\, S_i I_i U_i$$

We observe that C represents the total for CO_2 emissions and C_i is the result of CO_2 emissions from the industrial sector i. Variable Q stands for the total industrial activity level and Si is the activity or output share given by Qi/Q. Furthermore, Ii is given by Ei/Qi which stands for the energy intensity of sector i. Lastly, variable Ui is the CO2 emission factor of sector i given by Ci/Ei. The LMDI technique formula using the additive decomposition is:

Equation 6.

$$\Delta C_{tot} = C^{T} - C^{0} = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{emf}$$

In equation 6, the changes in total CO2 emissions from year 0 to year T can be decomposed into various effects: activity effects (ΔC_{act}), structural effects (ΔC_{str}), intensity effects (ΔC_{int}), energy mix (ΔC_{mix}) and CO2 intensity effects (ΔC_{emf}). (ΔC_{act}) measure the changes in total CO2 emissions that occur due to changes in the overall activity level (or GDP), (ΔC_{str}) will show the CO2 emissions caused by structural change in sector i and will be shown through measuring the impact changes in the share of output from different sectors. (ΔC_{int}) measures the contribution of changes in sectoral energy intensity to changes in total CO2 emissions. Additionally, sectoral energy intensity displays that technological change in sector i, meaning that the higher energy intensity in sector I, then the less technological change within sector i. Lastly, (ΔC_{emf}) shows the contribution of changes in the CO2 intensity of the energy basket to changes in total CO2 emissions. Each of the drivers is then calculated with the formulas as displayed in equation 7.

Equation 7.

$$\Delta C_{act} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{Q^T}{Q^0})$$

$$\Delta C_{str} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{S_i^T}{S_i^0})$$

$$\Delta C_{int} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{I_i^T}{I_i^0})$$

$$\Delta C_{emf} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{U_i^T}{U_i^0})$$

Source: *Ang (2005)*

4.3 Description of the decomposition factors

After explaining the equations that are used in the methodology, the following sections of this paper, we will explain the components of the LMDI decomposition method. They are: activity, structural change, fuel switch/ CO_2 emissions intensity, and technological change.

4.3.1 Activity effect – output effect

One of the ways of reducing the level of CO_2 emissions is limiting the economic activity. However, this would be in direct effect on the economic growth in a country. Due to the nature of the Chinese economy and countries characteristics, it is unlikely that this would be recommended approach. Instead the primary approach would have to be on technology advancements and energy efficiency policies.

4.3.2 Structural change

One of the two components that drives the changes in energy intensity is structural change. Zhang, Z., (2003) explains that the importance of structural change and energy intensity is that it enables policy makers to understand the impact of energy from policy implementation and the credibility for future plans. Structural change also provides insight into the change between sectors and the understand the influence of changes in the share of output from different sectors in order to understand the structural transformation moving from an industrial economy to a post-industrial (service economy) (S, Islam, & K, Iversen., 2018).

4.3.3 Technological change

Technological change within sectors is the second component that compliments structural change and drives the changes in energy intensity. Old technology can be replaced by new, innovative technology in order to improve energy efficiency. Furthermore, industrial energy intensity can be lowered by improving technology (the change) in order to produce more goods that would require less energy (structural change) (UNIDO, 2011).

4.3.4 Fuel switch (CO_2 emissions intensity)

Effects from Fuel switching or also referred to as CO_2 emissions intensity is the occurrence of changes in the energy basket to fuels with an opposing CO_2 emissions content per tera joule

(TJ). Fuel switching, and the development of renewable energy can also contribute to the decline of energy consumption and CO_2 emissions (Xu, et al., 2014).

5. DATA

5.1 Data used for LMDI analysis

This study covers the period from 1990 to 2015 for which the validated energy balance data in China are available. The data was collected from the International Energy Agency (IEA, 2018). The World Energy Balance online data service contains energy balances for over 150 countries and regions. The figures are expressed in thousand tonnes of oil equivalent (ktoe) and in TJ. The data set provides the availability of data from 1971 (1960 for OECD countries), however, this study has chosen to use data solely from 1990 to 2015 as previous studies have explained that renewable energy policies were not implemented until the 1990s.

