Economic and Environmental Impact Analysis of CPEC Coal Power Plants

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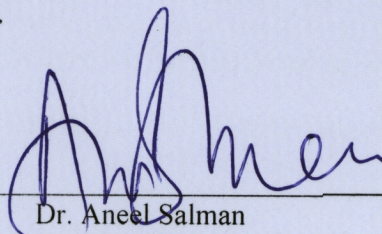**PAKISTAN INSTITUTE OF DEVELOPMENT ECONOMICS (PIDE)**

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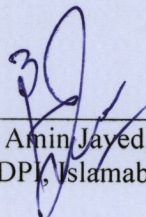# Pakistan Institute of Development Economic

<u>CERTIFICATE</u>

This is to certify that this thesis entitled: **"Economic and Environmental Impact Analysis of CPEC Coal Power Plants."**. submitted by Naureen Fatima is accepted in its present form by the Department of Environmental Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree in **Master of Philosophy in Environmental Economics**.
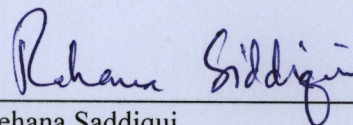
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DEDICATION

This thesis is dedicated to my beloved parents who have always encouraged, supported, trusted and taught me that even the hardest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AGE	Applied General Equilibrium
BOI	Board of Investment
CCCC	China Communication Construction Company
CGE	Computable General Equilibrium
CO	Carbon Monoxide
COLE	Carbon Online Estimator
COP	Conference of Parties
CPEC	China Pakistan Economic Corridor
CPHGC	China Power Hub Generation Company
EIA	Energy Information Administration
ESIA	Environmental & Social Impact Assessment
FDI	Federal Direct Investment
GDP	Gross Domestic Product
GEMPACK	General Equilibrium Modelling Package
GHG	Greenhouse Gases
GMS	Greater Mekong Sub-region
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
HIV/AIDS	Human Immuno Deficiency Virus / Acquired Immuno Deficiency Syndrome
HUBCO	Hub Power Company Limited
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
LCA	Life Cycle Analysis
MDC	Maputo Development Corridor

MW	Mega-Watt
NEPRA	National Electric Power Regulation Authority
OBOR	One Belt One Road
PPIB	Private Power & Infrastructure Board
SADC	Southern African Development Community
SAM	Social Accounting Matrix
SEC	Shanghai Electric Group Co
SEZ	Special Economic Zone
SSRL	Sino-Sindh Resources Limited
WAP	Wearing Apparels
WTA	Wirbelschicht-Trocknungmit interne Abwärmenutzung
UNFCCC	United Nations Framework Convention on Climate Change

ABSTRACT

China Pakistan Economic Corridor (CPEC) is a mega project of worth U.S$46 billion, out of which U.S$34 billion are marked for energy projects. Concerns have been raised about the effect of carbon emissions associated with these coal-fired projects and their impacts on climate and the economy of Pakistan. This study provides carbon emissions estimates to understand the environmental viability of these projects. .Our estimated results of carbon emissions show that as the percentage of carbon content increases in the amount of fuel used for power generation, the emissions from these power plants are also increased. It is also found that Sub-bituminous coal, which is imported from Indonesia and South Africa has a higher percentage of carbon content (71-77%) as compared to indigenous lignite reserves of coal (60-70%). Our estimated results for macroeconomic indicators have also shown a positive increase in Pakistan's Economy due to investment in these coal projects for power production. The results after simulations show a positive change in real GDP of Pakistan due to an increase in energy output production. This increase in GDP will also increase our real exports and imports i.e., 0.12349% and 0.15026 % respectively .Therefore, indigenous lignite coal reserves in Thar District and Chamalung in Baluchistan should be used to run these power projects to minimize the environmental damages and overcome energy crisis of Pakistan which will improve the economy of Pakistan.

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CHAPTER- I

INTRODUCTION

1.1 Infrastructure & Economic Growth

An adequate supply of infrastructure services acts as a vital component for economic development (Aschauer 1989). Vickerman et al., (1997) theoretically emphasized that advanced efficient transport systems are essential for the European economy to strive with the global world. The investment in the new transport infrastructure is an essential component for the economic development of any state. As better infrastructure will lead to a reduction in transportation costs, which will lead to better access to raw materials. This will make the firms more productive and competitive in the market economy. Transport improvements not only serve to promote effectiveness in the connectivity but also plays a vital role in achieving growth and development of a country (Ibid). Calderon and Serven (2004) empirically calculated the positive relationship of infrastructure development with economic growth.

Although Asian countries are among the fastest growing regions in the world but are still facing the hindrance of weak infrastructure. These infrastructure gaps are found to be higher in Indonesia, the Philippines and Vietnam than other countries. Two indices (infrastructure quality & quantity) are used in capturing information for three main infrastructure sectors: communication, power and road network (Seneviratne *et al,* 2013). Therefore, comparative advantage in technology led to better infrastructure among countries leading to the origin of economic corridors.

1.2 Concept of Economic Corridors

Transport and economic activities are found to be exclusively connected to each other. "*Transport corridors are a set of roads, routes that connect the economic activities within and across a region*" (ADB, 2014). Transport corridors in a local level link with regional transport systems to urban spaces in a state. Development in transport infrastructure and energy sector increases investment in a region which ultimately enhance the economic growth of a state. Therefore, transport corridor in a geographical area gets uplifted with development in the infrastructure sector and serves as an economic corridor. An economic corridor not only includes transport of goods and services by providing paths, gates for the developing countries but also stimulate the social and economic development in the surrounding areas of the routes of the economic corridor (Ibid).The following figure shows how economic corridor evolved through different stages:

| Transport Corridor | Transport and trade Facilitation Corridor | Logistics Corridor | Urban Develoupment Corridor | Economic Corridor |

Figure 1.1: Stages of Economic Corridor

(Source: Srivastava, 2011)

1.3 History of Economic Corridors

The economic corridor approach was initiated in 1992 by Asian Development Bank to support the Greater Mekong Sub-region (GMS) [1](ADB). This support of GMS helped in better transport facilities and development of economic corridors in the sub-region: the East-West, the North-South, and the Southern . The economic corridor's approach has been executed in various regions of the world including Europe & America to promote regional connectivity and trade. The most successful examples of economic corridors are found in Asia and Africa which are aided by ADB and African Development Bank (ADB) respectively. These banks support the economic corridors to enhance inter-regional and global trade opportunities and market development. The right planning can correspond to the efficient working of economic corridors and better socioeconomic development of the region (AD, 2011).

1.4 Environmental and Social Impacts of Economic Corridors

However, along with positive impacts of economic corridors on the society discussed above, there also exists several negative impacts of developing economic corridors on the areas and individuals in the pathways of these corridors. These externalities include both environmental and social impacts. Environmental degradation due to infrastructure development includes habitat destruction of animals and human beings which leads to displacement of species along the pathways of corridors. Migration of people causes over burden to the other areas which include inequitable compensation payments to affected persons. This leads to disturbance to the local communities' cultural values and norms. Illegal migration is also expected due to dislocation of local people.

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[1] The Greater Mekong Sub region is an economic territory bound by river mekong, covers a zone of 2.6 million sq km with an approx326 million population.
The state include in GMS China, Cambodia, Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, &Viet Nam.

The spread of contagious diseases i.e. HIV/AIDS also coincides since there is more human interaction which leads to the spread of chronic and non-chronic diseases (La Thi, N, 2008).

