# THE IMPERATIVE TO IMPROVE ENERGY EFFICIENCY IN A WARMING WORLD
## The case of India and China

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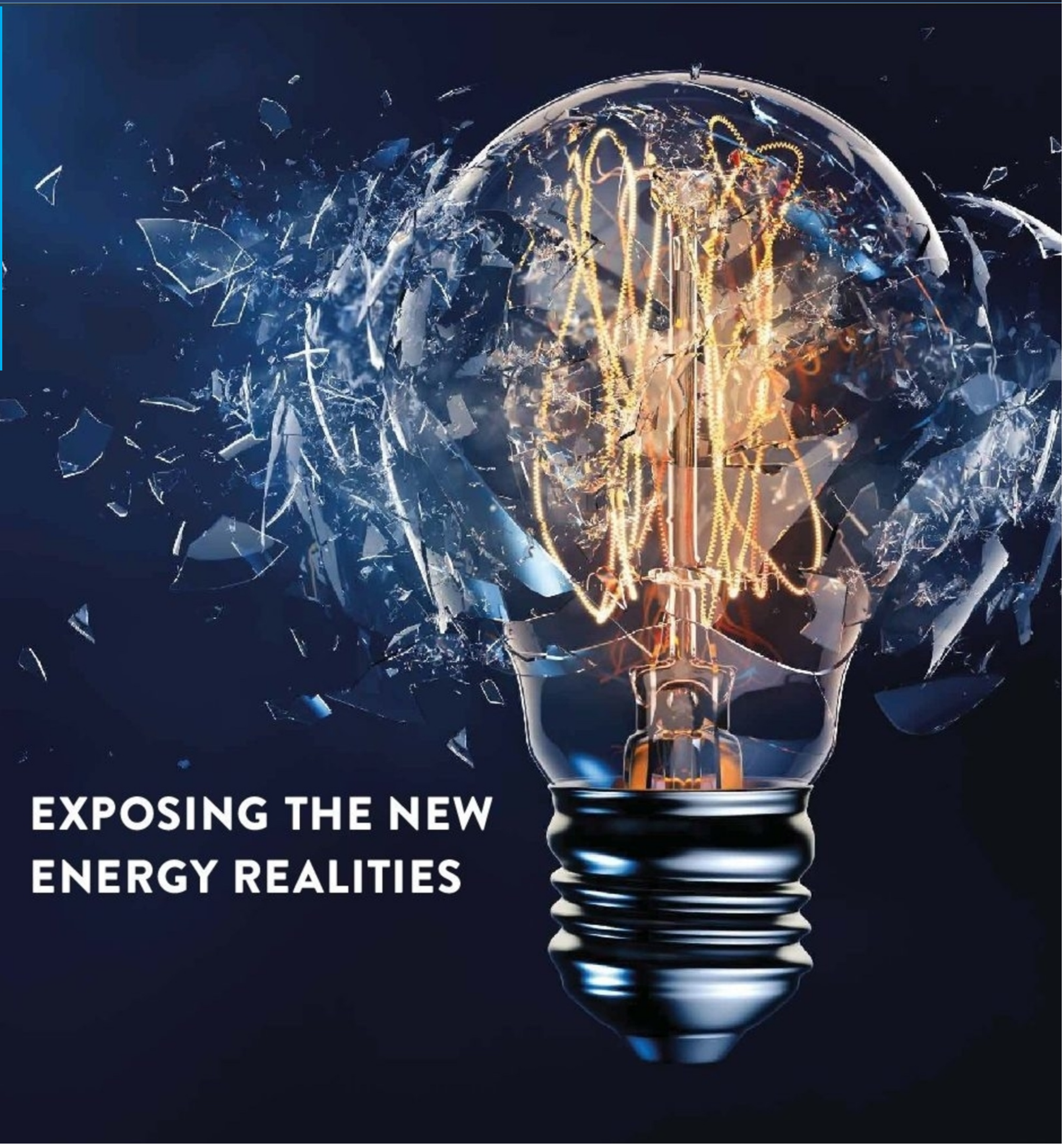


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# The imperative to energy efficiency in a warming world

## The case of India and China

By

Prateek Gupta

in partial fulfilment of the requirements for the degree of

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|---|---|---|
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# Executive Summary

Over the course of the past centuries, humanity's influence on the Earth's atmosphere and climate system has become so significant as to induce geophysical feedback effects, specifically in the form of a self-reinforcing process of global warming. In order to contain the global warming and prevent the expected impacts of climate change from happening, it has become imperative to undertake drastic steps directed towards reducing emissions of greenhouse gases (including CO2). Action needs to be taken soon, as with the growing population, the demand for carbon-intensive (conventional) energy sources is growing and thus greenhouse gas emissions (the main cause for global warming) are increasing. To slow down global warming, energy conservation, energy efficiency improvement and renewable energy generation are the only practical solutions available to mankind.

This research is an attempt to understand the mechanics behind the growing energy consumption in the two most populous and fastest growing economies, India and China. This has been achieved by means of detailed data analysis of World Input-Output Database (2013 release). The database offers insights in the productive structure of 40 major economies and rest of the world during the period 1995-2009. It also provides their interrelatedness in production and demand structure and energy use. The analysis has been performed by adopting Structural Decomposition Analysis (SDA) method on the inter-country Input-Output tables and a harmonized set of environmental accounts. By empirically analyzing the historical evolution of changes in energy consumption in India and China, this thesis furthermore aims at providing new line of thought to, Indian and Chinese, policy makers in their search for solutions to drive energy consumption down and up the share of renewable energy in energy mix.

SDA as a technique is efficient in quantifying the fundamental "sources" of change (in this case final demand, technology and energy intensity) in a range of variables (in this case energy use). SDA decomposes the energy use change into final demand change, technology change and energy intensity change. Final demand change is the part of energy use change that results from a change in final demand. Technology change quantifies the energy use change that occurs as a result of changes in inter-industry dependencies. And the energy intensity change is the part of energy use change that is experienced because of the change in energy use to gross output ratio.

The findings of this research bring out that India and China are not only economically developing but are also undergoing significant structural changes during our period of analysis. Indian economic growth was driven relatively strongly by its services sectors (a phenomenon called "services-led growth"), whereas China's economic development was based firmly on (export-led) industrialization (or "manufacturing-led growth"). The differences in the nature of their development strategies show up in the evolution of their energy consumption during 1995-2009: China, the factory of the world, an energy-intensive manufacturing hub experienced a continuous high growth in energy consumption while India, a services (less energy intensive)-led economy experienced comparatively low rate of energy consumption growth.

Both the countries have recognized, the importance of energy conservation and renewable energy development, in improving energy security and controlling global warming. Policies have been formulated and steps taken, to control the energy consumption and carbon emission growth by focusing on reducing energy intensity and introducing more renewable energy into energy mix, by both the economies. The results of our input-output analysis reveal that China has been more successful in the past with its policies in reducing the energy intensity of its production and increasing the renewable energy share, as compared to India. China, even during the time when its manufacturing-led economic growth was highest, managed to reduce energy intensity and to follow the same trend through the years of the global financial crisis as well. However, India experienced a falling energy intensity trend only post 2002 until the years of global financial crisis of 2008. The energy consumption growth, in both the economies, was a result of growing final demand of goods and services. The technology effect, which hides the effects of structural changes, had a positive contribution to energy consumption in China (an energy intensive manufacturing-led economy) and a comparatively small (sometimes negative) positive contribution to energy consumption in India (a less energy intensive services-led economy).

This research also finds that China was more successful in implementing renewable energy generation at a larger scale than India. China was able to maintain an increasing growth rate of renewable energy consumption. An analysis of the energy consumption growth in the top four main energy consuming sectors and the agriculture sector of both the economies was also performed as part of the research. The analysis reveals that neither in China nor India energy conservation efforts did offset the growth of energy consumption due to growing final demand.

Finally, an effort has been made to provide the policy makers with extra information, in the form of results of the analysis, to construct new and more effective policies to tackle the growing energy consumption problem. The writer, also provides his ideas for policy discussion based on the studied policies, implemented during and/or before 1995-2009 for energy conservation and for promoting renewable energy generation in the two economies, and results of the analysis.

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# List of Acronyms

| | |
|---|---|
| AHFF | Agriculture, Hunting, Forestry and Fishing |
| BMFM | Basic Metals and Fabricated Metal sector |
| CASE | Commission for Additional Sources of Energy |
| CEA | Central Electricity Authority |
| CERC | Central Electricity Regulatory Commission |
| CPC | Communist Party of China |
| CPN | Coke, Refined Petroleum and Nuclear Fuel sector |
| DST | Department of Science and Technology |
| EGWS | Electricity, Gas and Water Supply sector |
| EU | European Union |
| FBT | Food, Beverages and Tobacco |
| FIT | Feed-in tariff |
| GDP | Gross Domestic Product |
| IDA | Index Decomposition Analysis |
| IEA | International Energy Agency |
| LMDI | Logarithmic Mean Divisia Index |
| MNRES | Ministry of New and Renewable Energy Sources |
| NDRC | National Development and Reform Commission |
| NLC | New Leadership Committee |
| OPEC | Organization of Petroleum Exporting Countries |
| PPP | Purchasing Power Parity |
| PV | Photovoltaic |
| RPS/RPO | Renewable Portfolio Standards/Obligations |
| SDA | Structural Decomposition Analysis |
| SERC | State Electricity Regulatory Commission |
| SUT | Supply and Use Table |
| WIOD | World Input-Output Database |
| WIOT | World Input-Output Tables |
| WTO | World Trade Organization |

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# Acknowledgements

This thesis became a reality with the kind support, help and blessings of many individuals. I am extremely grateful to all of them and cannot thank them enough.

First and foremost, I would like to express my sincere gratitude to my supervisor Dr. S.T.H. (Servaas) Storm for his continuous support during my master's thesis research work. I cannot imagine having a better supervisor and mentor. He has constantly motivated me to work harder but at the same time supporting me when I seemed to get disappointed. I cannot thank him enough for his patience, motivation, enthusiasm, and immense knowledge. His constant guidance has helped me find my way through this research work and in writing of this thesis.

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Besides my advisors, I would also like to thank the rest of my thesis committee: Prof.dr. C.P. (Cees) van Beers and Dr. S. (Scott) Cunningham for their insightful comments and hard questions.

I would also like to acknowledge friends and family for their constant love and support throughout all these years.

I would be amiss if I did not specifically mention my grandfather Dr. B. (Bhagwati) Prasad who, since my early childhood instilled in me a desire to pursue knowledge. His life and the way he led it has been a beacon of inspiration to not only me but everybody whose life he touched. Even though he left for his heavenly abode during the course of my research work, but it is due to his blessings that I have been able to complete my work.

(Prateek Gupta)

# 1 Introduction

*The more you know about the past, the better prepared you are for the future.*
*-Theodore Roosevelt*

## 1.1 Background of the research project: The need to improve energy efficiency in a warming world

Energy is the pre-requisite to economic development. The prosperity which results from economic development is, in turn, reinvested to stimulate demand for more and better quality of services. These modern day services require more and more energy. Energy is required to provide for the basic human needs, such as food and shelter. Social developments, such as education and public health care developments, require energy. Thus, humans are heavily dependent on energy, in the form of electricity, heat or chemical energy, for their existence and development. Many developed countries have tried to establish a virtuous cycle of energy infrastructure improvements and economic development. But the increased exploitation and use, by developed and developing countries, of energy resources to power their economic development has led us today to the world of pollution and global warming (IEA 2004).

Today, humanity is facing an existential crisis. Energy is required for existence and development, while energy production is the major source of green-house gas emissions and thus global warming. It is the need of the hour, to have sustainable low- or zero-carbon energy production which provides humanity with growing energy production without emissions. As of today's scenario it is required that between 2045 and 2060 production achieves net zero green-house gas emissions to keep the global average temperature rise to below 2℃ (ETC, 2016).

In today's world scenario, the fossil fuels (i.e. Petroleum, Coal, Natural Gas etc.) supply more than 85 percent of World's total energy need ("Fossile Energie", 2017). Renewables only supply 10 percent of the energy needs. The energy produced from fossil fuels not only generate vast amount of green-house gases, but are also majorly controlled by developed economies. The access to fossil fuel based energy sources by developing countries is not only expensive but also restricted, because of its limited availability.

Thus, to tackle both the growing energy need, in times of energy crisis, and the green-house gases emissions, the only two-part solution available is: reduction of energy production from carbon emitting energy sources by increasing the share of renewables and moderating energy consumption growth by increasing energy productivity (i.e. economic output generated per unit of energy consumption) (ETC, 2016).

Against the above background, it is important to analyze the current situation and the historic energy consumption change, and the reasons behind the same. The two most populous developing countries, India and China, were chosen for the energy consumption change analysis, since they observed the large energy consumption changes and are heavily dependent on energy for their development.

## 1.2 India and China: General Background

### 1.2.1 India

India, officially known as Republic of India is the most populous democratic country with population over 1.2 billion. India is the seventh largest country by area and stands at second number, just after China, in terms of population. The Indian Peninsula is surrounded by Himalayas in the north, Bay of Bengal in the east, Arabian Sea in the west and Indian Ocean in the south.

India was once inhabited by one of the world's earliest civilization, Indus Valley Civilization, in 3rd millennium BCE. India has seen several dynastic rules. India was colonized by British crown in mid-19th Century. India attained its independence from British rule on 15th August 1947, to be established as a sovereign democratic state.

India is a federation with a parliamentary system, governed under Constitution of India, which is regarded as country's supreme legal document. India is a constitutional republic and representative democracy. The current democratically elected government is led by Narendra Damodardas Modi, current Prime Minister of India. The Head of State and Commander-in-chief of Armed Forces, The President of India, is currently Ram Nath Kovind.

#### 1.2.1.1 India's General Economic Background

India is one of the world's fastest growing economies with an average annual growth rate of 5.8 percent over past two decades. Indian economy was ranked seventh largest by nominal GDP, sixth largest by market exchange rates, and third largest by purchasing power parity GDP in the year 2015. However, India ranks 140th and 129th in the world, in nominal GDP per capita and GDP per capita at Purchasing Power Parity respectively ("India", 2017).

The Indian economy was governed by more protectionist policies influenced by socialist ideology until 1991. The economic reforms of 1991 are regarded as a major step towards the new India. These reforms liberalized the economy and

India slowly moved towards a free-market economy. The reforms were a desperate measure to an acute balance of payment crisis in 1991 ("India", 2017).

### 1.2.2 China

China is officially known as People's Republic of China. China is a unitary sovereign state with a population of over 1.4 billion people, making it the world's most populous country. It is world's second largest country in terms of land area. Chinese civilization is considered to be one of the world's earliest civilizations. China has been ruled by several dynasties until 1912, when the Republic of China dethroned the last dynasty and ruled the Chinese mainland till 1949. Republic of China was defeated by Peoples Liberation Army in the Chinese civil war. Finally, in 1949, the communist party formed the Peoples Republic of China, the China we know of today ("China", 2017).

China's constitution states that The Peoples Republic of China is a socialist state under people's democratic dictatorship. China's constitution declares that the country is ruled under the leadership of Communist Party of China (CPC). China's incumbent president is Xi Jinping and incumbent premier is Li Keqiang. Steps have been taken toward political liberalization with open contested elections being held in villages and towns, however CPC retains effective control over government appointments.

#### 1.2.2.1 China's General Economic Background

By 2014 China was the world's second largest economy in nominal GDP terms, while largest in Purchasing Power Parity GDP. However, similar to India, China also ranks quite low, after almost 80 other countries, in nominal GDP per capita and per capita Purchasing Power Parity GDP ("China", 2017).

Until 1978, China was a Soviet styled centrally planned economy. Following Mao's death, the new leadership began to reform the economy into market oriented mixed economy under one party rule. Modern day China, characterized by private property ownership based market economy, is a great example of state capitalism.

Since economic liberalization of 1978, China has been among the world's fastest growing economies relying heavily on investment and export-led growth. China's average annual GDP growth in the past decade was 10.5 percent. China is WTO's member and the largest trading power ("China", 2017). China has been ranked third in the world in attracting the largest foreign direct investment (Jingli, 2017).

## 1.3 Energy Consumption and Carbon Emissions in India and China

Figure 1 shows the historic development of energy consumption of India and China. It is evident from the graph that India and, especially China observed a growth in energy consumption. During late 20th Century and early 21st Century, China witnessed a sudden increase in growth of energy consumption.

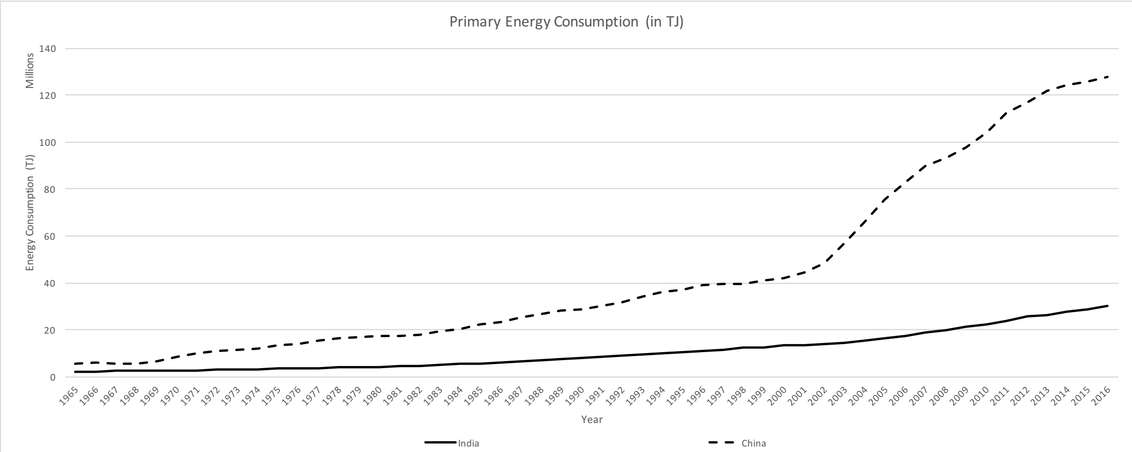



*Figure 1: Total primary energy consumption (in TJ) by India and China (Source: BP Global, 2017).*

The rising demand for energy in China has turned it from net energy exporter to net energy importer. China's energy production was higher than the energy consumption in 1990s, but since 2000 consumption has surpassed production by 23% in 2016. India had been a net energy importer even during 1990s, but the percentage of extra consumption to production increased from 14.8% in 1995 to 50.18% in 2016 (Enerdata, 2017). Growing reliance on global market for their energy supply raises economic concerns and political tensions for energy security of both the economies (Ma et al., 2009).

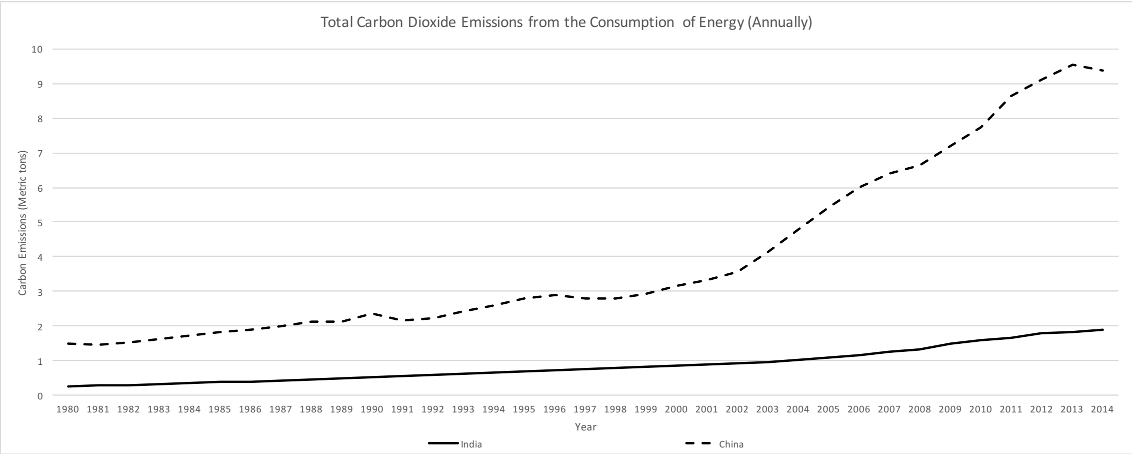
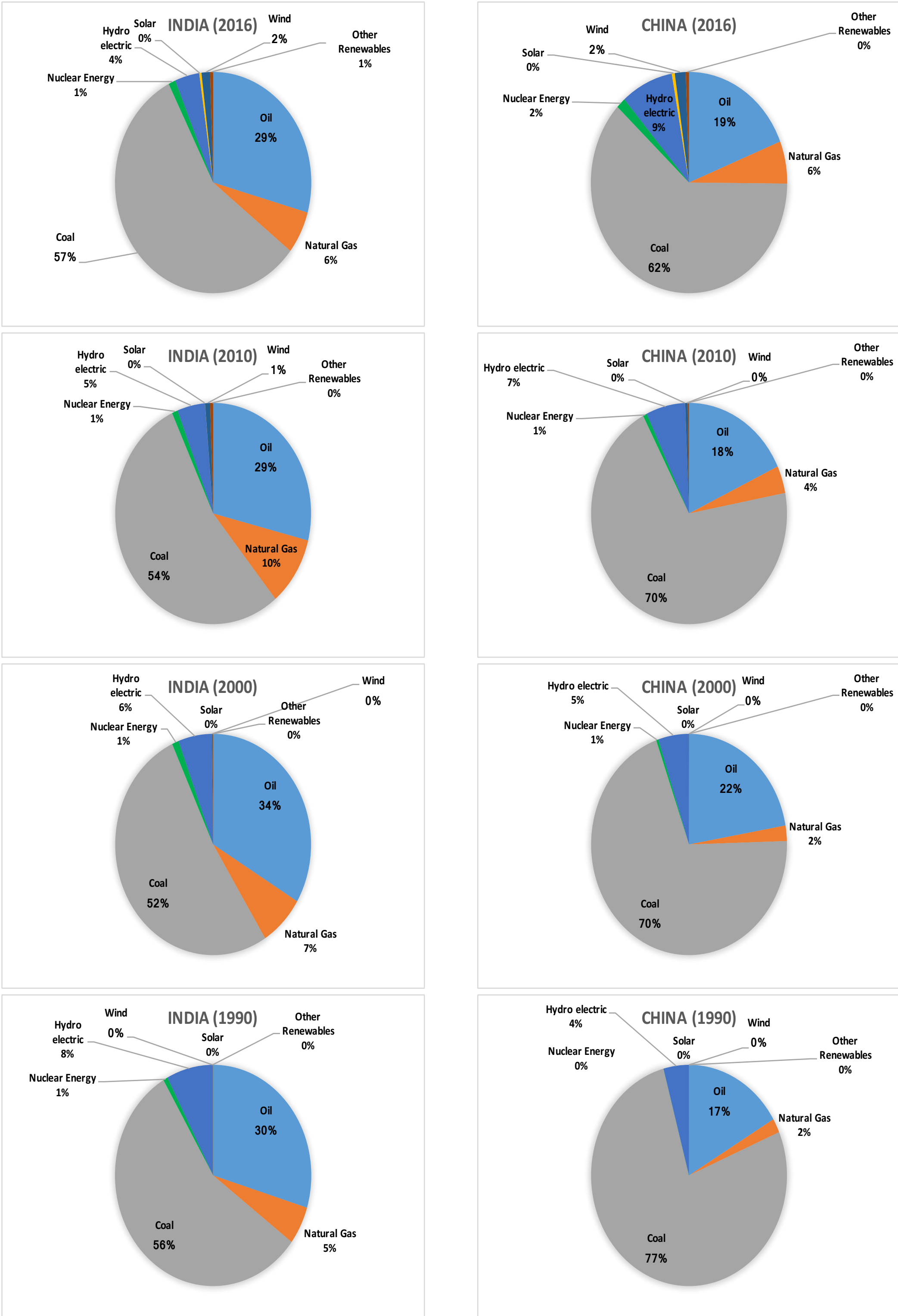



*Figure 2: Total Carbon-dioxide emissions from energy consumption by India and China (Source: EIA, 2017).*

Figure 2 shows the carbon-dioxide emissions as a result of energy consumption of India and China. In 2014, China was the largest and India fourth largest carbon-dioxide emitter. Referring to the need of the hour to contain the global warming by reducing carbon-dioxide emissions, it becomes the responsibility of the large carbon-dioxide emitters to take measures to reduce emissions. 1995 to 2009 played a critical role as it not only witnessed a sudden increase in growth of energy consumption by the two developing economies, but also an increased growth of green-house gases emissions.

As discussed before, the main source of emissions is energy production from fossil fuels. It is easy to figure out, from Figure 3, that both India and China were and still are heavily dependent on fossil fuels for their energy needs. Development of renewables such as, hydro-power, solar-power, wind-power etc., as energy source has been very limited in both the countries. Both the economies are heavily dependent on coal as the source of energy.

In 2014, the energy consumption per capita in India and China was 26.6878 GJ and 93.6474 GJ, respectively (World Bank, 2017). If India and China were to follow the footsteps of USA to achieve the economic development, this would mean a similar level of energy consumption per capita. The energy consumption per capita of USA in 2014 was 276.1954 GJ (World Bank, 2017). Maintaining the same energy mix as now in India and China (Figure 3) and using the carbon-dioxide generation per GJ of energy generation from the specific fuel (Quaschning, 2015), the resultant carbon-dioxide emissions per capita per year would be 22.022 tCO2 and 21.191 tCO2, respectively. Considering the population of the two countries to be constant i.e. 1.324 billion in India and 1.379 billion in China (World Bank, 2017), the total carbon emissions will be 29.157million ktCO2 per year and 29.222million ktCO2 per year, respectively. This is almost 26.340million ktCO2 per year more than India's and 19.314million ktCO2 per year more than China's, current emissions. To provide a level of comparison, the carbon emissions of the whole world in 2014 was 36.138million ktCO2, which is already high and is of great concern due to increasing global warming. If India and China are to follow the development path of USA, it would result in an inhabitable world. Thus, it becomes even more necessary to take steps right now, so that India and China move towards economic development, but in a sustainable way.




Fuel composition of Total Energy Consumption

**Other Renewables include Geothermal, Biomass and other renewables.*

*Figure 3: Fuel composition of Total Energy Consumption in India and China, for 2016, 2010, 2000 and 1990 (Source: BP Global, 2017).*

## 1.4 Research Motivation and Research Questions

It is clear from Figure 1 and Figure 2 that both India and China witnessed energy consumption growth, and carbon-dioxide emissions growth (which is a direct consequence of their energy consumption growth). From Figure 3 it becomes clear that carbon-dioxide emissions grew because the two economies were and still are deeply dependent on fossil fuels (coal, oil and natural gas) to supply for their energy needs. It is also well known that renewables not only supply emission free energy but form a good energy mix making the country, energy independent.

In view of the current scenario, it has become imperative to analyze historical developments to determine the effects of different factors on energy consumption change and conceive a strategy to deal with energy crisis and global warming. Also, since the renewables have not seen a remarkable growth during the past decades, it is also important to identify the factors which are responsible for renewable energy consumption growth and how they can be augmented.

In conclusion, the motivation of this research is to identify the underlying causes for the increase in energy consumption growth, resulting in global warming, and to suggest policy instruments to mitigate the same, without debilitating the economic growth We will specifically focus on the changes in energy intensity (or energy efficiency) both at the aggregate level and at the level of industries, because this is a variable which could be influenced by policy.

### 1.4.1 Research Questions

**Main Question 1:** What were the main factors which led to energy consumption growth in India and China between 1995 and 2009?

> **Sub-Question 1.1:** What were the policies implemented before and/or during the chosen time-period which affected energy efficiency and renewable energy developments in both the countries?
>
> **Sub-Question 1.2:** To what extent can we observe differences in energy consumption growth and energy intensity growth in the two countries and if we find differences, what were the reasons behind these?

The answers to the above formulated questions should provide an understanding on the evolution of the internal dynamics of energy consumption growth in the two countries. The chosen time-period, 1995 to 2009, played a crucial role in the change of energy consumption growth of India and especially China, as during that time China experienced high (manufacturing-led) growth and a sudden increase in the energy consumption growth.

The results of the analysis and study of policies will make it possible to correlate the effects of policies on each factor responsible for energy consumption change. Also, the two economies can be compared based on the energy consumption change and energy intensity change developments.

**Main Question 2:** What were the main factors which affected the growth of renewable energy in India and China between 1995 and 2009?

> **Sub-Question 2.1:** Which were the major renewable energy technologies which contributed to renewable energy consumption change in the two countries?
>
> **Sub-Question 2.2:** What were the underlying reasons for the change in the energy consumption of the determined renewable energy technologies in both the countries?

Based on the results obtained, it would be possible to get a good understanding of the situation of renewables in both the countries. Also, the analysis will allow us to identify key factors which could be strengthened to support and increase the composition of renewables in the energy mix.

**Main Question 3:** What were the main factors which affected the change in energy consumption of the top energy consuming sectors of India and China between 1995 and 2009?

> **Sub-Question 3.1:** What were the common sectors, of India and China, which saw the maximum energy consumption change between 1995 and 2009?
>
> **Sub-Question 3.2:** What were the main factors which affected each of the determined sectors and in what way?

The answers to the above questions would provide with the understanding of the top energy consuming sectors and the main factors behind the same. It also provides us with insights in the input-output structure of the economies and the interdependency between key sectors.

In conclusion, answering the above questions will provide a better understanding of energy consumption needs of both the fast growing economies, and of energy intensity changes (and their drivers), helping policy makers to analyze the effects of energy support policies and devise new and better policies.

## 1.5 Introduction to all the chapters

This section will provide a brief outline of the thesis chapters.

**Chapter 2: Economic Development, Energy Use and Energy Intensity in China and India: A Literature Review** – This chapter is the literature survey (summarizing findings) of the reports and previously performed studies on energy use and energy intensity change in India and China, for the time period 1995 to 2009.

**Chapter 3: Renewable Energy Policies and Current Scenario in India and China** – This chapter discusses the energy efficiency and renewable energy policies of both the countries during the chosen time period. Further, a discussion of the renewable energy developments and the status of different renewable energy technologies in the two countries are presented.

**Chapter 4: Methodology** – This chapter explains in detail the input-output analysis and the structural decomposition analysis which are applied to perform the analysis.

**Chapter 5: World Input-Output Database** – This chapter discusses the database utilized to perform this research. The reader can find a comparison of the technology change that took place in the two economies between 1995 and 2009.

**Chapter 6: Energy Consumption Change: A Decomposition Analysis for China and India (1995-2009)** – In this chapter, the reader finds the results of the analysis. An effort has been made to connect the implemented policies and certain important events with the established results by visualizing the changes in the graphs.

**Chapter 7: Conclusions, Reflections and Policy Recommendations** – This chapter discusses the main findings of the research, with efforts to put forward some policy recommendations on the basis of the found results. We also reflect on what was learned during the research project and on its strengths and limitations. Finally, recommendations for future work according to the writer can also be found in this chapter.

# 2 Economic Development, Energy Use and Energy Intensity in China and India: A Literature Review

India and China are the two most populous developing economies of the World. The two countries have experienced high growth along a structural transformation of their economies in the past decades. The share of China in global GDP grew from 2 percent in 1980, to almost 15 percent in 2016. India's share in global GDP also grew but at a relatively low rate from around 2 percent of global GDP in 1980 to almost 3.5 percent in 2016. In comparison to these two economies most of the developed economies saw a decline in their share of the global GDP, which is quite visible from the Figure 4.

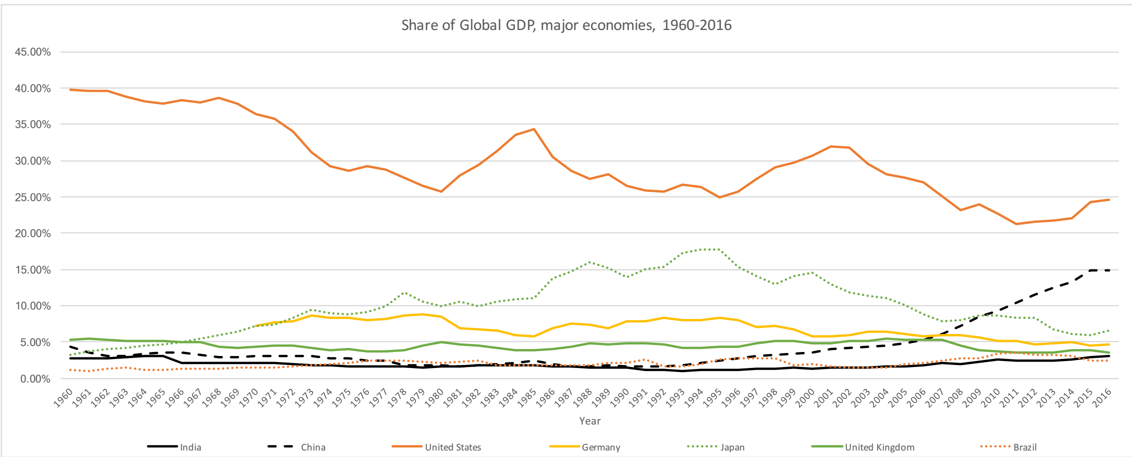



*Figure 4:Share (in percentage) of global GDP (Source: World Development Indicators, GDP (current US$), World Bank, 2017)*

The two economies show an upward trend in the real GDP as well as share of global GDP, from which a conclusion that the two economies have a higher GDP growth rate than the world average growth rate can be made. Also, a major observation that can be made from Figure 4 & Figure 5 is that the two countries starting from 1960 followed almost the same pattern of growth for almost three decades, till early 1990s. But, from early 1990s a divergence is visible and by early 2000s, China started experiencing a fast paced growth. China overtook many developed economies such as Japan, Germany etc. to become the second largest economy in 2016.

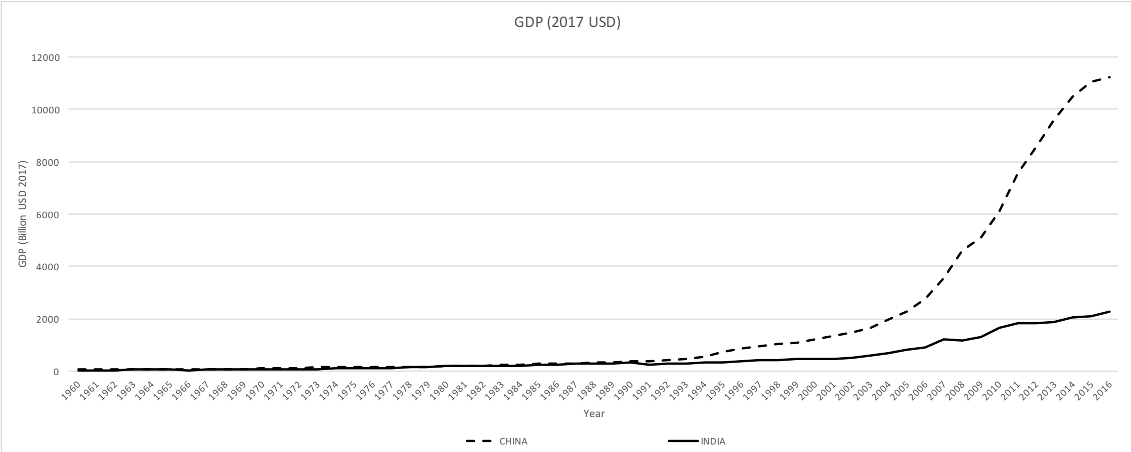



*Figure 5:GDP of INDIA and CHINA from 1960 to 2017 (in 2017 USD) (Source: World Development Indicators, GDP (current US$), World Bank 2017)*

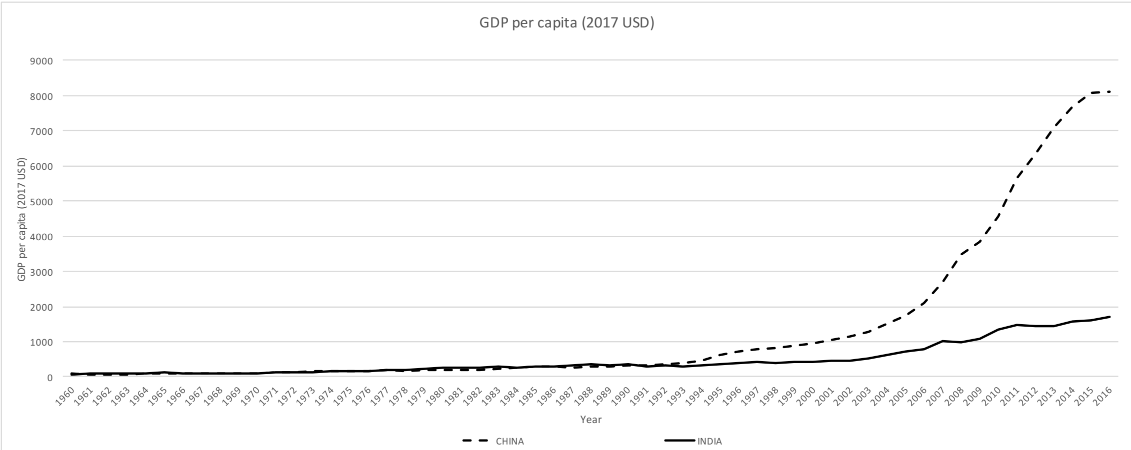



*Figure 6:GDP per capita of INDIA and CHINA from 1960 to 2017 (in 2017 USD) (Source: World Development Indicators, GDP per capita (current US$), World Bank 2017)*

A better comparison of the two economies can be made by comparing the GDP per capita over the years, which is shown in Figure 6. GDP per capita is the gross domestic product of a country, or value added of all final goods and services produced in a country in a given year, divided by the average (mid-year) population of that country for the same year. Figure 6 makes it clear that a vast difference between the two economies has been created in the preceding two decades. A detailed explanation of the two economies and their growth paths can be found in the later part of this chapter.

Looking deeper into the major sectors of the two economies (namely Agriculture, Industry, Services) and into their integration into the world economy (through Exports and Imports), it becomes clear that each followed a different path for development.

Comparing India and China (Table 1) it can be seen that both the economies transitioned from agriculture to industry or services. Data shows that the economic development of China relied more strongly on industrialization (as the shares in GDP of industry and manufacturing remained relatively high), while Indian development after 1980 became more dependent on the growth of the services sector. While a further explanation can be found in the later part of the chapter, it is important to note that the two economies developed differently and their respective policies played a major role in the different trajectories of growth.

*Table 1: Share (in percentage) of Sectors in China's and India's GDP in the respective years (Source: World Bank 2017).*

| Sectors | Country | 1980 | 1990 | 2000 | 2010 | 2016 |
|---|---|---|---|---|---|---|
| Agriculture | China | 29.7% | 26.6% | 14.7% | 9.5% | 8.6% |
| | India | 36.7% | 30.1% | 23.9% | 18.9% | 17.4% |
| Industry | China | 48.1% | 41% | 45.5% | 46.4% | 39.8% |
| | India | 29% | 31.6% | 31% | 32.4% | 28.8% |
| Services | China | 22.3% | 32.4% | 39.8% | 44.1% | 51.6% |
| | India | 34.3% | 38.3% | 45.1% | 48.7% | 53.8% |
| Manufacturing | China | 39.9% | 32.3% | 31.8% | 31.5% | - |
| | India | 19.1% | 19.1% | 18.1% | 17.5% | 16.5% |
| Exports of goods and services | China | 5.9% | 14% | 21.2% | 26.3% | 19.6% |
| | India | 6.2% | 7.1% | 13.1% | 22.6% | 19.2% |
| Imports of goods and services | China | 6.5% | 10.7% | 18.5% | 22.6% | 17.4% |
| | India | 9.3% | 8.5% | 14.1% | 27.1% | 20.6% |

Economic growth is dependent on (increased or more efficient) energy use (see Ozturk et al., 2010), who found that energy consumption and GDP are co-integrated (In technical terms, if there are two non-stationary time series X and Y that become stationary when differenced such that some linear combination of X and Y is stationary, then it is said that X and Y are co-integrated. In simple terms, let's suppose a drunk person walking with his/her dog, both of them have an unpredictable random walk. But, now given the position of one, a pretty good idea of the other's position can be established. Thus, the drunk and the dog form a co-integrating pair), thus justifying the observations that an increase in GDP in the past has resulted in increase of energy consumption). Looking at the developments in total energy consumption of the two countries from year 1990 onwards, shows that the energy consumption has increased multifold.

Figure 7 shows the increased energy consumption of the two countries. Both the countries show an increase in energy consumption of more than two-times in a time span of two-and-a-half decades. Just by looking at the graphs, it is clear that there is a constant increase in coal/peat consumption for both the countries during the time period 1990-2015. Oil, natural gas and hydropower energy consumption and production also exhibit an upward trend but not of the same magnitude as coal/peat. In the case of China (and not so much for India), there has been a push to increase wind and solar energy production and consumption from 2010 onwards. Another main observation that can be made from the graphs is that biomass energy makes up for a big proportion of India's energy consumption, but over the years not much change has been observed.

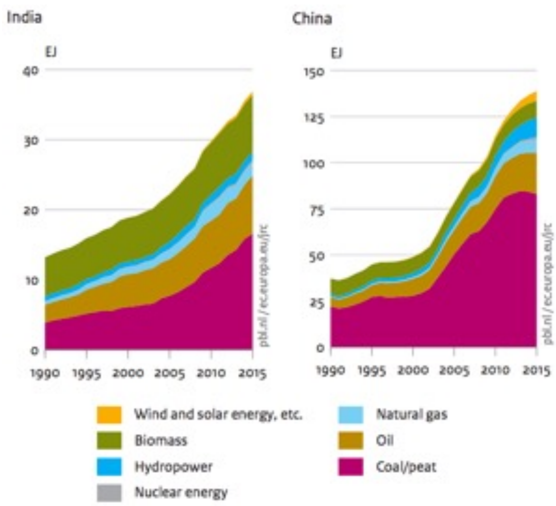



*Figure 7:Energy consumption (in EJ) and energy mix of India and China from 1990-2015 (Source: PBL and EC-JRC, 2016)*

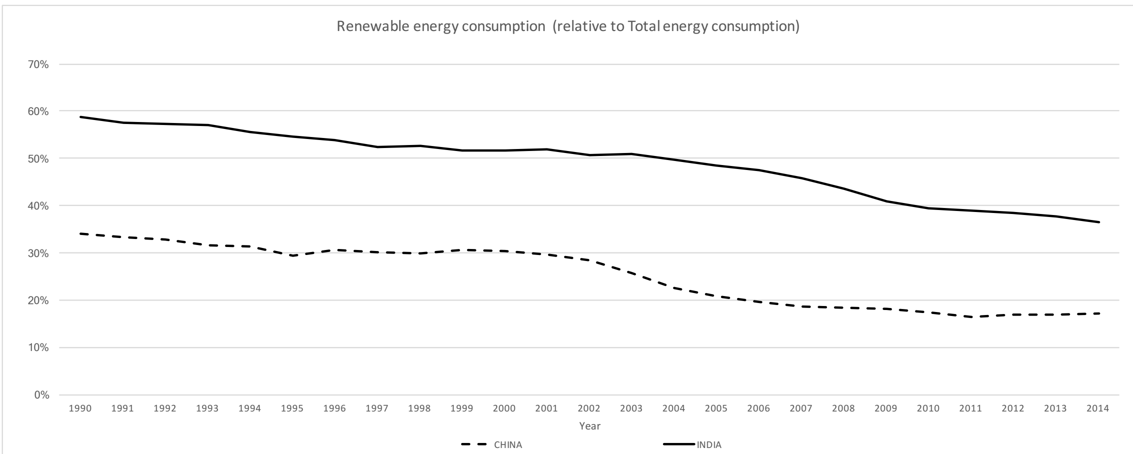



*Figure 8:Renewable energy consumption (% of total energy consumption) for India and China from 1990-2014 (Source: World Bank 2017)*

Figure 8 shows the renewable energy consumption as percentage of total energy consumption in the country in a given year. A deduction that can be made from the graph is that the share of renewables for both the countries is constantly on a decline. This can be a result of, either the investments in renewables is reducing year by year, or the rate of growth of investment in renewables is less than the rate of growth of investment in other energy production sources. A detailed analysis of these changes is done in the later parts of the thesis.