We compiled and partially reconstructed the data under fossil fuel combustion we grouped together coal, oil and natural gas from individual types. Then we were able to calculate final energy consumption, emissions, activity output and energy intensity. Due to the lack of CO_2 emissions statistics on China, using the data set were able to calculate CO_2 emissions. Emissions were manually calculated using the factors of 94.6 kg CO_2 / GJ for coal and peat, 73.1 kg CO_2 / GJ for oil and 56.1 kg CO_2 / GJ for natural gas. Furthermore, GDP was also used in the study, and this was taken from a previous United Nations Statistics (UN Statistics, 2015). However, GDP data for household was unavailable and therefore, not considering for each component for the LMDI analysis.

5.1 Limitations

For this thesis, it should be reasonable to point out the limitations given the nature of the study and its aims. The limitations with the data and methodology are that the sectors are grouped together and not split in order to view at individual levels. This prevents the ability to view further analyses on the increases or decreases at sub levels, especially in the industrial level. Industry is not broken down into its sub levels of manufacturing, mining, and electricity and heat production, and to many studies the manufacturing industry has been the large influence towards CO_2 emissions in China. This means we have created a gap where other studies have filled and were able to conclude with interesting discoveries. Furthermore, the study does not include personal consumption effects. Are the energy consumption changes in households and informal economy in relation to total changes in GDP. Which is not measured or taken into consideration in this study. Therefore, it is missing from contributing to structural transformation

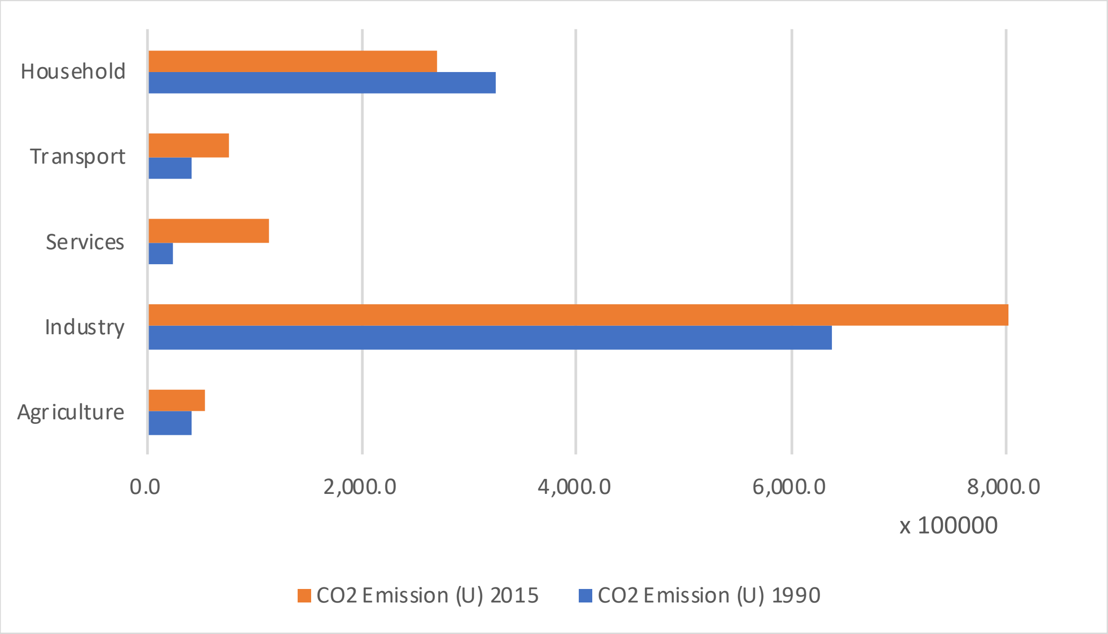
6. RESULTS AND DISCUSSION

In this section of the thesis, we discuss the result from the LMDI decomposition method presenting for the changes in the level of CO_2 emissions, viewing which sector had the greatest impact in China over the selected time period of 1990 – 2015.