The most successfully implemented economic corridors in the world include: The Greater Mekong Sub-region (GMS) includes: the East-West, the North-South, and the Southern corridors. In Africa, Welvis Bay Corridor (WBC) was initiated by Southern African Development Community (SADC) in 2000. The Delhi-Mumbai Industrial Corridor is a super infrastructure project of US$90 billion with the financial assistance provided by Japan. The Bangalore-Mumbai Corridor in India, The Maputo Development Corridor (MDC) between the north-eastern provinces of South Africa and Maputo was commenced in 1996(ADB, 2011).China Pakistan Economic Corridor (CPEC) is a mega project of investment which connects Kashgar in China to Gwadar in Pakistan through a network of roads and railway tracks around 2,442 km long channels (Bhattacharjee,2015).

1.5 Focus of Other Economic Corridors in the World

The emphasis of different economic corridors in the world is to provide better transport infrastructure and connectivity across various developed and developing countries in a region. The major focus is to enhance trade activities and regional development (ADB, 2011).The major areas of consideration in the GMS corridor include transport, human resource development, energy, telecommunication, tourism, agriculture, environment, and trade (Krongkaew, 2004).The main objective of the Maputo corridor was to provide jobs, investment in local and foreign areas and social impacts on the affected communities (Mitchell, 1998).

While the major focus of China Pakistan Economic Corridor (CPEC) is on the investment on Energy projects i.e. 70% in order to solve the energy crisis of Pakistan. CPEC also includes an investment of transport infrastructure development and industrial cooperation starting from Kashgar of China and passing through Pakistan southwestern port Gwadar. It also involves the

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construction of Gwadar port which would be the major trade hub in the coming years (Ministry of Planning and Development).

1.6 History of CPEC

The Sino-Pak agreement[2] was signed in 1963 between the two neighboring countries i.e. China and Pakistan. This Sino-Pak agreement was further strengthened in 2013 to give a pragmatic form by connecting Kashgar city of China and the Gwadar port of Pakistan through network system of roads, highways and railway tracks. This led to the origin of CPEC in Asia (Ahmer, 2015). The mega project of CPEC was officially launched in the month of April, 2015 during the visit of the Chinese President, Mr. Xi Jinping in Islamabad, Pakistan. CPEC is a long- term well-grounded project to develop a strong collaboration between the two neighboring countries of Pakistan & China for the mutual profits of China, Central, West & South Asia. This formal launch of mega project CPEC has created intense excitement among the people of Pakistan. As mega-scale $46billion project consisting huge investment projects will give rise the socioeconomic development in Pakistan in the next 15 years. This project is defined on the basis of economic, historical, cultural & geographical viewpoints of the region. Therefore, the purpose of this China-Pakistan Economic Corridor (CPEC) is to endorse economic growth, trade links among the neighboring countries through connections of highways, rail tracks (Ahmar,2015).

The route of China-Pakistan Economic Corridor (CPEC) can be outlined to the formation of the Karakorum highway in the 1970s from the Pakistan city of Havalian in the province of Hazara by passing through Khunjerab pass, the border between two countries of China and Pakistan. In 2010,

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[2] Sino-Pakistan agreement is a 1963 treaty among the two countries of Pakistan and China creating the border between these states. It resulted in China covering over 1,942 square kilometers to Pakistan and Pakistan covers Chinese territory over hundred square kilometers of land in Ladakh and northern Kashmir

China announced Kashgar, a central transit point on the old Silk route and an entrance between China and Pakistan, as Special Economic Zone (SEZ[3]). This SEZ was declared to develop Xinjiang, Chinese western province into a trade hub which will lead to energy and economic integration in Central & South Asia. In the SEZs, the Gwadar port of Pakistan and Kashgar are connected through roads and railway tracks (Ahmar, 2015).
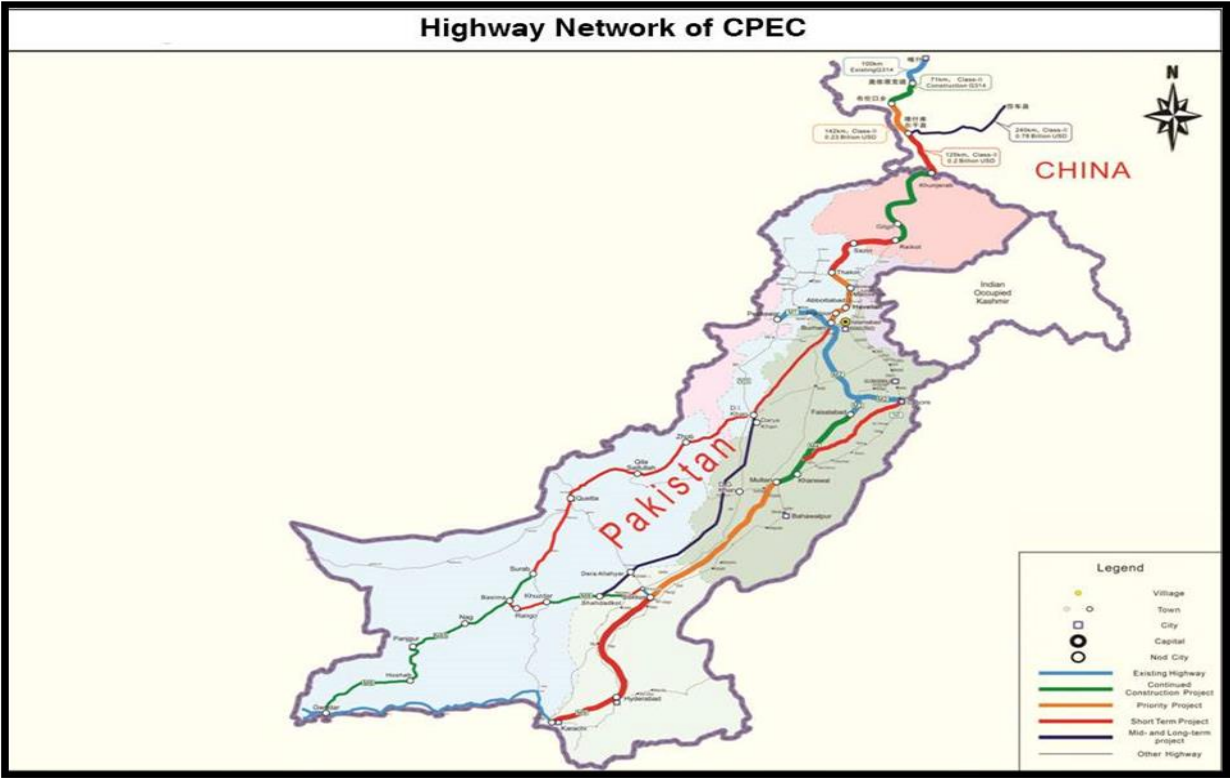
Figure 1.2: Map showing the route of Pak-China Corridor
(Source: Ministry of Planning & Development, Government of Pakistan)

1.7 Composition of CPEC

Overall, CPEC project of $46 billion expects to include nearly 17,000MW of power generation projects at the expense of U.S$34 billion. The remaining investment will be spent on transport

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[3] A Special Economic Zone is a geographical area, which has economic laws that are more advanced than country's own economic laws. It includes: free trade zones, export processing zones, free zones, free ports, industrial estates.

infrastructure development which includes reconstruction of railway tracks between the northwest of Peshawar and the mega -city of Karachi(Bhattacharjee, 2015).The infrastructure projects under CPEC includes three routes i.e. Western, Central and Eastern routes. The western route will begin from Gwadar and pass through Quetta, Bannu, D.I. Khan, Peshawar and forward to Karakoram highway. The central route starts from Gwadar through Khuzdar, Mianwali, D.G Khan, and Taxila ends up Karakoram highway and the eastern route starts from Gwadar to Karachi, Hyderabad, Multan, Lahore, Faisalabad, and Islamabad finally reaches up to Karakoram highway (Shah, 2017).