Energy consumption is by definition equal to,

$$Energy\ consumption = \left(\frac{Energy\ consumption}{GDP}\right) * GDP, or$$
$$Energy\ consumption = [Energy\ intensity] * GDP$$

where, GDP is defined real GDP and Energy intensity is defined as the energy consumption for each unit of national output (GDP) (Feng et al. 2009; Liao et al., 2007; Hang and Tu, 2007). Energy consumption may rise as real GDP increases and/or as energy intensity rises. Alternatively, if energy intensity declines, energy consumption declines. Accordingly, if economic growth (i.e. higher real GDP) is accompanied by declining energy intensity, energy consumption could – in principle – stay unchanged. To see this, we can write the above definition in growth rates:

$$g(Energy\ consumption) = g(Energy\ intensity) + g(GDP)$$

Every phase of development of an economy requires different level of energy resource input. Figure 9 shows the development of energy intensity of India and China between the years 1995 and 2009. A unique observation that could be made from the graphs is that the energy intensity curves, for both the economies, follow a sinusoidal wave like pattern. This pattern can be elucidated by the theory of dematerialization advocated by Bernardini and Galli (1993). According to the theory of dematerialization, the energy intensity of an economy follows an inverted U-shape pattern over a long term. Bernardini and Galli (1993) define dematerialization as "*the reduction of raw material (energy and material) intensity of economic activities, measured as the ratio of material (or energy) consumption in physical terms to gross domestic product (GDP) in deflated constant terms*."

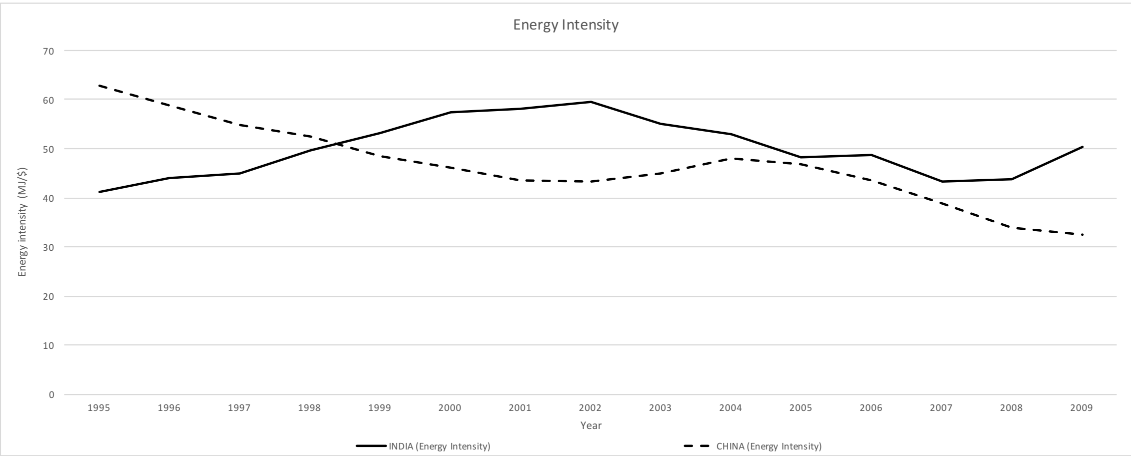



*Figure 9:Energy intensity of India and China from 1995-2009 (Source: Genty et al., 2012)*

Dematerialization is typically a long-term concept which results from the long term changes in several factors such as technology, economy, society, etc. Simply stating, the total energy use of an economy initially grows faster than its gross output and eventually the growth is slower in comparison to gross output growth during the economic development period. This can be reasoned as the increased production required to supply the growing demand results in first the energy consumption growth and slowly these increased profits are reinvested in technological advancements, they result in higher output with limited increase in energy and other inputs.

While India and China do not follow the strict rule of dematerialization, they show strong affinity towards it. The reason behind the same could be that they are fast developing economies and thus going through structural changes over the course of time. These structural changes meant that the energy needs were constantly changing and a constant change in the contribution of each sector to GDP. China, an agrarian economy in the past transformed into a manufacturing economy and is now fast developing its services sector. On the other hand, India's economic growth process after 1991 has been strongly led by services-sector growth (Ghose, 2015).

A review of the two fast developing economies, India and China, can be found in the subsequent sections. The sections on India and China will discuss the economic history and energy intensity findings of the two countries based on a review of several research papers.

## 2.1 CHINA

### 2.1.1 China's Economic Background

A distinctly different pattern of rapid economic growth can be observed in China since late 1970s. The real GDP of China grew at an average rate of 10%, annually. China was able to raise 679 million people out of extreme poverty between 1981 and 2010 (Morrison, 2014). China's implementation of economic reforms and the growth of the internal market in the 1980s eventuated in deep structural changes. By mid-1990s it was easily observable that China's industrial products had started to penetrate the world market (Saccone & Valli, 2009). Economists advocate the rapid economic rise of China to two main factors: large-scale capital investment and rapid growth in productivity (Morrison, 2014).

China and India are supposed to have entered the third phase of Fordist model of growth (Figure 10) in 1980s and 1990s respectively. The general concept of "Fordism" mainly associates to the strong growth phase of some industrial or services sectors which are interlinked and where scale economies and network economies play a big role (Saccone & Valli, 2009). As Figure 10 explains, a rapid growth of production in a sector may lead to economies of scale, to higher productivity, to increased profits, to higher investments, which again leads to increase in productivity and hence production. This is like a virtuous cycle which can go on and on until the sector matures and the demand for substitution becomes predominant. This Fordist model of growth especially holds true for sectors which possess the characteristics of economies of scale and the effect is particularly strong when the internal demand for the product or service is strong.

China and India supposedly also benefitted from some aspects of post-fordism effect and also gaining from the economic backwardness. The first wave of fordism was experienced by US for a few decades following 1908. The second wave of Fordism, in 1950s & 1960s resulted in the growth of West Europe, Japan and a few other Asian countries. 1980s, the economic and socio-political conditions of China were very different and the important sectors of the fordist model of growth were the electrical appliances(domestic) and their interlinked sectors. 1990s saw the addition of microelectronics, telecommunication and energy. Since 2000s, rapid growth was observed in production of different types of automobiles (Saccone & Valli, 2009).

The difference in the growth patterns of the two developing economies is visible from Figure 11. The effects of, post December 1978, economic reforms of China started to show their effects from mid 1980s when China started to overtake India in terms of Purchasing Power Parities (PPPs). China grew rapidly from 4.1% of US per capita GDP in 1978 to 19.1% in 2008 (GGDC, 2009).

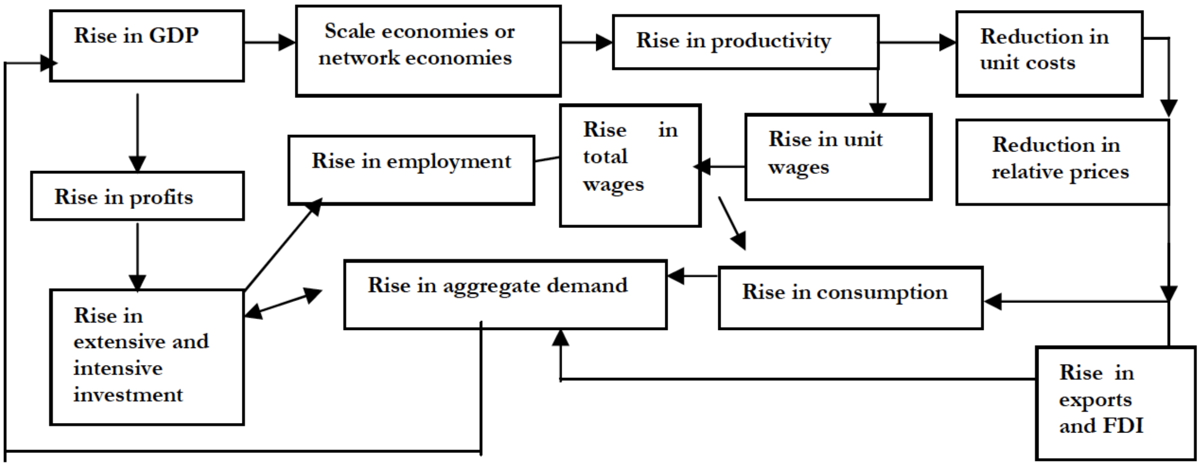



*Figure 10: Fordist model of growth in China (Saccone & Valli, 2009)*

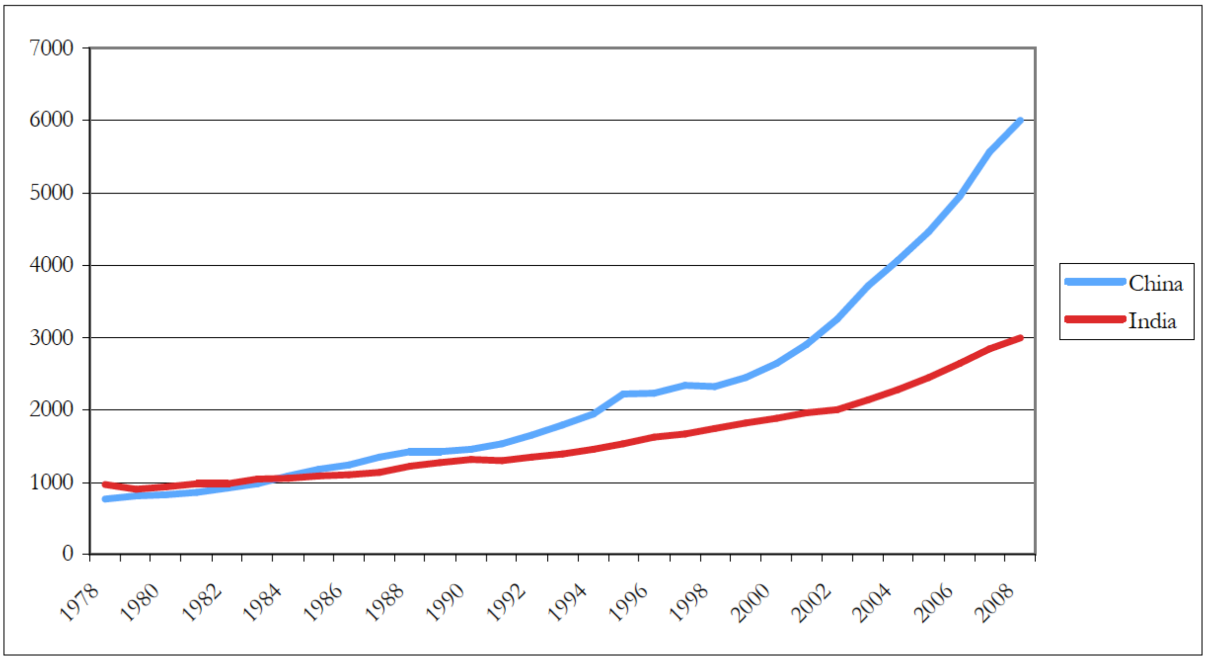



*Figure 11: Per Capita GDP in PPPs in China & India from 1978-2008 in international US dollars (yr. 1990) (Saccone & Valli (2009) derived from GGDC (2009))*

Major economic reforms introduced by China from late 1978 included (Morrison, 2014):

1. Price and ownership incentive to farmers, thus allowing them to sell a part of their produce in free market.
2. Introduction of four major economic zones facilitating more foreign investment, exports and import of high-tech products into China.
3. Decentralization of economic policymaking for different sectors.
4. Decentralization of economic control of organizations from center to provincial and local governments which could trade in free market.
5. Encourage individuals to start their own business.
6. Tax and trade incentives, to businesses in newly designated open cities and development zones, attracting foreign investment.

7. Gradual reduction of state price controls.
8. Trade liberalization.

China's rapid growth phase between 1978 and mid 1990s was predominantly based on rapid accumulation and the growth of internal market. Late 1990s and especially post China's entrance to World Trade Organisation (WTO), in December 2001, the rapid growth was a result of rapid rise of exports and the growing influx of foreign direct investment (Saccone & Valli, 2009).

From 1995 onwards the level of employment in tertiary sector was more than secondary sector, i.e. more people (32%) were working in services as opposed to those employed in mining, manufacturing, construction and utilities (27%) in year 2007. These characteristics resemble to both a developed as well as a developing economy (Saccone & Valli, 2009).

It should be noted that the 1997 Asian financial crisis had its effects felt in the Chinese economy as well. It had impacted China's industrial export and production. A deflation of China's domestic economy was seen and the output proportion of secondary industry saw a drop from 46.2 percent in 1998 to 45.1 percent in 2001. Recovery from the financial crisis and China's entrance to WTO in 2001, saw resurgence of the secondary industrial production especially the energy intensive sectors after 2003. The output share of secondary industry had increased to 48.9 percent in 2006 (Zhao et al., 2010).

China experienced a wide spread structural transformation as compared to India, partly as a result of deeper integration in the world economy. Chinese education system is less differentiated as compared to India's. The workforce on average is more educated but there is a growing inequality in access to higher education (Saccone & Valli, 2009; Saccone, 2008). China was also able to develop better communication and transport infrastructure in its economically dynamic areas, than India, owing to centralized decision making and early economic rapid growth. This resulted in low transport and trading cost as well as benefits of large scale economy for some sectors thus giving an upper edge in international competitiveness (Saccone & Valli, 2009).

### 2.1.2 China's Energy Intensity Developments and its Decomposition.

A decreasing trend in the China's energy intensity was observed during the 1980s and a prominent decreasing trend during 1990s, but a reversal in this trend was observed since 1998 and the following couple of years witnessed an increase in China's energy intensity (Zhao et al., 2010). Xie (2014) noted that the energy-GDP ratio (or energy intensity) dropped by 68 percent (i.e. approximately by two-thirds) between 1978 and 2001 i.e. an average decrease of five percent annually (NBS, 2010, 2011, 2012). Zhang (2003) recognized that it is rare accomplishment for a country to achieve such decreasing trend maintaining the level of development.

The reversal of a declining energy intensity trend took place since 2002 (Xie, 2014). Zeng et al. (2014) note that the decline of energy intensity of China was visibly slow since 2000 and the period 2002-2005 actually observed an increase in energy intensity (also seen in Figure 9). Clearly, it can be concluded from the studies that by the end of the 20th Century the decline in energy intensity was coming to an end and the start of the 21st Century saw an increasing trend in the energy intensity of China. In an interesting finding by Hang and Tu (2007), during late 1970s when China initiated its economic reform program, China's energy intensity was double that of USA and triple that of Japan.

China's primary energy consumption outpaced the energy production since 2001 (Figure 12). The demand for electricity saw a rapid decrease during China's ninth "Five-year plan" (1996-2000) as a result of adjustments made to the economic structure and the Asian financial crisis. This resulted in a very high electricity production in excess of demand over the same period. The new amendments, introduced by the Chinese government, gave the government stricter control over the investments in electricity industry from 1996 onwards. The electricity industry in China consumes more than 70 percent of coal, thus a slowdown in electricity production led to reduced consumption and production of coal (Zhao et al., 2010).

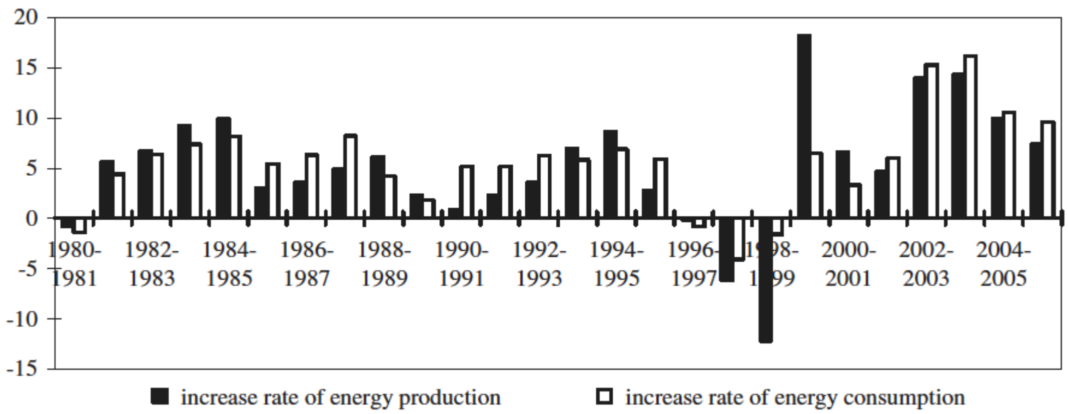



*Figure 12: Rate of change of energy production and consumption (in percentage) (Zhao et al., 2010)*

China became the world's largest consumer of coal since 1986, second largest consumer of oil since 2002, and of electricity since 1995 (Zhao et al., 2010; BP, 2009), plus 2010 saw China becoming the world's largest energy producer (Zeng et al., 2014; IEA, 2013). According to the findings of Xie (2014), the rapid economic growth of China, from 1992-2010, resulted in three-fold increase in primary energy supply of China, which is approximately six percent per annum.

From 1980 onwards till end of 20th century the growth rate of GDP has been typically higher in comparison to the growth of energy consumption in China (Liao et al., 2007). Thus explaining the effective drop in the energy intensity over the two decades from 1980-2000 but slowing down then onwards. As of 2007, when Hang and Tu (2007) concluded their research the level of China's energy intensity was comparable to those of USA and Japan.

#### 2.1.2.1 China's Energy Intensity Decomposition

Energy intensity can be considered to be dependent upon the following fundamental factors: changes in final demand structure, the changes in alternate inputs and changes in the energy use efficiency (Bernardini & Galli, 1993). To determine the effects of each of the factors on the energy use change, index decomposition analysis (IDA) and structural decomposition analysis (SDA) are the most widely applied techniques. Studies performed by Sinton and Levine (1994), Zhang (2003), Liao et al. (2007) and Zhao et al. (2010) have used IDA method to decompose China's energy use into technological effect, final demand effect and energy efficiency change effect. These studies concluded that the energy efficiency effect has been the major determining factor in energy intensity decline during 1980s and 1990s while the rapid growth of energy intensive sectors resulted in the intensity fluctuations seen after 2001 (Xie 2014).

Several studies have been done to quantitatively identify the structural effect and energy intensity effect which captures the contribution of the structural change and energy intensity change respectively, to the total energy use. Zhao et al. (2010) categorizes the findings into the following major groups:

1. The studies which found that the structural change/shift played the major role in China's energy consumption change, which has been supported by the findings of Kambara (1992) that the structural shift from energy intensive industrial subsectors to less energy intensive sectors was the main underlying factor.
2. The energy intensity changes and the structural changes have played different roles at different times. In the analysis to find the effects of structural change and energy intensity change on the energy consumption by 36 industrial sectors over the period 1993-2003, Zha et al. (2009) found that energy intensity change played a major role before 1998 while the later part i.e. 1999 onwards to 2003 the structural change effect dominated.
3. Remarkably many studies found that energy intensity change played a more important part in accounting for the total energy consumption changes. Sinton and Levine (1994) and Zhang (2003) performed a similar study for the periods 1980-1990 and 1990-1997 respectively. They concluded that energy intensity change accounted for 85 percent change during the 1980-1990 period and 88 percent savings in energy during the 1990-1997 period were a result of energy intensity change.

Applying SDA, from 1981-1987, Lin & Polenske (1995) observed primary energy use changes and found that the reduction in China's energy requirement was a result of changes in production technology, while final demand changes increased energy use, thus the effective decline in energy intensity was primarily because of increase in energy efficiency. Garbaccio et al. (1999) studied the energy intensity changes for the period 1987-1992 which showed a decline, and concluded that technological changes were the main driving force for the decline while structural changes actually increased energy intensity. The study of

China's energy intensity, divided into 30 sectors, for the period 1992-2004 was performed by Chai et al. (2009). Their decomposition concluded that the fluctuation in the energy intensity of China was a result of technological advancements and the changes in industrial structure. Fan & Xia (2012) studied the driving forces of China's energy intensity from 1987-2007 and found that changes in industrial structure and technological improvements have had major influence on energy intensity.

Zeng et al. (2014) in their study concluded that sectoral energy efficiency made the major contribution to the energy intensity decline which was a result of extensive implementation of energy saving technologies and management level advancements (Figure 13). The effect of sectoral energy efficiency was offset by structure change during 2002-2007. Also, final demand composition made a substantial contribution to the increase in energy intensity.

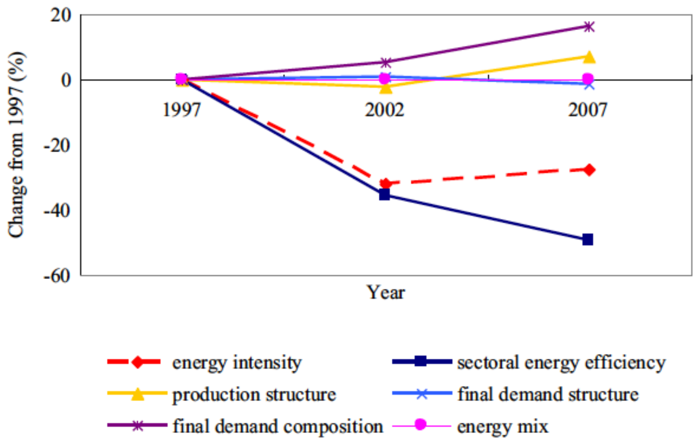



*Figure 13: Effects of different forces affecting China's energy intensity fluctuation from 1997-2007 (Zeng et al., 2014)*

A similar conclusion is made by Zhao et al. (2010) which utilized Logarithmic Mean Divisia Index (LMDI) method to decompose industrial energy consumption during 1998-2006. It found that factor responsible for China's energy intensity increase was rapid growth in energy intensive industries or in other words structural shift to energy intensive industries. It should be noted that these energy intensive sectors have also been responsible for implementing technologies to increase energy efficiency, but the progress has been offset by the rapid growth in these sectors.

## 2.2 INDIA

### 2.2.1 India's Economic Background

The rapid economic growth path followed by India is strikingly different from that of China in the way, that China followed a manufacturing-led growth while India made a big leap into services, after its industrialization process (which began in the 1950s) had stalled in the 1970s. Both the countries depict noticeably different growth patterns.

*Table 2: Growth Pattern (Ghose, 2015)*

| Sectors | Average annual rate of growth (%) | | | Contribution (%) of sectors to GDP growth | | |
|---|---|---|---|---|---|---|
| | 1951-82 | 1983-99 | 2000-10 | 1951-82 | 1983-99 | 2000-10 |
| Agriculture | 2.1 | 3.1 | 2.6 | 26.4 | 17.1 | 6.9 |
| Manufacturing | 5.1 | 5.9 | 7.9 | 17.0 | 16.5 | 16.9 |
| Construction | 4.9 | 5.0 | 9.5 | 9.0 | 6.3 | 9.6 |
| Other industries | 5.7 | 6.7 | 5.0 | 5.3 | 6.4 | 3.3 |
| Services | 4.4 | 6.6 | 8.6 | 42.3 | 53.7 | 63.3 |
| GDP | 3.5 | 5.4 | 7.2 | | | |

*Note: Other industries include "mining and quarrying" and "electricity, gas and water".*

The data suggest that India's economy experienced two instances of acceleration in GDP growth during the period 1951-2010. The first instance of acceleration of the economy was observed in early 1980s and the second instance during late 1990s. Both these accelerations can be attributed to the growth of services. Thus, it is safe to assume that India's services-led growth was not only triggered by the early 1990s economic reforms. Historical economic data show that India has ever been a services-led economy. Post 1982, growth of services was observingly faster than the growth of industry (Table 2) and thus also resulting in the contribution of services to GDP growth being greater than the contribution of all other sectors put together. (Ghose, 2015; Balakrishnan & Parameswaran, 2007). Findings of Balakrishnan & Parameswaran (2007) suggest that, since 1951, the growth of services have had a positive effect on the industry growth but not vice versa.

Ghani (2010) supported by Chenery (1960) and Kaldor (1966) states that India's 21st century growth pattern contradicts the belief that the only path to rapid economic development and growth is through industrialization.

Figure 14 depicts GDP growth versus Service output growth (for 136 countries) with a simultaneous comparison with the graph depicting the GDP growth versus Manufacturing output growth (for 134 countries) over a span of 5 years, from 2000 – 2005. Ghani (2010) uses Figure 14 to back his statement. He argues that, a comparison of the slopes of the two graphs shows that the aggregate economic growth is affected more by services growth as compared to manufacturing growth. India's experience suggests that rapid economic growth and poverty reduction riding on "services revolution" is possible. He talks about the service revolution in India, and argues that a service revolution can result in rapid growth and reduction in poverty, giving India's example. In his view, service revolution can act as an alternative to conventional manufacturing led growth, inspiring the late-comers to development. Findings of Dasgupta and Singh (2005, 2006) suggest that over time the characteristics which were, till now, exclusive to manufacturing ('learning by doing' company level effects, spillover effects at macroeconomic level and international tradability) are now also being acquired by services, thus empowering it to serve as a leading sector in economic growth comparable to manufacturing.

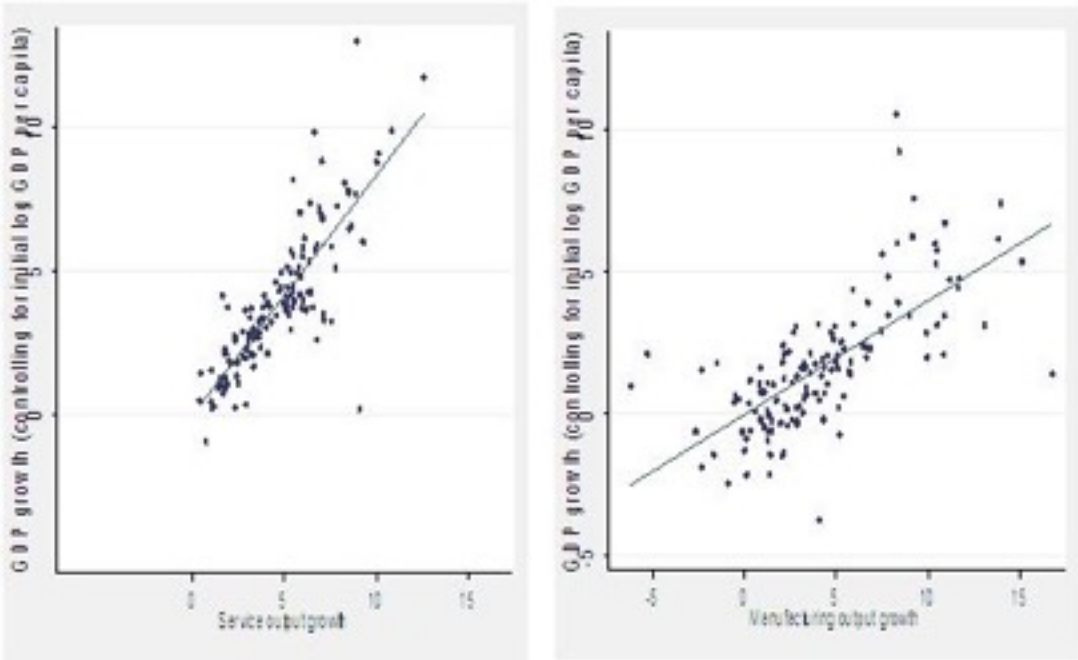



*Figure 14: GDP growth vs service value added growth(left) and GDP growth vs manufacturing value added growth(right) (2000-2005) (Ghani, 2010)*

*Note: Growth rates are compounded annual averages and all the values are in constant US dollars (yr. 2000)*

Ghose (2015) notes that there are studies discarding the relationship between share of services in GDP and per capita GDP (Kuznets (1957) & Chenery (1960)) and as well as studies which find a significant positive relationship between the two variables (Chenery and Syrquin (1975) & Kongsamut et al. (2001)).

The fact that India experienced an exceptional services-led growth at early stages of development stands true. This development trend becoming a prominent new-pattern for other developing countries at this point of time is not known and needs to be validated over the coming years. An exceptional quality of India's services-led growth is that it has been skill-intensive as opposed to the conventional employment-intensive (Ghose, 2015).

The economic reforms of 1990s are considered to have also played a important role towards the establishment of service sector as the key player in India's economic growth story. The economic reforms of 1990s liberalized foreign trade and made major changes to the domestic business environment. Sectors like telecommunication, banking & financial services benefited largely by this economic liberalization which in turn attracted foreign capital and technology (Das et al, 2013).

The reforms, in India, of 1990s (IOTT 1993-94 and 1998-99) (CSO, 2000, 2005), also known as first generation reforms, were focused on output expansion, privatization and opening up of borders of the economy. While the second generation reforms, since 2000s, were focused on performance improvement (Tandon & Ahmed 2016).

Between 2000-2010 the share of services in GDP grew from 50.1% to 54.7% and the share of industry in GDP from 25.1% to 28.3%. 2008-09, during the economic crisis, a growth of 6.7% was recorded of which only service sector contributed around 88% of the total observed growth (Das, Banga, and Kumar, 2011). India, when compared to three other growing Asian economies i.e. China, Indonesia and Thailand, stands out as the only economy which depicts a vast difference between the share of services in GDP and share of industry in GDP. China, Indonesia and Thailand, over the span of 30 years from 1980-2010, show the shares of both industry and services in GDP to be high and growing simultaneously (Ghose, 2015).

India doesn't seem to be the outlier until two additional variables namely: the share of industry in GDP and share of services in total employment in the country, are considered (Kochar et al, 2006; Ghose, 2015). Ghose (2015) argues that India's services-led growth in broader perspective is premature taking into consideration the fact that India's services sector is way more developed than the corresponding industrial sector which has led to low employment in services, because of its high-skill requirements, as compared to share of services in GDP.

Growth of services from 1981-2010 has been mostly driven by the growth in domestic demand. During the period 2000-2010 services exports increased considerably but this made only a small contribution to the growth of services output. This was because the export of services were a very small part of the total services output which was mainly internal demand driven. Software exports are the most important services export item, accounting for 34% and 52% of export value in 2000 and 2010 respectively. Only the software exports recorded impressive growth (Dossani, 2012; Murthy, 2012).

A conclusion that Ghose (2015) makes from his findings is that India acquired a comparative advantage in skill-intensive software services which was a result of policies, past and present. Using the findings of Kochar et al (2006), Ghose (2015) reasons that since the 1950s India had adopted a growth strategy which specialized in capital and skill intensive manufacturing industry. This meant the need for high-skilled labour and thus the education policies implemented thereafter paid more focus to tertiary education, neglecting primary and secondary education. This meant a large majority of the educated population was employed in high-skilled jobs which later on made possible the growth of demand for (ICT) services and exports, and hence the growth of services sector.

Policies which favoured services over manufacturing were (Ghose, 2015):

1. Manufacturing has been more heavily taxed as compared to services.
2. Slow development of the physical infrastructure discouraged the growth of manufacturing far more than it affected services.
3. Reforms of early 1990s liberalized the trade and foreign investments in services more than manufacturing.
4. Elimination of governmental monopoly and establishment of independent regulatory authority (Das et al, 2013).

As discussed earlier the rapid growth of domestic demand played a vital role in the growth of services. This rapid domestic demand growth can be explained partly by the rapid growth of both public and private final consumption expenditure and partly by the income elasticity of demand for services which have been greater than unity. The greater-than-unity income elasticity of demand for services is explained by the following developments: The "electronic revolution", which brought new and cheap products to the market, causing a change in expenditure pattern more in favour of services by people of all income groups. And the growing income inequality which favours more private expenditure on services (Ghose, 2015).

## 2.2.2 India's Energy Intensity Developments and its Decomposition

In a developing country, like India, the increasing energy demand is a result of the pursuit for higher economic growth, i.e. higher demand from industrial and manufacturing processes, as well as demand for better living standards which comes with increasing disposable incomes (Murthy et al., 1997). India's economic growth meant growth in energy requirements and are predicted to keep growing. Thus, the challenge to meet the energy requirements and provide energy at affordable prices is of fundamental importance. Changes in energy consumption can be studied to propose the best strategies to tackle the upcoming situation.

Not many, publically available, studies have been performed, relating to India, studying the various factors responsible for the change in national energy consumption. The changing energy consumption is associated with a transformation of the economic structure, exhibited by changing production patterns often termed as structural change (Ray & Reddy, 2007). Key factors responsible for the changed energy consumption are energy intensity, technological change and final demand change.

### 2.2.2.1 India's Energy Consumption Decomposition

Mukhopadhyay & Chakraborty (1999) analyzed the energy consumption changes in the Indian economy during 1973 and 1992. The motivation was to study the impact of the global energy crisis that had hit during 1970s and early 1980s thus adversely impacting major oil-importing countries, of which India was a part. The study revealed that the most significant role in the energy consumption change was played by final demand structure and technical changes. The changes in the final demand structure was the leading factor for the increase in energy consumption throughout the study period. The technical changes helped in lowering the energy consumption during the period 1973 to 1984 as a result of the measures, such as higher energy efficiency and inter-fuel substitution, adopted to reduce energy consumption because of the energy crisis. While the period 1983 to 1992 saw a rise in energy consumption as a result of technical changes and even measures to improve energy efficiency were found incapable in reducing the consumption significantly. The study states that changes in energy input coefficients and the interaction terms were acting to drive down the energy consumption during the study period.

Goldar (2010), using industrial level data, concludes in his study that the increasing energy efficiency of the energy intensive industries has resulted in an effective decline of the energy intensity of Indian manufacturing, since 1992. Mukherjee (2010) states that developments in the production technology are required in order to achieve the goals of optimal utilization and conservation of energy. He goes on to state that an improvement in technical efficiency can help to reduce energy input for the same level of output but it is indisputable that only adoption of advanced technology can assist in expansion of output with a simultaneous energy use reduction.

Tandon & Ahmed (2016) studied the period from 1993 to 2008. Their study found that the total energy consumption of India, between 1993 and 1999, increased as a result of both final demand changes and production technology change. The longer time scale of 1993 to 2004 showed that the production technology change actually helped in reducing the additional energy requirements as a result of final demand change. However, the increasing energy consumption effect of final demand change overwhelmed the reducing effect of technology improvement. For the whole period, 1993 to 2008, the study reveals that India's increased production levels which consume more energy than before are a result of growing population and high economic growth. A further upward trend in final demand is fueled by improved standards of living resulting from rising per capita income and increasing middle class population (Tandon & Ahmed, 2016; Chakraborty,2007). Also, exports expanded during the period, which increased output and amplified energy requirements. Authors note that a constant improvement in the production technology and efficiency could be seen during the whole reference period which helped in reducing two-third of the additional energy use resulting from increasing final demand.

Chakraborty (2007) performed SDA of total energy consumption for 1993 to 1999. The results of the study showed that both energy efficiency change and technological change were equally responsible for energy consumption changes. The demand for energy intensive products was observed to be increasing during the period. The author notes that technological change resulted in increasing energy consumption for almost all the sectors. This reflects the lack of implementation of energy conservation measures adopted in the reform strategy. Factors responsible for the same were (Mukhopadhyay, 2002):

1. Technological upgradation of energy industries is a costly and time consuming process and,
2. Emerging energy technologies lack the adequate intensification of Research and Development.

## 2.3 Conclusion: a comparison of the Chinese and Indian Experiences

China's economic growth success story is well known around the world. China, with its manufacturing-led economic growth, achieved an average real GDP growth rate of 10% annually between 1981 and 2010, and in the process was able to raise 679 million people out of poverty. India on the other hand took a totally different economic growth path. India took a great leap, direct from agriculture-led economy to services-led economy. India's services sector makes for approximately 55% share of total GDP, while the share of services in employment is only approximately 30%. This, big difference between the two, the share of services in GDP and share of services in employment, is a result of high-skill requirements of the jobs in services sector. These high-skilled jobs pay good and, these people spend their earnings more on services, thus promoting the growth of services sector even more.

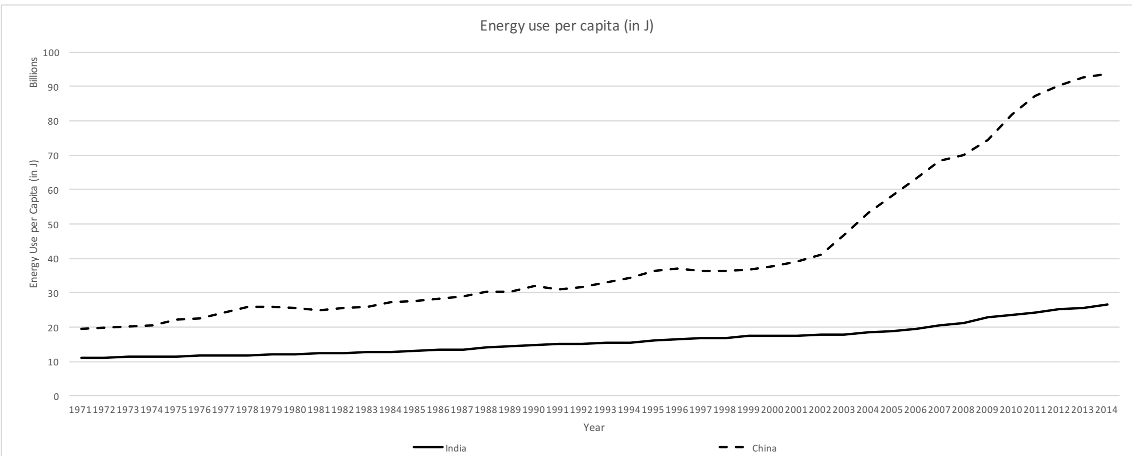



*Figure 15: Energy Use per Capita (in Joules) of India and China, between 1971 and 2014 (Source: World Development Indicators, Energy use and Population total, World Bank 2017).*

Both, China and India, over the course of economic growth have observed an ever growing demand for energy. Figure 15 presents the energy consumption per Capita in the two countries for almost four decades from 1971-2014. It is evident that China chose an energy intensive path for economic growth, as the per Capita energy consumption increased. This could be a result of increased demand for energy intensive services and/or growth of energy intensive manufacturing sector. China has experienced a growth of both GDP and energy consumption. The growth rate of GDP being higher than energy consumption meant a decreasing energy intensity over the period from 1980-2000, but a reversal of the trend is noticeable in the period following year 2000 for a few years till 2003, after which the energy intensity continues to decrease. India, on the other hand being a services-led economy also experienced a considerable growth in energy consumption annually. Energy consumption increase due to final demand change overshadowed the technology improvement effect. Not a major change in energy intensity is observed in India but a slow decrease in energy intensity is seen following mid-1990s. This could be attributed to increasing share of services in GDP, which is mainly a contribution of IT services which are less energy intensive.

# 3 Renewable Energy Policies and Current Scenario in India and China

Renewable energy is the energy generated from renewable (naturally replenished) resources, for e.g. sunlight, wind, rain, tide, geothermal heat etc. Renewable energy is most often used to generate electricity ("Renewable energy", 2017). It has become indispensable for each and every country to develop renewable energy sources because of the depleting non-renewable conventional sources of energy, i.e. fossil fuels resulting in unstable and increasing fossil fuel prices. Also, more than a century's extensive use of fossil fuel has resulted in global warming which has become a big threat. This has resulted in increased international pressure to reduce emission levels (Singh et al. 2009), thus reiterating the need to move towards renewable energy and also increase energy efficiency.

India and China belong to the fastest growing economies in the world. Energy is crucial to economic growth, social and industrial development of any country. With the growing instability in the fossil fuel market and the growing dependency of the two countries on a stable and growing supply of energy, it has become even more necessary to adopt more and more renewables into the system to attain energy security. Not only does renewable energy provide energy security but also helps in fighting the increasing carbon-dioxide emissions which is the main cause for global warming and pollution related health problems. Realizing the importance of renewable energy, India and China, formulated policies over the course of the past few decades to promote it. In the following sections, the renewable energy and energy efficiency policies adopted by the two countries to tackle the energy security and growing green-house gases issues, are reviewed. This review of policies is followed by a brief overview of the current scenario of major renewable energy technologies in the two countries.

## 3.1 China's renewable energy policies

In order to study the renewable energy policies implemented in China, it is important to first get a broad understanding of China as a country.

Until a few years back, China was the world's fastest growing economy. With the growing economy the demand for stable and growing source of energy is also needed. China is facing a critical challenge to secure its energy supplies. China's estimated annual oil demand in 2020 is 0.45-0.61 billion tons, while its domestic production can only supply about 0.18 billion tons. This means that the Chinese economy is heavily dependent on oil imports. Coal makes for the primary energy source of China. Coal is also the greatest source of pollution which China is battling with. Thus, in order to reduce China's dependence on coal and oil, and to have a more diversified energy mix, the only rational choice China is left with is increasing its reliance on renewable energy and improving its energy efficiency (OECD, 2009)

China has an abundance of renewable energy resources. China's ideology towards nature and environment can be divided into the following stages (OECD, 2009):

1. Pre-1949 – China followed the idea of nature-human harmony which had a deep impact on Chinese economic activity and lifestyle.
2. 1949-1976 – Under Chairman Mao's rule, the new doctrine was to conquer the nature. The natural resources were just another means of production.
3. 1978-2004 –There was a transition towards market economy, rapid industrialization and urbanization, accompanied by extensive environmental degradation. China's economic growth, industrialization and urbanization have resulted in a high demand for energy and raw materials. This has led to environmental degradation and health problems among the population.
4. Post-2004 – The need for cleaner environment by its domestic population and also international pressure to adopt a more sustainable development path, resulted in a paradigm shift in China's approach to development. The new ideology of the government could be characterized by "scientific approach to development", "harmonious society", "cleaner production", "circular economy" and "energy conservation and pollution reduction". These ideologies got reflected in its recent stimulus to energy conservation, emissions reduction, the development of renewable energy sources and lower emission vehicles.

Chinese government recognized the importance of renewable energy off-grid systems for rural and remote areas since 1970s (OECD, 2009), but integrating renewable energy systems to the main grid was not initiated until late 20$^{th}$ century. Considerable progress has been achieved in harnessing renewable energy resources but a vast potential of expansion throughout China still remains.

China strengthened its commitment towards renewable energy with the implementation of New and Renewable Energy Development Program (1996-2010), which aimed to improve renewable energy efficiency, reduce production costs, and increase the renewable energy share in the energy mix (OECD, 2009).

China reformed the institutional infrastructure of its environment management system, which can be summarized in the following categories (OECD, 2009):

1. Open access to environmental information to the public.
2. National Leadership Committee (NLC) established on climate change, energy saving and pollution reduction.
3. More power and efforts put in to energy efficiency and pollution reduction objectives.
4. Environmental excellence pursued by local governments with the help of innovative measures.

A major step towards renewable energy future was taken when the National People's Congress (NPC), on 28 February 2005, passed the Renewable Energy Law, 2005. The law aims to secure China's energy supply and to improve environmental protection efforts. The law mandates that by 2020, 10% of China's energy production should be sourced from renewables. The National Development and Reform Commission (NDRC), in 2007, went a step further to push the renewable energy implementation process. NDRC (2006) states that renewables must make for 10% of China's overall energy supply by 2010 and 15% by 2020 (OECD, 2009).

The following policies supported the strategy of renewable energy power generation and improvements in energy efficiency (OECD, 2009):

1. Preferential prices to renewable energy power generation. Government fixed electricity prices category wise, in order to support the renewable energy producers to recover their investment and gain market share. It was compulsory for power grid companies to purchase all the renewable energy generated at the government set prices.
2. A guarantee system was put in place to combine renewable energy to the grid, in order to increase competitiveness of renewable energy power, to reduce the trading costs of projects, to reduce the waiting time and better renewable energy projects financing options.
3. Fiscal subsidy and preferential taxation for renewable energy. The central government gave favorable tax rates to renewable energy power generated.
4. Implementation of Energy Conservation Law (1997), which has helped in improving energy efficiency in China. The law was amended in 2007, giving it more powers. With the new amendments, the coverage has been expanded to regulate energy saving in building and transport sector,

management regimes and energy conservation standards have been improved, and higher penalties for violation.

5. Formulation of energy efficiency standards for energy intensive sectors like petrochemical industry, metallurgy industry, chemical industry, power industry, construction materials industry etc. (IEA, 2008).
6. Government introduced energy efficiency labeling giving customers the ability to distinguish between energy efficient products and the rest, as well as making it possible for producers to charge more for energy efficient and environment friendly products.
7. Subsidies for using energy efficient devices.
8. Introduction of programs to ensure that industries meet the energy efficiency requirements. NDRC introduced one such program, "A Thousand Enterprise Program", in 2006. NDRC identified 1008 top firms which were consuming one-third of China's total energy, who had to devise a strategy in collaboration with local officials to improve their energy efficiency.
9. Favorable credit treatment policies – Preferential loans offered by Chinese financial institutions (such as national policy banks, national banks, bilateral aid banks, financial organizations etc.) with national financial subsidies to eligible energy development and utilization projects. The research by Bayaliyev et al. (2011) showed that the average real interest rate paid by Chinese firms was -1.6 percent, as compared to 2.3 percent for US and German firms. Chinese solar manufacturers benefitted from not only low interest rates but also from the large amounts of loans available to be taken.