Based on our data and chosen method, from the period of 1990 – 2015, we see the total change in CO_2 emissions for the key sectors of household, transport, services, industry and agriculture. Having selected the additive period wise form LMDI, it allows us to view solely the total difference between 1990 and 2015. Figure 7 displays the change in China's CO_2 emissions for 1990 and 2015. We observe that CO_2 emissions in 2015 continue to exceed the 1990 emission levels, thus following the previous conclusions and that of the United Nations (2011) that China remains the largest emerging economy emitting CO_2 emissions. And along-side Grubb et al, (2015), with their studies indicating a higher rate than the previous years.

To our initial and relatively ambitious outlook, we expected to find some decrease or relevance of China's policies in CO_2 emissions, we would have liked to see some decreasing pattern from the impact of RE and government policies, and against all the discussions based on the importance of RE and the forecasted scenarios. However, due to our selected years of study, the impact of RE and policies are not identifiable. Our calculated CO_2 emissions displays that the CO_2 emissions levels of industry, services, household and transport, provided by Figure 7 indicates that China's 2015 CO_2 emissions levels have exceeded 1990 levels by 1.1 billion tonnes. Industry and coal emissions confirmed from previous studies continues to be the key characteristics impacting China's CO_2 emissions. Where the energy consumption levels alone in industry increased by approximate 1 billion tonnes. This result is driven by the continuous high growth rates that China has been experiencing over the past few decades. And the 'new normal' rates that they are preparing for have not made an impact or, yet it is too soon to notice the impact of lower annual growth rates, RE and government policies. Services, agriculture and the transportation sector have all increased since 1990 and this would be in reason to the overall rate of economic development in China. However, households, has experienced a decrease in CO_2 emissions and has seen a decrease of 12.5 million tonnes of coal equivalent in this sector. This could be down to the explanation in Section 2.2, where biogas is being used in rural households and other technological improvements that have made an impact for this sector, or potential use of overall fuel switching. It is potential that China could reach the predicted increasing levels of CO_2 emissions by 2020/2030, as previously discussed in Section 2.5.

Figure 7. Total changes in CO_2 emissions in China: 1990 - 2015



Source: IEA. (2018).

Although based on a separate dataset Shan, Y et al., (2018) uses several other data sources for their energy-related sectoral approach emissions such as the energy balances from BP, EIA, MEIC, and their energy consumption results are between 4 – 5.5 million tonnes of standard coal equivalent. Whereas our data in total reaches approximately 2.2 million tonnes of standard coal equivalent, however, we are not able to explain the differences between the data sets. It is possible that there are data gaps in China's provincial CO_2 emissions and large uncertainties or that the energy data quality for China is limited reliability or actuality (Shan, Y et al., 2018). It is worth further noting that the methodology and emissions from electricity and heat generation within city boundaries were counted based on the energy input for their study and in our study, we did not consider the provincial regions separately.

Overtime CO_2 emissions have fluctuated, and this study would have liked to see more activity in the impact of each sector to China's emissions. However, these sectors are important is impacted by these key sectors, which is why these key sectors of household, transport, services, industry and agriculture have been chosen for the study. As mentioned in Section 2.1. energy consumption, GDP and CO_2 emissions have always intertwined; however, it would appear there is no decrease of CO_2 emissions for our chosen period.