Although current installed energy capacity of Pakistan is 24,830MW but still facing energy deficit of about 4,500MW with regular blackout for about twelve hours a day. Therefore, the major focus of the CPEC will be on energy sector of Pakistan. A major component of the CPEC includes energy projects i.e., an expected 10,400 MW of power plants are lined up for completion by March 2018. The CPEC energy projects will be formulated by private companies called Independent Power Producers (IPP) rather than the Chinese or Pakistani government. These private investments will be financed by the Chinese Exim Bank at some interest rate and the Government of Pakistan will be indulged to buy this electricity from these private firms at different interest rates.
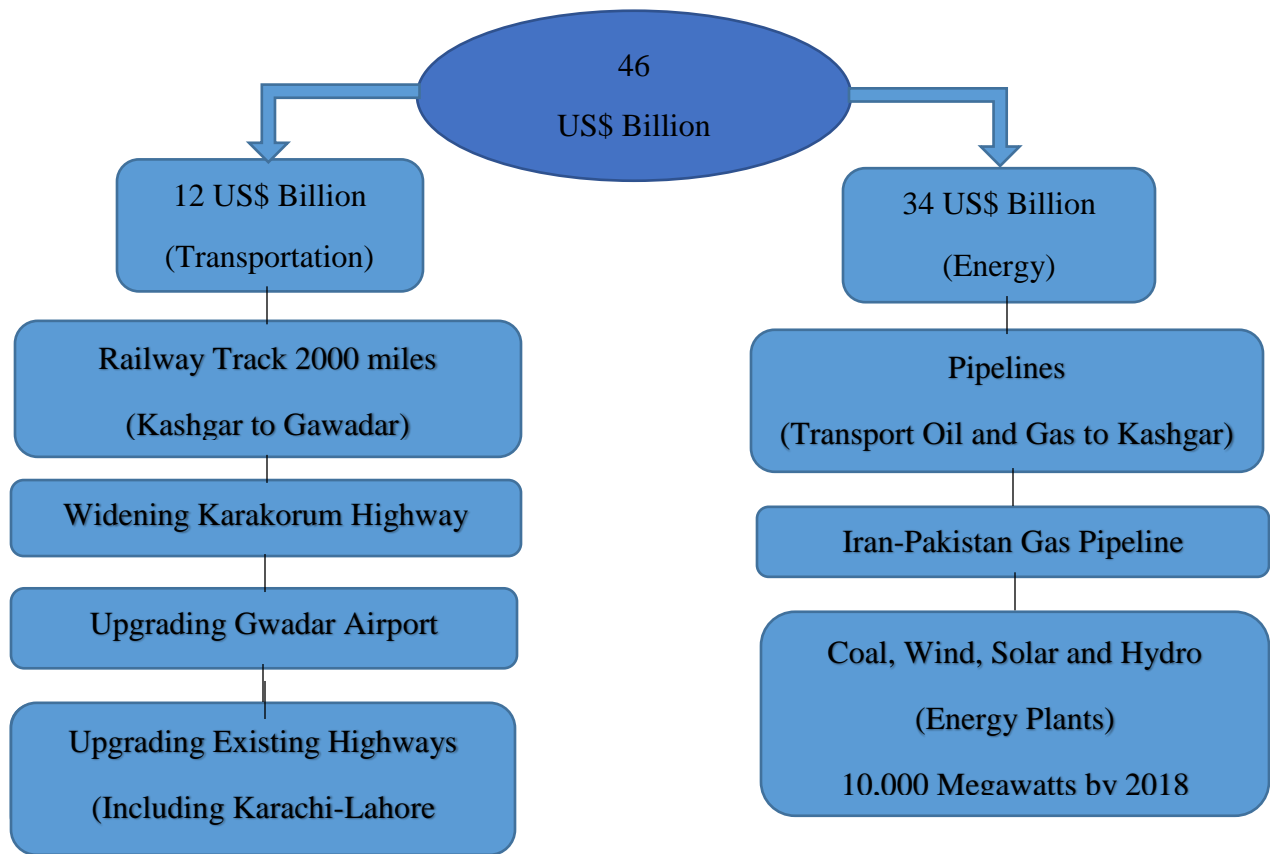
Figure 1.3: CPEC Investment Tree

(Source: Irshad et al., 2015)

Table 1.1: CPEC Energy Priority Projects

Sr. No.	Projects Name	Capacity (MW)	Estimated Cost (US$ M)
1	Port Qasim Electric Company Coal Fired, 2X660, Sindh	1320	1980
2	Sahiwal 2X660 MW Coal-fired Power Plant, Punjab	1320	1600
3	• Engro Thar 4X330 MW Coal-Fired, Thar, Sindh • Surface mine in Block 2 of Thar Coal field, 6.5 mtpa, Thar Sindh	1320	2000 1470
4	Gwadar Coal Power Project, Gwadar	300	360
5	HUBCO Coal power plant, Hub Baluchistan	1320	970
6	Rahimyar Khan Coal Power Project, Punjab	1320	1600
7	• SSRL Thar Coal Block 1-6.5mpta Thar, Sindh • SSRL 2X660 MW Mine Mouth Power Plant	1320	1300 2000
8	Quaid-e-Azam 1000MW Solar Park, Bahawalpur, Punjab	1000	1350
9	Dawood 50MW wind farm, Bhambore, Sindh	50	125
10	UEP 100MW Wind Farm, Jhimpur, Sindh	100	250
11	Sachal 50MW Wind Farm, Jhimpur, Sindh	50	134
12	Sunnec 50MW wind Farm, Jhimpur, Sindh	50	125
13	Suki Kinari Hydropower Station, KPK	870	1802
14	Karot Hydropower Station, AJK & Punjab	720	1420

(Source: Ministry of Planning & Development, Government of Pakistan)

1.8 Negative Impacts of CPEC on Pakistan

The CPEC, a $46 billion investment on infrastructure development and on energy projects is considered to be a "game changer" for the economic growth of Pakistan and regional connectivity in South Asia. CPEC is found to be the only hope for the accomplishment of the initiative taken by China known as "One Belt One Road"(OBOR) in order to connect Asia with Europe, the Middle East, and Africa. Besides the mystery of implementation of CPEC or its possible impacts

on the entire South Asia region, this mega project also poses some challenges and negative impacts on the Pakistan (Wolf, 2016).Some of the major negative impacts of CPEC or challenges in the accomplishment of CPEC in Pakistan are as follows:

1) No Transparency in the CPEC Projects

There is no transparency has been found in all the CPEC projects including transport infrastructure and energy projects. No details have been mentioned in the documents about the projects. All of the information was kept confidential and secret from the public and relevant stakeholders which makes CPEC a mystery for Pakistan. Clarity and transparency should be maintained in order to make the successful implementation of CPEC[4].

2) Rising Threat of Global Climate Change

The climate change is the most serious global threat of the 21st century. Pakistan has ranked among the 8th most vulnerable country which would be exposed to adverse effects of climate change (UNDP).It is observed that most of the energy projects in CPEC are coal-based power plants than renewable energy projects (Ministry of Planning & Development, Government of Pakistan). It is a matter of fact that coal power plants emit a huge amount of carbon emissions, which are the main cause of climate change. Therefore, these coal-based power plants will affect the air quality and exacerbate the vulnerability of Pakistan towards the global threat of climate change. Thus, Government should convince the Chinese government to replace these coal projects with more renewable energy projects (solar, hydro, wind) in order to tackle the global threat of climate change (IPRI, 2017).