# 3.2 India's renewable energy policies

India, officially known as Republic of India is the most populous democratic country with a population over 1.2 billion. India is the seventh largest country by area and stands at number two, just after China, in terms of population. The Indian economy was ranked seventh largest by nominal GDP and third largest by purchasing power parity in the year 2015 ("India", 2017).

Today's India is aiming towards high economic growth. Energy is a major factor for economic growth, social and industrial development of a country. However, India is suffering from energy shortage; almost 300 million out of 1.25 billion Indians live without electricity (Martin, 2017). On the other hand, increasing use of non-renewable energy (more than 65%) to supplement this energy gap is resulting in environmental degradation and pollution (Singh, 2012)

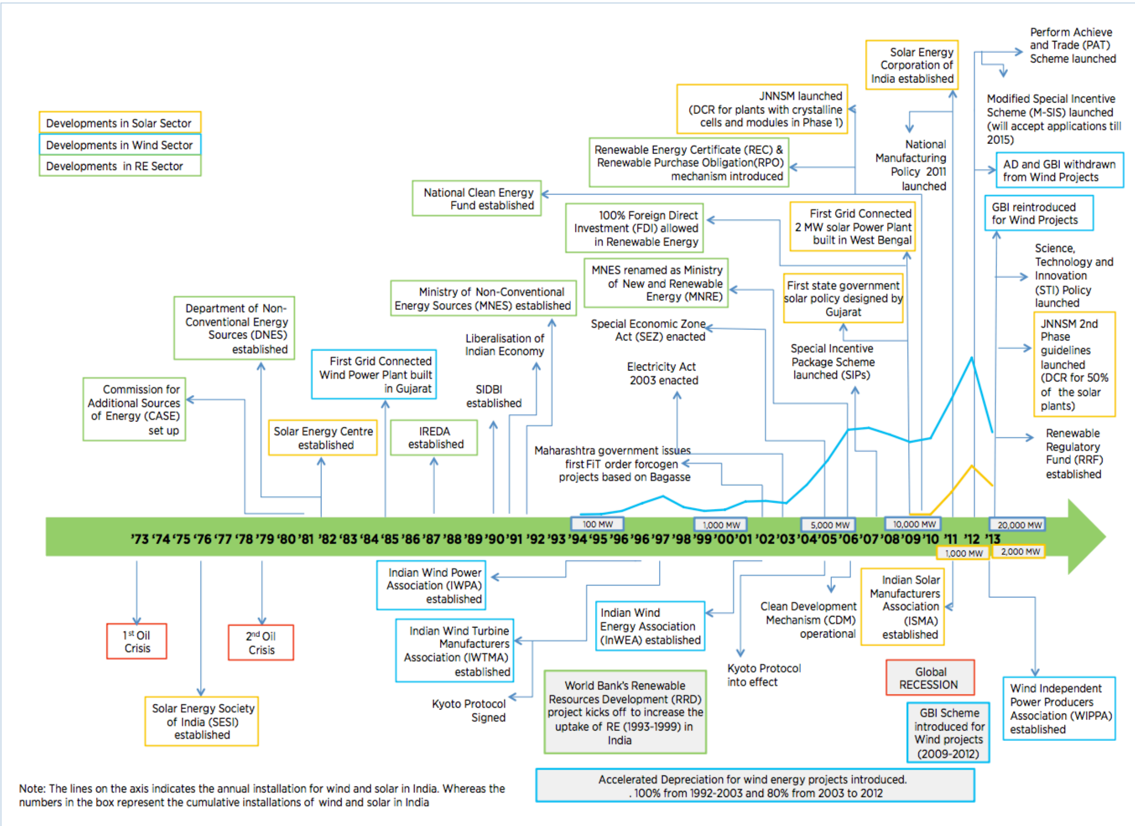



*Figure 16: Timeline of Renewable Energy policy development in India (Source: IRENA, 2017).*

Thus to combat, climate change and energy security issues, opting for renewable energy and encouraging energy efficiency improvements appears to be the most sustainable path. Government of India realized the high potential of harnessing clean and green energy from renewable energy sources early. As early as 1981, the Commission for Additional Sources of Energy (CASE) was founded under Department of Science and Technology (DST) by Government of India. The commission's main objective was to devise policies and implement the development of new and renewable energy sources. It also looked into accelerating the Research and Development in the sector. In 1982, the status of a full department, Department of Non-Conventional Energy Sources, was given to the commission. Finally, in 1992, the department was upgraded to Ministry of Non-Conventional Energy Sources which was later, in 2006, renamed as Ministry of New and Renewable Energy Sources (MNRES) (Singh et al. 2009). Figure 16 shows the renewable energy policy developments in India since 1981.

To meet the future energy demand and reduce green-house gas emissions for a sustainable future, renewable energy generation needs to be promoted. Realizing this need several measures, in the form of Acts and policies, taken by the Government of India are as follows:

1. Energy Conservation Act 2001 – Realizing the vast potential and wide spread benefits of energy saving, the Government of India enacted the Energy Conservation Act 2001. The act provides for the legal framework, institutional arrangement and regulatory mechanism at both Central and State level for smooth functioning of energy efficiency drive. The major provisions the Act relates to are Designated Consumers, Standards and Labeling of Appliances, Energy Conservation Building Codes, Creation of Bureau of Energy Efficiency (BEE) institution and the establishment of Energy Conservation Fund ("Glossary", 2017).
2. Electricity Act 2003 (GOI, 2003) – The Sections 86(1)(e) and 61(h) of the act state that State Electricity Regulatory Commission (SERC) is responsible for promoting the cogeneration and generation of electricity from renewables, by providing suitable grid connectivity, sale from such sources and a minimum purchase of electricity from such sources by the distribution licensees. SERC is also responsible for determining the tariff, wheeling charges, and also appropriate differential in prices to promote renewable energy technology until they can compete in competitive bidding process (Singh and Sood, 2011).
3. Renewable Portfolio Standards/Obligations (RPS/RPO) – With the setting up of SERC in several states and the restructured power sector, every state has set RPS/RPO in their respective states. RPS/RPO is states policies which mandates a state to produce a certain percentage of its electricity production from renewable energy sources (Singh and Sood, 2011).
4. Feed-in tariff (FIT) – This economic policy helps in the reducing the inherent risks involved with renewable energy production, by offering long-term contracts and guaranteed pricing to the producer ("Glossary", 2017; Singh and Sood, 2011). India was the first, among the developing countries, to have adopted the FIT scheme (REN21, 2014).
5. National Tariff Policy 2006 – The Central Electricity Regulatory Commission (CERC) and SERC are to follow the guidelines stated in Tariff Policy while framing its regulations. The Policy recognizes the importance of striking a balance between fair and appropriate return on investment to attract investors in renewable energy sector and also ensure reasonable charges to the customers ("Glossary", 2017). The procurement of electricity by distribution companies should be done at preferential tariffs,

determined by appropriate commission, recognizing the inability of renewable energy technologies to compete with conventional technologies in cost of electricity terms (Singh and Sood, 2011).

6. National Rural Electrification Policy (NREP) 2006 – It includes provision of access to electricity to all households by 2009 end. For the villages, where grid connection is not feasible or not cost effective, renewable based standalone off-grid solutions can be taken up to provide access to electricity to all households. If neither grid connectivity nor stand-alone system is feasible, then isolated lighting technologies like solar photovoltaics can be adopted (Singh and Sood, 2011).
7. Foreign Investment Policy – Entry into the Indian markets, for a Foreign investor, is possible by entering into a joint venture with an Indian partner for financial and/or technical collaboration and for setting up Renewable energy based power plants. Government of India also encourages a Build Own and Operate (BOO) renewable energy generation projects by foreign investors (Singh and Sood, 2011; Ghosh et al. 2001). Investors are required to enter into a power purchase agreement with the concerned state government. In order to promote the foreign investment, Ministry of Commerce and Industry established Foreign Investment Implementation Authority (FIIA) to act as a single point interface between the investors and government agencies. It helps the foreign investors in facilitating approvals and clearances, and settle operational complications with other government agencies (Singh and Sood, 2011).
8. Incentives – Financial incentives such as interest and capital subsidy, and soft loans are provided by MNRES. Other fiscal incentives provided by the government are: (a) Accelerated Depreciation – It allows the renewable energy based devices/projects investors claim 80% depreciation in first year itself, making it possible to write off the investment quickly ("Glossary", 2017; Singh and Sood, 2011), (b) Exemption/Reduction in excise duty (Singh and Sood, 2011) and (c) Exemption from central sales tax and import of materials, components and equipment used in renewable energy projects are given custom duty concessions under Income Tax Rules (Singh and Sood, 2011).
9. Jawaharlal Nehru National Solar Mission (JNNSM) – Government of India launched JNNSM in January, 2010. The mission has set ambitious target to achieve fast solar energy development through: 1) long term policies, 2) goals of large scale deployment, 3) intensive R&D and 4) domestic production of critical components and products (Sahoo, 2016).

## 3.3 Renewable Energy Scenario in India and China

Energy is now known as 'strategic commodity' and strategically it has become important to achieve energy security. Energy independence can be achieved by developing alternative sources of energy, i.e. improved energy mix, which is augmented by renewable energy sources. Apart from strengthening energy supply reliability, renewable resources also help in mitigating climate change. Energy generation from renewable energy sources plays an important role in achieving variety of policy goals such as, improved energy mix and security of energy supply, reduction in green-house gases emissions, regional and rural development, and utilization of opportunities for value addition and employment generation at local and regional level (Sen et al. 2016).

It is evident from Figure 17 that China has been leading the way to renewable energy future among the two countries. China has observed a high growth in renewable power installations, especially in the past few decades. The total renewable cumulative installation includes all the non-conventional renewable energy sources such as sunlight, wind, rain, geothermal heat, tide, wave etc. of which the current scenario of the major renewable energy sources will be discussed further in this section.

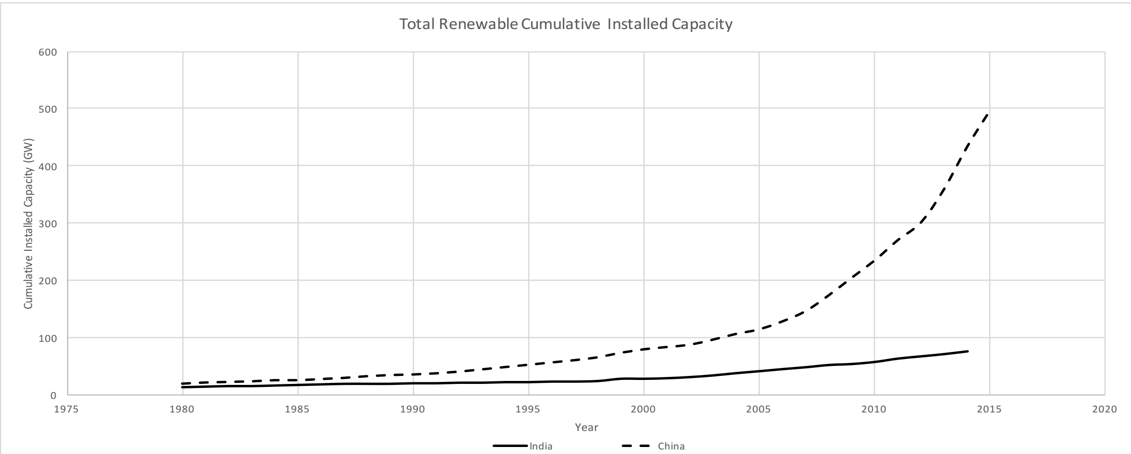



*Figure 17: Total Renewable Cumulative Installed Capacity in India and China (Source: developed from EIA, 2017)*

### 3.3.1 Solar energy

Solar energy is the energy of the sun in the form of light and heat. Theoretically, solar energy can be considered an ideal energy source as it is not only free but virtually limitless. In one year, the amount of solar radiation reaching earth is 10,000 times the world's yearly energy needs.

India has a huge solar potential (around 750 GWp (Kumar, 2015)), considering that major part of India lies between Equator and Tropic of Cancer (thus high solar insolation), and an average temperature range between 25-27.5 (degree Celsius) (Khanna et al. 2008). India targets 20GW of installed Solar capacity by 2022. India's solar energy sector is expanding. India is ranked 7th in solar photovoltaic cell production and 9th in solar thermal power generation. In 2009 India had 9 solar cell manufacturers, 23 Photovoltaic (PV) modules manufacturers and 60 PV systems manufacturers (Sahoo, 2016; Parikh and Ghosh 2009).

China also possesses a vast solar energy potential. Many regions of China experience a high annual solar radiation, which include Xinjiang, Qinghai, Gansu etc. (Li et al. 2007). Realizing the abundance and potential of solar energy in China, the solar industry has experienced a fast growth, increase of more than 100% averagely per year, since 2009 as is evident from Figure 18. Since 2007, China has maintained first place in the world for production of PV cells.

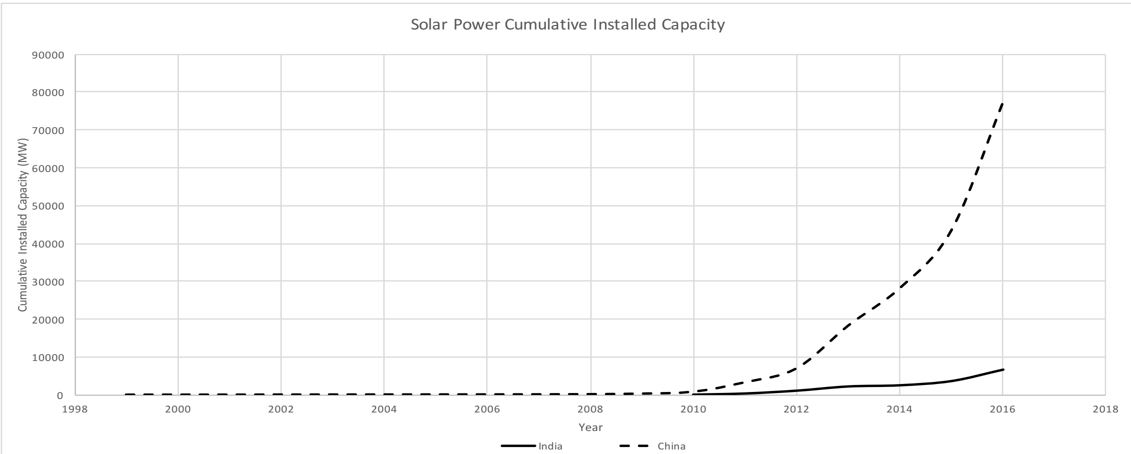



*Figure 18: Cumulative Installed Capacity of Solar power in India and China (Source: developed from "Solar power in India", 2017; "Solar power in China", 2017).*

Comparing the growth of the solar power in the two countries, it is clear that China experienced unprecedented growth in the solar power sector and especially in 2009 and onwards. The growth in solar power installed capacity in China can be attributed to a series of incentives (3.1) launched by the Chinese government in 2009 and especially between 2011 and 2015. Incentives, such as direct subsidies for solar PV installations, a national FIT scheme etc. were government initiatives to boost the solar power sector (Zhang et al. 2017). China has seen close to 100-fold increase in solar power installed capacity in 2016 as of 2010. Compared to China, solar power growth in India was low. Economically, solar energy is still expensive considering the high initial investment, difficulties in integration to grid because of intermittency in electricity generation, low conversion efficiency, component price sensitivity, lack of public awareness etc. (Sen et al. 2016).

## 3.3.2 Wind energy

Wind energy is a second renewable energy alternative to the conventional sources of energy and possesses the advantage of being harnessed even in remote locations. In comparison to solar energy, wind energy is continuously available and is cheaper in terms of cost of power generation at the site. Wind power has emerged as commercially viable and competitive energy source in the past decade. The wind energy generation cost is determined by investment cost, land cost, operation and maintenance cost, average wind speed at hub-height, and financial parameters as interest rate (Lu et al. 2009).

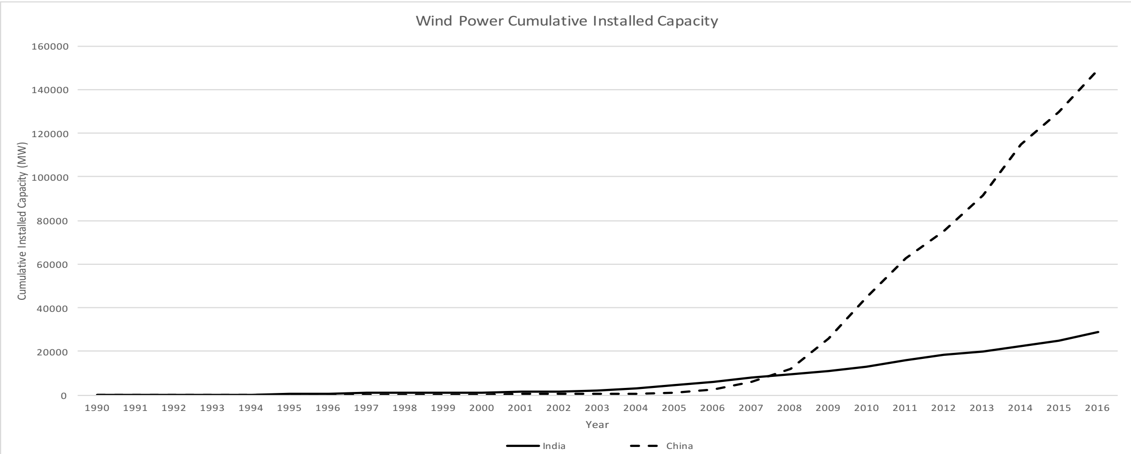



*Figure 19: Cumulative Installed Capacity of Wind power in India and China (Source: developed from Van Kooten and Timilsina, 2009; GWEC, 2017; "Wind power in China", 2017).*

As is visible from Figure 19, India maintained a constant growth rate, while China experienced a high growth rate in wind power installation post 2008. Even with a growth rate comparatively smaller than that of China, India still occupies the fifth spot in wind power total installed capacity. India possesses a potential between 253 GW (excluding farmland) and 306 GW (including farmland) (Hossain et al. 2011). China is the world leader in wind power generation with the largest installed capacity. China possesses a considerably large wind energy potential of approximately 600-1000 GW onshore and 400-500 GW offshore. Despite experiencing such a high growth rate in wind power installations, the distribution is uneven and not matched with economic development (Zhang et al. 2017).

## 3.3.3 Hydro power

Hydropower is the power generated out of falling or running water. Hydropower is a renewable energy source which is among the priority list of development of most of the countries because of economic, technical and environmental benefits (Huang and Yan, 2009). Hydropower is one of the most efficient ways of generating electricity with turbines having a conversion rate of approximately 90% ("Facts about Hydropower", 2017), compared to 22% efficiency of solar panels ("Power System, 2017) and around 45% efficiency of wind turbines ("The wind energy fact sheet", 2010). Hydropower is also capable of rapidly changing the power output, thus also providing the service of balancing demand and supply.

As in the case of other two renewable energy sources type, in the case of Hydropower installations also, China observed an unprecedented growth rate. Both the countries have been employing the use of hydro-energy to generate electricity almost since their independence. Comparing Figure 18, Figure 19, & Figure 20, it is clear that India experienced the maximum growth in hydropower installations among all the renewable power installations. 26% of India's electrical energy requirements are fulfilled by hydropower (Bhoi and Ali, 2014). India's hydro resources are the 7th largest in the world. According to Central Electricity Authority (CEA) India possesses 150 GW hydro potential (Ahmed et al. 2016).

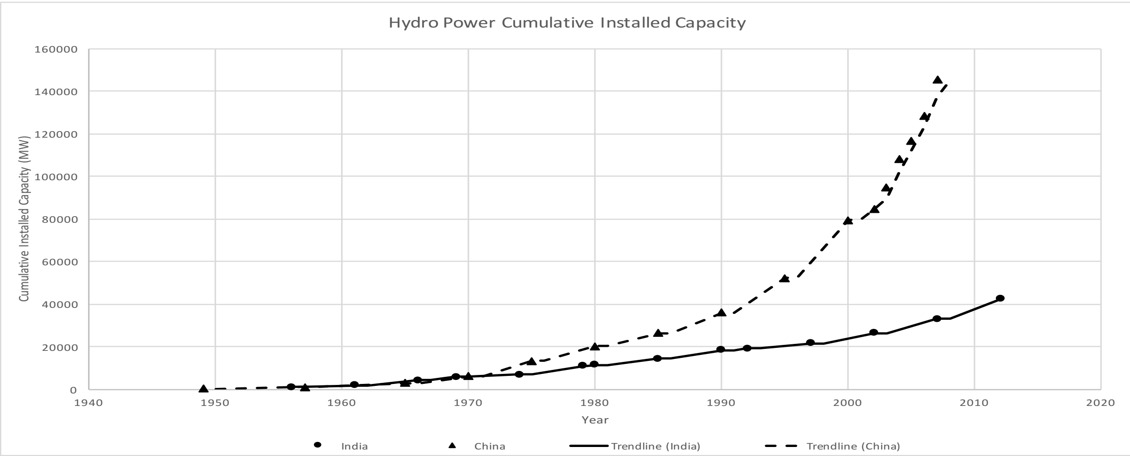



*Figure 20: Cumulative Installed Capacity of Hydropower in India and China (Source: developed from Bhoi and Ali, 2014; Huang and Yan, 2009).*

China possesses the richest hydro resources in the whole world with a theoretical potential of 694 GW. Development of Hydropower has become essential for China to counter energy crisis and environmental pollution resulting from high economic growth in the recent years. The annual average growth rate of hydropower installations has been approximately 12.4% (Huang and Yan, 2009).

### 3.3.4 Geothermal energy

Geothermal energy is the heat energy which is generated and stored in earth. The geothermal energy is the result of formation of planet and radioactive decay of materials. This continuous drive of heat energy from the core to the surface of earth is the result of geothermal gradient, or temperature difference between the core and the surface, which drives a continuous conduction of heat to the surface. Geothermal power is the power generated from the geothermal energy. Geothermal power generation is considered to be renewable because the energy utilized to generate energy is miniscule in comparison to the Earth's heat content ("Geothermal energy", 2017; "Geothermal power", 2017).

For the last 25 years Government of India has been supporting the R&D on exploration and resource assessment for harnessing Geothermal energy. MNRE plans to roll out a 1000 MW capacity Geothermal power plant in its initial phase till 2022. Geothermal energy has not been exploited at mass scale owing to availability of cheap coal, production of pollutants if harnessed incorrectly and problems involved with deep drilling (Sen et al. 2016).

China possesses abundant and widely distributed geothermal energy resources which account for approximately 7.9% of the world's geothermal energy resources (Ling-zhen, 2006). Fast growth of geothermal power in terms of geothermal heating is observable (Zhang et al. 2017).

## 3.4 Conclusion

Considering a business-as-usual scenario, continued economic development of India and China, the two most populous countries in the world, with an even growing population, will face two major challenges: (1) a domestic shortage of fossil fuels, especially oil; this would lead to even larger energy import dependency and could compromise the energy security of the two countries; and (2) further growth of carbon emissions, which will not only contribute to accelerating global warming but will also be a growing cause for severe health problems; both India and China are likely to suffer the economic damage of climate change. Accordingly, both countries face the imperative of developing their renewable energy sources. Both countries have substantial potential in terms of renewable energy and improving energy efficiency. We have reviewed the economic (support) policies and (consequent) growth of various renewable energy sources (solar power; wind power; hydro-power; geothermal power).

China has made strong progress in implementation of renewable energy generation since around 2005, while India lags behind. Both India and China experienced highest growth in hydro-power generation since their respective independence. China experienced an extraordinary growth of Wind-power generation post 2008 and similarly of solar-power generation post 2010. However, India experienced growth in renewable power generation but not as astonishing as that of China. Geothermal power generation technology is at R&D stage in India, more investments are being made in exploring and assessing the resource availability. China is slowly investing in harnessing the geothermal resource to generate power. Governments of both the countries have recognized the necessity of developing renewable energy sources and improving energy efficiency in the (near) future, and are making plans and formulating support policies to achieve these.

# 4 Methodology

This chapter presents the research methodology used in the empirical analysis. To address the research objective, of acquiring a greater understanding of the underlying causes resulting in variations in energy intensity of the different sectors of India and China – described in greater detail in Chapter 6 – we will use the World Input-Output Database (2013 Release) which provides consistent time-series data (for the period 1995-2009) on energy use and output for 35 sectors for 40 countries. We apply techniques of Input-Output Analysis (Miller and Blair 2009) to estimate changes in energy intensity at the aggregate and the industry-levels and to decompose aggregate energy intensity change. The 2013 public release of World Input-Output Database provides an internationally standardized input-output table covering over 40 countries and Rest of the World over a 15-year period from 1995 – 2009. The World Input-Output Database (2013 Release) also includes the tables for Socio-Economics accounts and Environmental accounts for years 1995-2009 which are used in conjunction with Input-Output tables during our analysis.

## 4.1 Introduction to Input-Output Analysis

Input-Output analysis is an analytical framework developed, by Professor Wassily Leontief in late 1930s, that analyses the interdependencies between the different industries in an economy. Leontief was awarded with Nobel Prize in Economic Science in 1973, in recognition for his work in developing the input-output analysis. Input-Output model is the matrix representation of a system of linear equations, where in each equation signifies the distribution of output of one industry throughout the economy in the form of inter-industry transfers, final demand to the market, and also the gross output generated through these transfers. The easy access to high processing power with the development of powerful computers has made Leontief's Input-Output analysis a tool that is being extensively used for economic analysis at various levels from local to international (Miller and Blair, 2009). In this chapter, an explicit explanation of the method used to map the energy consumption with respect to the economic activity of the different sectors will be given.

## 4.2 Fundamentals and Notations

In this section, an explanation of the working methodology of Input-Output basic model, i.e. for a specific geographical region (a country), will be provided. The basic model can be referred to, to understand the larger world model which needs to be used to analyze the World Input-Output Database. Essentially, the world economy can be described as a system of inter-reliant processes similar to processes taking place in the economy of a single country (Leontief, 1974). The following description is based upon the Miller and Blair textbook, 2009 publication.

Input-Output tables are concerned with the movement of finished goods (output) from each sector of the economy to every other sector, including itself, which requires it as input to produce its output. This matrix containing the input-output values is termed as inter-industry transactions table. An Input-Output table is the transactions taking place in an economy over a certain period of time, generally taken as one year. The rows of inter-industry transactions table illustrate the distribution of generated output by the producer throughout the economy. The columns illustrate the composition of input from each producer required to produce the industry's output. These inter-industry transactions are shaded in light green colour in the table depicted in Figure 21.

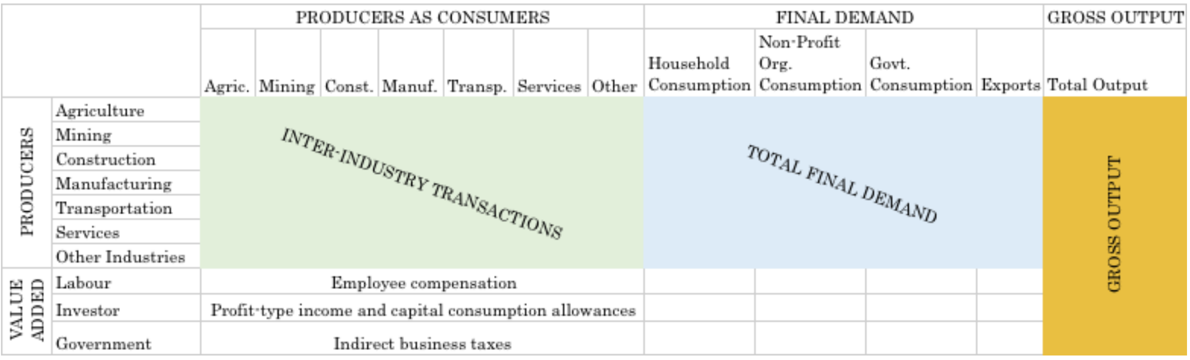



*Figure 21: Basic Input-Output table. (adapted from Miller and Blair, 2009)*

The final demand section records the sales of outputs of the corresponding producers in the final market, such as household consumption and government consumption etc. Value added includes all other transactions taking place in the economy which act as non-industrial inputs to production, such as labour, capital, depreciation of capital, taxes, interests, profits, losses and many more (Miller and Blair, 2009).

The transactions of goods and services among the different sectors is essentially sale and purchase of physical goods. The accounts of these transactions, between all the sectors, can be in principle kept in physical or monetary terms. Even with the physical measure showing a better reflection of the transactions taking place in an economy, the accounts are kept in monetary terms because of the difficulties faced while aggregating the information in tables. The difficulty of aggregation results from the significant measurement problems as a result of numerous varieties of products being generated and sold by a single sector.

The inter-industry transaction of goods and services between pairs of sector, i.e. from sector $i$ to sector $j$, in the monetary terms is represented as $z_{ij}$. The demand for inputs by sector $j$ from other sectors during a time-period, reflects the goods production by sector $j$ during the same time-period. Supplementary to this inter-industry demands there is more exogenous demands created by households, government and exports. This demand is generally referred to as final demand considering it is for goods to be used as such and not as an input for another process in a sector.

A simple equation that can be formulated considering $n$ sector economy, $x_i$ representing the total output of sector $i$, $f_i$ the total final demand for the products of sector $i$, $z_{ij}$ the interindustry sales by sector $i$ to sector $j$, is:

$$x_i = z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{1}$$

Equation (1) includes the possibility of purchases by sector $i$ of its own output as an input, thus these inter-industry transactions include the possibility of intra-industry transactions as well. Similar equations can be identified for the output of the $n$ different sectors of the economy:

$$\begin{aligned} x_1 &= z_{11} + \cdots + z_{1j} + \cdots + z_{1n} + f_1 \\ &\vdots \\ x_i &= z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i \\ &\vdots \\ x_n &= z_{n1} + \cdots + z_{nj} + \cdots + z_{nn} + f_n \end{aligned} \tag{2}$$

Let,

$$\mathbf{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, \mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix} \text{ and } \mathbf{f} = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} \tag{3}$$

The above information in equations (2) has been summarized in matrix notations. For simplicity of understanding, the column vectors will be represented by lower-case bold letters while matrices will be represented by upper-case bold letters, from here on in the text. The above matrix notation can be put as:

$$\mathbf{x} = \mathbf{Zi} + \mathbf{f} \tag{4}$$

Here, **i** represents a column vector of 1's, of suitable dimensions with $n$ number of rows, to produce a column vector whose elements represent the row sums of matrix **Z**. The transpose of a matrix in the text is denoted by matrix representing letter followed by " ′ ". Thus, corresponding transpose of **x** column vector is represented as $\mathbf{x}'$, which is a row vector.

As demonstrated in Figure 21 the table records the magnitude of transactions taking place among the different sectors of economy. A column point of view indicates the inputs to each sector, while the row point of view indicates the output of each sector. Thus, given the name Input-Output table. These tables are the fundamental to Input-Output analysis.

## 4.3 Input-Output table properties

This section describes in detail the characteristic properties on which the Input-Output table is constructed on. Firstly, the sum of a row is equal to the corresponding sum of column. This means that the monetary value of outputs of an industry equate to the monetary value of all its inputs. This results from the accounting conventions used for constructing the tables. The data is based on income accounts which are based upon the double-entry accounting principle. Thus, a sale by one industry to another results in the account of the seller industry being credited by an amount that records the revenue while the account of the purchaser industry gets debited by the same amount, as an expenditure.

Secondly, the total final demand is equivalent to all the primary inputs, i.e. payments made for labour, capital, taxes, interests etc, also termed as value added. This means:

$$C + I + G + E = L + N + M \quad (5)$$

where,

C = Consumer (household) purchases
I = Private investment purchases
G = Government purchases
E = Exports
L = Labour payments
N = All other value added items, that include taxes, interest payments, rental payment, profit and so on.
M = Imports

Thus, the following equation holds true by inference:

$$\sum_{i=1}^{n} f_i = \sum_{i=1}^{n} (l_i + n_i + m_i) \quad (6)$$

An important point that needs to be noted is, that the output is always equal to demand. Inventories play a major role in maintaining this balance. Inventories acts as reservoir, it shows a rise in inventories in case of a fall in final demand in the market and a negative demand (or inventory liquidation) in case of demand exceeding output. Thus, this results in output equal to demand with inventories serving to provide accounting convention to handle surpluses or shortages (Miller and Blair, 2009, p. 133).

The capital gains resulting from price changes are not accounted for, in valuations made during a time period. The creation or destruction of value is not taken into consideration while determining the real economic output. Thus, the effect of revaluation is not considered while constructing the Input-Output table (Miller and Blair, 2009, p. 134).

## 4.4 Production functions

The fundamental assumption in Input-Output model is, that the interindustry transaction from sector *i* to sector *j*, made during a given period, are dependent on the output from sector *j* during the same time period. Also, the fundamental assumption of constant returns to scale is made while constructing production functions. The model ignores the concept of economies of scale in production. It shows the linear dependency of the output from a sector on the different inputs. The model assumes that, for a given period, each unit of output from each sector utilizes a fixed proportion of inputs from each sector. Thus, this proportion of input from sector *i* ($z_{ij}$, interindustry transaction from sector *i* to sector *j*) required for each unit of output from sector *j* is given by:

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{7}$$

$a_{ij}$, technical coefficient (also termed as input-output coefficients or direct input coefficient), is assumed to remain constant during the given period for which the input-output table is constructed. The technical coefficient ($a_{ij}$) reflects the prevailing production technology of industry *j* corresponding to the inputs from sector *i*. The matrix comprising all the technical coefficients can be represented in the matrix form:

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{8}$$

Hence, equation (4) becomes:

$$\mathrm{x} = \mathbf{A}\mathrm{x} + \mathrm{f} \tag{9}$$

From Equation (7) it is visible that $z_{ij}$ can also be shown as a function of $a_{ij}$ and $x_j$, by:

$$z_{ij} = a_{ij} * x_j \tag{10}$$

Thus, Equation (2) can also be written as:

$$\begin{aligned} &x_1 = a_{11}x_1 + \cdots + a_{1i}x_i + \cdots + a_{1n}x_n + f_1 \\ &\vdots \\ &x_i = a_{i1}x_1 + \cdots + a_{ii}x_i + \cdots + a_{in}x_n + f_i \\ &\vdots \\ &x_n = a_{n1}x_1 + \cdots + a_{ni}x_i + \cdots + a_{nn}x_n + f_n \end{aligned} \tag{11}$$

These equations explicitly explain the dependence of inter-industry transactions on the total output of each sector. This form of representation takes us closer to answering the questions relating to the output from each sector that would be required to supply for the forecasted final demands. Thus, considering $f_1,\ldots,f_n$ are known and $x_1,\ldots,x_n$ are to be found, the equation can be rearranged in the following way:

$$\begin{gathered} x_1 - a_{11}x_1 - \cdots - a_{1i}x_i - \cdots - a_{1n}x_n = f_1 \\ \vdots \\ x_i - a_{i1}x_1 - \cdots - a_{ii}x_i - \cdots - a_{in}x_n = f_i \\ \vdots \\ x_n - a_{n1}x_1 - \cdots - a_{ni}x_i - \cdots - a_{nn}x_n = f_n \end{gathered} \tag{12}$$

Now grouping $x_1$ terms in the first equation and $x_2$ terms in second equation and so on,

$$\begin{gathered} (1 - a_{11})x_1 - \cdots - a_{1i}x_i - \cdots - a_{1n}x_n = f_1 \\ \vdots \\ -a_{i1}x_1 - \cdots + (1 - a_{ii})x_i - \cdots - a_{in}x_n = f_i \\ \vdots \\ -a_{n1}x_1 - \cdots - a_{ni}x_i - \cdots + (1 - a_{nn})x_n = f_n \end{gathered} \tag{13}$$

The matrix representation for equation set (13) and equation (9) can be represented as:

$$\begin{gathered} (\mathrm{I} - \mathrm{A})\ \mathrm{x} = \mathrm{f} \\ \mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1}\ \mathrm{f} \\ \mathrm{x} = \mathrm{Lf} \end{gathered} \tag{14}$$

Where,

$$(\mathrm{I} - \mathrm{A}) = \begin{bmatrix} (1 - a_{11}) & -a_{12} & \cdots & -a_{1n} \\ -a_{21} & (1 - a_{22}) & \cdots & -a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ -a_{n1} & -a_{n2} & \cdots & (1 - a_{nn}) \end{bmatrix}$$

and $\mathrm{L} = (\mathrm{I} - \mathrm{A})^{-1}$ is called as the *Leontief inverse* or also as the *total requirements matrix*.

Thus, the equations (13) can be summarized as:

$$\begin{aligned} & x_1 = l_{11}f_1 + \cdots + l_{1j}f_j + \cdots + l_{1n}f_n \\ & \vdots \\ & x_i = l_{i1}f_1 + \cdots + l_{ij}f_j + \cdots + l_{in}f_n \\ & \vdots \\ & x_n = l_{n1}f_1 + \cdots + l_{nj}f_j + \cdots + l_{nn}f_n \end{aligned} \tag{15}$$

Leontief inverse (L) can also be interpreted in literal terms as a set of $l_{ij}$, which represent the ratio of increase in output by sector *i* as a result of unit increase in final demand by sector *j*. This means that:

$$l_{ij} = \frac{\partial x_i}{\partial f_j} \quad (16)$$

All the elements of L ($l_{ij}$) can also be referred to as sector to sector output multiplier, which expresses the effective change in output from sector $i$ required for a unit increase in final demand for sector $j$'s output, simultaneously capturing both the direct and indirect effects.

Output multiplier is the ratio of change in direct and indirect output (combined) of sector $i$ to a unit increase in final demand of sector $j$.

1) The direct output is defined as the output of sector $i$ as a result of final demand of the sector $i$'s output. This direct effect only accounts for the production as a result of demand in the final goods market. Direct output doesn't take into consideration the intermediate inputs to other sectors (i.e. inter-industry flows).
2) The indirect output captures the output of sector $i$ which is the result of inter-industry flow to sector $j$. This arises from the demand of sector $j$ products in the market, which includes both direct and indirect output.

## 4.5 Energy Input-Output Analysis

The input-output framework has been extended, by the contribution of numerous researchers, to include physical units. Considerable research has taken place, henceforth, in industrial ecology and ecological economics. Also, public policy concerns have pushed for significant development in related areas. This has been complemented by extensive data collection to help in the implementation of framework. The following description will make it clear on how the Input-Output analysis stipulates a useful framework to track the energy use and related environmental pollution.

### 4.5.1 Energy Input-Output Analysis (Early approaches)

United States, in late 1960s and 1970s, as an economy was growing increasingly dependent on oil. Back then, oil was imported into USA mostly from foreign lands and particularly Arab countries. In the early 1960s, major oil producing countries organized into a cartel known as Organization of Petroleum Exporting Countries (OPEC) and subsequently enforced restrictions on the oil trade during early 1970s. This resulted in shortage of supply for heavily oil dependent economy of USA. During the same time there was a growing concern regarding the environmental impacts related to increasing energy use and principally the air pollution caused by burning coal. Since, energy is critical to production for predominantly every type of industry, researchers and policy makers sought to find the interrelation between energy and economy. Notable development, of energy use focused Input-Output models, was during the early 1970s. Recently, a resurgence in use and further development of these models is visible in order to analyze the correlation between energy use and climate change.

The most common and widely used energy extension of Leontief framework is to clearly account for energy use per dollars' worth of sectoral output. In other words, this set of linear energy coefficients can also be termed as energy intensity. This approach evolved and was used extensively in the early 1970s. This approach comes with its own methodological and practical limitations but is used frequently even today pertaining to limited data availability necessary to address the key weaknesses of ensuring internal consistency in accounting for energy supply and use (Miller and Blair, 2009, p. 400). This limitation of ensuring the internal consistency of energy flows accounting can be overcome only when the condition of uniform energy prices across all sectors is fulfilled.

### 4.5.2 Concepts of Energy Input-Output Analysis

First we start with the discussion of how the Input-Output framework has be developed to incorporate the inter-industry energy flows, which was extensively researched on in 1970s in the wake of OPEC oil embargoes, significantly impacting US economy. The mathematical model of this extension is predominantly based upon the classical Leontief model. However, to maintain the consistency between the energy consumption (in physical units) and economic activity (in monetary units), basic analytical model needs to be altered.

Generally, Energy Input-Output ascertains the total amount of energy required to produce the output for final demand. This energy consumed incorporates all the energy expended directly and indirectly. Direct energy use is the energy consumption by the industry's production process, while the indirect energy consumption is the energy encompassed in its inputs. This calculation of total energy requirement is the product of *process analysis*. This process involves making a list of the directly required goods and services for manufacturing the target product. The inputs include direct energy use and other non-energy goods and services. These non-energy goods and services are further bifurcated into their direct energy use and other non-energy goods and services. This process analysis helps in tracking the inputs back to primary resources. Thus, the *direct energy requirements* are determined from the first round of energy inputs; consecutive rounds ascertain the *indirect energy requirements*. The summation of both direct and indirect energy requirements make for the *total energy requirement* (Miller and Blair, 2009, p. 401). Complications may arise if certain inputs are imported and some cases where energy is produced as a by-product or co-product. These situations also need to be accounted for, in the basic framework. Figure 22 and Figure 23 are energy flows and use schematics for India's and China's economy in 2007. Energy Input-Output analysis is mainly concerned with energy measurement in physical units – such as Tera Joules (TJ), rather than in monetary terms. As is expected, to secure these quantities in physical energy units, they have to be first computed in monetary terms following the conventional Input-Output analysis and later converted back to physical energy units (for e.g. TJ) using the prices which relate monetary output to physical energy output. This introduces inconsistencies in the resulting energy flows which have to be taken care of by necessary adjustments to reach reasonable results. To overcome these limitations of the earlier formulations of the Energy Input-Output model a new "hybrid" formulation was proposed by Bullard and Herendeen (1975).