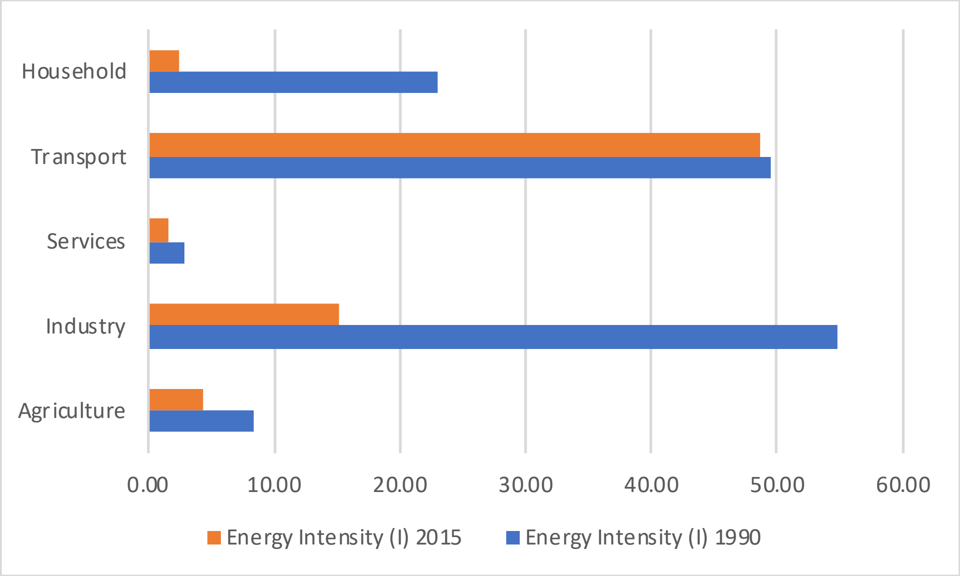
Figure 8 displays the level of energy intensity decrease by 2015 in comparison to 1990 levels. The recent drop in energy intensity levels would be parallel to the recent expectations from the Chinese government and according to their initiatives. As explained in Sections 2.2 and 2.4, the importance of RE could be even more valued based on the results and the experience of decreasing levels of energy intensity. Table 1 provides a display of the development of RE sources within the 12th FYP in aims of reducing energy intensity significantly by 2015. Based on the results, it could be due to this plan amongst other initiatives that they were able to decrease energy intensity levels. Furthermore, the recent submission in 2016 to the INDCs, in order to continue decreasing carbon intensity by further 60% - 65% in 2030, could possibly be achievable, as per the study of Cepal N, (2016).

The lower levels of energy intensity in 2015 in households and industry could be due to the implementation of technological change, as previously discussed above. The change in technology replacing old to new innovative and efficient technologies could explain the lower levels in these two sectors, while policies and initiatives could improve the condition in households amongst the use of RE such as a biogas to be used for cooking and lighting in the rural areas.

Further to the decreasing levels in industry, households, services, transport and agriculture are the Copenhagen negotiations in 2009, which has been previously discussed in this study. The Chinese government promised to cut intensity around the approximate range of 40 – 45%. According to our data energy intensity in industry was cut by 39%, while households decrease was 20%, 4% in agriculture and 1% in services. These also could be in correlation with Grubb et al., (2015) where he indicated that primary consumption of coal fell by 2.9%. although the levels of crude oil and natural gas rose.

The effects from fuel switching could also explain the reduction seen in Figure 8. Whereas explained above there has been changes in China's energy through switching to fuels in order to decrease CO_2 emissions content. Also, the development of renewable energy could also be a contributor to the decline of energy consumption and CO_2 emissions (Xu, et al., 2014).

Figure 8. Total energy intensity changes in China from 1990 to 2015

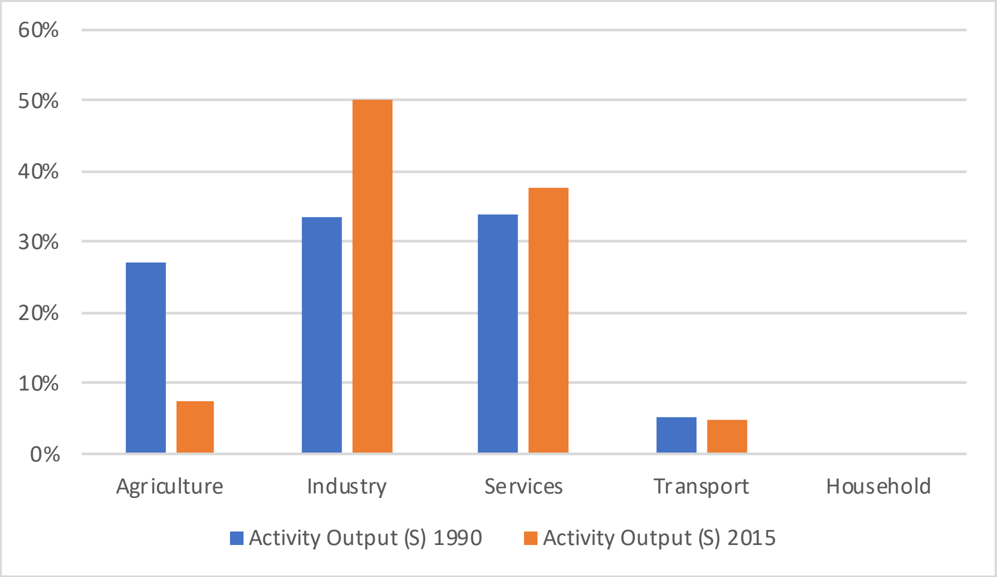


Source: IEA. (2018).