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[4] IPRI, 2017(CPEC: Macro and Micro-Economic Dividends for Pakistan and the Region.)

3) Impacts on traders & investors in Pakistan

CPEC has directly affected the investors and local merchants of Pakistan. No evidence has been found for the general consultation with the relevant stakeholders about the details of the project. Projects have been projected beneficial for all stakeholders on the basis of assumptions (Qureshi, 2015).

4) Disturbance in Local Markets

The Chinese imported goods will affect local markets and foreign trade of Pakistan with other countries. It will become difficult for the goods of Pakistan to compete with the Chinese products in the global trade market. It has also been found that Chinese companies will utilize Chinese products without preference to local market products in the CPEC projects.Therefore, this will greatly affect our local industries (Qureshi, 2015).

5) Environmental Impacts

Pakistan is a signatory of a large number of international environmental agreements. However, the CPEC will extrapolate significant environmental impacts on Pakistan including displacement of habitat fragmentation of different species of flora and fauna, biodiversity loss, deforestation, water pollution, air pollution etc. Therefore, the Chinese government should take concern on the environmental issues that would be generated on the implementation of the CPEC projects. Environmental friendly technologies should be used in the proposed projects and preventive measures should be taken in order to avoid environmental degradation (Qureshi, 2015).

The above mentioned negative impacts will be conceived in Pakistan by the implementation of CPEC project. The Government of Pakistan and the Chinese government should consider these impacts and take preventive measures in order to make this mega project a win-win situation.

1.9 Advantages of CPEC for China

It's already mentioned above that, CPEC is surely beneficial for Pakistan, at the same it also carries various advantages for China. Firstly, CPEC forms an important border of China's objective to set itself a leading economic power passing through OBOR initiative to connect China physically within Asia, Africa, and Europe. The new Silk Road will connect China to Europe through Central Asia and with the Maritime Silk road for ensuring an impregnable pathway to Chinese shipments by the Indian Ocean and the South China Sea. Thus, China will then able to connect around half of the world's population. Access to the Indian Ocean by Gwadar port will then allow shipments of China to bypass Strait of Malacca and this will reduce its shipment cost from 45 to 10 days (Butt &Butt, 2015). This will result in an increase in the influence of China in specific Central Asia, in general, the whole Asia continent and rest of the world (Monnoo, 2017).

1.10 Major Countries Influenced By CPEC

Following countries will be influenced after completion of CPEC

1) Afghanistan

Afghanistan is a landlocked country, CPEC is of significant importance due to its geographical location. The country will become a major recipient of this mega project with the extension of this corridor. This will contribute in the economic development of this fragile country by improving economic activities which will boost up Afghanistan economy (Butt & Butt, 2015).

2) Iran

Initially, Iran showed resistance to the CPEC, by working with India for the construction of its Chabahar port. However, in Sep 2015, Iran showed options for participation in CPEC. It aimed to

improve regional connectivity through roads & railway networks to expand trade and transportation. China will construct a Liquid Natural Gas (LNG) at Gwadar terminal and these pipelines will also pass through Iran (Butt & Butt, 2015).

3) United Arab Emirates (UAE)

UAE is another country after U.S that seems not happy with this mega project of CPEC. It is a known fact the ports play a major role in the UAE economy. Once the Gwadar port will become fully operational, it will affect 70% economy of Dubai port (Butt & Butt, 2015).

4) United States (U.S)

Although U.S has not shown any resistance to CPEC yet, in the long run it may cause strategic implications of CPEC.As this proposed corridor may have significant geostrategic & political impacts on U.S policy in the region. Due to this regional connectivity, the influence of U.S in Asia and rest of the world will be overpowered by China (Butt & Butt, 2015).

5) India

The major concern of India for CPEC is that, it will enhance the access of China to Arabian Sea, Indian Ocean & the Persian Gulf. Therefore, China will have direct access of trade land routes towards Afghanistan and Iran which India does not have. For India, CPEC means that China will have complete access on Arabian Sea by controlling the Strait of Hormuz via Gwadar port. Thus, it will have adverse effects on trade route of India (Butt & Butt, 2015).

1.11 Foreign Policies against CPEC

The major neighboring countries influenced by the completion of CPEC includes: USA, China, Iran, Afghanistan, India & Central Asian Republic. Following policies will be taken by these countries against successful implementation of CPEC.

1) China's Supremacy in Asia

The construction of Gwadar port will reduce the distance of China to the Strait of Malacca from 45 to10days, which is an expensive and risky trade route. This will decrease the distance and shipment cost of China and increase its regional connectivity in Asia. This will make China's ranking in top economies of Asia. Therefore, China will gain the dominant power in Asia by enhancing its growth and securing stability in the region (Ali et al, 2016)

2) Decline in U.S Influence

As CPEC includes a huge multi-billion dollar investment of China in Pakistan different infrastructure development and energy projects. After completion of Gwadar port, Pakistan will become a major trade hub for trade economic activities. This will enhance the economy of Pakistan. As Pakistan will have back up the support of China, this will reduce the U.S influence in Pakistan [5](Pakistan Defense Forum: November, 2016).

3) Construction of Chabahar Port in Iran

After signing the project of CPEC between Pakistan and China in 2015, India has raised its efforts for the completion of Chabahar port in Iran. The project of Chabahar port construction was started in 2003 but delayed due to late international approvals to Iran until 2013. At the end of 2013,

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[5] https://defence.pk/pdf/threads/is-america-against-the-cpec.461157/

Pakistan handed over the Gwadar port to a Chinese company for the advanced development and functioning of the port. This development provoked India and it started meetings with Iran officials to restart the construction of the Chabahar port, which is located approximately 150km from Gwadar port. Therefore, this port development by India is a strategic competition against Gwadar port (Muhammad Khan, CSS Current Affairs: June, 2016[6])**.**

4) Iran's Desire to Participate CPEC

Due to the large investment of China in Pakistan under CPEC in transport infrastructure and energy projects. Iran is also anxious to participate in this mega project of CPEC. Iran has realized that this huge investment in Pakistan will increase Pakistan's economy and increase its connectivity in the Asia. Therefore, the Ambassador of Iran Mehdi Honardoust gave statement on media about willingness of Iran to participate in the CPEC. (Syed Sammer Abbas, 10 Sep 2016, Dawn)

5) Improved Pakistan-Russia Relations

Russia is a part of OBOR initiative taken by China. The OBOR includes two routes: The new Silk Road Economic Belt, which will pass towards west on land through Central Asia and forward towards Europe. The second route, 21st Century Maritime Silk Route Economic Belt will run south and west side through ocean to Europe and will end in South Asia, South East Asia and Africa. CPEC is only one of the parts of the OBOR. The CPEC magnifies the significance of Gwadar port for Russia. Pakistan can provide western corridor to Russia .So, by using Gwadar port, it can get access to Indian Ocean through Arabian Sea. Thus, it will improve Pakistan's relations with Russia which will further improve Pakistan's economic growth in Asia (IPRI, 4th February, 2016)

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[6] www.scribd.com

1.12 Current Energy Status of Pakistan

Pakistan is facing a huge electricity deficit from a past decade. Due to this massive electricity shortfall, people in urban areas are facing ten to twelve hours blackout while the condition in rural areas is worst where people face 14 to 18hours of blackout. Industrial sector is adversely affected by this every day power deficit, which is affecting our output production, export rate and the employment rate. It is found that this energy deficit gap is between 4500-5000MW.Due to these power deficits and unstable Pakistan economy, the whole nation is facing high electricity bills due to insufficient power supply, increase rate of electricity theft and inefficient power technologies. (Samad et al., 2016).