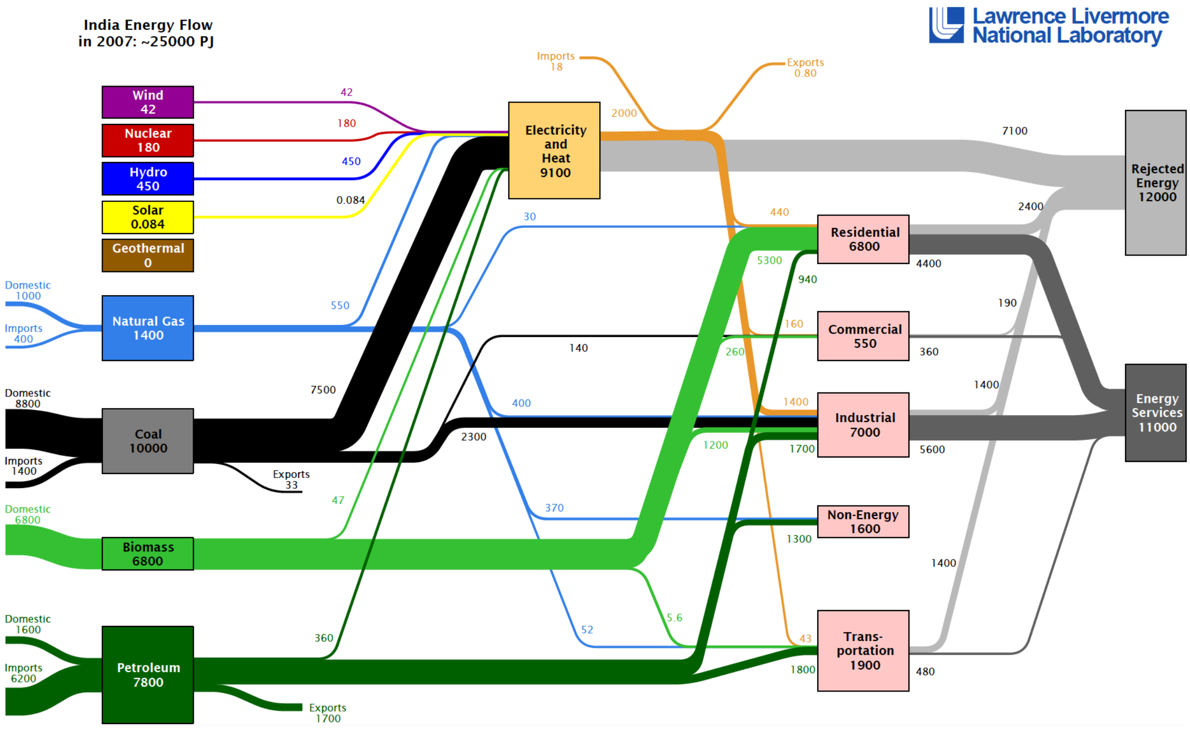



*Figure 22: India Energy Use for 2007 (in PJ) (Lawrence Livermore National Laboratory, 2011)*

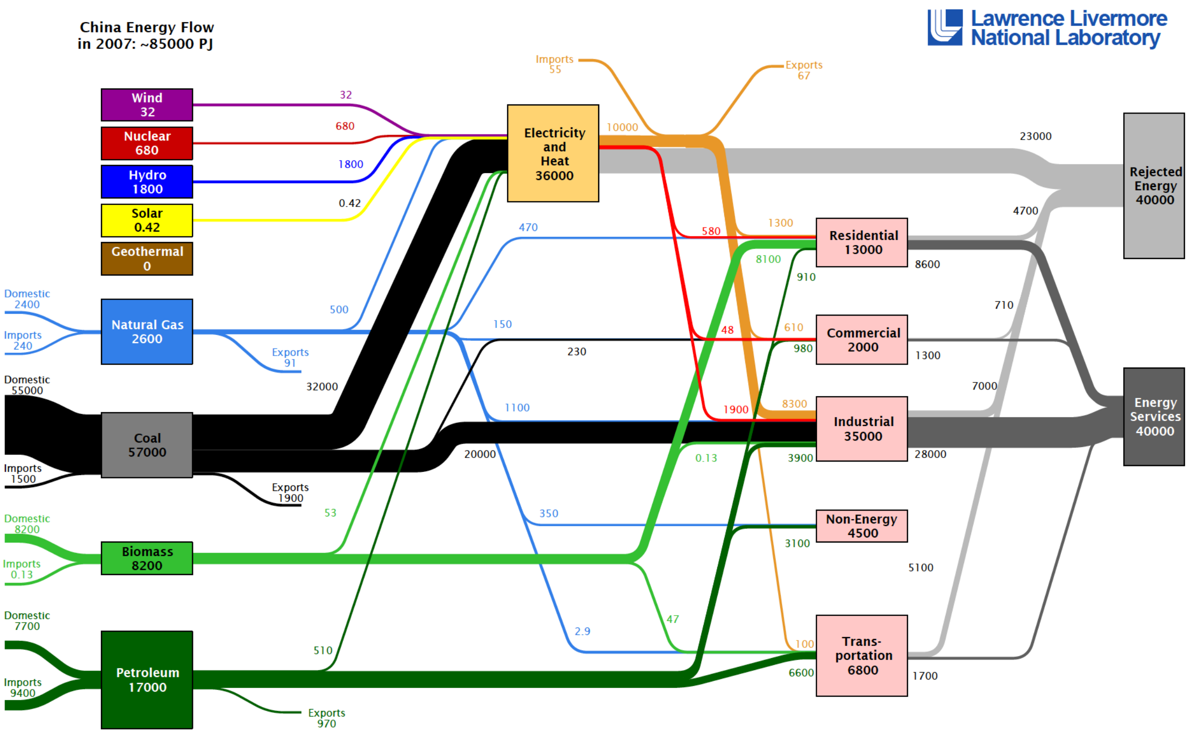



*Figure 23: China Energy Use for 2007 (in PJ) (Lawrence Livermore National Laboratory, 2011)*

### 4.5.3 Basic Formulation

To begin with, the contemporary framework of Energy Input-Output is chosen. It requires the construction of transactions table in "hybrid" units, i.e. energy flows are recorded in TJs and the non-energy flows are recorded in monetary terms (say US dollar). This type of formulation is observed to be superior to other types of formulations extensively applied in the literature, although "hybrid" formulation suffers from the applicability issue as a result of limitations from the available data (Miller and Blair, 2009, p. 403).

The ratio of sectoral direct energy use to the total sectoral gross output is defined as coefficient of energy in this text. The column matrix of coefficients of energy (ec) of all the sectors for the specified time period is computed by dividing the Total Energy Use (Genty et. al., 2012) of a sector by the Total Gross Output (Timmer et. al., 2015) from the same sector for that time period. The resulting column matrix (ec) is converted into a diagonal matrix ($\widehat{ec}$). The units of this ($\widehat{ec}$) matrix are TJ/$.

## 4.6 Structural Decomposition Analysis (SDA)

In cases where an economy has two or more sets of Input-Output data, the analysts in order to find the contributions made by its several components try to disaggregate the total change observed. For example, to compute the effects of changes in technology (reflected by the changes in Leontief inverse over a period) and final demand on the total change in gross outputs between two time periods. Further, the changes in technology and final demand can be disaggregated further to determine the contributions of its various components. This practical tool provides the possibility to quantify fundamental "sources" of change in a range of variables such as economic growth, energy use, trade etc. (Rose and Casler, 1996). Rose and Chen (1991) define SDA as "*the analysis of economic change by means of a set of comparative static changes in key parameters in an input-output table*".

### 4.6.1 Mathematics behind SDA

To start with, the gross output changes are explored to get a general idea of SDA. Considering, two time periods with input-output data available, and differentiated by superscripts 0 and 1 (0 preceded by 1). The focus of the illustration of structural decomposition is on the differences in the gross output vector for the two time periods. The gross output for the time period $t$, is defined as $x^t$ ($t = 0,1$).

$$x^1 = L^1 f^1 \text{ and } x^0 = L^0 f^0 \tag{17}$$

where,
$f^t$ = the final demand vector for time period $t$, and
$L^t = (I - A^t)^{-1}$.

Thus, the change in gross output can be represented as:

$$\Delta x = x^1 - x^0 = L^1 f^1 - L^0 f^0 \qquad (18)$$

With the task to disaggregate the total change in gross output into changes in its various components, which means firstly the separation of changes in,

$$L\ (\Delta L = L^1 - L^0) \text{ and } f\ (\Delta f = f^1 - f^0) \qquad (19)$$

The data is assumed to be expressed in prices for a common year, to eliminate the effects of price changes.

The alternative expansions and rearrangements of equation (18) using equation (19) are:

$$\begin{aligned}
\Delta x &= L^1(f^0 + \Delta f) - (L^1 - \Delta L)f^0 = (\Delta L)f^0 + L^1(\Delta f) && \text{(a)}\\
\Delta x &= (L^0 + \Delta L)f^1 - L^0(f^1 - \Delta f) = (\Delta L)f^1 + L^0(\Delta f) && \text{(b)}\\
\Delta x &= \left(L^0 + \Delta L)(f^0 + \Delta f\right) - L^0 f^0 = (\Delta L)f^0 + L^0(\Delta f) + (\Delta L)(\Delta f) && \text{(c)}\\
\Delta x &= L^1 f^1 - (L^1 - \Delta L)(f^1 - \Delta f) = (\Delta L)f^1 + L^1(\Delta f) - (\Delta L)(\Delta f) && \text{(d)}
\end{aligned} \qquad (20)$$

Interestingly, the equations (20(a) & 20(b)) have an intuitive appeal to it – for e.g. $(\Delta L)f^0 = L^1f^0 - L^0f^0$, the term $(L^1f^0)$ quantifies the required output to satisfy old (time period 0) demand with new (time period 1) technology; the term $(L^0f^0)$ similarly quantifies the required output to satisfy old demand with old technology. Thus, in the process analyzing the effect of technology change. On the similar lines of thought $L^1(\Delta f)$ helps in analyzing the effect of change in final demand on the total gross output.

Yet, it is quite clear that the effect of changed technology and changed final demand will differ from equation (20(a)) to equation (20(b)).

In the case of equation (20(c)) and equation (20(d)) the expressions emerge from using only time-period (0) and time-period (1) respectively, for weights on both the change terms. But the term – $(\Delta L)(\Delta f)$ – do not have the same intuitive interpretation to it as the other terms.

After examining a wide variety of decompositions possible, Dietzenbacher and Los (1997) concluded, that an average of equation (20(c)) and equation (20(d)) is the most acceptable approach. i.e.

$$\begin{aligned}
&2\Delta x = (\Delta L)f^0 + L^1(\Delta f) + (\Delta L)f^1 + L^0(\Delta f)\\
&\text{thus,}\\
&\Delta x = \underbrace{\left(1/2)(\Delta L)(f^0 + f^1\right)}_{\text{Technology change}} + \underbrace{(1/2)(L^0 + L^1)(\Delta f)}_{\text{Final-demand change}}
\end{aligned} \qquad (21)$$

### 4.6.2 Decomposition of changes in function of x

Based on the same mathematical foundations, as discussed in the section (1.6.1), not only can the gross output change but also variables dependent on output can be decomposed. Let take, for example set of coefficients of energy – direct total energy use per monetary unit (eg dollar) of output in sector $j$ for time period $t$ ($ec_j^t$) – let $(ec^t)' = [ec_1^t, \dots, ec_n^t]$, then the column matrix of direct total energy use, associated with gross output will be $\varepsilon^t = \widehat{ec}^t x^t = \widehat{ec}^t L^t f^t$, and thus the column matrix of change in direct total energy use is:

$$\Delta\varepsilon = \varepsilon^1 - \varepsilon^0 = \widehat{ec}^1 L^1 f^1 - \widehat{ec}^0 L^0 f^0 \tag{22}$$

Following the standard pattern and decomposing into contributions by the three elements results into:

$$\begin{aligned}\Delta\varepsilon = &\underbrace{(1/2)(\Delta\widehat{ec})(L^0 f^0 + L^1 f^1)}_{\text{coefficient of energy change}}\\ &+ \underbrace{(1/2)[\widehat{ec}^0(\Delta L)f^1 + \widehat{ec}^1(\Delta L)f^0]}_{\text{technology change}}\\ &+ \underbrace{(1/2)(\widehat{ec}^0 L^0 + \widehat{ec}^1 L^1)(\Delta f)}_{\text{final-demand change}}\end{aligned} \tag{23}$$

The matrix format of the above equation is helpful in analyzing the contributions made by its several components on the total direct energy use, sector-wise. Similar principal can be applied for any other economic variable which relates to gross output by a similar coefficient set (per monetary unit of sectoral output) – pollution generation, value added, employment, etc.

SDA provides only a unique set of results on decomposing energy use change into final demand change effect, technology change effect and coefficient of energy change effect. The method of normalization of these results might vary, but will essentially not affect the trends. The results obtained by SDA have been normalized by the previous year total energy use of that country; thus providing the rate of change of energy consumption per year. The matrix calculations have been performed in R. The source code and the flow chart explaining the steps undertaken can be found in Appendix A3.

## 4.7 Understanding Decomposition Results

To better understand the decomposition and its results, let us consider the following example of 3 industries with the base case considerations as given below:

Table 3 is a self-created example of a system that comprises of three industries which are interdependent for their production. This composition is taken as a base case for all the simulations performed in this section. The inter-dependency ratios of the industries are represented in technical coefficient matrix. The technical coefficient matrix for

*Table 3: Input Output table with Total Energy Use (TEU) per industry for Year 1 (Base Case)*

| Year 1 (Base case) | | | | | | |
|---|---|---|---|---|---|---|
| | **Industry 1** | **Industry 2** | **Industry 3** | **Final Demand** | **Gross Output** | **TEU (TJ)** |
| **Industry 1** | 100 | 250 | 250 | 500 | 1100 | 300 |
| **Industry 2** | 200 | 150 | 300 | 700 | 1350 | 400 |
| **Industry 3** | 300 | 400 | 100 | 600 | 1400 | 500 |

Table 3 is represented in Table 4.

*Table 4:Technical coefficients matrix for Year 1 (Base case)*

| A (Technical coefficients matrix) | | | |
|---|---|---|---|
| | **Industry 1** | **Industry 2** | **Industry 3** |
| **Industry 1** | 0.090 | 0.185 | 0.178 |
| **Industry 2** | 0.181 | 0.111 | 0.214 |
| **Industry 3** | 0.272 | 0.296 | 0.071 |

The energy coefficients matrix provides the direct energy consumption per unit of generated gross output for each industry. The energy coefficient vector for all the three industries in Year 1 (Base case) is exemplified in Table 5.

*Table 5: Energy coefficients matrix for Year 1 (Base case)*

| Energy coefficients matrix | |
|---|---|
| **Industry 1** | 0.272 |
| **Industry 2** | 0.296 |
| **Industry 3** | 0.357 |

The following systematic variations will help develop a better understanding of the decomposition results from the structural decomposition analysis of energy consumption change:

1) Year 2 – The final demand of industry 2's products is increased by 100, while keeping the technical and energy coefficients constant.
2) Year 3 – The energy coefficient of industry 2 is doubled, while the final demand and all other technical and energy coefficients remain same as in Year 2.
3) Year 4 – The technical coefficient (2,1), i.e. industry 1's dependency on sector 2's output for its production, is approximately doubled, to 0.36. The final demand and all other technical and energy coefficients are kept constant to Year 3 values.

4) Year 5 – The technical coefficient (2,2), i.e. industry 2's dependency on its own output for production, is approximately doubled, to 0.22. The final demand and all other technical and energy coefficients are kept constant to Year 4 values.

The results of the above step by step variations on each industry are given in Table 6, Table 7 and Table 8

*Table 6: Industry 1 energy consumption change decomposition results from Year 1 to Year 5.*

| Industry 1 | | | | |
|---|---|---|---|---|
| | Year 1-2 | Year 2-3 | Year 3-4 | Year 4-5 |
| Energy coefficient effect | 0 | 0 | 0 | 0 |
| Technology effect | -1.135E-14 | 0 | 22.295 | 25.129 |
| Final demand effect | 10.261 | 0 | 0 | 0 |

*Table 7: Industry 2 energy consumption change decomposition results from Year 1 to Year 5.*

| Industry 2 | | | | |
|---|---|---|---|---|
| | Year 1-2 | Year 2-3 | Year 3-4 | Year 4-5 |
| Energy coefficient effect | 0 | 439.436 | 0 | 0 |
| Technology effect | 0 | 0 | 171.368 | 193.154 |
| Final demand effect | 39.436 | 0 | 0 | 0 |

*Table 8: Industry 3 energy consumption change decomposition results from Year 1 to Year 5.*

| Industry 3 | | | | |
|---|---|---|---|---|
| | Year 1-2 | Year 2-3 | Year 3-4 | Year 4-5 |
| Energy coefficient effect | -7.920E-14 | 0 | 0 | 0 |
| Technology effect | 0 | 0 | 41.530 | 46.810 |
| Final demand effect | 19.114 | 0 | 0 | 0 |

Studying the effects of each variation on all the industries, following conclusion can be drawn about the results of structural decomposition analysis.

1. Change in final demand of any one industry in the matrix will trigger a change in energy consumption reflected in final demand effect of all the interlinked industries, as can be deduced from Year 1-2 results of all the industries.
2. A change in energy coefficient of any industry will result in energy consumption change reflected by energy coefficient effect of that same industry only. This conclusion is a result of analysis of changes in all the industries from Year 2-3.
3. The inter-linkage of industries becomes much more clear from Year 3-4 energy consumption change decomposition results. All the industries encountered a change in energy consumption (technology effect) because of increased dependency of industry 1 on industry 2's inputs for its production. The results can be read as increased production by industry 2

to supply industry 1, which in turn requires more inputs from itself, i.e. industry 2, industry 3 and also industry 1.

4. The increased dependency of industry 2 on itself, reciprocated by doubling the technical coefficient (2,2), results in energy consumption change reflected by way of technology effect in all the industries for Year 4-5. Thus, it can be concluded from points 3 and 4 that a change in technical coefficients of any one industry will result in energy consumption change in all the interlinked industries, reflected by technology effect in the decomposition.
5. Another important conclusion that could be drawn from Year 3-4 and Year 4-5 energy consumption change decomposition results is that maximum energy consumption change is reflected by the industry on which the dependency change is maximum, i.e. in our sample case 'Industry 2'.

After understanding the selective effect of each variation on energy consumption change decomposition, a cumulative effect of such variations simultaneously on same industry or different industries, as in real, is simulated by taking 3 scenarios (The base case from which the energy consumption change is measured is Year 1 for all the considered scenarios), as described below:

1) Scenario 1 – The final demand of industry 2 and 3 change by +100 and -100 respectively and the technical coefficient (2,1), i.e. dependency of industry 1 on industry 2 for its production, is approximately doubled (to 0.36) from the base case (Year 1).
2) Scenario 2 – The final demand of industry 2 is increased by 100, technical coefficient (3,2), i.e. dependency of industry 2 on industry 3 for its production, is approximately halved (to 0.15) and energy coefficient for industry 2 is doubled (to approx. 0.593) from the base case (Year 1).
3) Scenario 3 – The final demand of industry 2 in increased by 100, technical coefficients (2,1) and (2,2) are approximately doubled (to 0.36 and 0.22 respectively) and energy coefficient for industry 2 is doubled (to approx. 0.593) from the base case (Year 1).

The results of the energy consumption change decomposition analysis are given are given in

*Table 9: Industry 1 energy consumption change decomposition results for Scenario 1,2 and 3(S1, S2 and S3).*

| Industry 1 | | | |
|---|---|---|---|
| | **Year 1-S1** | **Year 1-S2** | **Year 1-S3** |
| **Energy coefficient effect** | 0 | 0 | 0 |
| **Technology effect** | 21.601 | -17.774 | 46.045 |
| **Final demand effect** | 1.250 | 9.426 | 11.641 |

*Table 10: Industry 2 energy consumption change decomposition results for Scenario 1,2 and 3(S1, S2 and S3).*

| Industry 2 | | | |
|---|---|---|---|
| | Year 1-S1 | Year 1-S2 | Year 1-S3 |
| Energy coefficient effect | 0 | 408.138 | 510.848 |
| Technology effect | 83.016 | -32.660 | 262.783 |
| Final demand effect | 28.335 | 57.076 | 69.762 |

*Table 11: Industry 3 energy consumption change decomposition results for Scenario 1,2 and 3(S1, S2 and S3).*

| Industry 3 | | | |
|---|---|---|---|
| | Year 1-S1 | Year 1-S2 | Year 1-S3 |
| Energy coefficient effect | 0 | 0 | 0 |
| Technology effect | 40.237 | -90.849 | 85.770 |
| Final demand effect | -27.082 | 14.846 | 21.685 |

From the developed results of the energy consumption change decomposition analysis for Scenario 1, 2 and 3, the following conclusions can be drawn:

1. No energy coefficient effect is observable unless there is a changed energy coefficient of that industry.
2. Final demand effect is observable in all the inter-linked industries even if there is a change in final demand in only one industry. The final demand effect, of an industry, is a cumulative effect of all the final demand changes of its inter-linked industries.
3. The technology effect results from the changes in technical coefficients and affect all the inter-dependent industries. The technology effect is a cumulative effect of technical coefficient changes, anywhere in the technical coefficient matrix.

### 4.7.1 Conclusion

Thus, with the conclusions from the different scenarios the following about the observable energy coefficient effect, technology effect and final demand effect can be inferred:

1. Energy coefficient effect is independent of any changes occurring in the input-output matrix. It is directly dependent on the changes in energy coefficient of the industry, i.e. a change in energy intensity/efficiency of the industry itself, without any influence from outside.
2. Final demand effect is a cumulative effect of final demand change of the industry itself or its inter-linked/interdependent industries. The more the inter-dependency, the larger is observable effect from a small final demand change.
3. Technology effect, similar to final demand effect, is a cumulative effect of technical coefficient changes anywhere in the technical coefficients matrix. The larger the change, the larger are its observable technology effects. Also, the more the inter-dependence, the larger its effects on the inter-dependent industries.

# 5 World Input-Output Database

In our analysis of energy intensity change in China and India we are using the World Input-Output Database. This chapter presents information about the World Input-Output Database, its characteristics and important considerations involved in its construction. Later in the chapter, a small analysis of the important sectors of the two economies under investigation (China and India) is also provided.

The European Union, in its Seventh Framework Programme for research and technological development financed the WIOD (World Input-Output Database) project. The project was envisioned as a tool based on a comprehensive database, which could provide the policy-makers with the right indicators and also be used by academic researchers to test and quantify theories (Dietzenbacher et al. 2013). The aim of the project was to develop databases, accounting works and models that could help in understanding the trade-offs between socio-economic and environmental developments on global scale. The foundation of the database lies in the economic linkages between industries in the chosen countries, which are represented as a set of harmonized supply and use tables (SUTs). The World Input-Output Database also provides data on international trade in goods and services integrated into inter-country input-output tables (Genty et al. 2012). The database incorporates these data for 27 European Union (EU) countries and 13 major economies (Australia, Brazil, Canada, China, India, Indonesia, Japan, South Korea, Mexico, Russia, Taiwan, Turkey and USA) and remaining world-regions aggregated under RoW (Rest of the World); for the time-period 1995-2009 (data for 2008 and 2009 are based upon estimates). The countries were chosen taking into consideration the sufficient quality of the data and the motive to cover major part of world-economy. The countries together formed more than 85 percent of the gross domestic product (GDP) in 2008 (Timmer et al. 2015). The database is helpful in addressing issues correlated with socio-economic aspects (such as employment and value added creation), including environmental aspects (such as energy use, greenhouse gas emissions, water use) (Dietzenbacher et al. 2013).

The World Input-Output Database provides yearly world input-output tables (WIOT) from 1995 onwards. These tables have been constructed keeping a well-defined conceptual framework based on the system of national accounts. The tables are based on officially published input-output tables incorporated with national accounts data and international trade statistics.

## 5.1 WIOD Characteristics

The core of the WIOD is a time-series of world input-output tables, which can be considered as a set of national input-output tables connected with each other by bilateral international trade. WIOT provides a complete and consistent outline of all transactions in the global economy between industries and final users across the chosen countries. WIOT characteristics are (Timmer et al. 2015):

1. WIOT represents the imports in broken form according to the country and industry of origin.
2. The transactions among industries in WIOT are represented in millions of US dollars and currency conversion was based on market exchange rates.
3. The transaction values are in basic prices reflecting all costs borne by producer.
4. International trade flows are expressed in "free on board" (fob) prices (i.e. zero cost of transportation to the ship) estimating international trade and transport margins.
5. The overall economy of each country has been divided into 35 industries for which the details are provided. It includes agriculture, mining, construction, utilities, 14 manufacturing industries, telecom, finance, business services, personal services, 8 trade and transport services, and 3 public services industries (Appendix A1).
6. The WIOTs utilize the published and publicly available data from national statistical institutes around the globe, to build these tables. They also acquire data from several international statistical sources (such as OECD and UN National Accounts). This ensures consistency and high data quality level.
7. The WIOTs represent a set of linear equations which are not linearly dependent and are fully determinate.

World Input-Output Database also provides database of environmental satellite accounts. They cover the widest range of environmental matters, while maintaining the data quality available in primary data. The themes covered by environmental satellites are: energy use; emissions related to main green-house gases; other main air-pollutants emissions; mineral and fossil resources use; land use and water use (Timmer et al. 2015).

## 5.2 Concepts and Structure of WIOD Energy database

WIOD has used IEA data (Energy balances of OECD and non-OECD countries) as the starting point to compile energy accounts. IEA provides the data in the form of extended energy balances. Details about the procedure undertaken and the assumptions made in developing the database can be found in Timmer et al. (2015).

WIOD employed the "Gross energy" concept to develop these energy accounts. The following equations govern the concept of gross energy supply and use.

$$\mathit{Gross\ supply}: \mathit{Domestic\ production} + \mathit{Imports} + \mathit{Inventory\ changes}$$
$$=$$
$$\mathit{Gross\ use}: \mathit{Intermediate\ consumption} + \mathit{Final\ use} + \mathit{Exports}$$

The downside of gross energy concept is that double counting is involved, but on the upside it is fully consistent with the way inputs are recorded in national accounts Use table. The implications of gross energy concept are:

1. Recorded oil inputs to refineries: The energy (in TJ) in the oil products is recorded twice; first in the oil products used for transportation, and in chemical and other sectors, and also in inputs to refineries.
2. Recorded fuel inputs to power sector: The power sector records the energy (in TJ) inputs to the power sector as energy commodities (i.e. gas input, coal input, uranium input etc.). All other sectors and households which utilize the electricity produced by power sector also record the energy input (in TJ), in the form of electricity. Thus resulting in double counting across the economy.

The schematic representation of the energy accounts in World Input-Output Database is provided in Table 12. The energy accounts are available for all 40 chosen countries for the time period 1995-2009. The WIOD sectors and energy commodities (fuels or energy sources) are listed in Appendix A1 (listing) and A2 respectively. From here on, in this document Gross energy use is addressed as Energy Use/Consumption.

*Table 12:Energy accounts in WIOD, a schematic representation.*

| Year | | World Input-Output Database Fuels | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| World Input-Output Database Sectors | | | | | | |
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## 5.3 China and India: major structural features

The importance of any sector can be determined by its impact on the economy, in terms of energy use, or value added, or the level of imports required to produce its output. Here in this section, a comparison of the different sectors and their contributions to the economic growth of the two economies is performed.

First, a comparison of India and China's Value Added as a percentage of World Value Added (left axis) is provided in Figure 24. The Real World Value Added (right axis) in USD is also provided in Figure 24.Value Added (in gross terms) is the sum of profit, depreciation cost and labor cost.

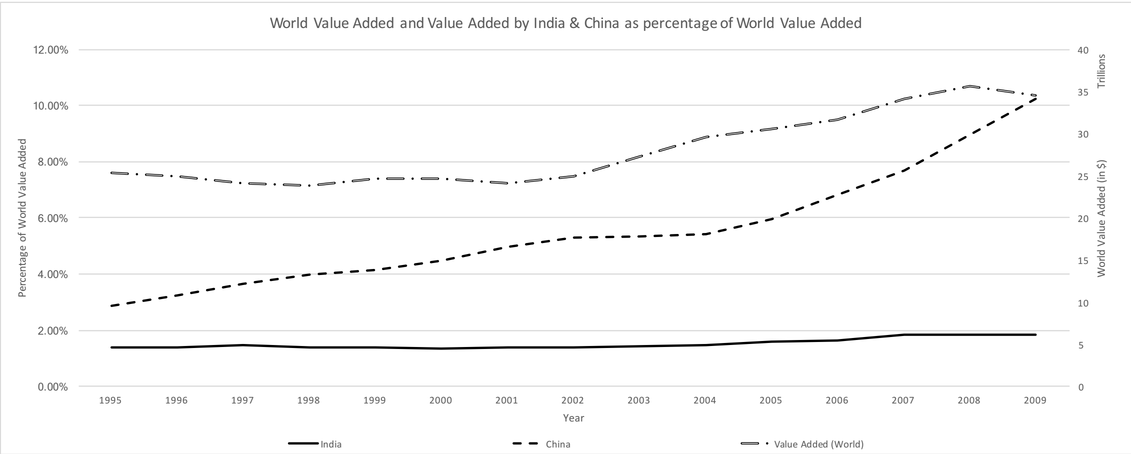


*Figure 24: Growth of REAL World Value Added and Value Added by India and China as percentage of the World Value Added.*

From Figure 24 it is clear that China experienced a higher growth in Value Added as compared to India, during 1995-2009. China's share in global value added increases steadily – from about 3% in 1995 to more than 10% in 2009. In contrast, India's growth in Value Added was just in-line with the growth in Value Added by the World and hence India's share in global value added stayed about constant at 2%. The two economies thus experienced strikingly different growth patterns during 1995-2009.

To understand the difference in growth, a comparison of the Value Added by important sectors of Indian and Chinese economy is available in Table 13. The sectors included in the comparison are:

1. Agriculture, Hunting, Forestry and Fishing sector – The sector with the maximum contribution in the total value added by the respective economy.
2. Two top performing service sectors of India - Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods sector and Financial Intermediation sector.
3. Top performing manufacturing sector of China – Electrical and Optical Equipment sector.

4. Top performing trading sector of China – Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles **sector.**
5. Four top energy consuming sectors of both the economies – Electricity, Gas and Water Supply sector, Coke, Refined Petroleum and Nuclear Fuel sector, Basic Metals and Fabricated Metal sector and, Food, Beverages and Tobacco sector.

*Table 13: Value Added by important sectors of India and China, as percentage of World Value Added (displayed as average percentage per year).*

| Value Added (as percentage of World Value Added) | | | | |
|---|---|---|---|---|
| | **1995-1999** | **2000-2003** | **2004-2007** | **2008-2009** |
| **Agriculture, Hunting, Forestry and Fishing** | | | | |
| India | 0.35% | 0.30% | 0.29% | 0.26% |
| China | 0.65% | 0.72% | 0.71% | 0.84% |
| **Retail Trade. Except of Motor Vehicles and Motorcycles; Repair of Household Goods** | | | | |
| India | 0.12% | 0.12% | 0.14% | 0.16% |
| China | 0.05% | 0.07% | 0.14% | 0.14% |
| **Financial Intermediation** | | | | |
| India | 0.08% | 0.09% | 0.12% | 0.15% |
| China | 0.16% | 0.20% | 0.25% | 0.42% |
| **Electrical and Optical Equipment** | | | | |
| India | 0.02% | 0.02% | 0.03% | 0.03% |
| China | 0.14% | 0.28% | 0.49% | 0.82% |
| **Wholesale Trade and Commission Trade. Except of Motor Vehicles and Motorcycles** | | | | |
| India | 0.06% | 0.07% | 0.09% | 0.10% |
| China | 0.23% | 0.32% | 0.35% | 0.66% |
| **Electricity. Gas and Water Supply** | | | | |
| India | 0.04% | 0.04% | 0.04% | 0.04% |
| China | 0.07% | 0.11% | 0.17% | 0.23% |
| **Coke. Refined Petroleum and Nuclear Fuel** | | | | |
| India | 0.01% | 0.01% | 0.02% | 0.02% |
| China | 0.03% | 0.05% | 0.06% | 0.08% |
| **Basic Metals and Fabricated Metal** | | | | |
| India | 0.04% | 0.03% | 0.03% | 0.04% |
| China | 0.18% | 0.26% | 0.38% | 0.59% |
| **Food. Beverages and Tobacco** | | | | |
| India | 0.03% | 0.02% | 0.03% | 0.03% |
| China | 0.18% | 0.24% | 0.31% | 0.44% |

In 1995, both India and China still had large agricultural sectors. The share of agriculture in value added in China in 1995 was 20% in 1995 and in India it was 26%.

Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods sector and Financial Intermediation sector were responsible for making the second and third largest contribution, on average, to Value Added by India. The growth was more prominent in almost all the sectors of China as compared to India. India experienced growth in primarily the services sector, while China's growth was a result of growth in manufacturing and trading sectors.

*Table 14: Imports as a percentage of the total inputs required for production by the sector (displayed as average percentage per year).*

| Imports (as percentage of total inputs for production in the sector) | | | | |
|---|---|---|---|---|
| | 1995-1999 | 2000-2003 | 2004-2007 | 2008-2009 |
| **Agriculture, Hunting, Forestry and Fishing** | | | | |
| India | 3% | 2% | 3% | 3% |
| China | 4% | 4% | 5% | 4% |
| **Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods** | | | | |
| India | 6% | 4% | 7% | 8% |
| China | 5% | 5% | 8% | 7% |
| **Financial Intermediation** | | | | |
| India | 5% | 3% | 7% | 6% |
| China | 4% | 5% | 7% | 6% |
| **Electrical and Optical Equipment** | | | | |
| India | 10% | 10% | 15% | 14% |
| China | 13% | 18% | 26% | 19% |
| **Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles** | | | | |
| India | 6% | 4% | 7% | 8% |
| China | 5% | 5% | 8% | 7% |
| **Electricity, Gas and Water Supply** | | | | |
| India | 4% | 4% | 7% | 8% |
| China | 4% | 6% | 8% | 7% |
| **Coke, Refined Petroleum and Nuclear Fuel** | | | | |
| India | 2% | 2% | 2% | 3% |
| China | 5% | 4% | 5% | 4% |
| **Basic Metals and Fabricated Metal** | | | | |
| India | 6% | 7% | 9% | 8% |
| China | 6% | 6% | 8% | 7% |
| **Food, Beverages and Tobacco** | | | | |
| India | 3% | 2% | 3% | 3% |
| China | 3% | 2% | 3% | 3% |
| **Post and Telecommunications** | | | | |
| India | 13% | 13% | 17% | 14% |
| China | 9% | 14% | 18% | 13% |
| **Other Non-Metallic Minerals** | | | | |
| India | 17% | 13% | 12% | 9% |
| China | 4% | 5% | 6% | 4% |
| **Manufacturing, Nec; Recycling** | | | | |
| India | 7% | 20% | 41% | 51% |
| China | 7% | 7% | 7% | 5% |
| **Air Transport** | | | | |
| India | 6% | 9% | 21% | 29% |
| China | 7% | 6% | 8% | 7% |
| **Other Community, Social and Personal Services** | | | | |
| India | 11% | 16% | 35% | 45% |
| China | 6% | 7% | 10% | 8% |

This result is supported by Ghose (2015), which states that India experienced services led growth post-1980 period and the economic reforms of early 1990s strengthened it even more. It also goes on to state that the acceleration in GDP growth in India, towards the end of 1990s was a result of growth of services. The services growth was related to growth of non-traded services and was mainly a result of growth in domestic demand and not growth of exports. Ghose (2015) also found that the share of both industry and services, in GDP, was high and growing simultaneously in China.

Table 14 presents the average import percentages for the different sectors. The sectors selected are the ones compared above (on the basis of Value Added) and a few other sectors which show high imports in either or both the countries. Import along with export forms the backbone of international trade. The higher the imports as compared to exports the more negative the economies Balance of Trade (BOT). BOT is the difference between a country's imports and exports over a given time-period. It is clear from Table 14 that Electrical and Optical Equipment sector is one of the more importing sectors in both the economies. The Post and Telecommunications sector, of both the economies, also imports comparatively large percentage of its inputs. The other sectors of India with large imports as inputs are: 1) Other Non-Metallic Minerals, 2) Manufacturing, Nec; Recycling, 3) Air Transport, and 4) Other Community, Social and Personal Services.

*Table 15: Exports, Imports and Balance of Trade, of India and China, as a percentage of Value Added (displayed as average percentage per year).*

| | 1995-1999 | 2000-2003 | 2004-2007 | 2008-2009 |
|---|---|---|---|---|
| **Exports/Value Added** | | | | |
| India | 13.51% | 21.16% | 32.22% | 33.82% |
| China | 22.75% | 32.26% | 61.75% | 64.17% |
| **Imports/Value Added** | | | | |
| India | 15.14% | 22.19% | 41.81% | 52.06% |
| China | 17.50% | 24.19% | 39.89% | 37.31% |
| **Balance of Trade/Value Added** | | | | |
| India | -1.63% | -1.03% | -9.59% | -18.24% |
| China | 5.25% | 8.07% | 21.86% | 26.86% |

Table 15 presents the aggregate Exports, Imports and Balance of Trade (BOT), of India and China, as a percentage of aggregate Value Added of India and China respectively. It is evident, that exports and imports of both India and China grew over the considered time-period, but the rate of increase of imports was more than exports for India and vice-versa for China. This, resulted in an increasing BOT deficit for India and surplus BOT for China. From the table it is clear that China essentially has grown into a large exporter of goods and services in the world. India's exports were growing but not at the same rate as that of China's.

Table 16 presents the export percentages of the top three exporting sectors of both the economies. The exports of each sector are represented as percentage of the total exports of the country in the year.

*Table 16: Sectoral exports as percentage of Total exports (displayed as average percentage per year).*

| Sectoral exports as percentage of Total export | | | | |
|---|---|---|---|---|
| | 1995-1999 | 2000-2003 | 2004-2007 | 2008-2009 |
| **Textiles and Textile Products** | | | | |
| India | 21.75% | 20.63% | 13.44% | 12.50% |
| China | 20.33% | 16.17% | 13.23% | 14.48% |
| **Manufacturing, Nec; Recycling** | | | | |
| India | 9.86% | 7.92% | 11.95% | 16.00% |
| China | 2.95% | 4.09% | 2.82% | 3.38% |
| **Chemicals and Chemical Products** | | | | |
| India | 9.49% | 12.12% | 10.33% | 7.34% |
| China | 4.40% | 4.33% | 4.20% | 3.90% |
| **Electrical and Optical Equipment** | | | | |
| India | 3.05% | 3.46% | 5.35% | 9.87% |
| China | 20.58% | 27.50% | 38.23% | 37.55% |
| **Basic Metals and Fabricated Metal** | | | | |
| India | 3.74% | 6.60% | 7.72% | 7.99% |
| China | 7.93% | 6.86% | 7.28% | 7.26% |

Textiles and Textile Products sector was a major exporting sector of both the economies, but it is visible that, on the whole, the share of exports of the sector experienced a continuous drop in both the economies during the considered time-period. On average, Electrical and Optical Equipment sector was the maximum exporting sector of China and its share of exports continuously rose during 1995-2009. This finding is also backed by Saccone and Valli (2009), who found that in 1990s and later, the electrical appliances sector accompanied by microelectronics, telecommunication and energy were the crucial sectors for growth. Contradictory to the popular belief, Manufacturing, Nec; Recycling was, on average, the second largest exporting sector of India and also the share of exports of the sector grew during the considered time-period. The findings of Ghose (2015) also state that even though the service sectors were the main driving force for economic growth, but their contribution to exports was comparatively small. Chemicals and Chemical Products and Basic Metals and Fabricated Metal sectors were the third largest exporting sectors (on average) of India and China, respectively.

Table 17 presents the top three importing sectors of both the economies. The sectoral imports are defined as a percentage of the total imports by the country in the year.

Ironically, Electrical and Optical Equipment sector is not only the maximum (on average) exporting sector but also the maximum importing sector. This observation is explained by Uegaki (2010); the research showed that many raw materials and half-finished products are imported, processed and then exported by Chinese companies. This is why China is also termed as the factory of the world. This explains the observation that Chinese Electrical and Optical Equipment sector is both, a large exporter as well as an importer.

*Table 17: Sectoral imports as percentage of Total imports (displayed as average percentage per year)*

| Sectoral imports as percentage of Total imports | | | | |
|---|---|---|---|---|
| | 1995-1999 | 2000-2003 | 2004-2007 | 2008-2009 |
| **Coke, Refined Petroleum and Nuclear Fuel** | | | | |
| India | 9.45% | 20.70% | 13.31% | 10.70% |
| China | 2.88% | 4.37% | 4.52% | 5.53% |
| **Construction** | | | | |
| India | 8.79% | 9.90% | 11.62% | 11.49% |
| China | 4.80% | 6.03% | 5.27% | 5.43% |
| **Basic Metals and Fabricated Metal** | | | | |
| India | 6.31% | 6.05% | 6.80% | 6.09% |
| China | 6.22% | 4.75% | 6.59% | 7.76% |
| **Electrical and Optical Equipment** | | | | |
| India | 1.51% | 2.48% | 2.77% | 2.51% |
| China | 9.86% | 15.03% | 20.67% | 19.29% |
| **Chemicals and Chemical Products** | | | | |
| India | 5.82% | 5.59% | 4.24% | 3.66% |
| China | 4.94% | 4.96% | 5.88% | 6.75% |

Coke, Refined Petroleum and Nuclear Fuel sector of India is the largest importer. This also shows India's dependence on externally produced non-renewable sources of energy. But, it is also evident from the table that the sector's share of imports declined post-2000. India's Construction sector constituted a large share of total imports of India. Similar to electrical equipment sector, Basic Metals and Fabricated Metal sector was also a large importer and exporter in the Chinese economy. These observations explain that China during the study period was acting as the manufacturing hub of the world.

## 5.4 Summary

World Input-Output Database is a free of cost accessible database available from www.wiod.org. It is a European Union financed project. It provides the Input-Output data for 27 EU countries and 13 other major economies between 1995-2009 in its 2013 release. The rest of the countries, which form the remaining 15 percent of the world economy are included in database under the name "Rest of the World". The database also provides harmonized environmental accounts for the countries, which includes energy use, emissions related to main green-house gases, other main air-pollutants emissions, mineral and fossil resources use, land use and water use. The energy use data, in combination with world input-output data will be used to decompose and analyze the energy use change year over year during 1995-2009, in both the economies and respective sectors.

Comparing the Value Added by India and China, during 1995-2009, it is evident that China was growing and its share of the World Total Value Added was constantly increasing during the considered study period. However, India's share of World Value Added was almost stagnant. Considering that the world economy was growing during the considered study period, by virtue of logic the Indian economy was also growing but at almost the same rate as the World economy. Further a comparison of the different sectors of India and China on Value Added basis, it is clear that agriculture sector (Agriculture, Hunting, Forestry and Fishing), of both economies, had the maximum contribution to total Value Added by India and China, respectively. The Value Added by India's agriculture sector experienced a decrease, during the time-period 1995-2009, while that of China's was increasing. The Indian economy was moving towards a services-led economy, on the other hand Chinese economy was becoming more manufacturing and trading-led. The imports by the different sectors of India and China also experienced growth during 1995-2009. The maximum energy consuming sectors (Electricity, Gas and Water Supply, and Coke, Refined Petroleum and Nuclear Fuel) were neither heavily contributing to Value Added, nor to imports. The other high energy consuming sectors (Basic Metals and Fabricated Metal, and Food, Beverages and Tobacco) made a fair contribution to Value Added of both India and China. Their imports were almost constant during 1995-2009.

Comparing the exports and imports of the different sectors of India and China, it can be concluded that both exports and imports of both the economies were growing, but China's exports were growing faster than its imports and vice versa for India. The BOT deficit of India was constantly increasing while China's BOT surplus was increasing. China's imports and exports were mainly the result of China's manufacturing sectors which import raw or half-finished goods and process it and then export it again. China was rightly termed as factory of the world. India's service sectors experienced the maximum growth, but this growth was fueled by growth in internal demand and not because of exports; the manufacturing sector was the largest exporting sector. Non-renewable energy sources were the main imports of India, which experienced a decline in share of imports over the study period.

# 6 Energy Intensity Change: A Decomposition Analysis for China and India (1995-2009)

This chapter presents and evaluates the findings of the Structural Decomposition Analysis of energy consumption in China and India (1995-2009) based on data from the World Input-Output Database. The results are discussed in a step by step manner, moving from the aggregate (country) level to different renewable energy technologies and further to the top industries with the highest energy consumption change observed during the chosen time period.

## 6.1 India v/s China Energy Use and Energy Intensity

Before we decompose total energy use, it is useful to consider the evolution of Total Energy Use in China and India over the period of analysis – which is illustrated in Figure 1. As Figure 1 shows, China has had higher energy consumption than India during the whole period. This observation can be attributed to the bigger size of China's economy. Another observation from Figure 25, which is further elaborated in Figure 26 and Figure 28, is that China experienced a steep increase in energy consumption since 2002, which can be accredited to acceleration in China's economic growth following its entry into the World Trade Organization (WTO) in December 2001. China's entry into the WTO meant, a more liberalized market for Chinese producers with less restrictions on retail activities and more foreign investment flow into China (Saccone & Valli, 2009). This meant an increased production and increased energy need (Zhao et al., 2010), which is illustrated by the sudden and continuous increase in Total Energy Use since 2002.