In Figure 9, based on our data set and calculations the total activity output in China from 1990 to 2015. As expected, and based on the result of Figure 7, the activity levels in industry still lead as the key sector where levels reached up to 50% in 2015 as compared to 34% in 1990. The increase is natural given the current standpoint of the economy and relatively understandable position of China's activity and revealing that industry remains as the key sector to drive CO_2 emissions.

The activity output is another indicator of the pathway to reducing CO_2 emissions. Although China is expected to experience a 'new normal' of steady growth and income, Figure 9 suggests that reduction has been successful in agriculture levels, but this could be down to the productivity levels, where they have already experienced a shift onto more productive and emitting sectors such as industry and services. Although services would not be considered a major threat to China's CO_2 emissions. Industry however remains at a 16% difference in 2015 as compared to the levels in 1990. Meanwhile it is just that agriculture no longer contributes as much to the levels of 1990 considering structural transformation. While it could be arguable that transportation levels would continue to be the same, due to the continuation of growth in infrastructure in the country that would require high levels of transportation. Furthermore, to what extent we would have expected to see an increase is indeterminable. Unfortunately, due to the lack of GDP data on households, the results were unable to account for its activity output levels.

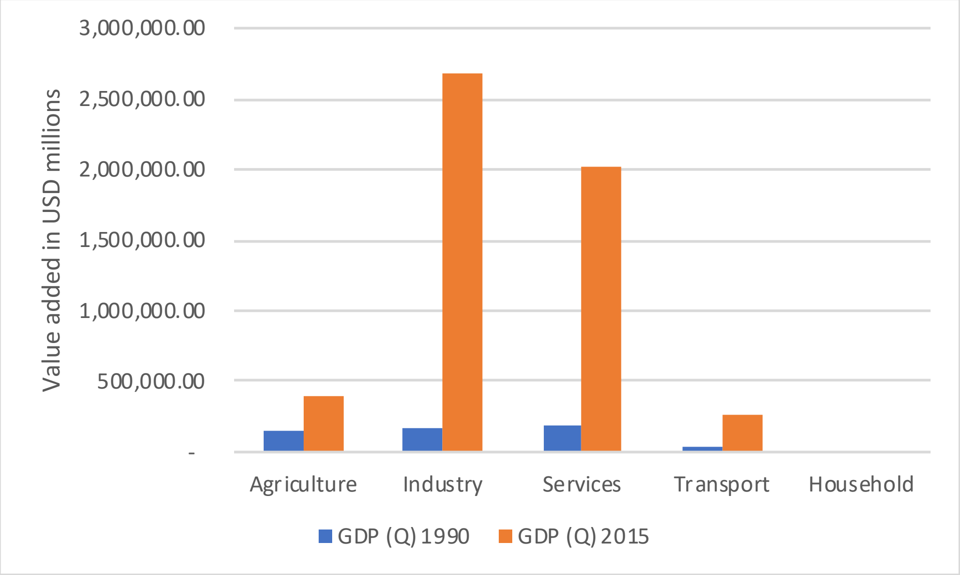
Figure 9. Total activity output in China from 1990 to 2015



Source: IEA. (2018).

In Figure 10, we observe that China's GDP in value added millions, is in total 4.8 million USD difference. The enormous difference in GDP is not surprising after all the researches and conclusions and China's well known rapid economic growth levels. Although levels remain considerably high in 2015 and seeing the decreasing results in other Figures, it could also result in investments moving into other directions where China's CO_2 emissions are not at risk.