According to PEPCO[7], The current energy demand for Pakistan is 16,814MW, with total supply of electricity is 10,800 MW with the total installed capacity of power generation of 21,375MW (WAPDA, 2014, Power Generation Statistics). The demand for electricity is increasing at a rate of 10% annually while the generation of power capacity is growing only 7%.Pakistan power generation includes three technologies: thermal, nuclear & hydel sources. Pakistan's 65% energy is produced from thermal power (oil, natural gas & coal).The remaining 30 % and 5% of power generation come from hydro and nuclear energy respectively. IPPs are the main contributors to power generation in Pakistan. They use thermal technologies for power production. In order to reduce this energy deficit in Pakistan, it is needed to expand our energy resources i.e. solar, wind, hydropower, biomass energy (Rafique & Rehman, 2017).

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[7] Pakistan electric power company (PEPCO)
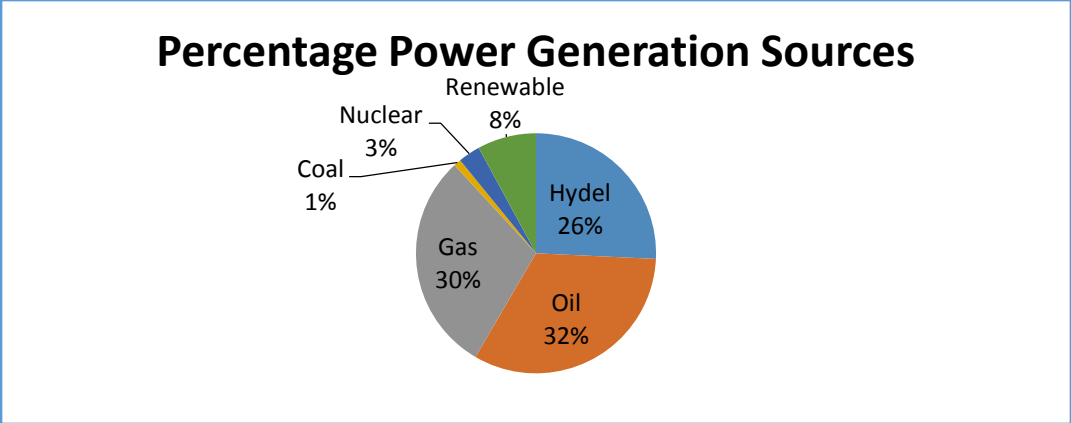
Fig 1.4: Power Generation Mix in Pakistan (2015-16)

(Pakistan Energy Year Book, 2015)

As figure 1.4 shows energy mix ratio in Pakistan for the year 2015-16 which shows that power production in Pakistan comes mostly from oil(32%) and gas(thermal 30%) sources which are followed by hydal sources i.e.26%, nuclear 3% and coal 1% respectively. These thermal power generation sources are not only costly but also not environment-friendly sources of energy as compared to other different energy sources. Pakistan is blessed with abundant renewable energy resources (solar, wind, hydal) and these energy sources can be used to reduce power shortfall in the country (Narejo et al., 2016).
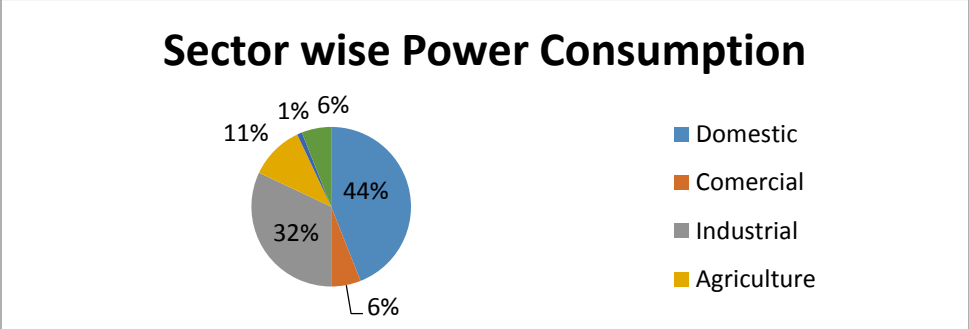
Figure 1.5: Sector- wise Power Consumption in Pakistan

(Source: Federal Bureau of Statistics of Pakistan)
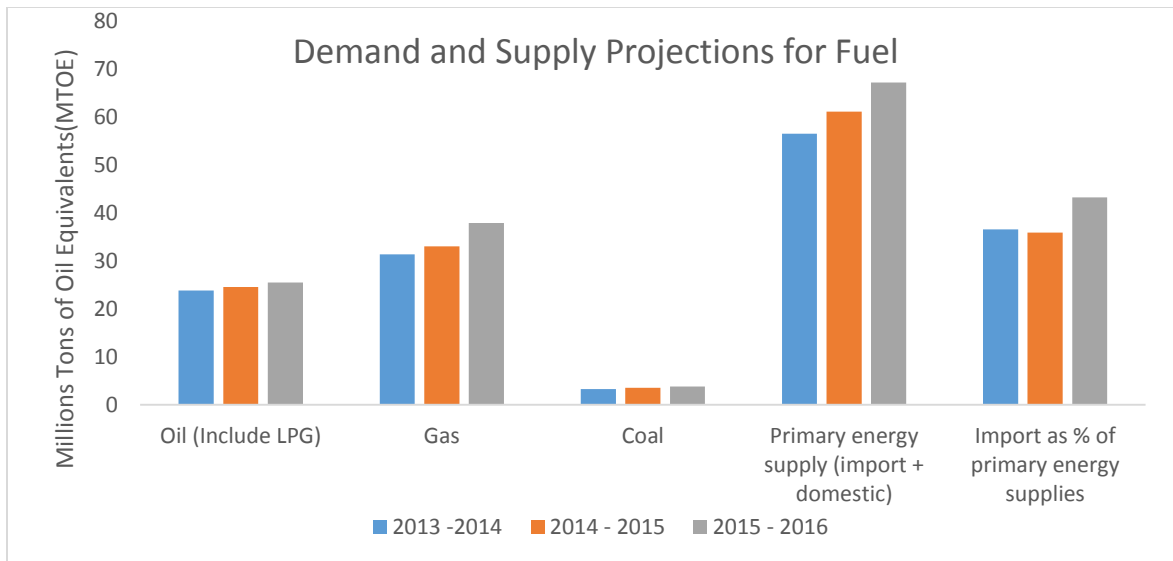
Figure 1.6: Demand and Supply Projections for Fuel (2013-2016)

(Source: Pakistan Energy Year Book, 2015-2016)

As figure 1.5 and 1.6 show the sector- wise consumption percentages of energy consumption and demand- supply projections of fuel in Pakistan. After domestic use, a greater percentage of energy is consumed by our industry sector i.e., textiles, food processing, beverages, construction materials, paper products, agricultural products etc. As industrial sector executes a substantial role in the economic growth of Pakistan, this sector of Pakistan has been greatly affected due to this energy deficit of Pakistan. Thus, in order to confront the growing energy demand, we need to explore renewable energy resources of Pakistan to increase the economy of Pakistan.

1.13 Coal Reserves of Pakistan

Pakistan has blessed with more than more than 185billlion tonnes of coal reserves.   98% of Coal Resources are located in Sindh Province. Only Thar alone contains 175billion tones lignite coal reserves. The Thar Desert contains the world's 7th largest coal reserves. After the discovery of 175.5 billion tonnes of coal in Thar area of Sindh, Pakistan's coal power potential has increased manifold. It is projected that, if Pakistan's coal resources properly exploited, may generate more than 100,000

MW of electricity for the next 30 years. Following table shows the coal distribution in different provinces of Pakistan (PPIB, 2008).