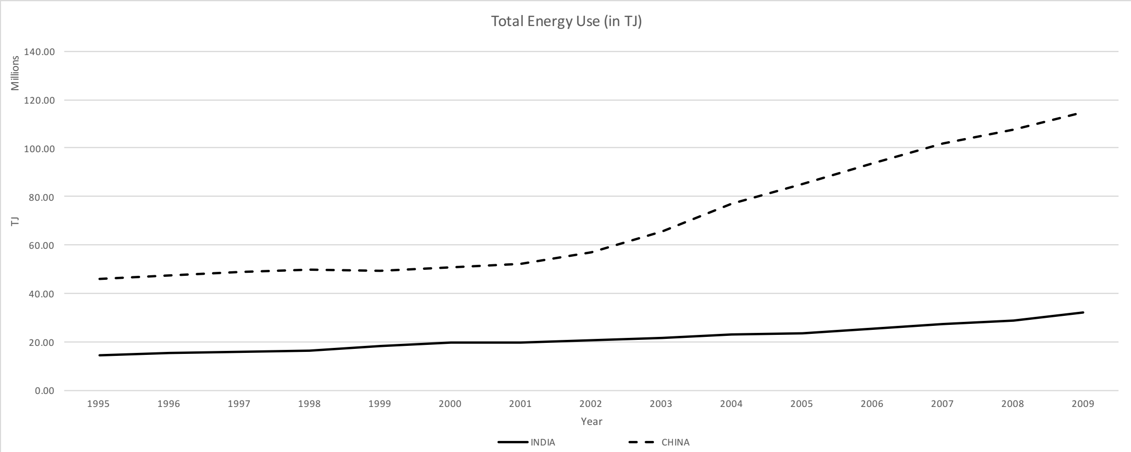


*Figure 25: Total Energy Use of India and China between 1995 and 2009.*

Figure 26 and Figure 27 show the developments in Total Energy Use and Value Added, of India and China, as percentage of World's Total Energy Use and World's Total Value Added respectively. Observing the two graphs, it is clear that China had, for major part of the chosen time period, a growing energy consumption and value added. India on the other hand registered a growth rate of energy consumption which was about equal to the growth of global energy use; the growth of Indian value added was also close to the growth of global value added for major part of chosen time period. China, on the other hand, experienced a growth rate of value added higher than the average growth rate of the world value added for the whole time period (Figure 27).

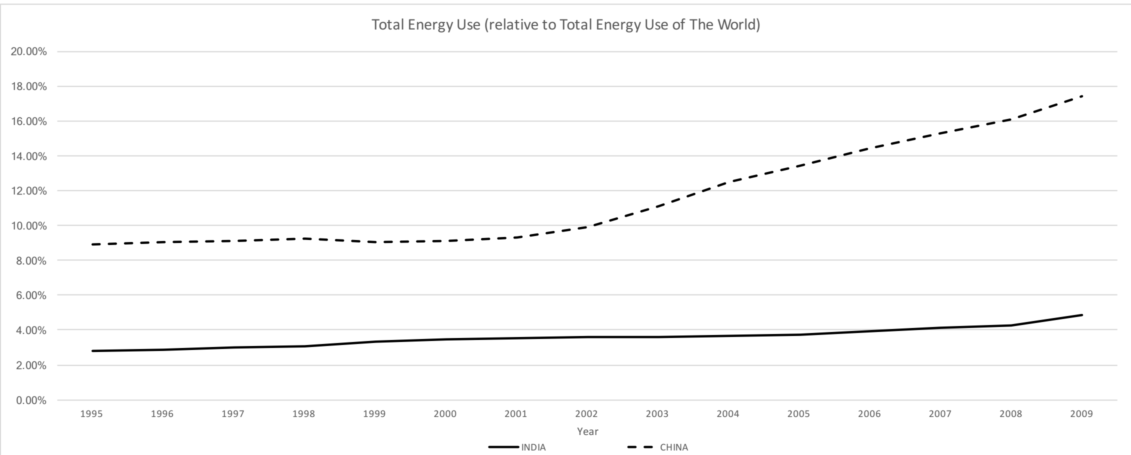


*Figure 26: Percentage Total Energy Use of India and China relative to World's Total Energy Use for the respective year.*

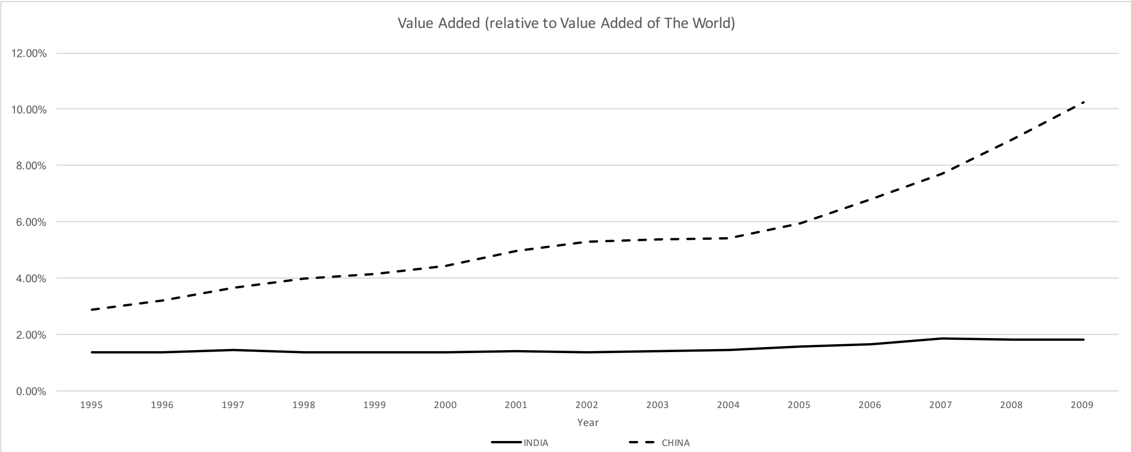


*Figure 27: Percentage Value Added of India and China relative to World's Total Value Added for the respective year.*

An interesting observation in Figure 26, which is corroborated by Figure 28, is that China experienced a decline in energy consumption in 1999 followed by a slow growth in energy consumption for the next few years. This can be associated with the enactment of the Energy Conservation Law (1997) passed by National People's Congress (NPC). The effects of the implementation of a similar Act, Energy Conservation Act 2001, a Government of India initiative, seems to have had almost a negligible effect, as illustrated by Figure 28, other than a comparatively slow growth in energy consumption, for the next few years since the Act was launched. In Figure 29 we compare trends in Total Energy Use (left axis) and in Energy Intensity (right axis) in India. Looking at Figure 29 closely, the effects of Energy Conservation Act 2001 become clearer. Although Total Energy Use was constantly increasing, the energy intensity saw a decline, for almost six years during 2002 - 2008.

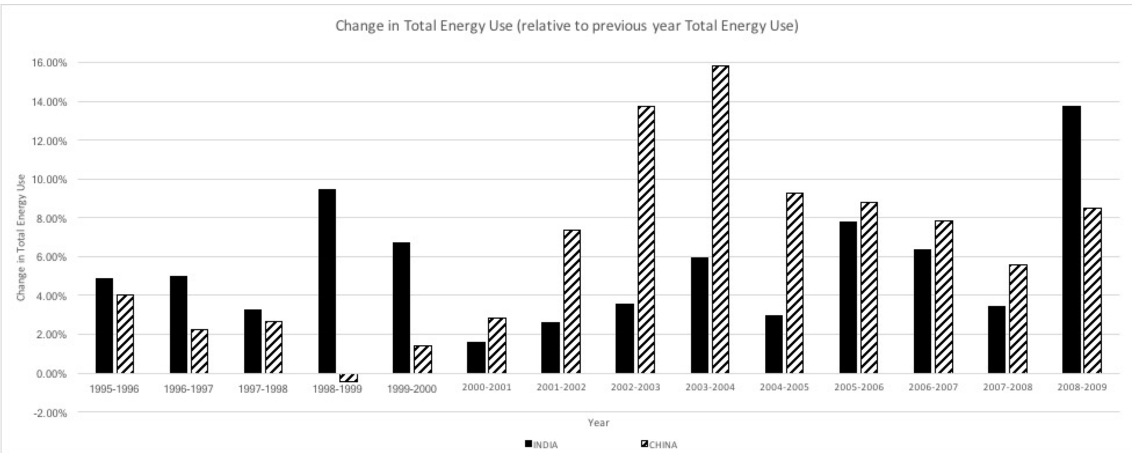


*Figure 28: Percentage Total Energy Use change for India and China, between 1995 and 2009, relative to the previous year Total Energy Use of India and China respectively.*

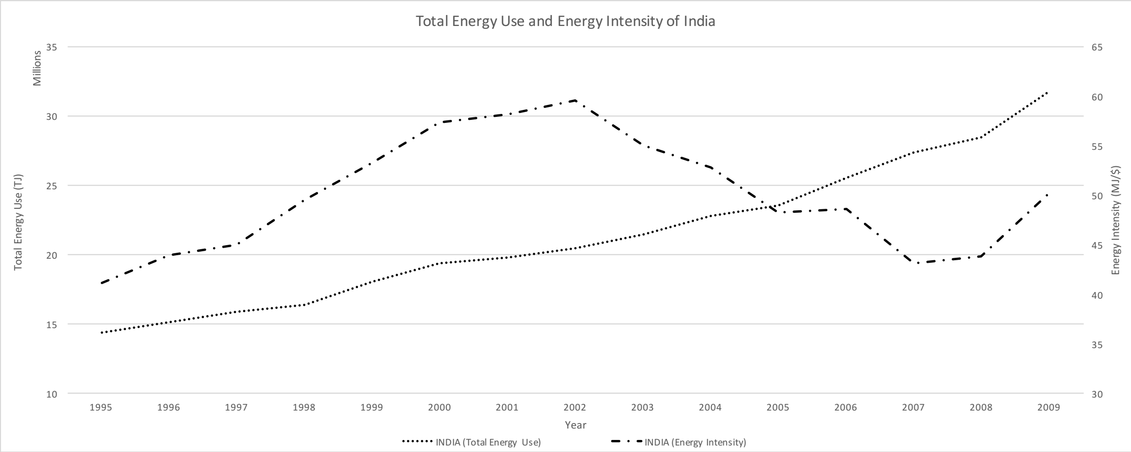


*Figure 29: Total Energy Use and Energy Intensity of India between 1995 and 2009.*

Simultaneous observation of Figure 26 and Figure 27 shows that while the Total Energy Use (as a share of global energy use), for China, was increasing constantly post-2002, the Value Added (as a share of global value added) stagnated until 2004 before increasing again until the end of period. Taken together, this meant a relative increase in China's energy intensity for the same time-period, a pattern that is also visible in Figure 30. An explanation of this observation (increasing energy consumption and stagnating value added) can be that entry of China to WTO meant increased production, from increased exports and increased foreign investment, meaning an increase in energy consumption while there were no commensurate improvements in energy technology. Thus, this energy technology stagnation meant an increasing energy consumption and a stable growth in value added.

Comparing energy intensity developments of India and China, using Figure 29 and Figure 30, it becomes clear that China managed to reduce its energy intensity more than what India was able to achieve, even though China remained a manufacturing (energy intensive sector) led economy. However, India, despite being a services (less energy intensive) -led economy, could not match the reduction in energy intensity to the extent achieved by China.

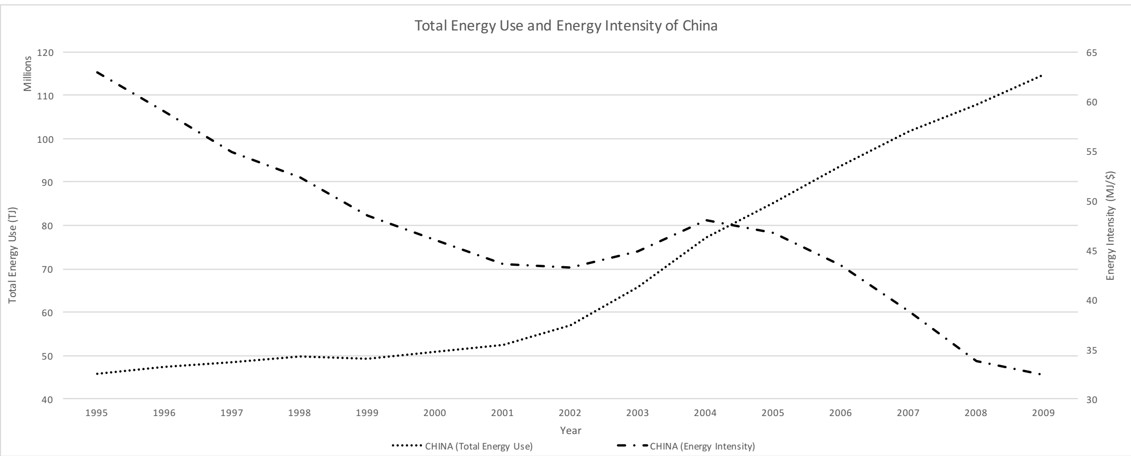


*Figure 30: Total Energy Use and Energy Intensity of China between 1995 and 2009.*

A detailed analysis of the effects of 2008 financial crisis on the energy consumption was not possible because of the limitation of availability of data only until 2009. However, as shown by Figure 30, the data up to 2009 suggest that the financial crisis did little to upset the declining trend in China's aggregate energy intensity. In contrast, as shown by Figure 29, aggregate energy intensity in India increased in 2009, compared to the years 2007 and 2008. This difference in post-financial crisis experiences is remarkable. We can try to investigate its causes by looking at the results of Structural Decomposition Analysis which appear in Figure 31 (for India) and Figure 32 (for China).

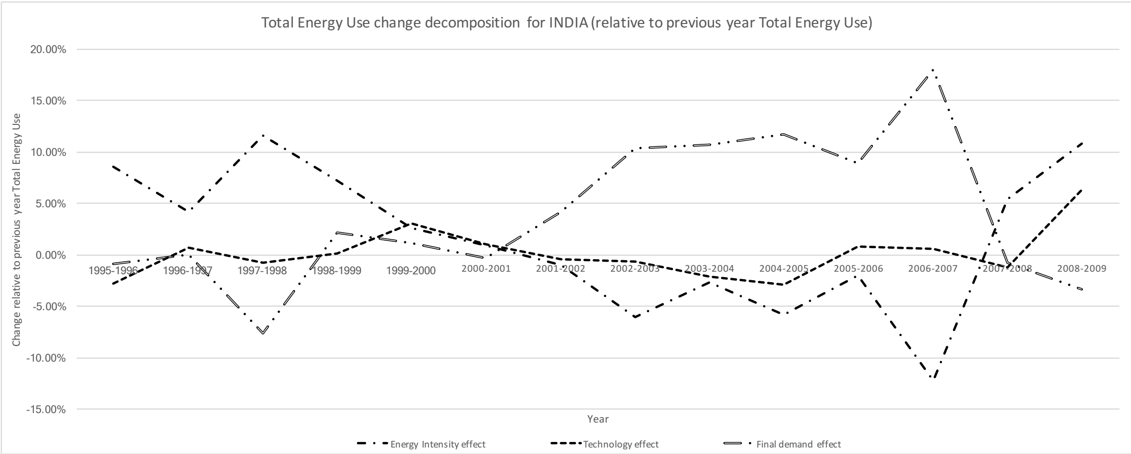


*Figure 31: Total Energy Use change decomposition for India between 1995 and 2009.*

Using the SDA method outlined in Chapter 4, Figure 31 and Figure 32 provide a graphical representation of the effects of energy intensity change, technology change and final demand change on the Total Energy Use change; all changes are expressed as percentage of previous year Total Energy Use of the country.

The change in final demand has, on an average, resulted in increasing the Total Energy Use for both the countries during the pre-crisis period 2000-2008. Viewing Figure 31 carefully, it can be noticed that in the case of India the energy intensity changes and final demand changes had opposite effects on the Total Energy Use change throughout the time-period. Until the launch of India's Energy Conservation Act 2001, energy intensity was increasing, thus leading to an increasing Total Energy Use. It is safe to consider that Energy Conservation Act did lead to decreasing Total Energy Use by way of energy intensity changes acting to reduce the energy consumption, until the financial crisis of 2008. However, final demand changes had a negative effect (in aggregate) on Total Energy Use until 2001, after which final demand changes seem to have been the major reason behind India's increasing Total Energy Use.

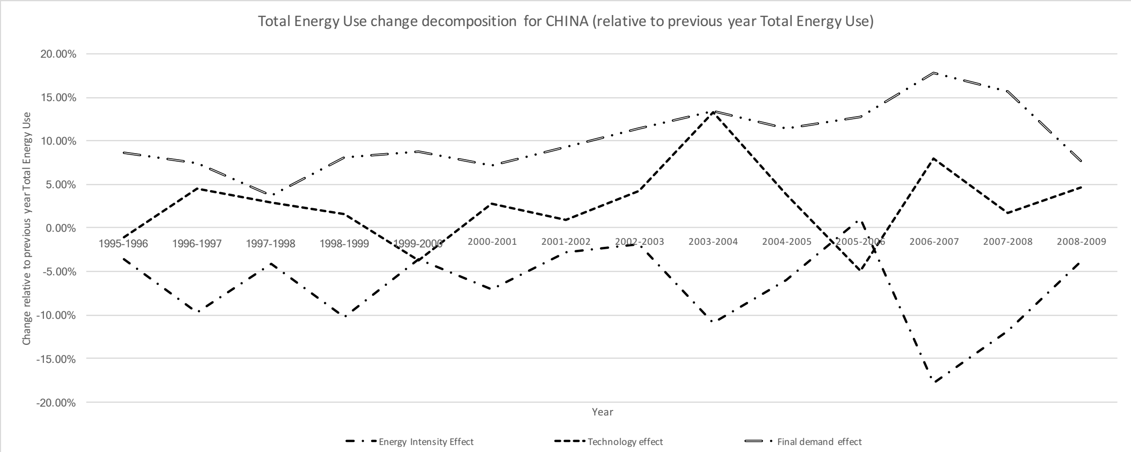


*Figure 32: Total Energy Use change decomposition for China between 1995 and 2009.*

For China, it is reasonable to conclude that final demand change has been the leading factor and technology change the second leading factor for the energy consumption increase over the whole study period. Conversely, energy intensity changes acted to reduce the Total Energy Use, throughout the considered time-period. This means that China experienced a reduction in energy intensity during 1995-2009 (as was shown already in Figure 30). This means that China's energy efficiency increased.

In conclusion, the Total Energy Use of both the countries increased over the considered study period, and this increase was largely caused by growing final demand. This means that the markets in both the countries were expanding, either internally or by way of exports or both. It is reasonable to infer from the SDA that the energy conservation efforts by both the countries bore fruit as the energy intensity change had a negative effect on Total Energy Use over the years; energy intensity declined and (conversely) energy efficiency improved in both economies. Thus, the energy conservation efforts helped to lower the Total Energy Use increase, due to final demand change and technology change. The results from the SDA so far do not shed much light on the structural changes taking place in the two economies. In Section 6.3 the five sectors, of both the countries, which experienced the highest Total Energy Use changes, are evaluated and their Total Energy Use change is decomposed to provide a better understanding of the structural changes taking place in the two economies.

## 6.2 Renewable Energy Consumption Decomposition

This section reviews the developments and trends in China's and India's renewable energy sectors in the period 1995-2009. Both economies have considerable potential in terms of renewable energy generation, as was discussed in Chapter 4. This section looks into actual developments (realizations) in terms of renewable energy use. Consider first, Figure 33 which shows the developments of Renewable energy consumption in the two countries.

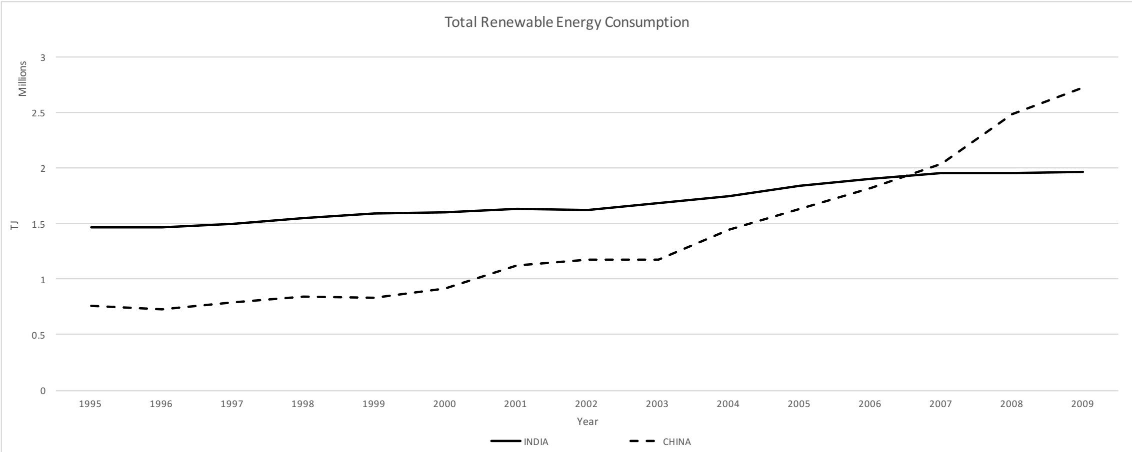


*Figure 33: Total Renewable Energy consumption of India and China, between 1995 and 2009.*

Both the countries showed an increasing trend in the renewable energy use, but of the two, China displayed a higher growth in renewable energy consumption.

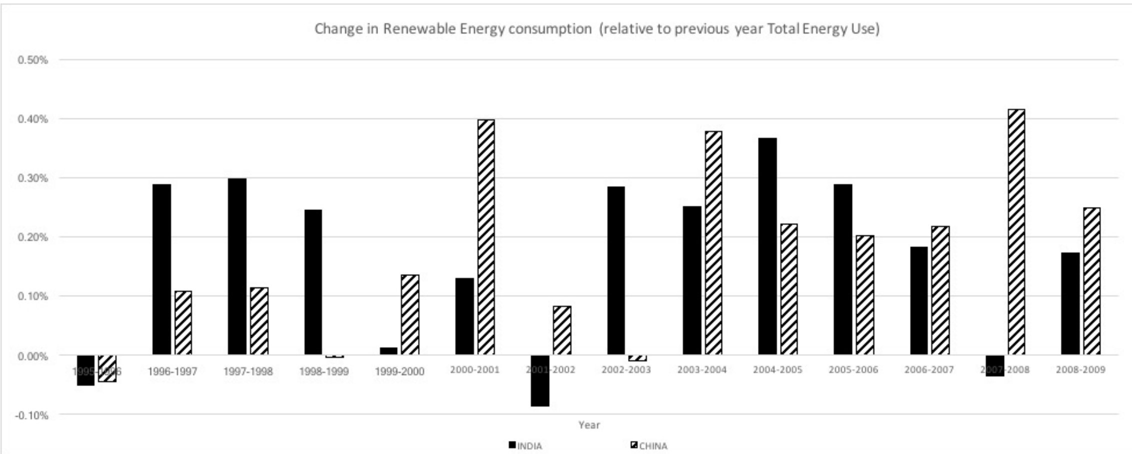


*Figure 34: Percentage Total Renewable Energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Energy Use of India and China respectively.*

The observations of Figure 33 are borne out by Figure 34 . However, it can be seen that the change in Renewable energy consumption as percentage of Total Energy Use for India was comparable to that of China for most of the years, while Figure 33 shows a slow growth in renewable energy consumption in India. Taken together, this means that the renewable energy consumption growth rates in the two countries over the period 1995-2009 were almost equal, in terms of total energy use of each country, but the actual growth of renewable installed capacities were different. Another interesting observation that could be made from Figure 34 is that every sixth year India measured a slump in renewable energy consumption growth.

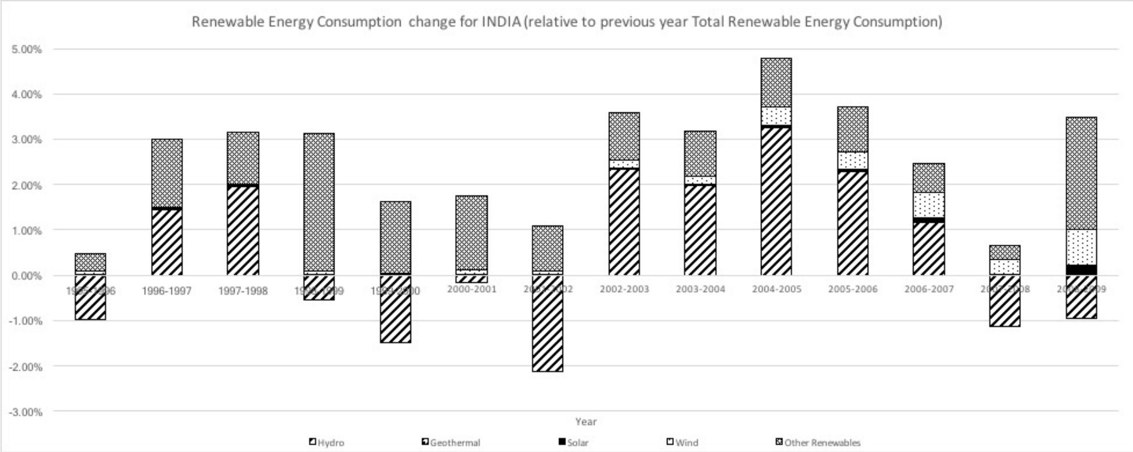


*Figure 35: Percentage Total Renewable Energy consumption change of India, between 1995 and 2009, relative to previous year Total Renewable Energy Use of India.*

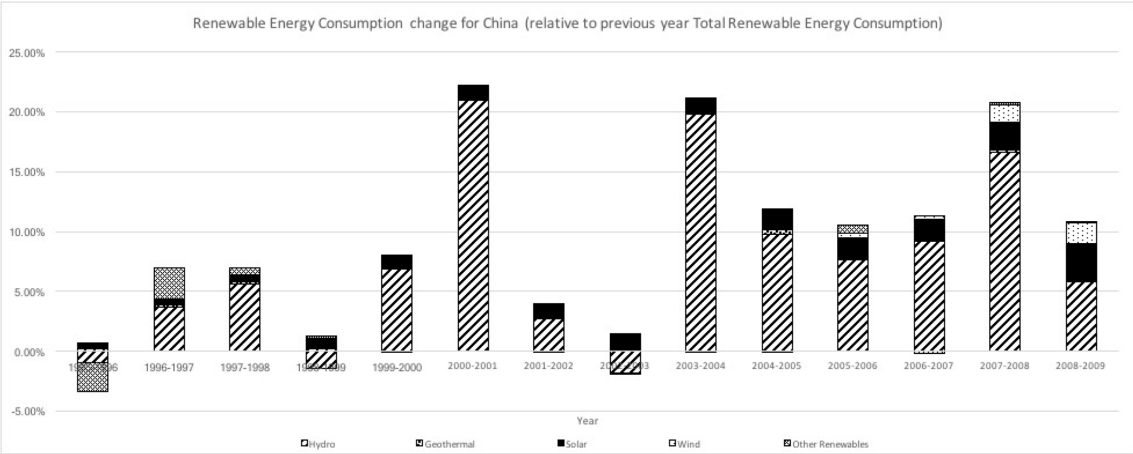


*Figure 36: Percentage Total Renewable Energy consumption change of China, between 1995 and 2009, relative to previous year Total Renewable Energy Use of China.*

China registered the highest growth in renewable energy consumption in the second half of the chosen time-period. Comparing Figure 36 and Figure 28 for China, it becomes clear that the renewable energy consumption growth was on an average more than the total energy consumption growth, while on the other hand India's total energy consumption was growing much faster than the growth of India's renewable energy consumption (Figure 35 and Figure 28).

It is clear, for both the countries, that the growth of the renewable energy sector was limited when compared to the total energy consumption growth during 1995 and 2009. Renewable energy consumption registered an average annual growth rate of 2.05% (India) and 9.34% (China), expressed as percentage of previous year Total Renewable Energy Consumption, but only 0.17% (India) and 0.18% (China), when expressed as percentage of previous year Total Energy Use. The renewable energy consumption annual growth percentages are low when compared to average annual growth of 5.50% (India) and 6.40% (China) in Total Energy Use, expressed as percentage of previous year Total Energy Use.

The total energy consumption of both the countries was growing and considerable growth in the renewable energy sector was also visible, but the renewable energy consumption was such a small part of the total energy consumption that its effects were not really visible as a percentage of the total energy use (Figure 34).

Figure 35 and Figure 36 also show a breakup of the Total Renewable Energy growth into Hydro-powered, Solar-powered, Wind-powered, Geothermal-powered and Other renewables powered energy consumption growth. The highest growth, in both the countries, was observed in Hydro-powered energy consumption.

In case of India, contribution of Other Renewables (Bio-gasoline, Bio-diesel, Bio-gas etc.) was a significant proportion of the renewable energy consumption growth, all throughout the study period. The contribution of Wind-powered energy consumption towards renewable energy consumption growth is only visible in the second half of the study time-period. Solar-powered energy consumption growth was almost negligible during the period 1995-2009, while geothermal-powered energy consumption growth was (close to) zero.

In China's case (Figure 36) after Hydro-powered energy, the major renewable energy growth contribution came from Solar-powered energy which saw a uniformly growing trend. The growth of Wind-powered energy during major part of study period was miniscule except the last two years.

### 6.2.1 A decomposition of the hydro-powered energy consumption change: India and China (1995-2009)

This section takes a closer look at the change in hydro-powered energy use in India and China (1995-2009), as this is the fastest growing source of renewable energy in both economies.

Figure 37 compares the growth of Hydro-powered energy consumption change as a percentage of Total Renewable Energy Use. It can be seen from the graph that Hydro-powered energy growth was higher in China than in India, also illustrated in Figure 20 showing hydropower cumulative installed capacity developments in the two countries.

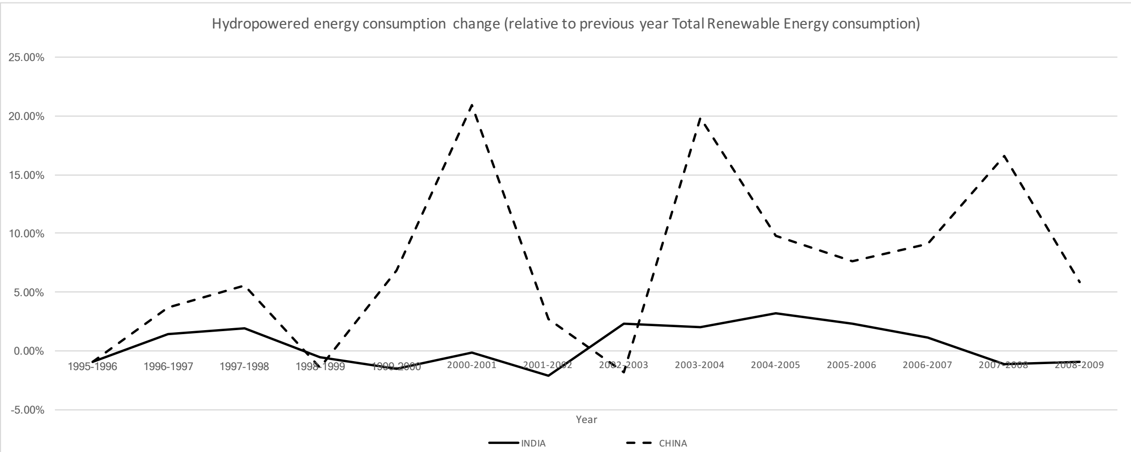


*Figure 37: Percentage Hydro-powered energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Renewable Energy Use of India and China respectively.*

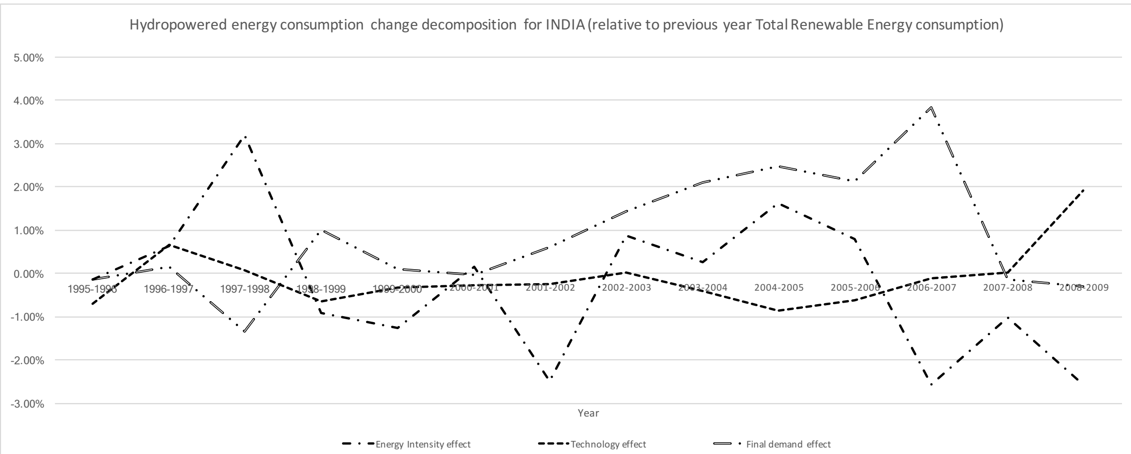


*Figure 38: Hydro-powered energy consumption change decomposition for India, between 1995 and 2009.*

Figure 38 provides the decomposition of the Hydro-powered energy consumption change for India. As per the analysis, the growth of final demand was the major driver of the Hydro-power based energy consumption growth. The technology change effect on the hydro-powered energy consumption was not considerable, while the energy intensity change contributed positively as well as negatively to the growth of hydro-powered energy use.

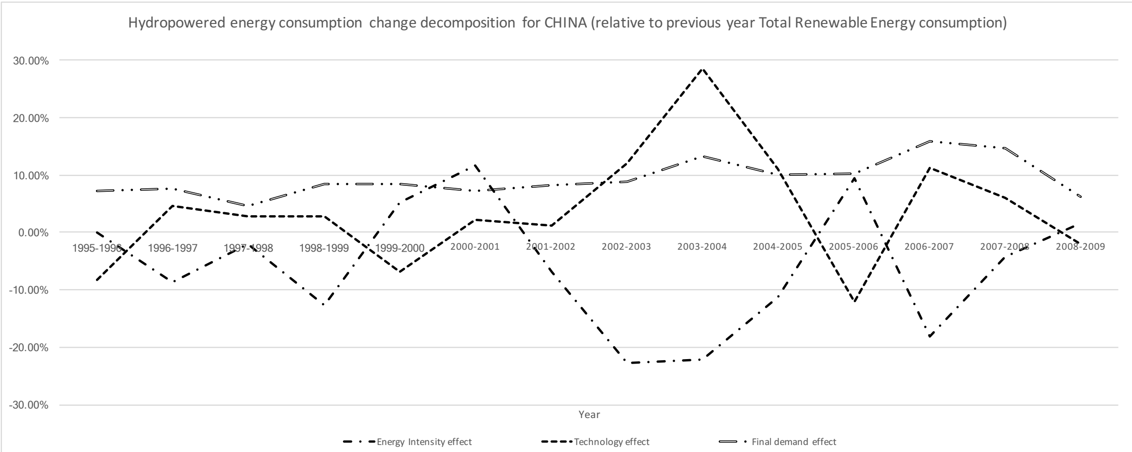


*Figure 39: Hydro-powered energy consumption change decomposition for China, between 1995 and 2009.*

As compared to India, China's growth of Hydro-powered energy consumption was higher and a major reason behind this was the final demand change effect. But, the contribution of technology change and energy intensity change were also considerable. It is interesting to note that technology change and energy intensity followed an opposite trend to each other throughout the study period, essentially nullifying the effects of each on the Hydro-powered energy consumption change.

### 6.2.2 A decomposition of geothermal-powered energy consumption change: India and China (1995-2009)

As discussed before, India had a zero growth in Geothermal-powered energy consumption and China also had a very limited growth in the area; the same is evident from Figure 40.

Decomposing the Geothermal-powered energy consumption for China (Figure 41), the major factor for the growth was final demand change, while technology change effect was insignificant and energy intensity change effect was variable for the time period considered. This resulted in an oscillating effect on the growth of Geothermal-powered energy consumption.

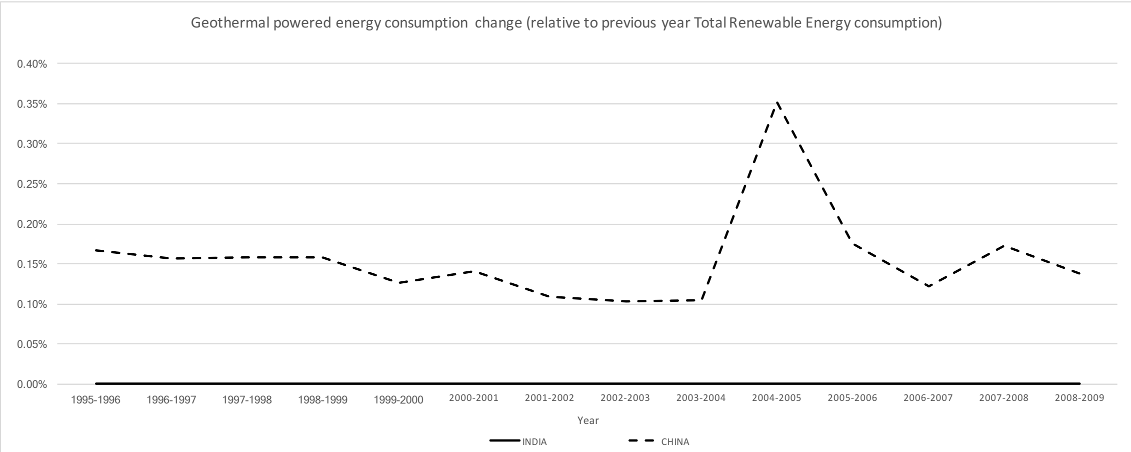


*Figure 40: Percentage Geothermal-powered energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Renewable Energy Use of India and China respectively.*

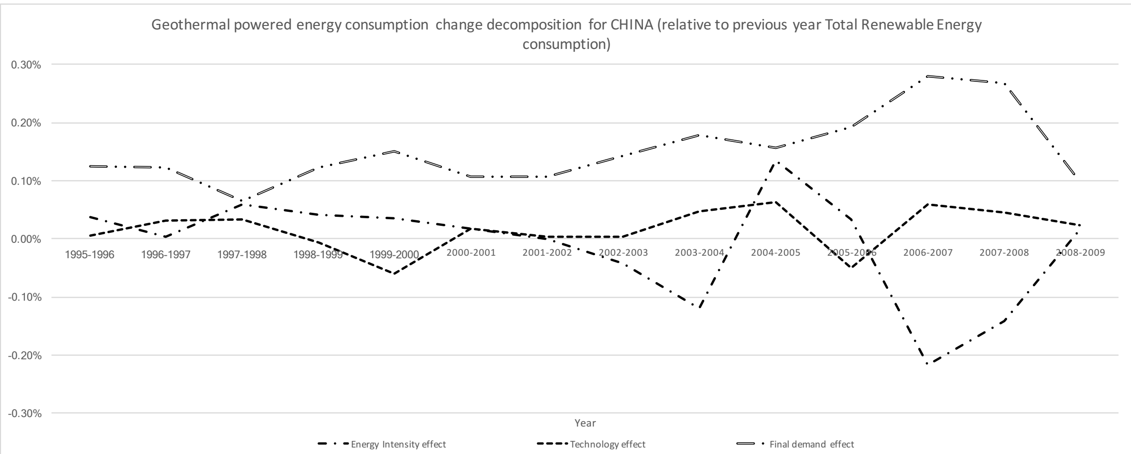


*Figure 41: Geothermal-powered energy consumption change decomposition for China, between 1995 and 2009.*

### 6.2.3 A decomposition of solar-powered energy consumption change: India and China (1995-2009)

Solar photovoltaic energy is the most promoted renewable energy source in India and China. In the past few years the solar-power market has encountered unexpected (high) growth rates in the two economies. This section provides the decomposition analysis of the solar-powered energy consumption change in India and China (1995-2009).

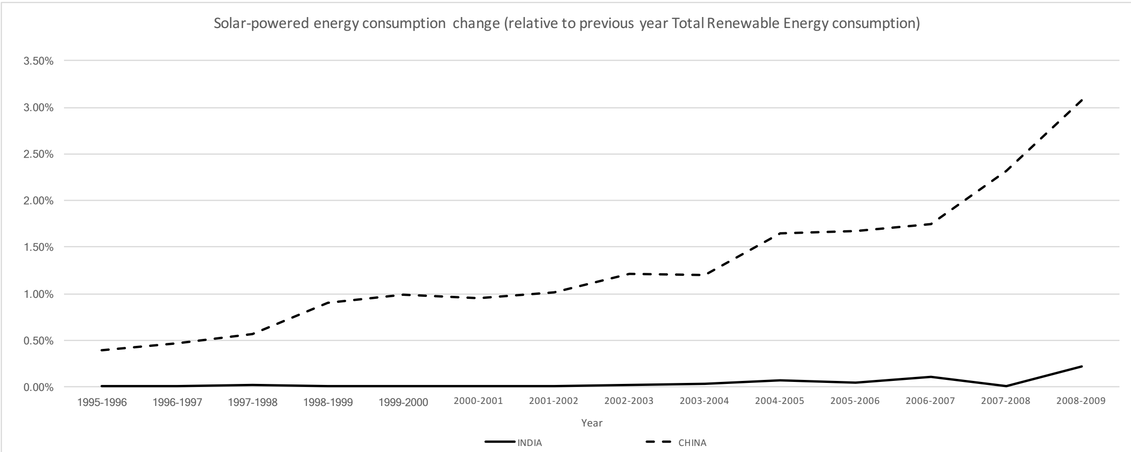


*Figure 42: Percentage Solar-powered energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Renewable Energy Use of India and China respectively.*

Comparing India and China on the basis of growth of Solar-powered energy consumption, it becomes clear that China's Solar-power energy sector followed a higher growth path than India's counterpart. The growth rate of Solar-powered energy in India was almost zero, until the last few years of the study period. China, on the other hand experienced an accelerating growth rate of Solar-powered energy consumption.

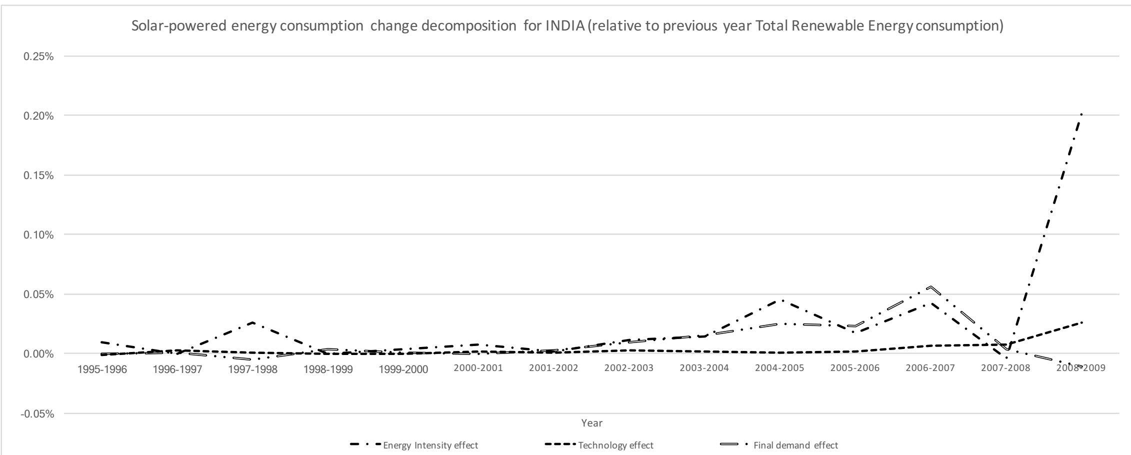


*Figure 43: Solar-powered energy consumption change decomposition for India, between 1995 and 2009.*

The decomposition of Solar-powered energy consumption change, for both India and China (Figure 43 and Figure 44), shows that the major factor of growth was final demand change. The effects of final demand change were more pronounced for China than for India. For both the countries, at the time of 2008 financial crisis, the energy intensity change led to an increase in solar-powered energy consumption and as expected final demand change saw a drop.

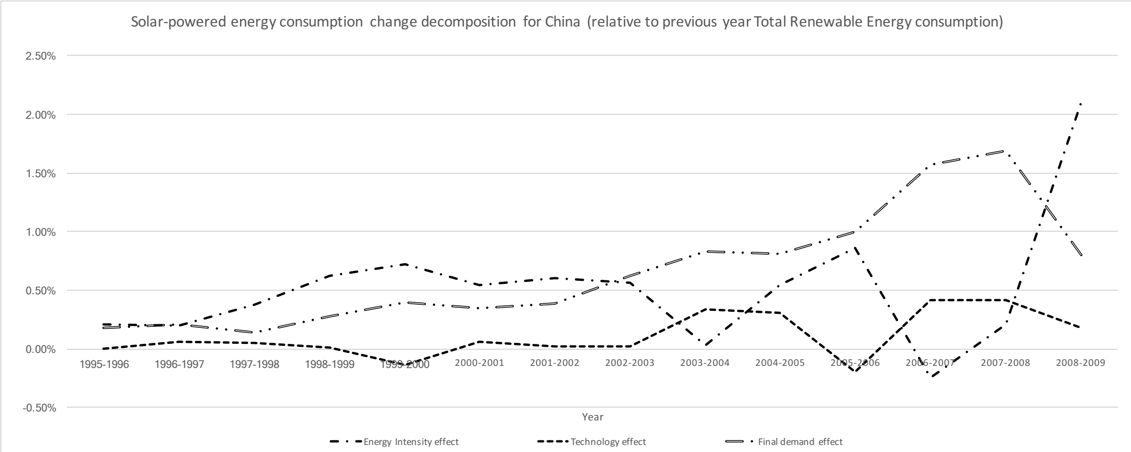


*Figure 44: Solar-powered energy consumption change decomposition for China, between 1995 and 2009.*

India saw a sluggish growth of solar-powered energy growth during the chosen time-period, with major contribution from final demand change followed by energy intensity change.