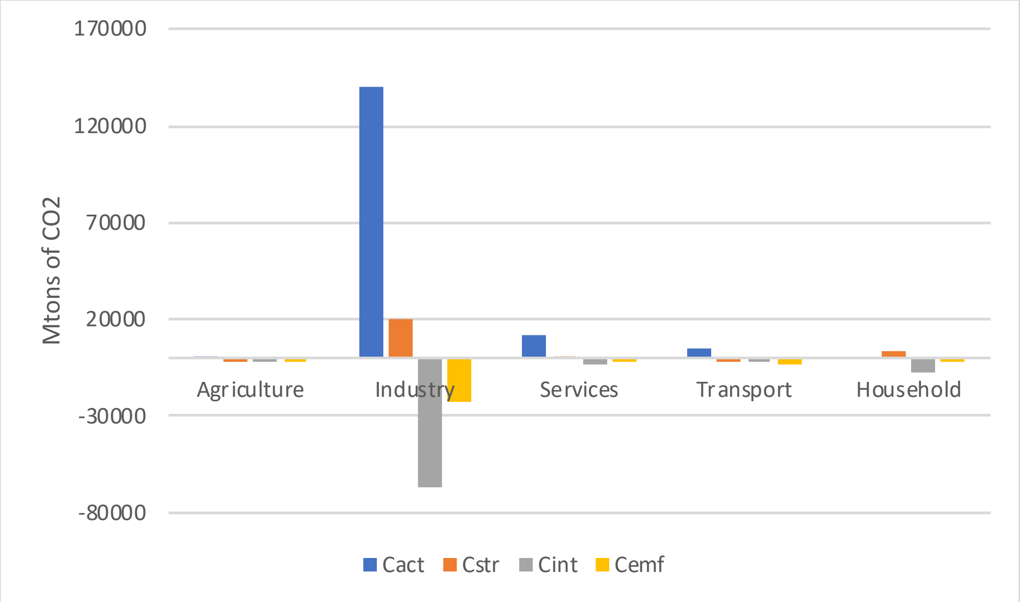
Figure 10. Total changes value added in millions GDP in China 1990 – 2015.



Source: IEA. (2018).

Figure 11 potentially enables a better understanding of how the changes of CO_2 emissions have been behaving comparing the two years of 1990 and 2015. Using the additive decomposition of LMDI we did not take into consideration the years in between but rather wanted to see how 1990 and 2015 have been reacting to the various external factors that could alter the activity, technological, energy, CO_2 emissions, factors for these two years.

Figure 11. Additive decomposition of China's CO_2 emissions from 1990 to 2015



Source: IEA. (2018).

As in previous figures such as figure 7, 8, 9 and 10, shows that industry sector remains as the most concentrated area for China's CO_2 emissions. Figure 11 confirms that industry and its activity output remain at high levels in China. The levels in agriculture remain relatively low and is declining to make an impact, transportation has also seen a decline, although there is an influence from transportations activity output also contributing to CO_2 emissions. The intensity in households, could be explained by our previous reason that RE sources have been effective in households.

However, and interesting conclusion is that intensity has seen an overall reduction. As explained in Figure 8, this can be an indicator that there has been considerable amount of reductions due to initiatives and even RE.

As per the study of Wang (2009) it was stated in a previous section that it is not feasible solution for China to cut energy consumption due to the cost for continuous growth. Although as previously discussed that China's oversupply of coal has been decreasing this could mean these results are at the beginning of China's decline in energy consumption. Given the 'new normal' expectations, the decreasing results in structural change and emissions as displayed in Figure 11.

As previously discussed in section 1.1 with the purpose of this study to be able to provide an assessment on China's current stand point along the EKC and whether or not it fits into one of the three divided parts, pre-industrial economies, industrial economies, post-industrial economics (service economy). After having completed this study and analysis we would asses China according to Figure 5, that China remains an industrial economy but experiencing a turning point in the overall structure of their economy and nonetheless their stance on policies.

7. CONCLUSION

By adopting the LMDI approach, this paper attempts to make an assessment on the driving factors of China's CO_2 emissions from 1990 – 2015. Although the approach might have been ambitious, the effort was trying to understand where China currently lies on their situation on whether or not they been benefitting from their policies and other initiatives or whether or not it has not been fully implemented and needing more time to see results.

This paper discussed the background of China's rapid economic movements and the success from key sectors which saw the transformation from rural, agricultural to an industrious economy through their levels of GDP. We then explained China's policies and government initiatives and mostly their Five-Year Plans. We briefly outlined the success and expectations from each FYP. Furthermore, we discussed the importance of RE sources and the challenges China faces in order to fully incorporate these sources. Of course, there are plenty of challenges that remain undiscussed of RE in China however, the importance was to briefly examine whether or not there was any impact of these sources to recent data results for their CO_2 emissions and to understand the potential of RE sources based on other studies.