Table 1.2 Coal Distribution in Different Provinces of Pakistan

Province	Resources in million/billion tonnes
Sindh	186billion
Punjab	235million
Baluchistan	217million
NWFP	90million
AJK	9 million
Total	185,551 billion approx.

(Source: http://sindhenergy.gov.pk/)

1.14 Problem Statement

Climate change is the most serious threat of the 21st century. The AR-5 of Intergovernmental Panel on Climate Change (IPCC) has highly recommended curbing the rise of the world's temperature below 2° C compared to preindustrial levels (IPCC : AR-5, 2013). Therefore many countries and firms have started including carbon emission inventory projects in order to control their carbon emissions. It has been observed that majority of the CPEC energy projects are coal - based rather than renewables based even of the fact that coal emits more carbon emissions than renewable energy sources. Therefore, in order to control carbon emissions, the number of emissions need to be calculated first. Pakistan has also committed in its INDCs (Intended Nationally Determined Contributions) for COP(Conference of Parties)'21 to reduce its carbon emissions to 20% by 20230(Pak-INDC). But we all know the fact that coal projects under CPEC would emit a huge amount of GHG's, which are the main drivers of climate change. Therefore, we need to calculate the number of carbon emissions that will be emitted from these coal power

plants, first. Calculated values would be helpful for understanding the magnitude of environmental impacts of CPEC coal projects and future possible adaptive and mitigation measures to reduce carbon emissions.

Federal Direct Investment (FDI) has been seen an indispensable factor in stimulating economic growth, enhancing productivity & capital, employment rate, innovation, and technology transfer (Kornecki, 2010). As CPEC will bring US\$46 billion investment in Pakistan which will improve the economy of Pakistan. Out of this huge investment, \$34 billion will be spent on energy projects. It has been found that majority of the projects are Coal- based power plants rather than renewables, which will overcome the energy deficit of Pakistan which will ultimately increase the output production of our industries of Pakistan. Therefore, output production will increase the economic growth of Pakistan by increasing GDP and trade of Pakistan. Thus, there is need to determine how the investment in coal projects will affect Pakistan's economy i.e., alteration in GDP, sectoral imports exports and trade flows in the country.

1.15 Research Question

The current study will address:

How much carbon emissions will be emitted by the installation of CPEC coal power plants and what would be suggested policy implications in order to reduce carbon emissions from these coal power plants? How will the investment in coal projects impact the economy due to change in GDP, trade flows, sectorial exports & imports of the country? Is there any welfare implication of coal projects for Pakistan trading partner economies in terms of changes in macroeconomic aggregates?

1.16 Objectives of the Study

Following will be main objectives of our study

1.   To calculate carbon emissions from CPEC coal power plants.
2.   To study the impact of proposed coal projects under CPEC on Pakistan economy.
3.   To suggest policies for the government and the communities for adaptation measures to curb carbon emissions of coal power plants of CPEC.

1.17 Significance of the Study

Regional connectivity is a significant component of the disclosed Vision 2025 of the Government of Pakistan. The newly conceived CPEC project with total investment of $US46 billion is an example of Pakistan's commitment to greater regional connectivity. Out of total $US46 billion, $US34 billion will be spent on the energy sector. As discussed earlier, the majority of the CPEC projects are coal power plants rather than renewables based even on the fact that coal emits more carbon emissions than renewable energy sources. Thus the current study is being carried out to estimate the carbon emissions of CPEC coal energy projects. It is further needed to mention that how critical role energy sector plays in the economy of any state. As after investment of coal shock in Pakistan, significant positive change will take place in the output production and industrial sector of Pakistan. Therefore, the current study will analyze the impacts on macroeconomic indicators of Pakistan economy. Hence, this study will also address the potential economy -wide gains that would be resulted from the Coal projects investment under CPEC.

1.18 Organization of the study

The current study has been organized as follows: the first chapter has built the scenario about the introduction of the topic. The second chapter describes the literature review about different world

economic corridors, the origin of CPEC, major components of CPEC, impacts of coal power plants on the environment and different methodologies used for estimation of carbon emissions released from these coal power plants and the methodologies used to study economy-wide impacts of CPEC coal power plants and the methodologies used for the economic impacts of CPEC. The third chapter includes details of research methodologies for the estimation of carbon emissions of coal power plants & the methodologies used to study the impacts of these coal power plants on Pakistan economy and further analysis of the data. The fourth chapter comprises of all the results obtained from data analysis and their interpretation. The last and fifth chapter concludes the study outcomes and suggests policy recommendations to control the concentrations of carbon emissions and introducing efficient technologies to overcome the energy crisis of Pakistan.

CHAPTER-II

LITERATURE REVIEW

Climate change is found to be a most serious externality of 21st century that is being faced by the whole world (Rehman & Salman, 2013). This worldwide externality would have adverse economic, social, political and environmental impacts on our planet earth. The major factor responsible for climate change is the rise in greenhouse gas (GHG) emissions concentrations in the atmosphere. Therefore, by reducing these emissions, the extent of climate change effects can be reduced .It was observed that 60% emissions come from fossil fuel sources of energy that supply 66% of the world's electricity demand (EIA 2006, 2009).

Greenhouse gases (GHGs) can be defined as a group of gases in the atmosphere that are the main drivers of the greenhouse effect (Mohareb et al., 2004).IPCC's fourth report apprise that the global warming is impacting the human health dreadfully. According to AR4 report, greenhouse gas emissions, due to anthropogenic activities serve as a significant contributor towards global climate change (Salman et al, 2016).The main GHGs that are involved in greenhouse effect includes carbon dioxide, nitrous oxide, methane, ozone, water vapors, sulphur hexafluoride and chlorofluorocarbons. Every individual gas has a peculiar effect on the air that is determined by the Global Warming Potential (GWP) (Mohareb et al., 2004). The GWP describes the life span of GHGs and the efficiency of each GHG molecule in the atmosphere. GWP is usually calculated on a time span of 20-year scale or 100-year scale and compared to the relative mass of carbon dioxide (Mohareb et al., 2004).The GWPs of different GHGs is presented in the table given below:

Table 2.1: Relative global warming potential (GWP) and life- time of GHGs

GHG	Lifetime (Years)	Global Warming Potential	Global Warming Potential
		20-year	100-year
CO_2	*	1	1
CH_4	12	72	28
N_2O	114	289	265
CFCs	0.3-50000	5160-11000	140-11700
SF_6	3200	16300	23500

(Source: IPCC, AR5)

In the 20th century due to rising rate of GHGs, United Nations Framework Convention on Climate Change (UNFCCC) designed a global agreement called Kyoto Protocol in order to control the release of GHGs concentration in the atmosphere. According to this protocol, all countries should control their amount of GHG emissions in the atmosphere. The rise in the concentration of GHGs in the atmosphere has led to further studies of GHGs estimation techniques. (Bogner et al., 2008).