China experienced a commendable growth of solar-powered energy consumption throughout the time-period. All three factors – final demand change, energy intensity change and technology change – contributed to the growth of solar-powered energy consumption growth in China.

### 6.2.4 A decomposition of wind-powered energy consumption change: India and China (1995-2009)

Both India and China have high renewable energy targets for the near future, of which solar power and wind power are supposed to make the highest contribution. Wind power as a renewable energy source has grown in the recent past. This section provides a wind-powered energy consumption change decomposition analysis for India and China (1995-2009).

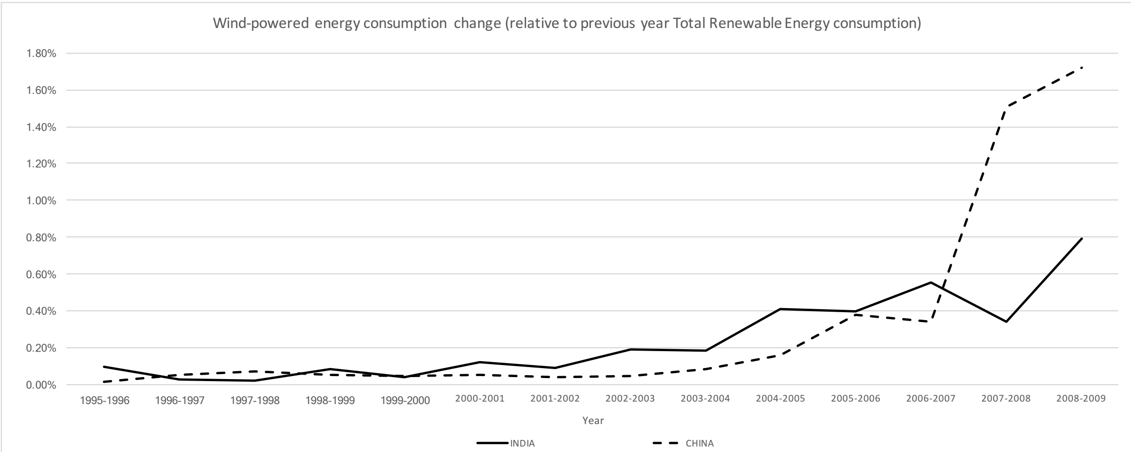


*Figure 45: Percentage Wind-powered energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Renewable Energy Use of India and China respectively.*

Comparing the growth rates of Wind-powered energy in India and China (Figure 45), it becomes clear that both followed almost a similar trend until 2006, from where on China experienced multifold jump in growth rate. The financial crisis years saw a growth in wind-powered energy in both the countries and this observation can be attributed to mainly energy intensity change (Figure 46 and Figure 47).

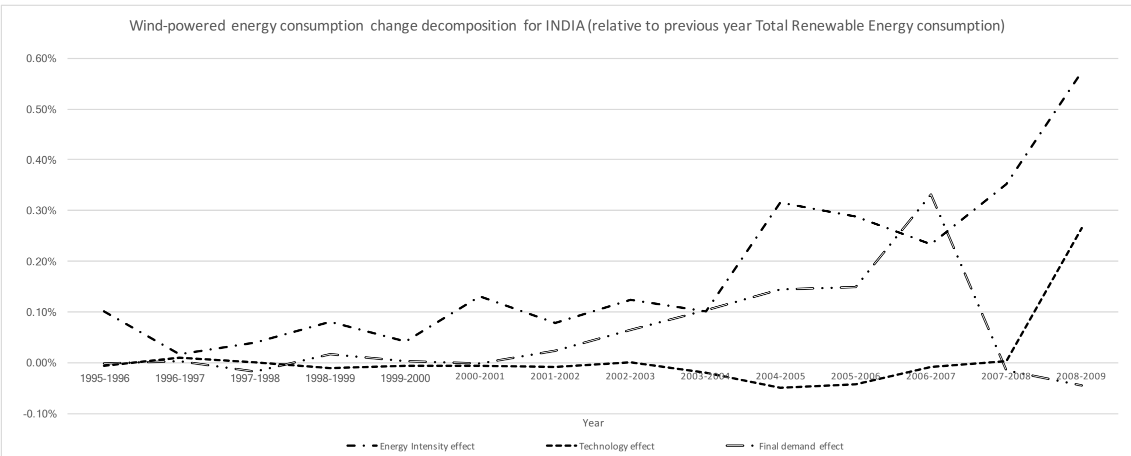


*Figure 46: Wind-powered energy consumption change decomposition for India, between 1995 and 2009.*

The Wind-powered energy growth, in India, was mainly result of increasing energy intensity change effect, as is visible from Figure 46. The other factor for this growth was final demand change which saw a slump during the 2008 financial crisis. The technology change effect was negligible until the last two years of the study period.

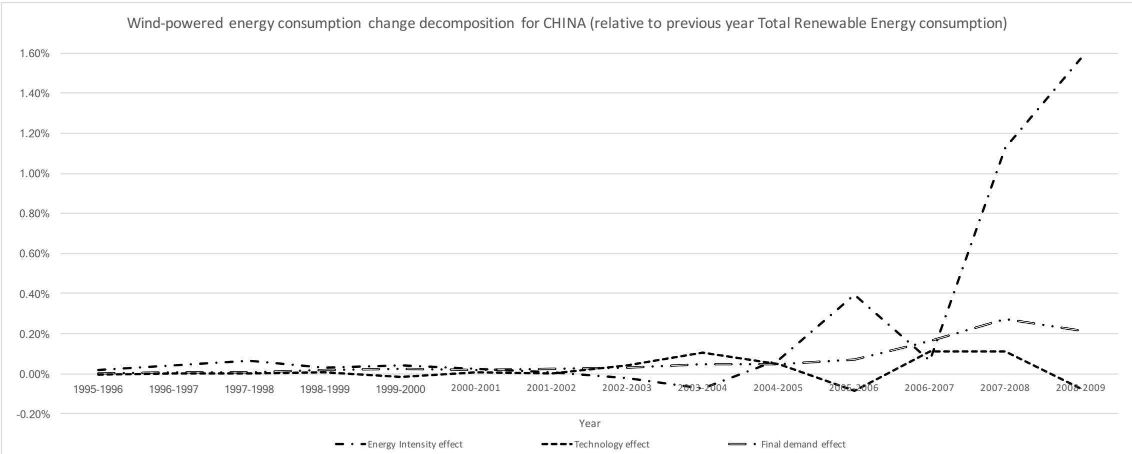


*Figure 47: Wind-powered energy consumption change decomposition for China, between 1995 and 2009.*

The steep increase in growth of Wind-powered energy in China, can be attributed to the energy intensity change effect (Figure 47). This could be understood as the increase in energy intensity of sectors relying on Wind-powered energy for their production and/or from more energy intensive sectors starting to get a part of their energy needs met by Wind-powered energy. The other final demand change and technology change effects were small in comparison to energy intensity change effect.

## 6.3 Sectoral Energy Consumption Change Decomposition

This section discusses the sector-wise comparison of the energy consumption decomposition of India and China. The top 5 common sectors of both the economies were selected based upon the average energy consumption change each year. The sectors in cumulative make for over 75 percent of the total average energy consumption changes that took place in the two economies between 1995 and 2009. Thus this sectoral energy consumption change decomposition study provides a good idea of the energy consumption changes happening in the two economies as a whole.

The selected 5 sectors are:

1. Electricity, Gas and Water Supply
2. Coke, Refined Petroleum and Nuclear Fuel
3. Basic Metals and Fabricated Metal
4. Agriculture, Hunting, Forestry and Fishing
5. Food, Beverages and Tobacco

The decomposition results are produced as average change per year over the time periods 1995-1999, 1999-2003, 2003-2007 and 2007-2009. Also an average change per year over the time period 1995-2007 is part of the produced results. The time-period 2007-2009 is separately analyzed because of the financial crisis of 2008 which could have created some temporary effects. The limitation of availability of data only till 2009 makes it difficult to analyze if the effects were temporary or permanent.

### 6.3.1 Electricity, Gas and Water Supply sector (EGWS)

The first sector under consideration is electricity and gas sector combined with water supply sector in the World Input-Output Database. EGWS was responsible for around 35 percent, on average, aggregate energy consumption growth in both the economies between 1995 and 2009. The results of the structural decomposition analysis appear in Table 18 for India and China.

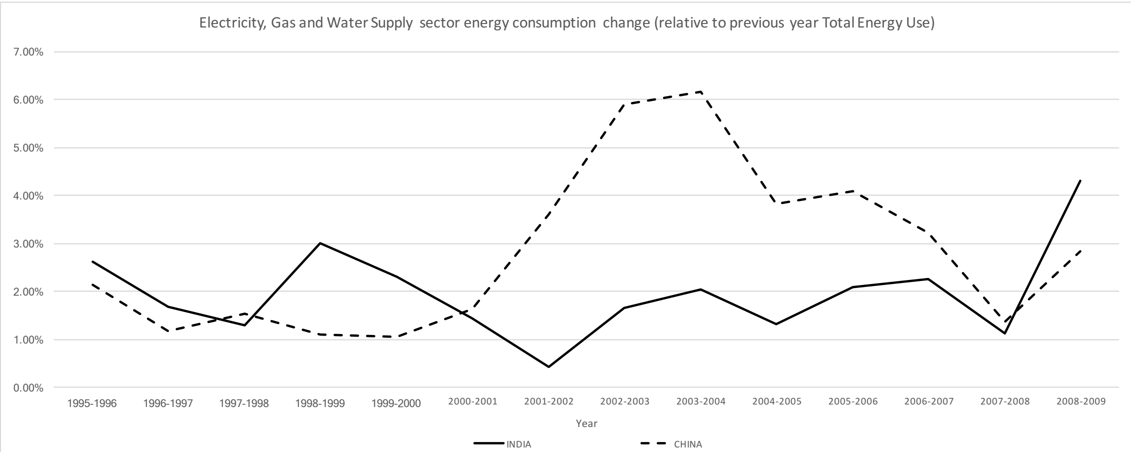


*Figure 48: Percentage Electricity, Gas and Water Supply sector energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Energy Use of India and China respectively.*

*Table 18: Electricity, Gas and Water Supply sector energy consumption change decomposition, between 1995 and 2009 (as percentage of previous year Total Energy Use) (displayed as average change per year).*

| Electricity, Gas and Water Supply (E) | | | | | |
|---|---|---|---|---|---|
| | 1995-1999 | 1999-2003 | 2003-2007 | 1995-2007 | 2007-2009 |
| **INDIA** | **2.15%** | **1.46%** | **1.93%** | **1.85%** | **2.72%** |
| Energy Intensity effect | 2.55% | 0.69% | -1.84% | **0.47%** | 1.37% |
| Technology effect | -0.29% | -0.44% | -0.92% | **-0.55%** | 1.72% |
| Final demand effect | -0.12% | 1.21% | 4.70% | **1.93%** | -0.37% |
| **CHINA** | **1.49%** | **3.05%** | **4.32%** | **2.95%** | **2.11%** |
| Energy Intensity effect | -1.04% | -1.03% | -4.70% | **-2.26%** | -3.04% |
| Technology effect | 0.18% | 0.96% | 3.90% | **1.68%** | 0.79% |
| Final demand effect | 2.35% | 3.11% | 5.12% | **3.53%** | 4.36% |

Considering the energy consumption growth by EGWS in the Indian economy, it becomes clear that during the time period 1995-2007 the energy consumption by EGWS increased by 1.85% on average per year. The main driver of energy consumption growth was final demand growth which contributed on average 1.93% annually. Higher incomes and increased level of economic activity lead to increased electricity consumption. The technology effect was negative but relatively small compared to final demand effect. The energy consumption change by EGWS sector as a result of technology effect was -0.55% on average per year during 1995 and 2007. This could be attributed to decreasing inter-dependency among sectors leading to decreasing electricity consumption. Energy intensity of India's EGWS sector increased, contributing 0.47% on average annually to energy consumption growth during 1995-2007. About one-fourth of the India's EGWS sector's annual energy consumption growth is due to increasing energy intensity (or decreasing energy efficiency) – which should be a cause for concern for policy makers.

Table 18 presents the decomposition results for the four sub-periods. These results illustrate that the average trends for 1995-2007 do hide a more varied experience over time. First, the final demand growth was negative during 1995-1999 (due to East Asian crisis) and 2007-2009 (due to Global financial crisis); hence during the specified two periods final demand growth had a negative contribution towards energy consumption growth by India's EGWS sector. Second, India's EGWS sector managed to reduce energy intensity (improve energy efficiency) during the high growth period of 2003-2007; result of the effective implementation of India's Energy Conservation Act 2001, and Electricity Act 2003 (explained in detail in Chapter 4). However, energy intensity increased in all other sub-periods, although it is possible that the rise in energy intensity after 2007 is related to economic recession and only temporary. Third, the "technology effect", i.e. the contribution to energy consumption change of EGWS sector caused mainly by India's input-output structure was negative during the period 1995-2007. This could be due to the fact that India's economic growth during these years was "services-led" (and not manufacturing-led); due to this, the inter-industry structure of India's economy shifted in favor of (high-tech) services which are less energy intensive than most of the (heavy) manufacturing industries. The positive "technology effect" during 2007-2009 could be due to recession following global financial crisis – as Indian services activities, often for exports, took a hit.

Now, considering the China's EGWS sector's energy consumption growth, it becomes clear that during the time period 1995-2007 the energy consumption by EGWS increased by 2.95% on average per year and by 2.11% during 2007-2009. This energy consumption growth was driven mainly by final demand growth, which contributed 3.53% and 4.36% on average during 1995-2007 and 2007-2009. Increased level of economic activity and growing incomes meant increasing demand for EGWS services. This also discards the popular belief that China's economy was export-led, as even during the global financial crisis, China recorded an increasing final demand; this could only mean that China's internal market and hence internal demand was driving this growth. The technology effect was small but not insignificant. The energy consumption change by China's EGWS sector as a result of technology effect was 1.68% and 0.79% on average per year during 1995-2007 and 2007-2009, respectively. This shows that the dependency of different sectors on China's EGWS sector was increasing. Energy intensity of China's EGWS sector decreased, contributing -2.26% and -3.04% on average annually to energy consumption growth during 1995-2007 and 2007-2009. This effect could be explained as a consequence of the effective implementation of China's Energy Conservation Law (1997).

The decomposition results of the four sub-periods are also present in Table 18. These results clearly illustrate that China was growing in the right direction.

First, the final demand effect was increasing which meant that final demand of China's EGWS sector or its interlinked sectors or both was growing. Compared to India, the impact of East Asian crisis and the Global financial crisis on final demand for China's goods and services was less. Chinese economy did not observe a negative final demand but the growth had been impacted. Second, the energy intensity was decreasing which indicates that China's energy conservation efforts were bearing fruit. China's EGWS sector managed to reduce energy intensity (improve energy efficiency) the most, during the high growth period of 2003-2007. As opposed to India, China was able to maintain its energy intensity reduction trend also during 2007-2009 (the global financial crisis period). The "technology effect", i.e. the contribution to energy consumption change of EGWS sector caused mostly by China's input-output structure, saw the highest growth during the period 2003-2007. This could be a result of growth and expansion of industry and manufacturing in China, which now started to incorporate and manufacture different varieties of products. According to the hypothesis, this lead to a change in input-output matrix, which effectively resulted in a positive contribution of technology effect to energy consumption growth of China's EGWS sector.

### 6.3.2 Coke, Refined Petroleum and Nuclear Fuel sector (CPN)

The second sector under consideration is non-renewable energy sources sector of "Coke, Refined Petroleum and Nuclear Fuel" as defined in the World Input-Output Database. CPN was responsible for, on average, annual energy consumption growth of approximate 34 percent and 19 percent in India and China, respectively. CPN, in both the economies, had the second largest contribution to energy consumption change after EGWS. The results of the structural decomposition analysis of energy consumption change by CPN appear in Table 19 for India and China.

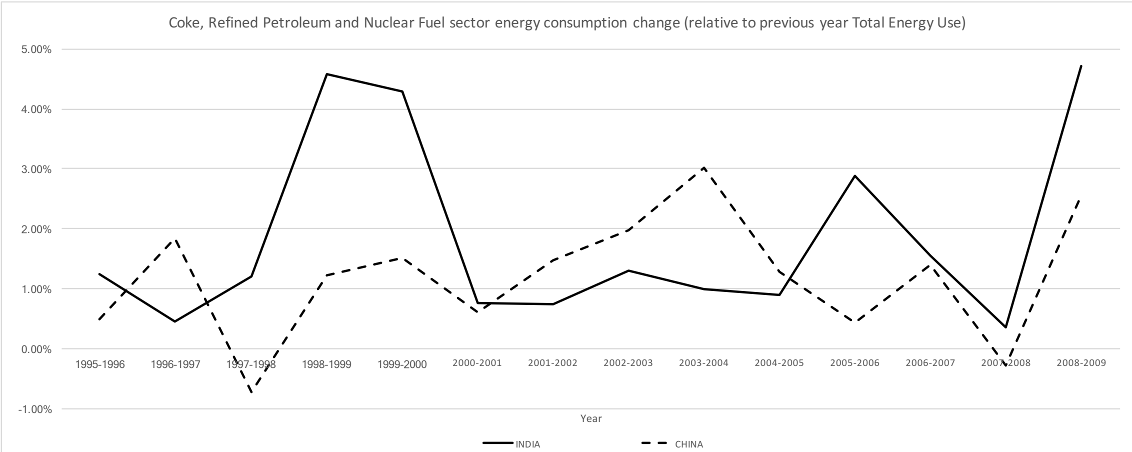


*Figure 49: Percentage Coke, Refined Petroleum and Nuclear Fuel sector energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Energy Use of India and China respectively.*

*Table 19: Coke, Refined Petroleum and Nuclear Fuel sector energy consumption change decomposition, between 1995 and 2009 (as percentage of previous year Total Energy Use) (displayed as average change per year).*

| Coke, Refined Petroleum and Nuclear Fuel (23) | | | | | |
|---|---|---|---|---|---|
| | 1995-1999 | 1999-2003 | 2003-2007 | 1995-2007 | 2007-2009 |
| **INDIA** | **1.87%** | **1.78%** | **1.58%** | **1.75%** | **2.54%** |
| Energy Intensity effect | 2.60% | -0.77% | -1.82% | **0.00%** | 2.45% |
| Technology effect | -0.01% | 1.18% | 0.32% | **0.49%** | 0.45% |
| Final demand effect | -0.71% | 1.36% | 3.08% | **1.25%** | -0.36% |
| **CHINA** | **0.71%** | **1.40%** | **1.54%** | **1.22%** | **1.13%** |
| Energy Intensity effect | -0.98% | -0.84% | -0.93% | **-0.92%** | -1.51% |
| Technology effect | 0.39% | 0.29% | -0.10% | **0.19%** | 0.61% |
| Final demand effect | 1.31% | 1.95% | 2.57% | **1.94%** | 2.04% |

Reflecting on the energy consumption growth by CPN in the India economy, it becomes evident that during the time period 1995-2007, the energy consumption by CPN sector increased by 1.75% per year on average and 2.54% in 2007-2009. Majority of this energy consumption growth, during 1995 and 2007, was final demand growth driven. As explained earlier economic growth lead to increased income levels which in turn lead to increased demand for goods and services which require inputs from CPN sector to generate their output. As expected, the final demand effect during 2007-2009 was negative as the world market was under slump and the demand for goods and services was declining; this meant that the contribution of final demand towards energy consumption change was negative. The technology effect, during 1995-2007 and 2007-2009, was relatively small; but still produced a positive contribution towards energy consumption growth. This meant that the dynamics between the different industries was not changing much. Energy intensity of India's CPN sector was constant, i.e. had 0% contribution towards India's energy consumption growth, during 1995-2007. Conversely, the energy consumption growth of India's CPN sector was energy intensity driven during 2007-2009, which should be a cause for concern if it was not a temporary effect (could not be verified because of lack of data), as a repercussion to global financial crisis.

The decomposition results of the four sub-periods are presented in Table 19. The results illustrate the varied experiences which were hidden in average trends for 1995-2007. Similar to EGWS sector, CPN sector was also affected by East Asian crisis and Global financial crisis which resulted in negative final demand growth; hence contributing with negative final demand effect, during the specified periods, on energy consumption growth by CPN sector. India's CPN sector also managed to reduce energy intensity (i.e. became more energy efficient) during India's growth period from 1999-2007. This could be attributed to 1) The fluctuating oil prices which acted as a motivation for the whole industry to become more energy efficient, and 2) The energy conservation efforts taken up by the Indian government, which focused on energy efficiency improvements. However, in other sub-periods energy intensity witnessed considerable increase. Although, it is possible that CPN's energy intensity increase post 2007 was only temporary, as an after effect of Global financial crisis. The technology effect was considerably large during 1999-2003 and dropped considerably during 2003-2007. This shows that India's economy was heavily dependent on non-renewable sources of energy in its early stages of development, i.e. 1999-2003; while with the advent of renewables especially Wind and Solar as energy sources, the dependency declined a bit, but still non-renewables maintained their status as primary source of energy. This reflected in the lower contribution of technology effect to energy consumption growth.

Now, considering the China's CPN sector's energy consumption growth, it becomes clear that during the time period 1995-2007 the energy consumption by CPN increased by 1.22% on average per year and by 1.13% during 2007-2009. Similar to previously discussed China's EGWS sector, the major culprit of CPN's energy consumption growth was final demand growth; contributing 1.94% and 2.04% on average annually to energy consumption growth during 1995-2007 and 2007-2009 respectively. This result also breaks the misconception that China's growth was only export-led, whereas during the Global Financial Crisis the demand kept growing leading to increased energy consumption. The technology effect was comparatively small, contributing 0.19% and 0.61% on average per year to energy consumption growth during 1995-2007 and 2007-2009, respectively. This shows that the dependency of other sectors on China's CPN sector was almost constant. Energy intensity of China's CPN sector decreased, contributing -0.92% and -1.51% on average annually to energy consumption change during 1995-2007 and 2007-2009. This effect could be explained as an outcome of the successful implementation of China's Energy Conservation Law (1997).

Diving deep into the decomposition, from average trends during 1995-2007 to sub-period decomposition trends, a clearer picture of China's energy consumption trends is achieved, which are presented in Table 19. The final demand growth was in line with China's economic growth. This lead to a growing final demand effect on the energy consumption growth. The growth was slightly impacted by the Global financial crisis, which is observable as final demand effect during 2007-2009. China's Energy Conservation Law (1997) and other energy conservation measures had their impacts felt all through the decade; leading to a negative energy intensity effect. The "technology effect", i.e. the contribution to energy consumption change of CPN sector caused mostly by China's input-output structure was negative during the period 2003-2007. This could be a result of China's implementation of Renewable Energy Law (2005), which focused on promoting renewable energy sources. This lead to change of dynamics and change of dependencies of other sectors on CPN sector's output as their source of energy supply.

### 6.3.3 Basic Metals and Fabricated Metal sector (BMFM)

The third sector under consideration is the manufacturing sector which utilizes the relatively high amounts of energy for its production. Basic Metals and Fabricated Metal is the third largest and fourth largest energy consuming sector in China and India, respectively. BMFM was responsible for, on average, annual energy consumption growth of around 5 percent and 14 percent in India and China respectively, during 1995-2009. The results of the structural decomposition analysis of energy consumption change by BMFM appear in Table 20 for India and China.

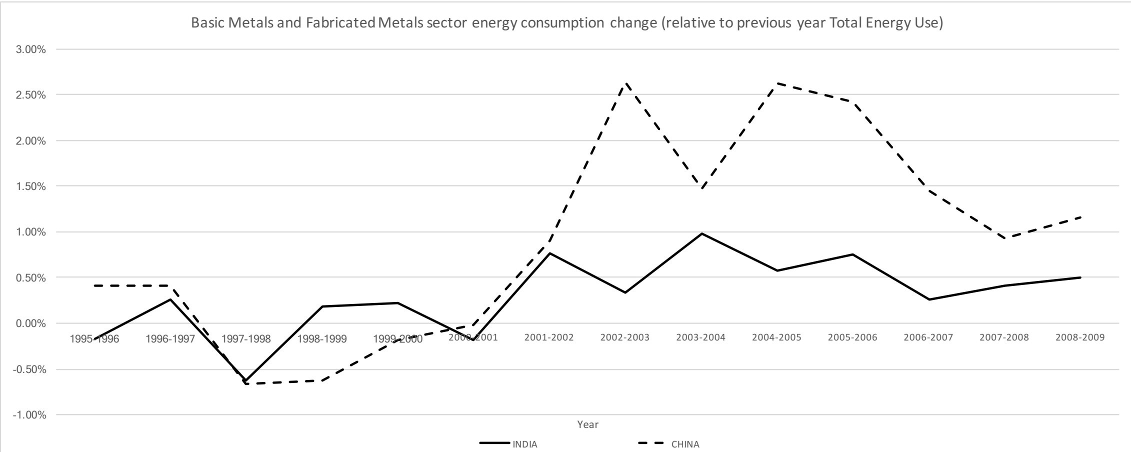


*Figure 50: Percentage Basic Metals and Fabricated Metals sector energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Energy Use of India and China respectively.*

*Table 20: Basic Metals and Fabricated Metals sector energy consumption change decomposition, between 1995 and 2009 (as percentage of previous year Total Energy Use) (displayed as average change per year).*

| Basic Metals and Fabricated Metal (27t28) | | | | | |
|---|---|---|---|---|---|
| | **1995-1999** | **1999-2003** | **2003-2007** | **1995-2007** | **2007-2009** |
| **INDIA** | **-0.08%** | **0.28%** | **0.64%** | **0.28%** | **0.46%** |
| Energy Intensity effect | 0.35% | 0.15% | -0.15% | **0.12%** | 0.27% |
| Technology effect | -0.34% | -0.10% | -0.10% | **-0.18%** | 0.38% |
| Final demand effect | -0.09% | 0.23% | 0.89% | **0.34%** | -0.20% |
| **CHINA** | **-0.12%** | **0.83%** | **1.99%** | **0.90%** | **1.04%** |
| Energy Intensity effect | -1.43% | -0.45% | -0.63% | **-0.84%** | -1.87% |
| Technology effect | 0.49% | -0.01% | 0.50% | **0.33%** | 1.14% |
| Final demand effect | 0.83% | 1.29% | 2.13% | **1.42%** | 1.78% |

The India's BMFM sector was responsible for contributing 0.28% average annual growth in energy consumption, during the time period 1995-2007 and 0.46% during 2007-2009. The energy consumption growth was mainly driven by final demand growth, which increased by 0.34% on average due to final demand effect, yearly from 1995-2007 and as expected its contribution was -0.20% during the crisis years i.e. 2007-2009. The technology effect had a negative contribution of 0.18% during 1995-2007. This meant that technical coefficients were changing. This could be due to the fact that India's economic growth during these years was "services-led" (and not manufacturing-led); due to this the intermediate demand structure had changed, thus changing the total dynamics of the technical coefficient matrix. The energy intensity increased during the time period 1995-2007, contributing 0.12% on average annually to energy consumption growth. Even-though the percentage was small in comparison to total energy consumption, but energy intensity increase (or energy efficiency decrease) was responsible for more than one-third of India's BMFM sector's annual energy consumption growth, which should be a cause for concern for the policy makers.

Table 20 also presents decomposition results for four sub-periods. These results illuminate the hidden varied experiences, not clear from the average trends for 1995-2007. First, the final demand grew most during the high growth period of 2003-2007 and experienced a negative growth during 1995-1999 (East Asian crisis) and 2007-2009 (Global financial crisis). The same trends were visible in the final demand effect of BMFM's energy consumption growth. The technology effect was negative in all the sub-periods 1995 and 2007. As explained earlier, this was due to the structural shift taking place in the Indian economy, where the economy was becoming services-led and manufacturing was reducing. India's BMFM sector was able to achieve reduction in energy intensity (or increase in energy efficiency) during the high growth period of 2003-2007. This could be due to effective implementation of India's Energy Conservation Act 2001.

China's BMFM sector was responsible for almost triple the energy consumption growth as compared to its Indian counterpart. The average annual energy consumption growth by BMFM sector was 0.90%, during 1995-2007. The main driver responsible for this energy consumption growth was final demand growth, which increased it by, on average, 1.42% annually reflected as final demand effect. The BMFM sector and its other dependent sectors were able to bear the brunt of Global financial crisis, time period 2007-2009, with a small drop in growth rate. China's Energy Conservation Law (1997) had its effects even after a decade, with negative energy intensity not only during 1995-2007 but also during 2007-2009 (Global financial crisis). The technology effect was relatively small but positive which meant that not many changes were happening in the technical coefficient matrix.

The decomposition results of the sub-periods present almost similar trends for China's BMFM sector energy consumption growth as the average trends. All the sub-periods observed a positive final demand effect resulting from final demand growth in all the sub-periods. Similar to other discussed Chinese sectors, BMFM also was able to improve energy efficiency and thus a negative energy intensity effect in all the sub-periods. From the decomposition results, it is safe to say that BMFM sector did not undergo much Input-Output structural changes and its inter-dependencies remained almost the same during the whole considered time-period.

### 6.3.4 Food, Beverages and Tobacco sector (FBT)

The fourth sector under consideration "Food, Beverages and Tobacco" is a manufacturing (agro-processing) sector which was the fourth and ninth largest energy consuming sector during 1995-2009, in India and China respectively. FBT was responsible for, on average, annual energy consumption change of around +6 percent and -0.14 percent in India and China respectively, during 1995-2009. The results of the structural decomposition analysis of energy consumption change by FBT appear in Table 21 for India and China.

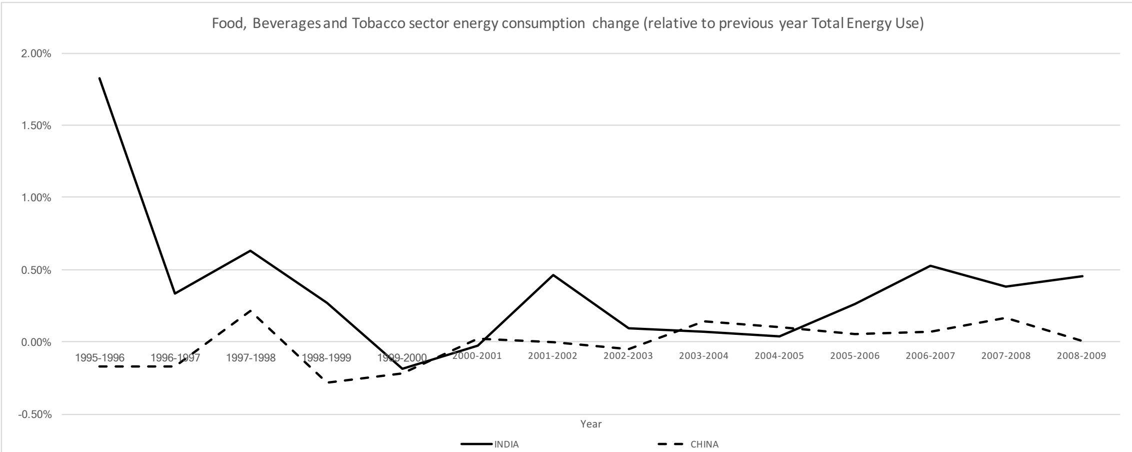


*Figure 51: Percentage Food, Beverages and Tobacco sector energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Energy Use of India and China respectively.*

*Table 21: Food, Beverages and Tobacco sector energy consumption change decomposition, between 1995 and 2009 (as percentage of previous year Total Energy Use) (displayed as average change per year).*

| Food, Beverages and Tobacco (15t16) | | | | | |
|---|---|---|---|---|---|
| | **1995-1999** | **1999-2003** | **2003-2007** | **1995-2007** | **2007-2009** |
| **INDIA** | **0,76%** | **0,09%** | **0,23%** | **0,36%** | **0,42%** |
| Energy Intensity effect | 1,05% | -0,33% | -0,30% | **0,14%** | 0,85% |
| Technology effect | -0,02% | 0,14% | 0,01% | **0,05%** | -0,09% |
| Final demand effect | -0,27% | 0,27% | 0,51% | **0,17%** | -0,34% |
| **CHINA** | **-0,10%** | **-0,06%** | **0,09%** | **-0,02%** | **0,09%** |
| Energy Intensity effect | -0,28% | -0,18% | -0,11% | **-0,19%** | -0,04% |
| Technology effect | 0,04% | 0,03% | 0,06% | **0,04%** | 0,02% |
| Final demand effect | 0,14% | 0,09% | 0,14% | **0,12%** | 0,11% |

The India's FBT sector was responsible for contributing 0.36% average annual growth in energy consumption, during the time period 1995-2007 and 0.42% during 2007-2009. The main driver of the energy consumption growth was final demand growth, which increased it by 0.17%, on average, annually during 1995-2007. The effects of Global financial crisis, were no different for India's FBT sector as its energy consumption dropped by 0.34% on average annually during 2007-2009 as a result of final demand effect. The technology effect was responsible for relatively small increase of 0.05% on average annually, during 1995-2007, to energy consumption growth. This meant that the sector was more or less stable and did not observe much technical coefficients changes in its related sectors. Technology effect was negative during the crisis period which meant a change in technical coefficients matrix. The effect could be temporary as well resulting from Global financial crisis. The energy intensity of India's FBT sector increased, i.e. energy efficiency decreased, during the period 1995-2007. Energy intensity effect increased the energy consumption by 0.14% on average annually. The energy intensity increase was responsible for almost one-third the energy consumption growth during 1995-2007, which should be a major cause of concern for the policy makers.

Table 21 presents the decomposition results for the four sub-periods. The results of decomposition for sub-periods show a much varied trend which were buried in the average trends over the period 1995-2007. India's FBT sector experienced final demand growth during 1999-2007 (services-led growth) which was reflected in energy consumption growth due to final demand effect. The technology effect was negligible during 2003-2007. The energy intensity effect, during 1999-2007 was opposite to the average readings for 1995-2007. The energy intensity effect had a negative stimulus to energy consumption growth during 1999-2007; which meant that India's FBT sector was growing in the right direction and energy conservation measures were being employed.

Considering the energy consumption growth by FBT in the Chinese economy, it becomes clear that during the time period 1995-2007 the energy consumption by FBT actually decreased by 0.02% on average per year. The main driver for this decrease was the dropping energy intensity, which contributed -0.19% on average annually to energy consumption change. This could be a good sign as well as a bad sign; it could mean that the sector is becoming more energy efficient, which is good, or it could also mean that the value of outputs of the sector in the market is losing, which is bad for the sector, or could be a cumulative effect of both. The technology effect was almost negligible during 1995-2007. The final demand effect was positive, as a result of final demand growth, contribution 0.12% on average per year to energy consumption growth.

The decomposition results of the sub-periods present almost similar trends for China's FBT sector energy consumption change as the average trends for 1995-2007. The energy intensity effect produced a negative contribution to energy consumption change, all through the time period 1995-2009. The technology effect was almost constant and relatively small. The positive final demand effect resulting from growth of China's consumer market managed to produce a positive energy consumption change during a few sub-periods.

### 6.3.5 Agriculture, Hunting, Forestry and Fishing sector (AHFF)

Agriculture, Hunting, Forestry and Fishing sector was responsible for employing over 20 percent of India's and China's total population during 1995-2009 (Figure 52). It is the largest sector in terms of number of people it employs in both the countries. Both the economies, India and China, grew from an agrarian based economy to services-led and manufacturing-led respectively.

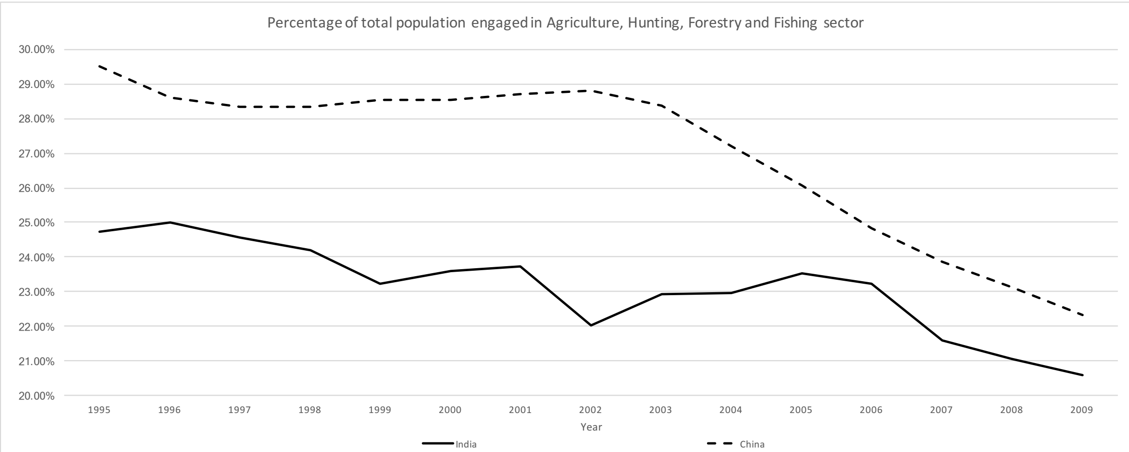


*Figure 52: Percentage of the total population engaged in Agriculture, Hunting, Forestry and Fishing sector in India and China, between 1995 and 2009.*

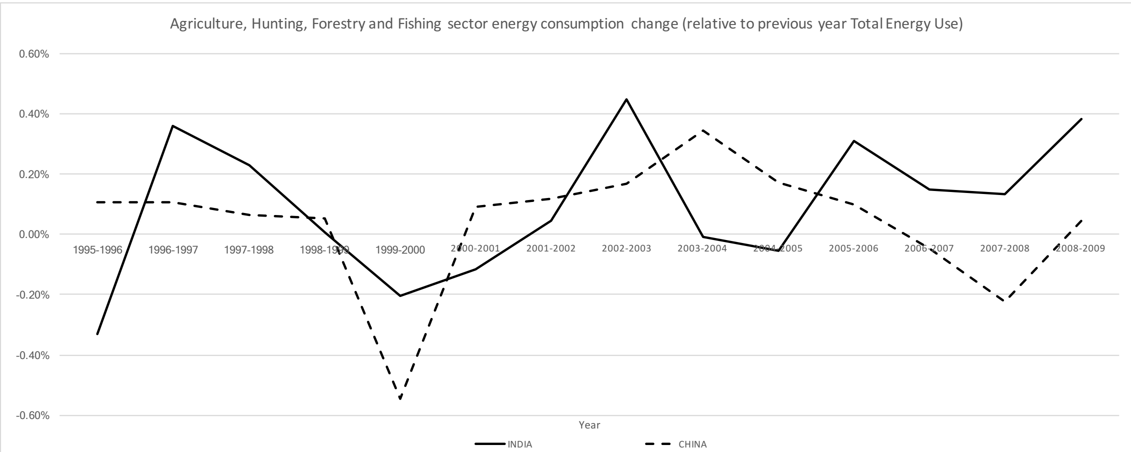


*Figure 53: Percentage Agriculture, hunting, Forestry and Fishing sector energy consumption change of India and China, between 1995 and 2009, relative to previous year Total Energy Use of India and China respectively.*

AHFF was responsible for, on average, annual energy consumption growth of around 1.74 percent and 0.61 percent in India and China respectively, during 1995-2009. The results of the structural decomposition analysis of energy consumption change by AHFF appear in Table 22 for India and China.

*Table 22: Agriculture, Hunting, Forestry and Fishing sector energy consumption change decomposition, between 1995 and 2009 (as percentage of previous year Total Energy Use) (displayed as average change per year).*

| Agriculture, Hunting, Forestry and Fishing (AtB) | | | | | |
|---|---|---|---|---|---|
| | 1995-1999 | 1999-2003 | 2003-2007 | 1995-2007 | 2007-2009 |
| **INDIA** | **0,07%** | **0,04%** | **0,10%** | **0,07%** | **0,26%** |
| Energy Intensity effect | 0,25% | 0,04% | -0,11% | **0,06%** | 0,55% |
| Technology effect | -0,05% | -0,02% | -0,06% | **-0,04%** | -0,08% |
| Final demand effect | -0,14% | 0,02% | 0,27% | **0,05%** | -0,22% |
| **CHINA** | **0,08%** | **-0,04%** | **0,14%** | **0,06%** | **-0,09%** |
| Energy Intensity effect | -0,08% | -0,12% | -0,02% | **-0,07%** | -0,27% |
| Technology effect | 0,00% | -0,04% | -0,03% | **-0,02%** | 0,00% |
| Final demand effect | 0,17% | 0,12% | 0,19% | **0,16%** | 0,18% |

India's AHFF sector was responsible for contributing 0.07% average annual growth in energy consumption, during the time period 1995-2007 and 0.26% during 2007-2009. The drivers for this energy consumption growth were energy intensity increase and final demand growth, which increased it with 0.06% and 0.05%, respectively on average per year during 1995-2007. The energy intensity effect should be a cause of concern as it was responsible for more than three-fourth of the energy consumption growth by India's AHFF sector. The final demand effect, a result of final demand effect, was small. The technology effect made a negative contribution to energy consumption growth; resulting from changes in the technical coefficient matrix. The changes could be related to the reducing employability of AHFF sector, or structural changes which led India to a services-led economy. The effects of Global financial crisis, during 2007-2009, are as expected; the final demand dropped, thus a negative final demand effect, and an increasing energy intensity effect.

Table 22 also presents the sub-period decomposition results, which provide a picture of more varied experiences of AHFF sector, not provided by the average trends for 1995-2007. First, the effect of East Asian crisis is prominent from the negative final demand effect, during 1995-1999, which a function of final demand. The final demand growth was highest during 2003-2007 resulting in a relatively high energy consumption growth. Second, the AHFF sector was able to improve energy efficiency, reflected by a negative energy intensity effect, during the high growth period of 2003-2007. This could be considered as successful implementation of energy conservation efforts by the Indian government. Third, the technology effect was negative during the whole time period of 1995-2009, reflecting a major structural change occurring in the industry; which could be the movement of Indian economy from largely agrarian based economy to services-led economy.

China's AHFF sector contributed 0.06% to average annual growth in energy consumption, during the time period 1995-2007 and -0.09% during 2007-2009. The main driver of energy consumption growth, during 1995-2007, was final demand. It is evident from the results that the final demand grew even during the Global financial crisis, i.e. 2007-2009. Similar to India's counterpart China's

AHFF experienced a negative technology effect, reflecting a shift from agrarian based economy to manufacturing based economy. China was also successful in implementing its energy conservation efforts, which are visible from the negative energy intensity effect (or improved energy efficiency).

The sub-period decomposition results presented in Table 22 show that they were similar to the average trends during 1995-2007. The final demand grew, as reflected by the positive final demand effect, unaffected by the East Asian crisis and Global financial crisis. The technology effect showed a small negative trend all throughout the period, reflecting the slow structural shift, from agriculture to manufacturing, taking place in the Chinese economy. China's AHFF sector was also able to maintain its energy efficiency improvement drive, which was mirrored by the negative energy intensity effect.

## 6.4 Summary and conclusions

Comparing energy consumption growth, China had more energy consumption growth post 2001. This observation can be attributed to China's entry to WTO in December 2001, which meant bigger market leading to increased production and thus more energy consumption (Saccone & Valli, 2009; Zhao et al., 2010). However, India had a constant growth of Energy Use and Value Added. Learning the need for energy conservation, India and China launched Energy Conservation Law (1997) and Energy Conservation Act 2001, respectively. The energy conservation initiatives seem to have played adequate role in reducing the energy intensity, of both the economies, post the launch.