Furthermore, the paper attempted to also explain the forecasted scenarios up to 2030 and what other research has forecasted for China and if any would expect a decrease in CO_2 emissions, however, many expressed concerns that China's CO_2 emissions would continue to rise to extreme levels. On the other hand, the 13th FYP took into consideration China's 'new normal' rates and even provided a forecast of their emissions with an expectation of decreasing levels or even advanced decreasing results. The study also explained the type of data and methodology that was used and why LMDI was chosen for this thesis.

Our results concluded that China's 2015 results are significantly higher than 1990. It is rather difficult to place China on any sort of path, with several studies indicating massive improvements in energy consumption and energy demand reduction in the prospects of achieving a decrease in emissions, to other studies suggesting that they will continue increasing CO_2 emissions and far exceeding levels than any other economy beforehand. However, we have chosen to state that China is still an industrial economy and continuing to face an uprise trend that may or may not have been the climax of their environmental degradation according to the EKC.

The recommendation would be for China to continue improving industrial energy efficiency and investing in the green industry, as it may continue to be profitable, even when compared to optimistic returns on financial investments (UNIDO, 2011). Energy efficiency has the potential to attract several other types of projects across all sectors and investment types. Thus, contributing to economic growth and sustainability (green growth).

For further study, it would be advisable to take into explicit consideration of RE and provide calculations in order to understand if how much, or at all these sources have contributed to China's energy efficiency overall development. It would also be advisable to use a time series analysis in order to capture the trend in recent years and make a comparison of years that China would have liked to see a decrease in trends.

References

Apergis, N. Danuletiu, D (2014). Renewable Energy and Economic Growth: Evidence from the Sign of Panel Long-Run Causality. *International Journal of Energy Economics and Policy*. 4 (4), pp.578-587.

Aglietta, M. and Bai, G., (2016) *China's 13th five-year plan. In pursuit of a "moderately prosperous society"* (No. 2016-12). CEPII research center.

Cepal, N., (2016) Horizons 2030: Equality at the centre of sustainable development.

Chai, Q. and Zhang, X., 2010. Technologies and policies for the transition to a sustainable energy system in China. *Energy*, *35*(10), pp.3995-4002.

Cui, H., 2016. China's Economic Growth and Energy Consumption. *International Journal of Energy Economics and Policy*, *6*(2).

Dai, H., Xie, X., Xie, Y., Liu, J. and Masui, T., 2016. Green growth: the economic impacts of large-scale renewable energy development in China. *Applied Energy*, *162*, pp.435-449.

Guan, D., Hubacek, K., Weber, C.L., Peters, G.P. and Reiner, D.M (2008) The drivers of Chinese CO2 emissions from 1980 to 2030. Global Environmental Change, 18 (4). pp. 626-634.

Grubb, et al., (2015) A review of Chinese CO2 emission projections to 2030: the role of economic structure and policy. *Climate Policy*, *15*(sup1), pp.S7-S39.

Henriques, S.T. and Borowiecki, K.J., 2017. The drivers of long-run CO2 emissions in Europe, North America and Japan since 1800. *Energy Policy*, *101*, pp.537-549.

IEA. (2018). *World Energy Balances.* Available: http://data.iea.org//payment/products/117-world-energy-balances-2018-edition-.aspx. Last accessed 14th August 2018.

Islam, S.N. and Iversen, K., (2018). *From "Structural Change" to "Transformative Change": Rationale and Implications* (No. 155).

Jiang, K. and Hu, X., 2006. Energy demand and emissions in 2030 in China: scenarios and policy options. *Environmental economics and policy studies*, *7*(3), pp.233-250.

Jalil, A. and Mahmud, S.F., 2009. Environment Kuznets curve for CO2 emissions: a cointegration analysis for China. *Energy policy*, *37*(12), pp.5167-5172.

Jalil, A. & Mahmud, S.F., (2009) Environment Kuznets curve for CO2 emissions: a cointegration analysis for China. *Energy policy*, *37*(12), pp.5167-5172.