Since 1990 to until now, IPCC has been addressing the serious global threat of global warming and climate change in its assessment reports which includes extreme weather events, high sea level rise, heavy precipitation rate which are affecting human life (IPCC: AR-5, 2014).The Rio Earth Summit Conference, in 1992, had laid the foundation of a convention named United Nations Framework Convention on Climate Change (UNFCCC) on the reaction of climate change. This convention has formed a framework to control greenhouse gases in the atmosphere in order to avoid anthropogenic interactions with the natural climate system. The UNFCCCC includes membership of 195 parties around the world. These all parties make collective promises to highlight the global issue of climate change through mitigation & adaptation measures. The main focus of the annual conference of these parties is to review the application strategies of this

convention. The first COP was held in Berlin, 1995 (Salman, 2015) .The details of other COP meeting highlights are shown in the given table below:

Table 2.2: COP Timelines & Highlights

Conference of Parties	Year	Achievements
COP3	1997	Kyoto Protocol adopted. It came into force on 16Feb, 2005.Its first commitment time period started in 2008 and ended in 2012.
COP7	2001	The Kyoto Protocol was fully adopted with its complete implementation of its rules & referred to Marrakesh Accords.
COP8	2002	It was hosted by India. Adopted Delhi Ministerial Declaration on Climate Change & Sustainable Development, rules for the execution of Clean Development Mechanism (CDM) & new guidelines for national communications among developing states.
COP11	2005	Montreal action Plan, First meeting of the parties to the Kyoto Protocol & the Joint Implementation Supervisory Committee was established.
COP15	2009	Copenhagen Accord adopted. Parties were unable to agree on the beneficiary to Kyoto Protocol.
COP17	2011	Durban Platform for Enhanced Action & Green Climate Fund was created.
COP21	2015	Paris agreement, which is the first universal climate agreement to keep global temperature below 2°C was adopted by 195 member states.

(Source: UNFCCCC calendar, unfccc.int)

The survey of Climate Change Vulnerability Index (CCVI) showed that Bangladesh, Pakistan, Nepal & India would be at high risk of climate change over the next three decades. South Asian countries mostly have agriculture economies which have more chances to face long -term impacts on water & food security, variation in monsoon rain pattern will negatively affect crop yields around 8% till 2050. Pakistan has ranked 8th among Yemen & Ethiopia most vulnerable country in Climate Change Sensitivity Index (Salman, 2015).

2.1 Pakistan's GHG Emissions

According to different World Bank indicators & World Development Report(2010), carbon emissions per capita of Pakistan generated from burning of fossil fuel, cement industries & gas burning from the year 1990 to till 2006, have been showing increasing trend of 0.6,0.8 & 0.9 metric tons respectively. However, these are still below global average emissions of 2.4 billion metric tons from 1850 to 2005.The total GHG emissions of Pakistan were 181.7 million tons of CO_2 equivalents in 1994 which have increased to 309.4million tons of CO_2 in 2010(GoP2010).

GoP projects in achieving the objective of vision 2030 with increasing economic growth, the total amount of GHG emissions will become more than double in 2020 and will increase nearly 14 folds by end of 2050.

2.1 Coal: The Highest Source of GHG Emissions

Fossil fuels are the conventional energy source for the world into the 21st century. Thus, discharges from extensive use of energy will increase the carbon emissions in the atmosphere which will result in global warming. Fossil fuel deposit fires are found to be a serious environmental threat and have been examined by various researchers from different fields of study. (Bhattacharya et al., 1991).

Table 2.3: World Trend of CO2 Emission from 1971 to 2020

Year	1971	2000	2010	2020
CO_2 total emission amount ,Mt	13,654	22,639	27,453	32,728
Coal,%	38	39	37	37
Petroleum,%	47	40	40	39
Natural Gas,%	15	21	23	24

(Source: International Energy Agency)

In Pakistan, whole carbon emissions are approximated to be increased from eighty million tons in 2003 to 147.8 million tons in 2008. These figures are predicted to become higher in 2020 to 250

million tons if strategies are not be adopted to curb GHG emissions. In 2008, it was observed that whole transport sector is accountable for 30% energy consumption in Pakistan. Therefore, the transport sector is considered to be a significant factor to rise in GHG emissions with an approximate of 26.7 million tonnes CO_2 eq and 37.1 million tones CO_2 eq in 2008 (UNDP).GHG emissions from geological changes i.e. volcanic activities, seabed release of hydrate gas, hydrocarbon seepage from underground as well as uncontrolled burning of fossil fuels is unpredictable and difficult to quantify (Dijk et al., 2011).

2.2 Composition of CPEC

Much of the literature showed that the major component of CPEC investment includes nearly 17,000MW power generation investment projects of about $34 billion while rest of the $12 billion will be spent on the reconstruction of railway tracks and road networks pass through the cities from Peshawar to Karachi (Bhattacharjee 2015).It was also found from the literature that majority of the CPEC energy projects include coal power plants, the major source of greenhouse gases. (Ministry of Planning, Development &Reform)[8].Therefore in order to control these carbon emissions, they have to be quantified first.

2.3 Quantification of Greenhouse Gas Emissions:

Different studies have been conducted for the estimation of carbon emissions from different sources they have released. Some of the studies are as follows:

(Malenta et al, 2013) projected a carbon footprint estimation tool for the valuation of GHG emissions mainly carbon dioxide, carbon monoxide, nitrous oxide and methane with other

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[8] See http://www.pc.gov.pk/

pollutants in the atmosphere. This tool uses a complete methodology to estimate overall project emissions including all stages of construction of a project.

The carbon on-line estimator (COLE) and carbon calculation tool (CCT) model developed by the USDA[9] estimate carbon stocks and measure carbon change for areas in the U.S on the basis of forest inventory data (NRS 2010).

Carbon footprint is found to be a great model to curb the pertinent emissions and their verifications to the international standards of the world (Pandey et al, 2011).

2.4 Quantification of GHGs from Coal Power Plants:

Various methodologies have been used for the estimation of carbon emissions from coal power plants. Some of them are as follows:

Rao & Rubin in 2002 applied cost and performance model of an amine-based CO_2 absorption system to examine the feasibility and cost of carbon sequestration and carbon capture for both existing and new coal combustion power plants. It was found that the cost of carbon storage for the old plants is higher than for the new power plants.

Hondo (2005) used Life Cycle Analysis (LCA) approach for the examination of nine power generation systems in Japan. Life cycle emissions of each power system were estimated through this approach.

Jaramillo et al. (2007) used Life Cycle Emissions analysis to compare greenhouse emissions released from the power generation from NG/LNG/SNG and coal burning. This life cycle comparison of these gas emissions from different fuel sources would be helpful in stating the

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[9] The United States Department of Agriculture is a U.S. federal executive department accountable for evolving & implementing federal laws relevant to agriculture, farming, forestry, and food.

advantages and disadvantages of these fuels. Results showed that emissions released from NG/LNG/SNG would be lower as compared to coal power plant fuel sources. If carbon capture storage system would be applied to coal power plants, their carbon emissions would also be decreased.

Odeh and Cockerill in 2008 examined the life cycle emissions emitted from three types of fossil fuel power plant:(Super –PC (pulverized coal), integrated gasification combined cycle (IGCC), natural gas combined cycle (NGCC) by using & without using carbon capture storage system (CCS).Results showed that by using CCS, 75-84% GHG emissions can be reduced depending on the type of technology used.

Kennedy et al., (2009), calculated lifecycle greenhouse emissions from ten cities of the world. Different parameters were used for the determination of greenhouse gases i.e. heating, electricity, industrial fuels, transport emissions etc. This study gave a comprehensive analysis of GHG emissions of these cities which help in reducing these emissions from the cities.[10]

Yu et al., (2014) applied LCA approach to calculate the impact of carbon emissions and the carbon emission coefficients in coal power projects in China. As coal power generation produces GHG emissions from four procedures: mining of coal, coal washing, transportation of coal and coal combustion. Therefore, they proposed a model that calculates carbon emission coefficients in coal power plants from the sum of these carbon emission sources:

$$Ekwh=Me+Se+Te+Ge^{11}$$

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[10] (Kennedy et al., 2009)
[11] Ekwh=Total GHG emissions released from the generation of a unit of coal-fired power plant in the life-cycle
Me=GHG emissions released from mining process
Se=GHG emissions releases in the selection and coal washing processes.
Ge=GHG emissions released from coal combustion process

However, data of various variables are required for the calculation of carbon emissions at each stage of Life Cycle Assessment.