According to the energy consumption change decomposition findings, in pre-2002 India, final demand decline had negative effect on energy consumption growth while energy intensity increase resulted in energy consumption growth. Post-2002, both the factors observed a role reversal; final demand growth led to growth in energy consumption, while energy intensity decline had a negative effect on energy consumption change. The technology change (change in technical coefficients matrix) had a negligible effect on the energy consumption growth during the whole study period. Thus, final demand growth (economic development) was the main driving force for energy consumption growth; this growth was not restricted by the relatively small improvements in energy efficiency (decreasing energy intensity). The energy consumption change during the years of the Global financial crisis (2007-2009), cannot be commented upon because of the lack of availability of data post 2009.

In the case of China, final demand growth led to increasing energy consumption, while energy intensity decline had a negative effect on energy consumption. The technology change had a smaller positive impact than final demand growth on the energy consumption growth. Thus, from China's total energy use change decomposition, it is clear that the major energy consumption growth driving force was final demand, which was relatively unaffected by the East Asian crisis and Global financial crisis; this means that Chinese growth was internally driven or supported. The energy conservation efforts of Chinese government had borne fruit, as throughout the chosen study period it was evident that the energy intensity was constantly decreasing, except for one or two outliers. The technology change (change in technical coefficients matrix) had a lower positive effect on the energy consumption growth than the final demand, but it signified that Chinese economy was undergoing some structural changes, which lead to energy consumption growth. According to previously performed studies this could only mean that the Chinese economy was moving towards energy intensive manufacturing.

Both India and China had their share of renewable energy consumption growth, between 1995 and 2009. Majority of this growth was powered by Hydro-power in both the economies, followed by Wind-power and other renewables in case of

India and Solar-power in case of China. China experienced a multifold renewable energy consumption growth in comparison to India.

The growth of hydro-power was much more dynamic in the China's case than that of India. The increasing growth of Solar-power was experienced by China, while there was almost stagnant or negligible Solar-power growth in India. India experienced (about) zero growth in Geothermal-power during the study-period. Until 2006, both the countries experienced almost similar and constantly growing Wind-power; post 2006 China's wind-power growth suddenly jumped to almost double that of India. The major factor for renewable energy consumption growth in both the economies had been final demand growth. The results of renewable energy consumption decomposition do not demonstrate energy conservation efforts of India's and China's government; the energy intensity change (sectoral energy efficiency changes) did not produce a constant negative contribution to renewable energy consumption change rather a much more varying effect. This leads to the conclusion that energy efficiency improvement efforts, by both the economies, were selective in nature and were aimed to reduce the dependency on non-renewable energy sources. The only claim that could be made here is that the renewable energy consumption growth was not restricted by energy efficiency improvements. The technology change had only a limited effect on renewable energy consumption growth; it was neither a consistent driver of renewable energy consumption growth (due for instance to energy intensive industrialization) nor a consistent factor reducing renewable energy consumption, for both the economies in general.

Referring to the co-integrated nature of energy consumption and GDP, found in literature study, the state of an economy can be analyzed by the growth of energy consumption in certain sectors. As assumed and verified by the analysis results, China observed more energy consumption growth in manufacturing based sectors (i.e. for e.g. Basic Metals and Fabricated Metals sector), while India observed more energy consumption growth, in consumer products based sector (i.e. for e.g. Food, Beverages and Tobacco sector). The energy producing and supplying sectors (i.e. for e.g. Electricity, Gas and Water Supply sector and Coke, Refined Petroleum and Nuclear Fuel sector) experienced the highest energy consumption growth in both the economies. The agriculture sector (i.e. Agriculture, Hunting, Forestry and Fishing sector) was responsible for employing the highest percentage of each country's population but was responsible for a very small contribution to energy consumption growth.

The energy consumption growth in different sectors, of both the economies, was mainly fueled by final demand growth. The energy intensity effect, post the launch of both the country's respective energy conservation initiatives, produced a negative contribution to energy consumption growth; meaning the initiatives were fruitful. The technology change had a rather small effect on the energy consumption growth; its effect was dependent upon the nature of the development process: if the economy is more services-led (as in India) it is likely less energy intensive, but if its manufacturing-led (as in China), it will be more energy intensive).

# 7 Conclusions, Reflections and Policy recommendations

Energy is the pivot to economic development of any country. Energy is not only required by modern day services, but is also necessary to provide for the basic human needs such as food and shelter. However, energy production is also the main source of today's global warming. The main sources of energy, the non-renewable energy sources, produce green-house gases which in turn result in global warming. Humanity is facing an existential crisis, the increasing need for energy for a better world (in terms of higher material standards of living) is also the source of global warming. The only solution to tackle this current situation is to improve on energy efficiency and to promote renewable energy technology. Thus, the motivation behind this research was to study the two most populous and growing economies, India and China (constituting more than one-third of total world population), to identify the sources of their energy consumption growth and discuss some policy recommendations to improve their economy's energy efficiency and to promote renewable energy. India and China were specifically chosen because, currently they are among the top growing economies and their energy needs are constantly rising. Both the economies are heavily dependent on non-renewable energy sources for their growing energy needs. As the saying goes "Prevention is better than the cure", the research was an attempt to analyze growth of energy consumption in the two economies and to provide their policy makers with the right factors affecting the change, for better policies in the future.

A Structural Decomposition Analysis was performed on the data available from World Input-Output Database. SDA as a decomposition technique was efficient in decomposing the energy consumption change effects into three factors, namely: 1) energy coefficient/intensity effect, 2) technology effect and, 3) final demand effect. The analysis was performed on a step-by-step level. First, the energy consumption change of India and China at the aggregate level was decomposed, providing a better understanding of the energy consumption changes in the two economies. Second, the growth in energy consumption of the top renewable energy technology produced energy was decomposed, providing a better understanding of the driving forces for the growth. Third, the energy consumption change of the top four energy consuming sectors and agriculture sector of both the economies was decomposed. This provided us with the factors for energy consumption change by each sector.

The policies, related to energy efficiency and renewable energy technology, implemented by the two economies during the chosen time-period were also studied to understand their effects on the energy consumption change, in aggregate as well as at the sectoral/industry level.

Finally, the results of the decomposition were analyzed keeping in view the implemented policies and other major developments in the world market and the two economies, during the same time-period.

## 7.1 SDA results and conclusions

It is clear from our data that the factory of the world "China" underwent an unprecedented growth during the time-period under consideration (1995-2009). China's share of Value Added to the World's Total Value Added grew from 3 percent in 1995 to 10 percent in 2009. This growth was mainly a manufacturing-led growth, which meant an increasing energy consumption (because manufacturing activities, by their very nature, are relatively energy intensive). However, economic growth of India was comparatively low during the same time-period. India's share of the World's Total Value Added grew by just half-a-percent from 1.5 percent to 2 percent by the end of the study period. India's growth was primarily services-led and services activities are on average not energy intensive. It follows that the growth of India was equal to the average growth of the world, while China was growing much faster.

Even with the growing energy need to support its growth, China was able to maintain a decreasing energy intensity trend. This could be reasoned as a result of the implementation of Energy Conservation Law (1997) by China's National People's Congress. The Indian economy, however experienced first a growth in energy intensity until 2002, post which its energy intensity dropped till the years of Global Financial Crisis. This drop in energy intensity can be associated with the Energy Conservation Act 2001, a Government of India initiative. The decomposition (using SDA) showed that final demand growth was the chief reason behind the energy consumption growth in China (1995-2009) and India (2000-2007). Technology change had a negligible effect on India's energy consumption growth. For China, technology change was the second largest factor responsible for energy consumption growth.

The renewable energy consumption in both the economies grew during 1995-2009. The renewable energy growth in China was multifold compared to India's. Hydro-power experienced the highest growth in both the economies, followed by Wind-power and Solar-power. The decomposition results showed that final demand growth was the main driver for renewable energy consumption growth. Energy intensity changes had a varying effect on the energy consumption growth for both the economies. The technology change had negligible effect on energy consumption change in most of the cases.

At the sectoral level, the main energy consuming sectors in both the economies were the energy producing and supplying sectors, followed by manufacturing sectors. The agriculture sector, which was responsible for employing the largest number of people in both the countries made only a small contribution to energy consumption growth. The final demand growth was the main reason behind the growing energy consumption by almost all the sectors of both economies. The energy conservation initiatives seemed to have been successful in curtailing the energy consumption growth to a certain extent by way of energy efficiency improvements. This showed in the negative energy intensity effect on energy consumption growth. The technology effect was relatively small for sectors of both the economies.

### 7.1.1 General Conclusions

From the above performed structural decomposition and analysis the following general conclusions relating to the cases at hand, i.e. India and China could be drawn:

1. The final demand growth was the main reason behind the energy consumption growth in both the economies. This finding can be generalized to other developing countries, because these countries, with growing final demand, will also experience energy consumption growth as per the co-integrated nature of energy consumption growth and economic development (Ozturk et al., 2010).
2. The structural changes occurring in the two economies are reflected in the technology effect. India, a services (less energy intensive)-led economy experienced a negative or small positive technology effect. While, China a manufacturing (energy intensive)-led economy experienced a comparatively higher positive technology effect. Although the technology effect is found to be small for both countries, we find that this effect is different (in sign) for China and India. According to this, it can be inferred that the development paths chosen by the developing economies will affect their energy needs, which if decomposed will be reflected in the technology effect. We can therefore expect that industrializing developing economies will exhibit a positive technology effect (raising energy use) as in the Chinese case.
3. The drop in energy consumption as a result of decreasing energy intensity is observed from the decomposition analysis of both the countries. The decrease in energy intensity effect in both the countries was observed post the respective energy conservation initiatives taken by both India's and China's governments. If the decline in energy intensity (or the improvement in energy efficiency) is (at least partly) due to policy, then we could expect to observe similar decline in energy intensity in other developing countries where comparable energy-conservation policies have been put in place.

## 7.2 Policy discussion

The energy conservation policies of both the economies, China's Energy Conservation Law (1997) and India's Energy Conservation Act 2001, seemed to have produced effective results. The years post their implementation experienced a restricted energy consumption increase because of negative energy intensity effect resulting out of improvements in energy efficiency. Unfortunately, the SDA results do not provide the right data to analyze the extent to which the goals of energy conservation initiatives/policies in both the economies have been realized. Claiming on the basis of our SDA results that the adoption of energy-conservation policies did "cause" the decline in energy intensity would amount to a "post hoc ergo propter hoc" fallacy ("after this, therefore because of this"). While our results therefore do not constitute causal proof, it is reasonable to assume that the implemented energy-conservation policies did generate results in terms of lower energy intensity – we did not find research evidence showing that these policies were fully ineffective. Also, the decrease or increase of energy intensity or renewable energy production is not solely a result of the energy conservation initiatives/policies taken/formed, but is also a result of many other factors such as energy market scenario, world energy prices, resources inherited by the country, technological advancements, level of implementation etc. To determine the exact effect of each policy, policy analysis needs to be performed, which was out of scope of this project but which could well be a follow-up project: to try and (econometrically) explain what was driving the observed reductions in energy intensity in both countries.

Regarding the renewable energy power production and its promotion in the two economies, it is evident from our data analysis that both the economies experienced a growth in renewable energy consumption from the start, till the end of the study period. Comparing the growth of renewable energy consumption in the two economies, the difference is prominent; China experienced a higher growth rate in renewable energy consumption (as a result of production) compared to India. This can be regarded as the result of the different policies implemented by the two countries to promote renewables. This leads us to conclude that China was more effective in making and implementing the policies to promote renewables (but, again, this conclusion has to be qualified by acknowledging the "post hoc ergo propter hoc" fallacy). As per my belief, the difference in policies of both the countries was not the only reason for such a big difference in both decreasing energy intensity and the growth of renewable energy production; the implementation of these policies played a big role. India, being a quasi-federal democratic nation experiences more hurdles in formation and further implementation of these policies, because of involvement of both central and state governments, who hold different views on different issues. However, China being a one-party state is able to implement the formed policies in a faster and effective manner.

The data refer to the state of the two economies almost a decade ago, and since then the two economies have undergone a number of policy changes related to energy conservation, energy efficiency improvements and renewable energy technology promotion. This makes it difficult to comment on specific policies. Still, an effort is made to provide the policy makers, of both the countries, with some general ideas derived from observed differences in approaches of the two countries and the general experience gained over the years:

1. The introduction of a program by Government of India, similar to China's "A Thousand Enterprise Program", which would help identify the top firms responsible for highest share of energy consumption and devise a strategy to make them more energy efficient. This would help tackle a big part of the growing energy consumption problem.
2. Both energy conservation (behavioral changes which would result in lower demand for energy-based services) and energy efficiency improvement (the technological advancement and optimization which would result in lowering of energy required while maintaining the level of services) should be given equal importance.
3. Introduction of a policy related to end of life of major energy consuming equipment. The high energy consuming equipment used in industries, factories and other sectors tend to become in-efficient over time with usage and relative to the new technology. To tackle this problem policy must be devised to discard or replace such equipment after a certain period of time. The same can be applied to old, inefficient and heavily polluting vehicles running on the roads.
4. Government should start a drive to replace the inefficient street-lighting and government office lighting with more efficient LED bulbs/lights.
5. A policy should be devised which controls the architectural design of new buildings in such a way that they follow energy efficient design philosophy.
6. Policy to encourage the fuel switching from solid and liquid fuels to electricity by electrifying processes. This would make it possible to better control the efficiency of production. Also, pollution control methods can be implemented efficiently.
7. Government should promote the development and implementation of off-grid renewable energy generation systems for rural locations.
8. Following on the lines of Chinese Government, Government of India can also benefit from the policy of favorable credit to renewable energy projects and production efficiency improvement projects. Under this scheme the financial institutions provide supply loans at favorable interest rates.
9. Governments of both the countries should focus on improving the grid connectivity over all the regions. It would not only improve the lives of the people in that region, but will also prove beneficial in extracting maximum benefits out of the regional renewable energy resources which could be transmitted in the form of electricity, over the grid.

## 7.3 Reflections

**Q1 Was the research able to answer all the questions posed at the start?**

To a large extent the research was successful as it allowed us to identify the effect of each factor (final demand growth, technology change, energy intensity change) on the energy consumption change. The study provided a good idea of the different paths followed by the two economies during 1995-2009. It was successful in analyzing the underlying effects of the energy conservation efforts of both the economies, hidden behind the energy consumption growth.

**Q2 What is Net energy concept? How is it different from Gross energy concept? And would it have been a better choice?**

Net energy concept is based on the following supply and use equations:

$$\begin{gathered} Net\ supply: Direct\ extraction + Imports + Inventory\ changes \\ = \\ Net\ use: Final\ uses + Losses\ due\ to\ conversion + Exports \end{gathered}$$

It is a useful concept in computing the total energy metabolism of the whole economy, as it removes the chances of double counting. In its calculations only the final energy use is recorded while the inputs used for transformation are ignored. The implications of Net energy concept are:

1. The energy content of oil (in TJ) is recorded in the oil products used by the sectors such as transport sector, chemical sector etc. and not as inputs to refineries. The energy used to run the refinery and the transformation related losses are recorded.
2. The power sector under the net energy concept, only records the energy transformation losses (energy lost due to conversion efficiency and in grid transmission). The energy content of produced electricity (in TJ) is recorded by all the sectors and households which consume electricity.

The shortcoming of Net energy concept over Gross energy concept is that the information regarding the energy mix is not available.

It is important to note that computing energy consumption change using Net energy concept or Gross energy concept the trends would remain the same, but the values obtained would be different. The Net energy concept can provide the real change in direct energy consumption (in TJ) but the energy mix used would not be available. If the WIOD energy use data was available based on Net energy concept, then the outcomes of the change in energy consumption would have been real values (without any double counting) but the possibility of segregating the data into the types of energy used, i.e. non-renewable and renewable, would not have been possible. Thus, the limitations of Gross energy concept in this research is that the energy consumption change values obtained are not real, but the trends obtained are similar to trends calculated using Net energy concept based data. The strengths of Gross energy concept based data have been that it was possible to segregate and calculate each type of energy used (for e.g. Solar energy, Wind energy, Hydro energy, Non-renewable energy etc.), separately.

To convert the available data into Net energy values, the following data is needed.

1. The energy output and type (i.e. Gasoline, electricity etc.) of each sector,
2. Conversion percentage of primary energy source to secondary energy source,
3. Efficiency of conversion and,
4. Other losses involved in between, like transportation loss or others.

Provided all the above data is available for all the countries, the exact values of energy consumption change could be calculated.

**Q3 What are other decomposition methods? And was SDA the best choice?**

Generally, researchers and analysts consider the four main points before selecting a method of analysis, namely: 1) Theoretical foundation, 2) Adaptability – It includes the type of data availability, the research direction etc. 3) Ease of use – If the decomposition method can be applied to the data with minimum changes, and 4) Ease of understanding the found results (Ang, 2004). One of the well-known and well researched decomposition method is Index Decomposition Analysis (IDA). IDA is more flexible compared to SDA as it has low data requirements but accounts for only direct effects and ignores indirect demand effects and final demand change effects (Su & Ang, 2012). Although both IDA and SDA are two techniques to study energy, but still there exists a difference in scope of studies; SDA studies are more capable of defining the economy wide energy use as they are developed from Input-Output tables, while IDA uses sectoral-level aggregate data which limits its decomposition abilities. Typically, SDA studies are able to provide a detailed analysis of the different factors, as technological effect (or Leontief effect) and final demand effect by both sector and demand source, and also encompasses estimations of indirect effect (Xie 2014) that are impossible to gauge in IDA model (Ma & Stern, 2008). A further detailed study of similarities and differences can be found in Hoekstra & Van den Bergh (2003) and Su & Ang (2012).

SDA uses the Input-Output model and the energy use data to decompose the energy use change into final demand change effect, technology change effect and energy intensity change effect. SDA is theoretically well founded and provides only a unique set of results for the available data. SDA is devised for Input-Output model and hence adaptability was never a problem. SDA is easy to use and the results obtained are easy to understand. Thus, after considering all the points i.e. theoretical foundation, adaptability, ease of use and ease of understanding the found results, it seems clear that SDA was the most appropriate decomposition method, in my knowledge, to be applied for decomposing the energy consumption changes, on the data available from World Input-Output Database.

### 7.3.1 Limitations

Every research encounters some or the other limitations, this research was not any different. The following are the limitations of the research: -

1. Data available from World Input-Output Database only covered the period 1995-2009 and not more recent years. The database provided the energy consumptions until 2009 only. This limited the analysis of the effects of Global Financial Crisis on the energy consumptions of the different sectors of India and China. Also, the results of the analysis for the global financial crisis years couldn't be analyzed for if they were temporary effects of crisis or were a permanent change in the system.
2. The vast amount of data availability for the years 1995-2009 made it difficult to process and analyze. Looking back, it seems a good idea to have firstly regrouped the 35 sectors into groups such as manufacturing, services, agriculture, large industries, transportation etc. This probably would have resulted in results which could have been better analyzed.
3. The distribution of energy sources is uneven in the different regions of both the countries. This uneven distribution and the rising energy demand might result into shortage of a particular type of energy in a particular region. This uneven energy supply across regions, makes inter-regional energy transportation inevitable. This leads to either high investment in construction of energy transportation system or a selection of energy source which might not be optimal but cheap. The inter-regional characteristics of energy production and consumption have an impact on regional economic growth and regional energy intensity. Ma et al. (2009) in their study found differences in energy intensity of the industries from the same sector but located in different regions of China. SDA, in its analysis is limited by the data available from WIOD. The analysis is limited by the fact that the variations in geography, climate and economic growth of the different regions of India and China have been ignored. The sectors have been considered as a whole with no information about the variations of the different production facilities in the different regions of both the countries.

## 7.4 Recommendations for Future Work

A research leads to several other questions which can be a basis for future work. Similarly, in this project, some new questions which emerged from the findings could not be researched further, as a result of time-constraint. Thus, a few ideas for future work are described:

1. As explained in the limitations, a grouping of the 35 sectors would have resulted in a better analysis; In future, research could be performed to

analyze the relation between the energy consumption growth and value addition growth of e.g. services and manufacturing to the two economies. This would provide a better analysis of the development paths chosen by the two growing economies and a comparison on which is more sustainable (energy-wise).

2. It is also important to research the effects of financial crisis on the two economies and what changes it lead to in their respective economic development paths.
3. It would also be interesting to research the carbon emissions related to the growing energy consumption and suggest some policy measures that could be implemented to counter this carbon-emissions increase and save the earth from global warming.

As production processes have become and are still becoming more and more fragmented along truly global commodity (or value) chains, it is important to study trends in energy use and energy intensity in a global setting. The WIOD provides a comprehensive and detailed multi-country production and consumption database which allows researchers to investigate energy use and energy intensity change by country but taking the whole production chain structure into account. Truly "global" analyses which exploit the novel databases such as WIOD, are still in their initial phase – and the present research project is part of the first wave of research, using the newly developed global databases. It intends to contribute to this effort: to analytically exploit the structural information which is implicit in these consistent global input-output tables, in order to address global problems such as energy use within the context of fossil-fuel emissions driven climate change. By focusing on the two most populous countries in the world (India and China) and investigating the drivers of their energy use, as well as the impacts of energy-conservation policies on energy intensity, this study is contributing to more informed, evidence-based, (global) policy discussions on energy efficiency and the mitigation of global warming. It is our hope that the WIOD database will be updated to more recent years soon and will be used in other projects focused on other regions/countries, so as to improve our understanding how to improve energy efficiency globally (along the various production chains).

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# Appendix

## A1

*Table 23:List of 36 sectors (35 industries plus households) covered in WIOD database.*

| Sectors | WIOD Code |
|---|---|
| Agriculture, Hunting, Forestry and Fishing | AtB |
| Mining and Quarrying | C |
| Food, Beverages and Tobacco | 15t16 |
| Textiles and Textile Products | 17t18 |
| Leather, Leather and Footwear | 19 |
| Wood and Products of Wood and Cork | 20 |
| Pulp, Paper, Paper, Printing and Publishing | 21t22 |
| Coke, Refined Petroleum and Nuclear Fuel | 23 |
| Chemicals and Chemical Products | 24 |
| Rubber and Plastics | 25 |
| Other Non-Metallic Mineral | 26 |
| Basic Metals and Fabricated Metal | 27t28 |
| Machinery, Nec | 29 |
| Electrical and Optical Equipment | 30t33 |
| Transport Equipment | 34t35 |
| Manufacturing, Nec; Recycling | 36t37 |
| Electricity, Gas and Water Supply | E |
| Construction | F |
| Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel | 50 |
| Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles | 51 |
| Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods | 52 |
| Hotels and Restaurants | H |
| Inland Transport | 60 |
| Water Transport | 61 |
| Air Transport | 62 |
| Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies | 63 |
| Post and Telecommunications | 64 |
| Financial Intermediation | J |
| Real Estate Activities | 70 |
| Renting of Machinery & Equipment and Other Business Activities | 71t74 |
| Public Admin and Defence; Compulsory Social Security | L |
| Education | M |
| Health and Social Work | N |
| Other Community, Social and Personal Services | O |
| Private Households with Employed Persons | P |

*Table 24: List of 26 energy commodities (plus losses) in the WIOD energy accounts*

| WIOD Code | Energy commodity |
|---|---|
| HCOAL | Hard coal and derivatives |
| BCOAL | Lignite and derivatives |
| COKE | Coke |
| CRUDE | Crude oil, NGL and feedstocks |
| DIESEL | Diesel oil for road transport |
| GASOLINE | Motor gasoline |
| JETFUEL | Jet fuel (kerosene and gasoline) |
| LFO | Light fuel oil |
| HFO | Heavy fuel oil |
| NAPHTA | Naphtha |
| OTHPETRO | Other petroleum products |
| NATGAS | Natural gas |
| OTHGAS | Derived gas |
| WASTE | Industrial and municipal waste |
| BIOGASOL | Bio-gasoline including hydrated ethanol |
| BIODIESEL | Biodiesel |
| BIOGAS | Biogas |
| OTHRENEW | Other combustible renewables |
| ELECTR | Electricity |
| HEATPROD | Heat |
| NUCLEAR | Nuclear |
| HYDRO | Hydroelectric |
| GEOTHERM | Geothermal |
| SOLAR | Solar |
| WIND | Wind power |
| OTHSOURC | Other sources |
| LOSS | Distribution losses |

## A3

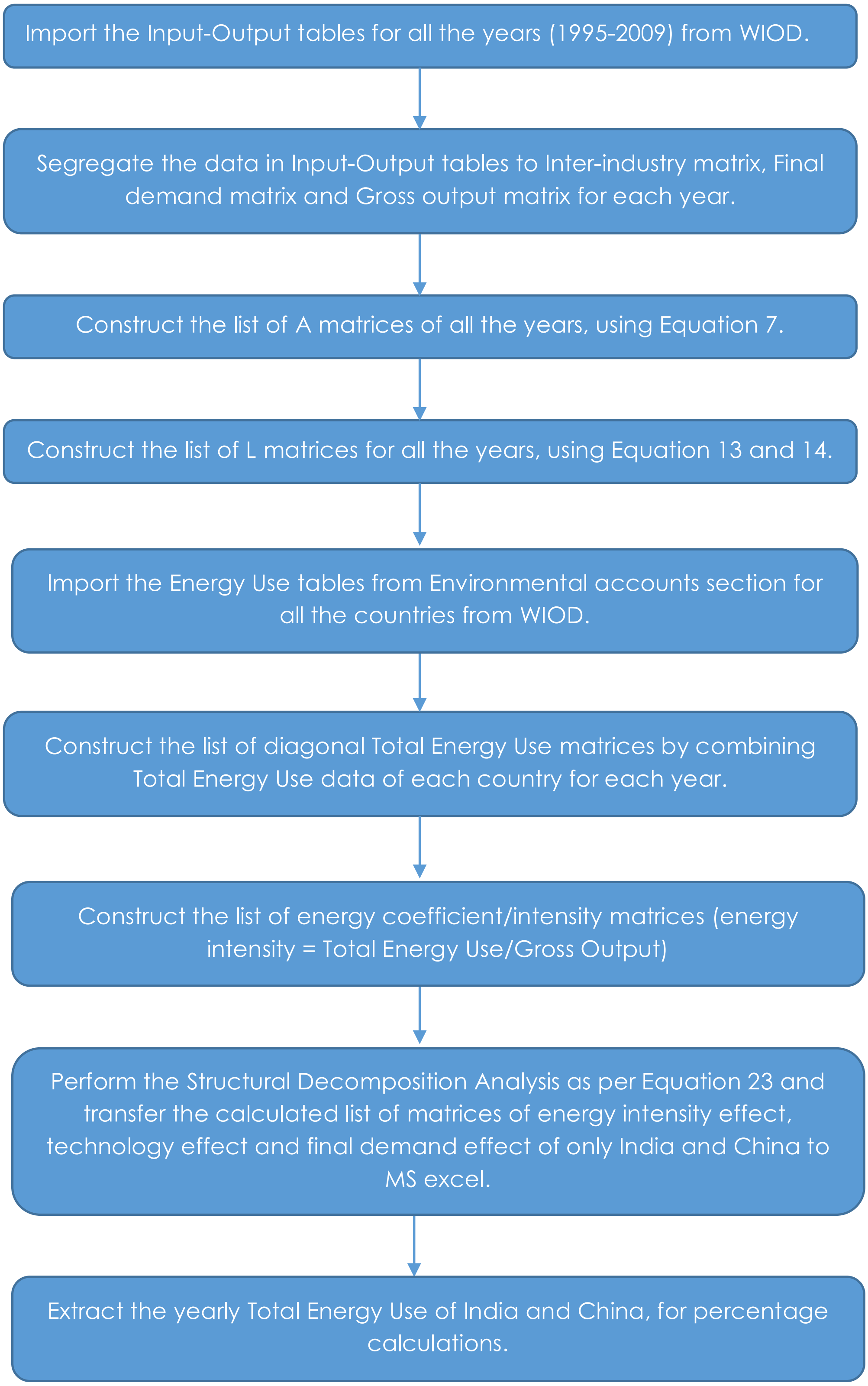


*Figure 54: Flow chart of the steps followed to perform the SDA in R.*

The similar steps have been followed to perform SDA of total renewable energy and selected renewable energy sources, i.e. Solar, Wind, Geothermal and Hydro. The R code used for the above calculations is provided below:

## The R code

```
## MATRIX EXTRACTION CODE FOR ALL (1995 - 2009) YEARS ##


m <- list()

m[[1]] <- readxl::read_excel("wiot95_row_apr12.xlsx") #m - imported WIOD matrix
m[[2]] <- readxl::read_excel("wiot96_row_apr12.xlsx")
m[[3]] <- readxl::read_excel("wiot97_row_apr12.xlsx")
m[[4]] <- readxl::read_excel("wiot98_row_apr12.xlsx")
m[[5]] <- readxl::read_excel("wiot99_row_apr12.xlsx")
m[[6]] <- readxl::read_excel("wiot00_row_apr12.xlsx")
m[[7]] <- readxl::read_excel("wiot01_row_apr12.xlsx")
m[[8]] <- readxl::read_excel("wiot02_row_apr12.xlsx")
m[[9]] <- readxl::read_excel("wiot03_row_apr12.xlsx")
m[[10]] <- readxl::read_excel("wiot04_row_apr12.xlsx")
m[[11]] <- readxl::read_excel("wiot05_row_apr12.xlsx")
m[[12]] <- readxl::read_excel("wiot06_row_apr12.xlsx")
m[[13]] <- readxl::read_excel("wiot07_row_apr12.xlsx")
m[[14]] <- readxl::read_excel("wiot08_row_sep12.xlsx")
m[[15]] <- readxl::read_excel("wiot09_row_sep12.xlsx")


I_C <- list()
intID <- list()
intIDm <- list()
FD <- list()
FDm <- list()
GO <- list()
GOn <- list()
GOm <- list()
GOt <- list()
f_FD <- list()
f_FDm <- list()

for(i in 1:15){

        I_C[[i]] <- paste(m[[i]][c(6:1440), 1], m[[i]][c(6:1440), 3], sep = "_")
#I_C - Industry_Country
        intID[[i]]  <-  m[[i]][c(6:1440),  c(5:1439)]  #intID  -  inter  industry
demand dataframe
        intIDm[[i]] <- data.matrix(intID[[i]], rownames.force = NA) #intIDm -
inter industry demand matrix
        FD[[i]] <- m[[i]][c(6:1440), c(1440:1644)] #FD - final demand dataframe
        FDm[[i]]  <-  data.matrix(FD[[i]],  rownames.force  =  NA)  #FDm  -  final
demand matrix
        GO[[i]] <- m[[i]][c(6:1440), 1645] #GO - Gross output dataframe
        #GOn <- apply(GO, 1, as.numeric) #GOn - Gross output numeric
        GOn[[i]]  <-  data.matrix(GO[[i]],  rownames.force  =  NA)  #GOn  -  Gross
output matrix
        GOm[[i]] <- as.matrix(as.data.frame(lapply(GOn[[i]], as.numeric))) #GOm
- Gross output numeric matrix
        GOt[[i]] <- t(GOm[[i]]) #GOt - Transpose of GOm to nX1 matrix
        f_FD[[i]] <- rowSums(FDm[[i]], na.rm = FALSE) #f_FD - final demand vector
        f_FDm[[i]] <- data.matrix(f_FD[[i]], rownames.force = NA) #f_FDm - final
demand 1435 X 1 matrix

}
```

```
## RELATIVE PRICE LEVELS ##


P <- readxl::read_excel("WIOD_SEA_Feb12.xlsx", sheet = 2) #relative price excel
file

P_c <- list()

for(i in 1:41){

        P_c[[i]]              <-              P[c(((362*i)+(34*(i-1))+(504*(i-
1))):((362*i)+(34*i)+(504*(i-1)))), c(5:19)]  #  Price  levels  of  different
countries for 1995-2009

}

P_f = base::do.call(what = rbind, args = P_c) #Final Price matrix


## A* (A-STAR I.E. NOT CONSIDERING RELATIVE PRICE LEVELS) CALCULATION FOR ALL
YEARS ##


A <- list()

for(k in 1:15){

        A[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #A - Constructing
a matrix with all NA.

        for(i in 1:dim(A[[k]])[1]){

                for(j in 1:dim(A[[k]])[2]){

                        A[[k]][i,j]  =  intIDm[[k]][i,j]/GOt[[k]][j,1]  #Both
values are in million $.

                        if (is.na(A[[k]][i,j])){

                                A[[k]][i,j] <- 0

                        }
                }
        }
}


## FILTERED (I.E. TAKING RELATIVE PRICE LEVELS INTO CONSIDERATION) A, GO AND FD
MATRICES ##


A_f <- list() # Final filtered A matrices
GO_f <- list() # Final filtered GO matrices
FD_f <- list() # Final filtered FD matrices

for(k in 1:15){

        A_f[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435)
        GO_f[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1)
        FD_f[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1)

        for(i in 1:dim(A[[k]])[1]){

                for(j in 1:dim(A[[k]])[2]){
```

```
                A_f[[k]][i,j] = A[[k]][i,j]/(P_f[i,k]/P_f[j,k])

                if(is.na(A_f[[k]][i,j])){

                        A_f[[k]][i,j] <- 0
                }
            }
        }

        for(i in 1:1435){

                GO_f[[k]][i,1]  =  GOt[[k]][i,1]/(P_f[i,k]/100)  #Values  are  in
million $

                if(is.na(GO_f[[k]][i,1])){

                        GO_f[[k]][i,1] <- 0

                }

                FD_f[[k]][i,1] = f_FDm[[k]][i,1]/(P_f[i,k]/100) #Values are in
million $

                if(is.na(FD_f[[k]][i,1])){

                        FD_f[[k]][i,1] <- 0

                }
        }
}


## CALCULATING L MATRIX FROM FILTERED A MATRIX ##


I <- list()
l <- list()
L <- list()

for(i in 1:15){

        I[[i]] <- diag(x=1, nrow = 1435, ncol = 1435) # I - Identity matrix of
1435 X 1435 size
        l[[i]] <- (I[[i]]-A_f[[i]])
        L[[i]] <- solve(l[[i]]) # L - Leontief inverse found by inverting (I-A)

}


## CONSTRUCTION TEU (TOTAL ENERGY USE) MATRICES FOR YEARS 1995 - 2009 ##


AUS_EU <- list()
AUT_EU <- list()
BEL_EU <- list()
BGR_EU <- list()
BRA_EU <- list()
CAN_EU <- list()
CHN_EU <- list()
CYP_EU <- list()
CZE_EU <- list()
DEU_EU <- list()
DNK_EU <- list()
ESP_EU <- list()
EST_EU <- list()
```

```
FIN_EU <- list()
FRA_EU <- list()
GBR_EU <- list()
GRC_EU <- list()
HUN_EU <- list()
IDN_EU <- list()
IND_EU <- list()
IRL_EU <- list()
ITA_EU <- list()
JPN_EU <- list()
KOR_EU <- list()
LTU_EU <- list()
LUX_EU <- list()
LVA_EU <- list()
MEX_EU <- list()
MLT_EU <- list()
NLD_EU <- list()
POL_EU <- list()
PRT_EU <- list()
ROU_EU <- list()
RUS_EU <- list()
SVK_EU <- list()
SVN_EU <- list()
SWE_EU <- list()
TUR_EU <- list()
TWN_EU <- list()
USA_EU <- list()
ROW_EU <- list()

for(i in 1:15){

      AUS_EU[[i]] <- readxl::read_excel("AUS_EU_May12.xls",sheet = (i+1) )
      AUT_EU[[i]] <- readxl::read_excel("AUT_EU_May12.xls",sheet = (i+1) )
      BEL_EU[[i]] <- readxl::read_excel("BEL_EU_May12.xls",sheet = (i+1) )
      BGR_EU[[i]] <- readxl::read_excel("BGR_EU_May12.xls",sheet = (i+1) )
      BRA_EU[[i]] <- readxl::read_excel("BRA_EU_May12.xls",sheet = (i+1) )
      CAN_EU[[i]] <- readxl::read_excel("CAN_EU_May12.xls",sheet = (i+1) )
      CHN_EU[[i]] <- readxl::read_excel("CHN_EU_May12.xls",sheet = (i+1) )
      CYP_EU[[i]] <- readxl::read_excel("CYP_EU_May12.xls",sheet = (i+1) )
      CZE_EU[[i]] <- readxl::read_excel("CZE_EU_May12.xls",sheet = (i+1) )
      DEU_EU[[i]] <- readxl::read_excel("DEU_EU_May12.xls",sheet = (i+1) )
      DNK_EU[[i]] <- readxl::read_excel("DNK_EU_May12.xls",sheet = (i+1) )
      ESP_EU[[i]] <- readxl::read_excel("ESP_EU_May12.xls",sheet = (i+1) )
      EST_EU[[i]] <- readxl::read_excel("EST_EU_May12.xls",sheet = (i+1) )
      FIN_EU[[i]] <- readxl::read_excel("FIN_EU_May12.xls",sheet = (i+1) )
      FRA_EU[[i]] <- readxl::read_excel("FRA_EU_May12.xls",sheet = (i+1) )
      GBR_EU[[i]] <- readxl::read_excel("GBR_EU_May12.xls",sheet = (i+1) )
      GRC_EU[[i]] <- readxl::read_excel("GRC_EU_May12.xls",sheet = (i+1) )
      HUN_EU[[i]] <- readxl::read_excel("HUN_EU_May12.xls",sheet = (i+1) )
      IDN_EU[[i]] <- readxl::read_excel("IDN_EU_May12.xls",sheet = (i+1) )
      IND_EU[[i]] <- readxl::read_excel("IND_EU_May12.xls",sheet = (i+1) )
      IRL_EU[[i]] <- readxl::read_excel("IRL_EU_May12.xls",sheet = (i+1) )
      ITA_EU[[i]] <- readxl::read_excel("ITA_EU_May12.xls",sheet = (i+1) )
      JPN_EU[[i]] <- readxl::read_excel("JPN_EU_May12.xls",sheet = (i+1) )
      KOR_EU[[i]] <- readxl::read_excel("KOR_EU_May12.xls",sheet = (i+1) )
      LTU_EU[[i]] <- readxl::read_excel("LTU_EU_May12.xls",sheet = (i+1) )
      LUX_EU[[i]] <- readxl::read_excel("LUX_EU_May12.xls",sheet = (i+1) )
      LVA_EU[[i]] <- readxl::read_excel("LVA_EU_May12.xls",sheet = (i+1) )
      MEX_EU[[i]] <- readxl::read_excel("MEX_EU_May12.xls",sheet = (i+1) )
      MLT_EU[[i]] <- readxl::read_excel("MLT_EU_May12.xls",sheet = (i+1) )
      NLD_EU[[i]] <- readxl::read_excel("NLD_EU_May12.xls",sheet = (i+1) )
      POL_EU[[i]] <- readxl::read_excel("POL_EU_May12.xls",sheet = (i+1) )
      PRT_EU[[i]] <- readxl::read_excel("PRT_EU_May12.xls",sheet = (i+1) )
      ROU_EU[[i]] <- readxl::read_excel("ROU_EU_May12.xls",sheet = (i+1) )
      RUS_EU[[i]] <- readxl::read_excel("RUS_EU_May12.xls",sheet = (i+1) )
      SVK_EU[[i]] <- readxl::read_excel("SVK_EU_May12.xls",sheet = (i+1) )
```

```
        SVN_EU[[i]] <- readxl::read_excel("SVN_EU_May12.xls",sheet = (i+1) )
        SWE_EU[[i]] <- readxl::read_excel("SWE_EU_May12.xls",sheet = (i+1) )
        TUR_EU[[i]] <- readxl::read_excel("TUR_EU_May12.xls",sheet = (i+1) )
        TWN_EU[[i]] <- readxl::read_excel("TWN_EU_May12.xls",sheet = (i+1) )
        USA_EU[[i]] <- readxl::read_excel("USA_EU_May12.xls",sheet = (i+1) )
        ROW_EU[[i]] <- readxl::read_excel("ROW_EU_May12.xls",sheet = (i+1) )

}

e <- list()
TEU <- list()
Diag_TEU <- list()

for(i in 1:15){

        e[[i]]      <-      c(AUS_EU[[i]][1:35,30],      AUT_EU[[i]][1:35,30],
BEL_EU[[i]][1:35,30],
                  BGR_EU[[i]][1:35,30],                  BRA_EU[[i]][1:35,30],
CAN_EU[[i]][1:35,30],
                  CHN_EU[[i]][1:35,30],                  CYP_EU[[i]][1:35,30],
CZE_EU[[i]][1:35,30],
                  DEU_EU[[i]][1:35,30],                  DNK_EU[[i]][1:35,30],
ESP_EU[[i]][1:35,30],
                  EST_EU[[i]][1:35,30],                  FIN_EU[[i]][1:35,30],
FRA_EU[[i]][1:35,30],
                  GBR_EU[[i]][1:35,30],                  GRC_EU[[i]][1:35,30],
HUN_EU[[i]][1:35,30],
                  IDN_EU[[i]][1:35,30],                  IND_EU[[i]][1:35,30],
IRL_EU[[i]][1:35,30],
                  ITA_EU[[i]][1:35,30],                  JPN_EU[[i]][1:35,30],
KOR_EU[[i]][1:35,30],
                  LTU_EU[[i]][1:35,30],                  LUX_EU[[i]][1:35,30],
LVA_EU[[i]][1:35,30],
                  MEX_EU[[i]][1:35,30],                  MLT_EU[[i]][1:35,30],
NLD_EU[[i]][1:35,30],
                  POL_EU[[i]][1:35,30],                  PRT_EU[[i]][1:35,30],
ROU_EU[[i]][1:35,30],
                  RUS_EU[[i]][1:35,30],                  SVK_EU[[i]][1:35,30],
SVN_EU[[i]][1:35,30],
                  SWE_EU[[i]][1:35,30],                  TUR_EU[[i]][1:35,30],
TWN_EU[[i]][1:35,30],
                  USA_EU[[i]][1:35,30], ROW_EU[[i]][1:35,30])

        TEU[[i]] <- data.matrix(e[[i]], rownames.force = NA) #List of Total
Energy Use column matrix

        Diag_TEU[[i]] <- vec2diag(TEU[[i]]) #List of Diagonal Matrix of TEU

}


## ENERGY INTENSITY (L & GO) CALCULATIONS ##


L_ei <- list()
GO_ei <- list()
EI <- list()

for(k in 1:15) {

        EI[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #EI - Constructing
a matrix with all NA.

        for(i in 1:1435){

                for(j in 1:1435){
```

```
                        EI[[k]][i,j] = Diag_TEU[[k]][i,j]/GO_f[[k]][j,1] #EI -
matrix of TEU(Total Energy Use)/GO(Gross Output)

                        if (is.na(EI[[k]][i,j])) {

                                EI[[k]][i,j] <- 0
                        }
                }
        }

        L_ei[[k]] <- EI[[k]] %*% L[[k]]
        GO_ei[[k]] <- EI[[k]] %*% GO_f[[k]]
}


## STRUCTURAL DECOMPOSITION ##


# del_EL <- list()
# del_F <- list()
# del_TEU <- list()

EI_cng <- list()
L_cng <- list()
F_cng <- list()

for(k in 1:14){

        EI_cng[[k]] <- matrix()
        L_cng[[k]] <- matrix()
        F_cng[[k]] <- matrix()

      #  del_EL[[k]] = L_ei[[k+1]] - L_ei[[k]]
        #del_EL corresponds to delta L in the structural decomposition equation,
where L = (TEU/X)*L (where, X = Gross Output)
      #  del_F[[k]] = FD_f[[k+1]] - FD_f[[k]]
        #del_F corresponds to delta F in the structural decomposition equation.
      #  del_TEU[[k]] = ((1/2)*(del_EL[[k]] %*% (FD_f[[k]] + FD_f[[k+1]]))) +
((1/2)*((L_ei[[k]] + L_ei[[k+1]]) %*% del_F[[k]]))
        #del_TEU  corresponds  to  delta  X  in  the  structural  decomposition
equation.
        #del_TEU = (TEU/X)*X

        EI_cng[[k]]         <-         ((1/2)*((EI[[k+1]]-EI[[k]])         %*%
((L[[k]]%*%FD_f[[k]])+(L[[k+1]]%*%FD_f[[k+1]]))))

        L_cng[[k]]              <-              ((1/2)*((EI[[k]]%*%(L[[k+1]]-
L[[k]])%*%FD_f[[k+1]])+(EI[[k+1]]%*%(L[[k+1]]-L[[k]])%*%FD_f[[k]])))

        F_cng[[k]]                                                          <-
((1/2)*(((EI[[k]]%*%L[[k]])+(EI[[k+1]]%*%L[[k+1]]))%*%(FD_f[[k+1]]-
FD_f[[k]])))

}


## EXTRACTING EI, L ,AND F CHANGE IN INDIA & CHINA ##


EI_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
L_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
F_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)

EI_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
L_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
```

```
F_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)

for(i in 1:35){

        for(j in 1:14){

                EI_ind_cng[i,j] = EI_cng[[j]][((19*35)+i),1]
                L_ind_cng[i,j] = L_cng[[j]][((19*35)+i),1]
                F_ind_cng[i,j] = F_cng[[j]][((19*35)+i),1]

                EI_chn_cng[i,j] = EI_cng[[j]][((6*35)+i),1]
                L_chn_cng[i,j] = L_cng[[j]][((6*35)+i),1]
                F_chn_cng[i,j] = F_cng[[j]][((6*35)+i),1]

        }

}


## EXPORTING TO EXCEL ##


EI_IND <- as.data.frame(EI_ind_cng)
WriteXLS::WriteXLS(EI_IND, ExcelFileName = "EI_IND.xls")

EI_CHN <- as.data.frame(EI_chn_cng)
WriteXLS::WriteXLS(EI_CHN, ExcelFileName = "EI_CHN.xls")

L_IND <- as.data.frame(L_ind_cng)
WriteXLS::WriteXLS(L_IND, ExcelFileName = "L_IND.xls")

L_CHN <- as.data.frame(L_chn_cng)
WriteXLS::WriteXLS(L_CHN, ExcelFileName = "L_CHN.xls")

F_IND <- as.data.frame(F_ind_cng)
WriteXLS::WriteXLS(F_IND, ExcelFileName = "F_IND.xls")

F_CHN <- as.data.frame(F_chn_cng)
WriteXLS::WriteXLS(F_CHN, ExcelFileName = "F_CHN.xls")


## EXTRACTING DELTA GO FROM GO_f ##


GO_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)#Gross Output change
GO_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
GO_ind_95_09 <- matrix(data = NA, nrow = 35, ncol = 15) #Gross Output from 1995
to 2009
GO_chn_95_09 <- matrix(data = NA, nrow = 35, ncol = 15)
FD_ind_95_09 <- matrix(data = NA, nrow = 35, ncol = 15) #Final Demand from 1995
to 2009
FD_chn_95_09 <- matrix(data = NA, nrow = 35, ncol = 15)
TEU_ind_95_09 <- matrix(data = NA, nrow = 35, ncol = 15) #Total Energy Use from
1995 to 2009
TEU_chn_95_09 <- matrix(data = NA, nrow = 35, ncol = 15)


        for(i in 1:35){

                for(j in 1:14){

                        GO_ind_cng[i,j]      =      GO_f[[j+1]][((19*35)+i),1]-
GO_f[[j]][((19*35)+i),1]
                        GO_chn_cng[i,j]      =      GO_f[[j+1]][((6*35)+i),1]-
GO_f[[j]][((6*35)+i),1]
```

```
                }

        }

for(i in 1:35){

                for(j in 1:15){

                    GO_ind_95_09[i,j] = GO_f[[j]][((19*35)+i),1]
                    GO_chn_95_09[i,j] = GO_f[[j]][((6*35)+i),1]
                    FD_ind_95_09[i,j] = FD_f[[j]][((19*35)+i),1]
                    FD_chn_95_09[i,j] = FD_f[[j]][((6*35)+i),1]
                    TEU_ind_95_09[i,j] = TEU[[j]][((19*35)+i),1]
                    TEU_chn_95_09[i,j] = TEU[[j]][((6*35)+i),1]

                }

        }



GO_IND <- as.data.frame(GO_ind_cng)
WriteXLS::WriteXLS(GO_IND, ExcelFileName = "GO_IND.xls")

GO_CHN <- as.data.frame(GO_chn_cng)
WriteXLS::WriteXLS(GO_CHN, ExcelFileName = "GO_CHN.xls")

GO_IND_95 <- as.data.frame(GO_ind_95_09)
WriteXLS::WriteXLS(GO_IND_95, ExcelFileName = "GO_IND_95.xls")

GO_CHN_95 <- as.data.frame(GO_chn_95_09)
WriteXLS::WriteXLS(GO_CHN_95, ExcelFileName = "GO_CHN_95.xls")

FD_IND_95 <- as.data.frame(FD_ind_95_09)
WriteXLS::WriteXLS(FD_IND_95, ExcelFileName = "FD_IND_95.xls")

FD_CHN_95 <- as.data.frame(FD_chn_95_09)
WriteXLS::WriteXLS(FD_CHN_95, ExcelFileName = "FD_CHN_95.xls")

TEU_IND_95 <- as.data.frame(TEU_ind_95_09)
WriteXLS::WriteXLS(TEU_IND_95, ExcelFileName = "TEU_IND_95.xls")

TEU_CHN_95 <- as.data.frame(TEU_chn_95_09)
WriteXLS::WriteXLS(TEU_CHN_95, ExcelFileName = "TEU_CHN_95.xls")


## VA (VALUE ADDED) EXTRACTION CODE ##


VA <- list()
VAm <- list()
VAt <- list()

for(i in 1:15){

        VA[[i]] <- m[[i]][1446, c(5:1439)] #VA - Value added data frame
        VAm[[i]] <- data.matrix(VA[[i]], rownames.force = NA) #VAm - Value added
matrix
        VAt[[i]] <- t(VAm[[i]]) #VAt - Transpose of VAm to nx1 matrix

}


## FILTERED (I.E. TAKING RELATIVE PRICE LEVELS INTO CONSIDERATION) VA MATRICES
##
```

```
VA_f <- list() # Final filtered VA matrices

for(k in 1:15){

        VA_f[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1)

        for(i in 1:1435){

                VA_f[[k]][i,1] = VAt[[k]][i,1]/(P_f[i,k]/100)

                if(is.na(VA_f[[k]][i,1])){

                        VA_f[[k]][i,1] <- 0 # VA_f for ROW goes 0 as a result
of no values for P_f

                }
        }
}


## COUNTRY-WISE SUM OF VA ##

#VA_sc <- list() #VA_sc - VA sum country-wise for all the years

#for(k in 1:15){

#        VA_sc[[k]] <- matrix(data = NA, nrow = 41, ncol = 1)

#        for(i in 1:41){

#                                        VA_sc[[k]][i,1]  =  sum(VA_f[[k]][((i-
1)*35+1),1]:VA_f[[k]][(i*35),1], na.rm = FALSE)
#        }
#}


## EXTRACTING VA FROM VA_f ##


VA_ind_95_09 <- matrix(data = NA, nrow = 35, ncol = 15) #Value Added from 1995
to 2009
VA_chn_95_09 <- matrix(data = NA, nrow = 35, ncol = 15)


for(i in 1:35){

        for(j in 1:15){

                VA_ind_95_09[i,j] = VA_f[[j]][((19*35)+i),1]
                VA_chn_95_09[i,j] = VA_f[[j]][((6*35)+i),1]

        }

}


VA_IND_95 <- as.data.frame(VA_ind_95_09)
WriteXLS::WriteXLS(VA_IND_95, ExcelFileName = "VA_IND_95.xls")

VA_CHN_95 <- as.data.frame(VA_chn_95_09)
WriteXLS::WriteXLS(VA_CHN_95, ExcelFileName = "VA_CHN_95.xls")


## CALCULATE AND EXTRACT TOTAL VALUE ADDED BY WORLD ECONOMY ##
```

```
VA_sum <- vector(mode = "numeric", length = 0)

for(i in 1:15){

        VA_sum[i] <- colSums(VA_f[[i]], na.rm = TRUE)
}

VA_sum_wrd <- as.data.frame(VA_sum)
WriteXLS::WriteXLS(VA_sum_wrd, ExcelFileName = "VA_sum_wrd.xls")


## TEU OF THE WORLD ##


TEU_sum <- vector(mode = "numeric", length = 0)

for(i in 1:15){

        TEU_sum[i] <- colSums(TEU[[i]], na.rm = TRUE)
}

TEU_sum_wrd <- as.data.frame(TEU_sum)
WriteXLS::WriteXLS(TEU_sum_wrd, ExcelFileName = "TEU_sum_wrd.xls")


## EXTRACTING TEU IND & CHN FROM TEU ##


TEU_ind_95_09 <- matrix(data = NA, nrow = 35, ncol = 15) #Total Energy Use from
1995 to 2009
TEU_chn_95_09 <- matrix(data = NA, nrow = 35, ncol = 15)


for(i in 1:35){

        for(j in 1:15){

                TEU_ind_95_09[i,j] = TEU[[j]][((19*35)+i),1]
                TEU_chn_95_09[i,j] = TEU[[j]][((6*35)+i),1]

        }

}


TEU_IND_95 <- as.data.frame(TEU_ind_95_09)
WriteXLS::WriteXLS(TEU_IND_95, ExcelFileName = "TEU_IND_95.xls")

TEU_CHN_95 <- as.data.frame(TEU_chn_95_09)
WriteXLS::WriteXLS(TEU_CHN_95, ExcelFileName = "TEU_CHN_95.xls")


## CONVERTING TO DATA MATRIX ##


AUS_EU_M <- list()
AUT_EU_M <- list()
BEL_EU_M <- list()
BGR_EU_M <- list()
BRA_EU_M <- list()
CAN_EU_M <- list()
CHN_EU_M <- list()
CYP_EU_M <- list()
CZE_EU_M <- list()
DEU_EU_M <- list()
```

```
DNK_EU_M <- list()
ESP_EU_M <- list()
EST_EU_M <- list()
FIN_EU_M <- list()
FRA_EU_M <- list()
GBR_EU_M <- list()
GRC_EU_M <- list()
HUN_EU_M <- list()
IDN_EU_M <- list()
IND_EU_M <- list()
IRL_EU_M <- list()
ITA_EU_M <- list()
JPN_EU_M <- list()
KOR_EU_M <- list()
LTU_EU_M <- list()
LUX_EU_M <- list()
LVA_EU_M <- list()
MEX_EU_M <- list()
MLT_EU_M <- list()
NLD_EU_M <- list()
POL_EU_M <- list()
PRT_EU_M <- list()
ROU_EU_M <- list()
RUS_EU_M <- list()
SVK_EU_M <- list()
SVN_EU_M <- list()
SWE_EU_M <- list()
TUR_EU_M <- list()
TWN_EU_M <- list()
USA_EU_M <- list()
ROW_EU_M <- list()

for(i in 1:15){

        AUS_EU_M[[i]] <- data.matrix(AUS_EU[[i]],rownames.force = NA)
        AUT_EU_M[[i]] <- data.matrix(AUT_EU[[i]],rownames.force = NA)
        BEL_EU_M[[i]] <- data.matrix(BEL_EU[[i]],rownames.force = NA)
        BGR_EU_M[[i]] <- data.matrix(BGR_EU[[i]],rownames.force = NA)
        BRA_EU_M[[i]] <- data.matrix(BRA_EU[[i]],rownames.force = NA)
        CAN_EU_M[[i]] <- data.matrix(CAN_EU[[i]],rownames.force = NA)
        CHN_EU_M[[i]] <- data.matrix(CHN_EU[[i]],rownames.force = NA)
        CYP_EU_M[[i]] <- data.matrix(CYP_EU[[i]],rownames.force = NA)
        CZE_EU_M[[i]] <- data.matrix(CZE_EU[[i]],rownames.force = NA)
        DEU_EU_M[[i]] <- data.matrix(DEU_EU[[i]],rownames.force = NA)
        DNK_EU_M[[i]] <- data.matrix(DNK_EU[[i]],rownames.force = NA)
        ESP_EU_M[[i]] <- data.matrix(ESP_EU[[i]],rownames.force = NA)
        EST_EU_M[[i]] <- data.matrix(EST_EU[[i]],rownames.force = NA)
        FIN_EU_M[[i]] <- data.matrix(FIN_EU[[i]],rownames.force = NA)
        FRA_EU_M[[i]] <- data.matrix(FRA_EU[[i]],rownames.force = NA)
        GBR_EU_M[[i]] <- data.matrix(GBR_EU[[i]],rownames.force = NA)
        GRC_EU_M[[i]] <- data.matrix(GRC_EU[[i]],rownames.force = NA)
        HUN_EU_M[[i]] <- data.matrix(HUN_EU[[i]],rownames.force = NA)
        IDN_EU_M[[i]] <- data.matrix(IDN_EU[[i]],rownames.force = NA)
        IND_EU_M[[i]] <- data.matrix(IND_EU[[i]],rownames.force = NA)
        IRL_EU_M[[i]] <- data.matrix(IRL_EU[[i]],rownames.force = NA)
        ITA_EU_M[[i]] <- data.matrix(ITA_EU[[i]],rownames.force = NA)
        JPN_EU_M[[i]] <- data.matrix(JPN_EU[[i]],rownames.force = NA)
        KOR_EU_M[[i]] <- data.matrix(KOR_EU[[i]],rownames.force = NA)
        LTU_EU_M[[i]] <- data.matrix(LTU_EU[[i]],rownames.force = NA)
        LUX_EU_M[[i]] <- data.matrix(LUX_EU[[i]],rownames.force = NA)
        LVA_EU_M[[i]] <- data.matrix(LVA_EU[[i]],rownames.force = NA)
        MEX_EU_M[[i]] <- data.matrix(MEX_EU[[i]],rownames.force = NA)
        MLT_EU_M[[i]] <- data.matrix(MLT_EU[[i]],rownames.force = NA)
        NLD_EU_M[[i]] <- data.matrix(NLD_EU[[i]],rownames.force = NA)
        POL_EU_M[[i]] <- data.matrix(POL_EU[[i]],rownames.force = NA)
        PRT_EU_M[[i]] <- data.matrix(PRT_EU[[i]],rownames.force = NA)
```

```
        ROU_EU_M[[i]] <- data.matrix(ROU_EU[[i]],rownames.force = NA)
        RUS_EU_M[[i]] <- data.matrix(RUS_EU[[i]],rownames.force = NA)
        SVK_EU_M[[i]] <- data.matrix(SVK_EU[[i]],rownames.force = NA)
        SVN_EU_M[[i]] <- data.matrix(SVN_EU[[i]],rownames.force = NA)
        SWE_EU_M[[i]] <- data.matrix(SWE_EU[[i]],rownames.force = NA)
        TUR_EU_M[[i]] <- data.matrix(TUR_EU[[i]],rownames.force = NA)
        TWN_EU_M[[i]] <- data.matrix(TWN_EU[[i]],rownames.force = NA)
        USA_EU_M[[i]] <- data.matrix(USA_EU[[i]],rownames.force = NA)
        ROW_EU_M[[i]] <- data.matrix(ROW_EU[[i]],rownames.force = NA)

}


## RENEWABLE ENERGY USE DIAGONAL MATRIX (includes all types of RENEWABLE SOURCES
of ENERGY) ##


re <- list()
Diag_RTEU <- list()

for(i in 1:15){

        re[[i]]  <-  c(rowSums(AUS_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(AUT_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(BEL_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(BGR_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(BRA_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(CAN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(CHN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(CYP_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(CZE_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(DEU_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(DNK_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(ESP_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(EST_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(FIN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(FRA_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(GBR_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(GRC_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(HUN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(IDN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(IND_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(IRL_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(ITA_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(JPN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(KOR_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(LTU_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(LUX_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(LVA_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(MEX_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(MLT_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(NLD_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(POL_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(PRT_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(ROU_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
```

```
                     rowSums(RUS_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(SVK_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(SVN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(SWE_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(TUR_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(TWN_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ),
                     rowSums(USA_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE      ),      rowSums(ROW_EU_M[[i]][1:35,c(17,18,19,20,24,25,26,27)],
na.rm=TRUE ))

        Diag_RTEU[[i]] <- vec2diag(re[[i]]) #List of Diagonal Matrix of re

}

## HYDRO POWER USE DIAGONAL MATRIX ##

hyd_e <- list()
Diag_HYD_TEU <- list()

for(i in 1:15){

        hyd_e[[i]]  <-  c(AUS_EU_M[[i]][1:35,24]  ,   AUT_EU_M[[i]][1:35,24]  ,
BEL_EU_M[[i]][1:35,24] ,
                      BGR_EU_M[[i]][1:35,24]   ,     BRA_EU_M[[i]][1:35,24]   ,
CAN_EU_M[[i]][1:35,24] ,
                      CHN_EU_M[[i]][1:35,24]   ,     CYP_EU_M[[i]][1:35,24]   ,
CZE_EU_M[[i]][1:35,24] ,
                      DEU_EU_M[[i]][1:35,24]   ,     DNK_EU_M[[i]][1:35,24]   ,
ESP_EU_M[[i]][1:35,24] ,
                      EST_EU_M[[i]][1:35,24]   ,     FIN_EU_M[[i]][1:35,24]   ,
FRA_EU_M[[i]][1:35,24] ,
                      GBR_EU_M[[i]][1:35,24]   ,     GRC_EU_M[[i]][1:35,24]   ,
HUN_EU_M[[i]][1:35,24] ,
                      IDN_EU_M[[i]][1:35,24]   ,     IND_EU_M[[i]][1:35,24]   ,
IRL_EU_M[[i]][1:35,24] ,
                      ITA_EU_M[[i]][1:35,24]   ,     JPN_EU_M[[i]][1:35,24]   ,
KOR_EU_M[[i]][1:35,24] ,
                      LTU_EU_M[[i]][1:35,24]   ,     LUX_EU_M[[i]][1:35,24]   ,
LVA_EU_M[[i]][1:35,24] ,
                      MEX_EU_M[[i]][1:35,24]   ,     MLT_EU_M[[i]][1:35,24]   ,
NLD_EU_M[[i]][1:35,24] ,
                      POL_EU_M[[i]][1:35,24]   ,     PRT_EU_M[[i]][1:35,24]   ,
ROU_EU_M[[i]][1:35,24] ,
                      RUS_EU_M[[i]][1:35,24]   ,     SVK_EU_M[[i]][1:35,24]   ,
SVN_EU_M[[i]][1:35,24] ,
                      SWE_EU_M[[i]][1:35,24]   ,     TUR_EU_M[[i]][1:35,24]   ,
TWN_EU_M[[i]][1:35,24] ,
                      USA_EU_M[[i]][1:35,24] ,  ROW_EU_M[[i]][1:35,24])

        Diag_HYD_TEU[[i]] <- vec2diag(hyd_e[[i]]) #List of Diagonal Matrix of
hyd_e

}

## GEOTHERMAL ENERGY USE DIAGONAL MATRIX ##

geo_e <- list()
Diag_GEO_TEU <- list()
```

```
for(i in 1:15){

        geo_e[[i]]  <-  c(AUS_EU_M[[i]][1:35,25]  ,   AUT_EU_M[[i]][1:35,25]  ,
BEL_EU_M[[i]][1:35,25] ,
                        BGR_EU_M[[i]][1:35,25]  ,    BRA_EU_M[[i]][1:35,25]  ,
CAN_EU_M[[i]][1:35,25] ,
                        CHN_EU_M[[i]][1:35,25]  ,    CYP_EU_M[[i]][1:35,25]  ,
CZE_EU_M[[i]][1:35,25] ,
                        DEU_EU_M[[i]][1:35,25]  ,    DNK_EU_M[[i]][1:35,25]  ,
ESP_EU_M[[i]][1:35,25] ,
                        EST_EU_M[[i]][1:35,25]  ,    FIN_EU_M[[i]][1:35,25]  ,
FRA_EU_M[[i]][1:35,25] ,
                        GBR_EU_M[[i]][1:35,25]  ,    GRC_EU_M[[i]][1:35,25]  ,
HUN_EU_M[[i]][1:35,25] ,
                        IDN_EU_M[[i]][1:35,25]  ,    IND_EU_M[[i]][1:35,25]  ,
IRL_EU_M[[i]][1:35,25] ,
                        ITA_EU_M[[i]][1:35,25]  ,    JPN_EU_M[[i]][1:35,25]  ,
KOR_EU_M[[i]][1:35,25] ,
                        LTU_EU_M[[i]][1:35,25]  ,    LUX_EU_M[[i]][1:35,25]  ,
LVA_EU_M[[i]][1:35,25] ,
                        MEX_EU_M[[i]][1:35,25]  ,    MLT_EU_M[[i]][1:35,25]  ,
NLD_EU_M[[i]][1:35,25] ,
                        POL_EU_M[[i]][1:35,25]  ,    PRT_EU_M[[i]][1:35,25]  ,
ROU_EU_M[[i]][1:35,25] ,
                        RUS_EU_M[[i]][1:35,25]  ,    SVK_EU_M[[i]][1:35,25]  ,
SVN_EU_M[[i]][1:35,25] ,
                        SWE_EU_M[[i]][1:35,25]  ,    TUR_EU_M[[i]][1:35,25]  ,
TWN_EU_M[[i]][1:35,25] ,
                        USA_EU_M[[i]][1:35,25] ,  ROW_EU_M[[i]][1:35,25])


        Diag_GEO_TEU[[i]] <- vec2diag(geo_e[[i]]) #List of Diagonal Matrix of
geo_e

}


## SOLAR ENERGY USE DIAGONAL MATRIX ##


sol_e <- list()
Diag_SOL_TEU <- list()

for(i in 1:15){

        sol_e[[i]]  <-  c(AUS_EU_M[[i]][1:35,26]  ,   AUT_EU_M[[i]][1:35,26]  ,
BEL_EU_M[[i]][1:35,26] ,
                        BGR_EU_M[[i]][1:35,26]  ,    BRA_EU_M[[i]][1:35,26]  ,
CAN_EU_M[[i]][1:35,26] ,
                        CHN_EU_M[[i]][1:35,26]  ,    CYP_EU_M[[i]][1:35,26]  ,
CZE_EU_M[[i]][1:35,26] ,
                        DEU_EU_M[[i]][1:35,26]  ,    DNK_EU_M[[i]][1:35,26]  ,
ESP_EU_M[[i]][1:35,26] ,
                        EST_EU_M[[i]][1:35,26]  ,    FIN_EU_M[[i]][1:35,26]  ,
FRA_EU_M[[i]][1:35,26] ,
                        GBR_EU_M[[i]][1:35,26]  ,    GRC_EU_M[[i]][1:35,26]  ,
HUN_EU_M[[i]][1:35,26] ,
                        IDN_EU_M[[i]][1:35,26]  ,    IND_EU_M[[i]][1:35,26]  ,
IRL_EU_M[[i]][1:35,26] ,
                        ITA_EU_M[[i]][1:35,26]  ,    JPN_EU_M[[i]][1:35,26]  ,
KOR_EU_M[[i]][1:35,26] ,
                        LTU_EU_M[[i]][1:35,26]  ,    LUX_EU_M[[i]][1:35,26]  ,
LVA_EU_M[[i]][1:35,26] ,
                        MEX_EU_M[[i]][1:35,26]  ,    MLT_EU_M[[i]][1:35,26]  ,
NLD_EU_M[[i]][1:35,26] ,
```

```
                        POL_EU_M[[i]][1:35,26]  ,    PRT_EU_M[[i]][1:35,26]  ,
ROU_EU_M[[i]][1:35,26] ,
                        RUS_EU_M[[i]][1:35,26]  ,    SVK_EU_M[[i]][1:35,26]  ,
SVN_EU_M[[i]][1:35,26] ,
                        SWE_EU_M[[i]][1:35,26]  ,    TUR_EU_M[[i]][1:35,26]  ,
TWN_EU_M[[i]][1:35,26] ,
                        USA_EU_M[[i]][1:35,26] ,  ROW_EU_M[[i]][1:35,26])


        Diag_SOL_TEU[[i]] <- vec2diag(sol_e[[i]]) #List of Diagonal Matrix of
sol_e

}


## WIND ENERGY USE DIAGONAL MATRIX ##


wnd_e <- list()
Diag_WND_TEU <- list()

for(i in 1:15){

        wnd_e[[i]]  <-  c(AUS_EU_M[[i]][1:35,27]  ,   AUT_EU_M[[i]][1:35,27]  ,
BEL_EU_M[[i]][1:35,27] ,
                        BGR_EU_M[[i]][1:35,27]  ,    BRA_EU_M[[i]][1:35,27]  ,
CAN_EU_M[[i]][1:35,27] ,
                        CHN_EU_M[[i]][1:35,27]  ,    CYP_EU_M[[i]][1:35,27]  ,
CZE_EU_M[[i]][1:35,27] ,
                        DEU_EU_M[[i]][1:35,27]  ,    DNK_EU_M[[i]][1:35,27]  ,
ESP_EU_M[[i]][1:35,27] ,
                        EST_EU_M[[i]][1:35,27]  ,    FIN_EU_M[[i]][1:35,27]  ,
FRA_EU_M[[i]][1:35,27] ,
                        GBR_EU_M[[i]][1:35,27]  ,    GRC_EU_M[[i]][1:35,27]  ,
HUN_EU_M[[i]][1:35,27] ,
                        IDN_EU_M[[i]][1:35,27]  ,    IND_EU_M[[i]][1:35,27]  ,
IRL_EU_M[[i]][1:35,27] ,
                        ITA_EU_M[[i]][1:35,27]  ,    JPN_EU_M[[i]][1:35,27]  ,
KOR_EU_M[[i]][1:35,27] ,
                        LTU_EU_M[[i]][1:35,27]  ,    LUX_EU_M[[i]][1:35,27]  ,
LVA_EU_M[[i]][1:35,27] ,
                        MEX_EU_M[[i]][1:35,27]  ,    MLT_EU_M[[i]][1:35,27]  ,
NLD_EU_M[[i]][1:35,27] ,
                        POL_EU_M[[i]][1:35,27]  ,    PRT_EU_M[[i]][1:35,27]  ,
ROU_EU_M[[i]][1:35,27] ,
                        RUS_EU_M[[i]][1:35,27]  ,    SVK_EU_M[[i]][1:35,27]  ,
SVN_EU_M[[i]][1:35,27] ,
                        SWE_EU_M[[i]][1:35,27]  ,    TUR_EU_M[[i]][1:35,27]  ,
TWN_EU_M[[i]][1:35,27] ,
                        USA_EU_M[[i]][1:35,27] ,  ROW_EU_M[[i]][1:35,27])


        Diag_WND_TEU[[i]] <- vec2diag(wnd_e[[i]]) #List of Diagonal Matrix of
wnd_e

}


## ENERGY INTENSITY CALCULATIONS ##


R_EI <- list() # Energy intensity matrix for renewable energy use

HYD_EI <- list() # Energy intensity matrix for hydro energy use

GEO_EI <- list() # Energy intensity matrix for geothermal energy use
```

```
SOL_EI <- list() # Energy intensity matrix for solar energy use

WND_EI <- list() # Energy intensity matrix for wind energy use

for(k in 1:15) {

        R_EI[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #R_EI - Constructing a matrix with all NA.
      HYD_EI[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #HYD_EI - Constructing a matrix with all NA.
        GEO_EI[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #GEO_EI - Constructing a matrix with all NA.
      SOL_EI[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #SOL_EI - Constructing a matrix with all NA.
      WND_EI[[k]] <- matrix(data = NA, nrow = 1435, ncol = 1435) #WND_EI - Constructing a matrix with all NA.

        for(i in 1:1435){

                for(j in 1:1435){

                        R_EI[[k]][i,j]  =  Diag_RTEU[[k]][i,j]/GO_f[[k]][j,1] #R_EI - matrix of RTEU(Renewable Total Energy Use)/GO(Gross Output)

                        if (is.na(R_EI[[k]][i,j])) {

                                R_EI[[k]][i,j] <- 0
                        }

                    HYD_EI[[k]][i,j]  =  Diag_HYD_TEU[[k]][i,j]/GO_f[[k]][j,1] #HYD_EI - matrix of HYD_TEU(Hydro Total Energy Use)/GO(Gross Output)

                    if (is.na(HYD_EI[[k]][i,j])) {

                                HYD_EI[[k]][i,j] <- 0
                        }

                    GEO_EI[[k]][i,j]  =  Diag_GEO_TEU[[k]][i,j]/GO_f[[k]][j,1] #GEO_EI - matrix of GEO_TEU(Geothermal Total Energy Use)/GO(Gross Output)

                        if (is.na(GEO_EI[[k]][i,j])) {

                                GEO_EI[[k]][i,j] <- 0
                        }

                    SOL_EI[[k]][i,j]  =  Diag_SOL_TEU[[k]][i,j]/GO_f[[k]][j,1] #SOL_EI - matrix of SOL_TEU(Solar Total Energy Use)/GO(Gross Output)

                        if (is.na(SOL_EI[[k]][i,j])) {

                                SOL_EI[[k]][i,j] <- 0
                        }

                    WND_EI[[k]][i,j]  =  Diag_WND_TEU[[k]][i,j]/GO_f[[k]][j,1] #WND_EI - matrix of WND_TEU(Wind Total Energy Use)/GO(Gross Output)

                        if (is.na(WND_EI[[k]][i,j])) {

                                WND_EI[[k]][i,j] <- 0
                        }

                }
        }
}
```

```
## STRUCTURAL DECOMPOSITION ##


R_EI_cng <- list()
R_L_cng <- list()
R_F_cng <- list()

HYD_EI_cng <- list()
HYD_L_cng <- list()
HYD_F_cng <- list()

GEO_EI_cng <- list()
GEO_L_cng <- list()
GEO_F_cng <- list()

SOL_EI_cng <- list()
SOL_L_cng <- list()
SOL_F_cng <- list()

WND_EI_cng <- list()
WND_L_cng <- list()
WND_F_cng <- list()


for(k in 1:14){

        R_EI_cng[[k]] <- matrix()
        R_L_cng[[k]] <- matrix()
        R_F_cng[[k]] <- matrix()

        R_EI_cng[[k]]       <-       ((1/2)*((R_EI[[k+1]]-R_EI[[k]])       %*%
((L[[k]]%*%FD_f[[k]])+(L[[k+1]]%*%FD_f[[k+1]]))))

        R_L_cng[[k]]            <-            ((1/2)*((R_EI[[k]]%*%(L[[k+1]]-
L[[k]])%*%FD_f[[k+1]])+(R_EI[[k+1]]%*%(L[[k+1]]-L[[k]])%*%FD_f[[k]])))

        R_F_cng[[k]]                                                      <-
((1/2)*(((R_EI[[k]]%*%L[[k]])+(R_EI[[k+1]]%*%L[[k+1]]))%*%(FD_f[[k+1]]-
FD_f[[k]])))


       HYD_EI_cng[[k]] <- matrix()
        HYD_L_cng[[k]] <- matrix()
        HYD_F_cng[[k]] <- matrix()

        HYD_EI_cng[[k]]     <-     ((1/2)*((HYD_EI[[k+1]]-HYD_EI[[k]])     %*%
((L[[k]]%*%FD_f[[k]])+(L[[k+1]]%*%FD_f[[k+1]]))))

        HYD_L_cng[[k]]          <-          ((1/2)*((HYD_EI[[k]]%*%(L[[k+1]]-
L[[k]])%*%FD_f[[k+1]])+(HYD_EI[[k+1]]%*%(L[[k+1]]-L[[k]])%*%FD_f[[k]])))

        HYD_F_cng[[k]]                                                    <-
((1/2)*(((HYD_EI[[k]]%*%L[[k]])+(HYD_EI[[k+1]]%*%L[[k+1]]))%*%(FD_f[[k+1]]-
FD_f[[k]])))


       GEO_EI_cng[[k]] <- matrix()
        GEO_L_cng[[k]] <- matrix()
        GEO_F_cng[[k]] <- matrix()

        GEO_EI_cng[[k]]     <-     ((1/2)*((GEO_EI[[k+1]]-GEO_EI[[k]])     %*%
((L[[k]]%*%FD_f[[k]])+(L[[k+1]]%*%FD_f[[k+1]]))))

        GEO_L_cng[[k]]          <-          ((1/2)*((GEO_EI[[k]]%*%(L[[k+1]]-
L[[k]])%*%FD_f[[k+1]])+(GEO_EI[[k+1]]%*%(L[[k+1]]-L[[k]])%*%FD_f[[k]])))
```

```
        GEO_F_cng[[k]]                                                        <-
((1/2)*(((GEO_EI[[k]]%*%L[[k]])+(GEO_EI[[k+1]]%*%L[[k+1]]))%*%(FD_f[[k+1]]-
FD_f[[k]])))


       SOL_EI_cng[[k]] <- matrix()
        SOL_L_cng[[k]] <- matrix()
        SOL_F_cng[[k]] <- matrix()

        SOL_EI_cng[[k]]     <-     ((1/2)*((SOL_EI[[k+1]]-SOL_EI[[k]])     %*%
((L[[k]]%*%FD_f[[k]])+(L[[k+1]]%*%FD_f[[k+1]]))))

        SOL_L_cng[[k]]          <-          ((1/2)*((SOL_EI[[k]]%*%(L[[k+1]]-
L[[k]])%*%FD_f[[k+1]])+(SOL_EI[[k+1]]%*%(L[[k+1]]-L[[k]])%*%FD_f[[k]])))

        SOL_F_cng[[k]]                                                        <-
((1/2)*(((SOL_EI[[k]]%*%L[[k]])+(SOL_EI[[k+1]]%*%L[[k+1]]))%*%(FD_f[[k+1]]-
FD_f[[k]])))


       WND_EI_cng[[k]] <- matrix()
        WND_L_cng[[k]] <- matrix()
        WND_F_cng[[k]] <- matrix()

        WND_EI_cng[[k]]     <-     ((1/2)*((WND_EI[[k+1]]-WND_EI[[k]])     %*%
((L[[k]]%*%FD_f[[k]])+(L[[k+1]]%*%FD_f[[k+1]]))))

        WND_L_cng[[k]]          <-          ((1/2)*((WND_EI[[k]]%*%(L[[k+1]]-
L[[k]])%*%FD_f[[k+1]])+(WND_EI[[k+1]]%*%(L[[k+1]]-L[[k]])%*%FD_f[[k]])))

        WND_F_cng[[k]]                                                        <-
((1/2)*(((WND_EI[[k]]%*%L[[k]])+(WND_EI[[k+1]]%*%L[[k+1]]))%*%(FD_f[[k+1]]-
FD_f[[k]])))



}


## EXTRACTING EI, L ,AND F CHANGE IN INDIA & CHINA ##


R_EI_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
R_L_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
R_F_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)

R_EI_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
R_L_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
R_F_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)


HYD_EI_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
HYD_L_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
HYD_F_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)

HYD_EI_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
HYD_L_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
HYD_F_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)


GEO_EI_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
GEO_L_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
GEO_F_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)

GEO_EI_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
```

```
GEO_L_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
GEO_F_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)


SOL_EI_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
SOL_L_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
SOL_F_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)

SOL_EI_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
SOL_L_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
SOL_F_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)


WND_EI_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
WND_L_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)
WND_F_ind_cng <- matrix(data = NA, nrow = 35, ncol = 14)

WND_EI_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
WND_L_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)
WND_F_chn_cng <- matrix(data = NA, nrow = 35, ncol = 14)



for(i in 1:35){

        for(j in 1:14){

                R_EI_ind_cng[i,j] = R_EI_cng[[j]][((19*35)+i),1]
                R_L_ind_cng[i,j] = R_L_cng[[j]][((19*35)+i),1]
                R_F_ind_cng[i,j] = R_F_cng[[j]][((19*35)+i),1]

                R_EI_chn_cng[i,j] = R_EI_cng[[j]][((6*35)+i),1]
                R_L_chn_cng[i,j] = R_L_cng[[j]][((6*35)+i),1]
                R_F_chn_cng[i,j] = R_F_cng[[j]][((6*35)+i),1]


             HYD_EI_ind_cng[i,j] = HYD_EI_cng[[j]][((19*35)+i),1]
                HYD_L_ind_cng[i,j] = HYD_L_cng[[j]][((19*35)+i),1]
                HYD_F_ind_cng[i,j] = HYD_F_cng[[j]][((19*35)+i),1]

                HYD_EI_chn_cng[i,j] = HYD_EI_cng[[j]][((6*35)+i),1]
                HYD_L_chn_cng[i,j] = HYD_L_cng[[j]][((6*35)+i),1]
                HYD_F_chn_cng[i,j] = HYD_F_cng[[j]][((6*35)+i),1]


             GEO_EI_ind_cng[i,j] = GEO_EI_cng[[j]][((19*35)+i),1]
                GEO_L_ind_cng[i,j] = GEO_L_cng[[j]][((19*35)+i),1]
                GEO_F_ind_cng[i,j] = GEO_F_cng[[j]][((19*35)+i),1]

                GEO_EI_chn_cng[i,j] = GEO_EI_cng[[j]][((6*35)+i),1]
                GEO_L_chn_cng[i,j] = GEO_L_cng[[j]][((6*35)+i),1]
                GEO_F_chn_cng[i,j] = GEO_F_cng[[j]][((6*35)+i),1]


             SOL_EI_ind_cng[i,j] = SOL_EI_cng[[j]][((19*35)+i),1]
                SOL_L_ind_cng[i,j] = SOL_L_cng[[j]][((19*35)+i),1]
                SOL_F_ind_cng[i,j] = SOL_F_cng[[j]][((19*35)+i),1]

                SOL_EI_chn_cng[i,j] = SOL_EI_cng[[j]][((6*35)+i),1]
                SOL_L_chn_cng[i,j] = SOL_L_cng[[j]][((6*35)+i),1]
                SOL_F_chn_cng[i,j] = SOL_F_cng[[j]][((6*35)+i),1]


             WND_EI_ind_cng[i,j] = WND_EI_cng[[j]][((19*35)+i),1]
                WND_L_ind_cng[i,j] = WND_L_cng[[j]][((19*35)+i),1]
                WND_F_ind_cng[i,j] = WND_F_cng[[j]][((19*35)+i),1]
```

```
                WND_EI_chn_cng[i,j] = WND_EI_cng[[j]][((6*35)+i),1]
                WND_L_chn_cng[i,j] = WND_L_cng[[j]][((6*35)+i),1]
                WND_F_chn_cng[i,j] = WND_F_cng[[j]][((6*35)+i),1]

        }

}


## EXPORTING TO EXCEL ##


R_EI_IND <- as.data.frame(R_EI_ind_cng)
WriteXLS::WriteXLS(R_EI_IND, ExcelFileName = "R_EI_IND.xls")

R_EI_CHN <- as.data.frame(R_EI_chn_cng)
WriteXLS::WriteXLS(R_EI_CHN, ExcelFileName = "R_EI_CHN.xls")

R_L_IND <- as.data.frame(R_L_ind_cng)
WriteXLS::WriteXLS(R_L_IND, ExcelFileName = "R_L_IND.xls")

R_L_CHN <- as.data.frame(R_L_chn_cng)
WriteXLS::WriteXLS(R_L_CHN, ExcelFileName = "R_L_CHN.xls")

R_F_IND <- as.data.frame(R_F_ind_cng)
WriteXLS::WriteXLS(R_F_IND, ExcelFileName = "R_F_IND.xls")

R_F_CHN <- as.data.frame(R_F_chn_cng)
WriteXLS::WriteXLS(R_F_CHN, ExcelFileName = "R_F_CHN.xls")


HYD_EI_IND <- as.data.frame(HYD_EI_ind_cng)
WriteXLS::WriteXLS(HYD_EI_IND, ExcelFileName = "HYD_EI_IND.xls")

HYD_EI_CHN <- as.data.frame(HYD_EI_chn_cng)
WriteXLS::WriteXLS(HYD_EI_CHN, ExcelFileName = "HYD_EI_CHN.xls")

HYD_L_IND <- as.data.frame(HYD_L_ind_cng)
WriteXLS::WriteXLS(HYD_L_IND, ExcelFileName = "HYD_L_IND.xls")

HYD_L_CHN <- as.data.frame(HYD_L_chn_cng)
WriteXLS::WriteXLS(HYD_L_CHN, ExcelFileName = "HYD_L_CHN.xls")

HYD_F_IND <- as.data.frame(HYD_F_ind_cng)
WriteXLS::WriteXLS(HYD_F_IND, ExcelFileName = "HYD_F_IND.xls")

HYD_F_CHN <- as.data.frame(HYD_F_chn_cng)
WriteXLS::WriteXLS(HYD_F_CHN, ExcelFileName = "HYD_F_CHN.xls")


GEO_EI_IND <- as.data.frame(GEO_EI_ind_cng)
WriteXLS::WriteXLS(GEO_EI_IND, ExcelFileName = "GEO_EI_IND.xls")

GEO_EI_CHN <- as.data.frame(GEO_EI_chn_cng)
WriteXLS::WriteXLS(GEO_EI_CHN, ExcelFileName = "GEO_EI_CHN.xls")

GEO_L_IND <- as.data.frame(GEO_L_ind_cng)
WriteXLS::WriteXLS(GEO_L_IND, ExcelFileName = "GEO_L_IND.xls")

GEO_L_CHN <- as.data.frame(GEO_L_chn_cng)
WriteXLS::WriteXLS(GEO_L_CHN, ExcelFileName = "GEO_L_CHN.xls")

GEO_F_IND <- as.data.frame(GEO_F_ind_cng)
WriteXLS::WriteXLS(GEO_F_IND, ExcelFileName = "GEO_F_IND.xls")
```

```
GEO_F_CHN <- as.data.frame(GEO_F_chn_cng)
WriteXLS::WriteXLS(GEO_F_CHN, ExcelFileName = "GEO_F_CHN.xls")


SOL_EI_IND <- as.data.frame(SOL_EI_ind_cng)
WriteXLS::WriteXLS(SOL_EI_IND, ExcelFileName = "SOL_EI_IND.xls")

SOL_EI_CHN <- as.data.frame(SOL_EI_chn_cng)
WriteXLS::WriteXLS(SOL_EI_CHN, ExcelFileName = "SOL_EI_CHN.xls")

SOL_L_IND <- as.data.frame(SOL_L_ind_cng)
WriteXLS::WriteXLS(SOL_L_IND, ExcelFileName = "SOL_L_IND.xls")

SOL_L_CHN <- as.data.frame(SOL_L_chn_cng)
WriteXLS::WriteXLS(SOL_L_CHN, ExcelFileName = "SOL_L_CHN.xls")

SOL_F_IND <- as.data.frame(SOL_F_ind_cng)
WriteXLS::WriteXLS(SOL_F_IND, ExcelFileName = "SOL_F_IND.xls")

SOL_F_CHN <- as.data.frame(SOL_F_chn_cng)
WriteXLS::WriteXLS(SOL_F_CHN, ExcelFileName = "SOL_F_CHN.xls")


WND_EI_IND <- as.data.frame(WND_EI_ind_cng)
WriteXLS::WriteXLS(WND_EI_IND, ExcelFileName = "WND_EI_IND.xls")

WND_EI_CHN <- as.data.frame(WND_EI_chn_cng)
WriteXLS::WriteXLS(WND_EI_CHN, ExcelFileName = "WND_EI_CHN.xls")

WND_L_IND <- as.data.frame(WND_L_ind_cng)
WriteXLS::WriteXLS(WND_L_IND, ExcelFileName = "WND_L_IND.xls")

WND_L_CHN <- as.data.frame(WND_L_chn_cng)
WriteXLS::WriteXLS(WND_L_CHN, ExcelFileName = "WND_L_CHN.xls")

WND_F_IND <- as.data.frame(WND_F_ind_cng)
WriteXLS::WriteXLS(WND_F_IND, ExcelFileName = "WND_F_IND.xls")

WND_F_CHN <- as.data.frame(WND_F_chn_cng)
WriteXLS::WriteXLS(WND_F_CHN, ExcelFileName = "WND_F_CHN.xls")


## EXTRACTING RENEWABLE ENERGY USE FOR ALL YEARS ##


RE_TEU_ind <- matrix(data = NA, nrow = 35, ncol = 15)
RE_TEU_chn <- matrix(data = NA, nrow = 35, ncol = 15)

Col_RTEU <- list()

for(i in 1:15){

        Col_RTEU[[i]] <- diag2vec(Diag_RTEU[[i]]) #List of Column Matrix of re

}

for(i in 1:35){

        for(j in 1:15){

                RE_TEU_ind[i,j] = Col_RTEU[[j]][((19*35)+i),1]

                RE_TEU_chn[i,j] = Col_RTEU[[j]][((6*35)+i),1]

        }
}
```

```
RE_TEU_IND <- as.data.frame(RE_TEU_ind)
WriteXLS::WriteXLS(RE_TEU_IND, ExcelFileName = "RE_TEU_IND.xls")

RE_TEU_CHN <- as.data.frame(RE_TEU_chn)
WriteXLS::WriteXLS(RE_TEU_CHN, ExcelFileName = "RE_TEU_CHN.xls")
```