Lund, H. (2005). Renewable energy strategies for sustainable development. In 3rd Dubrovnik conference on sustainable development of energy, water and environment systems: Dubrovnik, Croatia, June 2005. Faculty of Mechanical Engineering and Naval Architecture.
General

Liu, W., Lund, H., Mathiesen, B. V., & Zhang, X. (2011). Potential of renewable energy systems in China. *Applied Energy*, *88*(2), 518-525.

Lo, K., 2014. A critical review of China's rapidly developing renewable energy and energy efficiency policies. *Renewable and Sustainable Energy Reviews*, *29*, pp.508-516.

Mohlin, K., Camuzeaux, J.R., Muller, A., Schneider, M. and Wagner, G., 2018. Factoring in the forgotten role of renewables in CO 2 emission trends using decomposition analysis. *Energy Policy*, *116*, pp.290-296.

Ming, Z., Ximei, L., Na, L. and Song, X., 2013. Overall review of renewable energy tariff policy in China: evolution, implementation, problems and countermeasures. *Renewable and Sustainable Energy Reviews*, *25*, pp.260-271.

Ocal O, Aslan A (2013) Renewable energy consumption–economic growth nexus in Turkey. Renew Sustain Energy Rev,28, p.494–9

OECD. (2011). Towards Green Growth: Monitoring Progress OECD Indicators. *OECD*. p.1-144.

OECD (2018) Green growth in action China: Available at :http://www.oecd.org/china/greengrowthinactionchina.htm. Last accessed 17th Jan 2018.

Panayotou, T. (2003). ‘Economic growth and the environment’. Harvard University: International Institute of Management.
DOI: http://www.unece.org/fileadmin/DAM/ead/sem/sem2003/papers/panayotou.pdf

Qi, T., Weng, Y., Zhang, X. and He, J., 2016. An analysis of the driving factors of energy-related CO2 emission reduction in China from 2005 to 2013. *Energy Economics*, *60*, pp.15-22.

Qi, T., Weng, Y., Zhang, X. and He, J., 2016. An analysis of the driving factors of energy-related CO2 emission reduction in China from 2005 to 2013. *Energy Economics*, *60*, pp.15-22.

Shan, Y. Guan, D. Zheng, H. Ou, H. Li, Y. Meng, J. Mi, Z. Liu, Z. & Zhang, Q. (2018). China CO2 emission accounts 1997–2015. *Scientific Data*. p1-14.

UNIDO. (2011). Industrial Development Report 2011. No.442. DOI: https://www.unido.org/fileadmin/user_media_upgrade/Resources/Publications/EBOOK_IDR2016_FULLREPORT.pdf. p.33 (Last accessed on 13 August 2018).

UN Statistics. (2015). Value Added by Economic Activity. http://unstats.un.org/unsd/snaama/resCountry.asp (Last accessed on 13 April 2018)

Wang, F et al (2010) China’s renewable energy policy: Commitments and challenges. *Energy Policy*. 38, p.1872–1878.

Wang, Y., Gu, A. and Zhang, A., (2011) Recent development of energy supply and demand in China, and energy sector prospects through 2030. *Energy Policy*, *39*(11), pp.6745-6759

Wang, C., Chen, J. and Zou, J., 2005. Decomposition of energy-related CO2 emission in China: 1957–2000. *Energy*, *30*(1), pp.73-83.

World Bank and the Development Research Center of the State Council, PR China (DRC), 2013. China 2030: Building a modern, harmonious, and creative society.

Xu, S.C., He, Z.X. and Long, R.Y., 2014. Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI. *Applied Energy*, *127*, pp.182-193.

Xu, J.H., Fan, Y. and Yu, S.M., 2014. Energy conservation and CO2 emission reduction in China's 11th Five-Year Plan: A performance evaluation. *Energy Economics*, *46*, pp.348-359.

Zhang, N., Lior, N. and Jin, H., (2011) The energy situation and its sustainable development strategy in China. *Energy*, *36*(6), pp.3639-3649.

Zhang, W., Li, K., Zhou, D., Zhang, W. and Gao, H., 2016. Decomposition of intensity of energy-related CO2 emission in Chinese provinces using the LMDI method. *Energy Policy*, *92*, pp.369-381.

Zhang, Z., 2003. Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. *Energy economics*, *25*(6), pp.625-638.