Gouw et al., (2014) have estimated that how much carbon emissions (CO_2, SOx and NOx emissions) from fossil fuel combustion have decreased by switching from coal source towards natural gas with combined technology. This reduction in emissions is calculated by:

$$\Delta \text{ Emissions} = \text{GL combined cycle} \times (\text{EIcoal} - \text{EI combined cycle})^{12}$$

They have found that by switching from coal to natural gas with combined cycle technology, a substantial decrease in the concentration of CO_2, SOx and NOx were observed in the United States.

(Leu et al., 2015) have calculated carbon emissions released from fossil fuels combustion and cement production in China. Carbon emissions have computed by utilizing activity data, which are stated as the amount of fossil fuel used during manufacturing multiplied by the respective carbon emission factor (EF) [13].If data on sectoral and fuel activity data and EF are available, total emissions can be estimated by:

Emission=XXX (activity data i,j,k ×EFi,j,k)

Where i is an index for fuel types, j for sectors, and k for technology type. Activity data are measured in physical units.

Above different methodologies were used by many researchers for carbon emission estimations. But due to data unavailability issues in CPEC mega project, these studies cannot be applicable for calculation of carbon emissions of proposed CPEC coal power plants.

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b[12] Where GL stands for gross load & EI stands for emission intensity.

[13] Emission=activity data ×EF

2.5 Economic Impacts of CPEC on Pakistan Economy

According to Planning Commission's estimates, the long-term plans under CPEC after implementation can improve GDP of Pakistan approximately 1.50 % at initial stage and will further increase by 1% after 2020.The annual average trade of Pakistan will also increase 24% from 2016 to 2020 & further increase to 16% from 2020 to 2030.The average annual investment rate is also projected to rise to 25% after 2016 to 2030.Thus, industrial production will raise GDP by 1.5% by creating 800,000 new jobs for the unemployed labor and reducing poverty. The large -scale capital investment along with Chinese expertise in mega projects makes CPEC a" game changer" for Pakistan. Thus, Chinese investment under CPEC will also act as a catalyst to enhance Pakistan's GDP growth (Monnoo, 2017).

A regular massive FDI will greatly help Pakistan in improving its perception for other investors around the world. It will give a signal to other countries that Pakistan is open for business and it's a safe & productive place for investment. According to several GOP documents[14], the descending trend of growth has been observed in the year 2014-15 due to war against terrorism, energy shortages etc. For the year 2016-17,the real growth rate has been projected to 5.5% which would be higher from the current growth rate of last year i.e,4.5%.The growth is expected to increase in agriculture from its current rate in 2014 i.e., 2.9 % to 3.9%.While the industrial sector will grow from its current rate(2014) i.e,3.6 % to 6.8% and the services sector will increase to 5.7% from its current growth rate of 5%.The main drivers of growth in 2015-16 included: construction(2.6%), livestock(11.6%), transport ,storage, communication (13.3%), finance and insurance(3.31%) sub-

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[14] The documents include the Pakistan Economic Survey (2014-15), Quarterly report of State Bank of Pakistan (2015-16), Fiscal Policy Statement (2015-16) & the Debt Policy Statement (2015-16).

sectors. While the expected driver of growth for 2016-17 will include: agriculture, heavy manufacturing, transport, storage, communication, banking and insurance sectors (Ahmed, 2017).

The CPEC plan has also acknowledged the launch of many industrial parks near the cities. Although many industries are projected to get benefits from this plan however, the benefits in the following industries are expected to be more significant:

➢ **Textile Industry**

Textile & garments industry will be formed in Kashgar economic development zone by importing raw materials from Pakistan. While the garment & textile centers will be constructed in Karachi and Lahore. To improve varieties of cotton textile, investment is projected mainly on printing, top quality cotton yarn, jean fabric & dying fabrics.

➢ **Household Appliances Industry**

As a result of improved living conditions of people of Pakistan, their demand for freezers, washing machinist sets etc. will increase gradually. Thus, a Chinese household appliance industrial park is already working in Pakistan and the other one is also in the short term plans through joint projects. Their main objective is to reduce the imports of these goods and manufacture them locally.

➢ **Cement & Building Material**

According to an approximate estimate, 4% of overall CPEC project cost is projected to be spent on cement. This shows about Rs.190 billion, that is 19 million tones for the whole life of CPEC (Hashemy, 2016).

➢ **Automobile Sector**

By assuming the current road thickness of registered auto-vehicles, CPEC road projects will demand approx... 800,000 automobiles for next 15 years (Ahmed, 2017).

➢ **Petroleum &Petrochemical Sectors**

Huge quantities of asphalt/ bitumen will be needed in CPEC infrastructure projects. The demand for petroleum products is also projected to rise significantly.

➢ **Steel Industry**

The use of steel in civil works, rail tracks and gas pipelines is predicted to be high during every phase of all projects. Cables, electric goods & optical fibers will also be needed during the construction phase of different projects (Ahmed, 2017).

➢ **Mineral Exploration**

Two mineral projects mainly Saindak Copper-Gold Mine Project & Dudder Zinc-Lead Mine Project) are already under Chinese consideration, while other projects will start as the corridor get started (Ahmed, 2017).

Besides the impacts of CPEC on GDP growth & employment rate, the impacts on infrastructure development will also be highly significant. The lengths of newly constructed roads & upgraded roads & railway tracks would be 3,871km & 1,530km respectively which would complete by the end of 2030.Power generation from different newly developed energy sources will be enhanced to 19.785kW. The optical-fiber length will be extended to 2,084km.The Gwadar port & airport will also constructed. However human resource development & technology transfer are found to be weaker links in the whole situation, as these aspects are not elaborated completely in the strategic & planning documents (Ahmed, 2017).

2.6 CGE Model

Computable general equilibrium (CGE) model is a form of economic model that employ real economic data to determine the response of any economy to changes in technology, policies or

any other external factor in the economy. CGE models are also known as AGE (Applied General Equilibrium) models. A CGE model involves: equations relating model variables and a database that is accurate with model equations. CGE models have also been found recently to estimate economic measures to curb carbon emissions. CGE models also contain some exogenous variables a part from equations in the model. A CGE model generally includes steps: Construction of a structured model for an economy (Input-Output models), selection of a base year for the data, calibration of the model for datasets, counterfactual: by changing a policy or technology and then recalibrate the model to see the impact on the economy[15].

2.7 GTAP Database 9

GTAP (Global Trade Analysis Project) has found to be used in various economy- wide analysis projects from the last twenty- five years. Initially, the focus of GTAP database was on trade policy analysis and then modified later to include environmental issues i.e. climate change. The database includes a comprehensive set of accounts determining the circulation values for the circulation of goods & services on a regional level for the whole world economy. These trade inflows contain transport sector, bilateral trade matrices that connect specific country or different regional economic databases. The GTAP version 9 divided into 140 regions, 57 sectors, 8 factors of production for the three base years of data sets (2004, 2007 &2011).This database has been widely used due to study the improvement in the quality of analysis of global economic issues relevant to energy, economic growth & environment (Aguiar et al.,2016).

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[15] /www.iadb.org/en/topics/trade/understanding-a-computable-general-equilibrium model,1283.html

The GTAP database production depends on the efforts of many people and different organizations in the world. Individuals provide their input-output tables for their countries, while experts provide data for macroeconomic indicators and trade protection. The main center for GTAP, combines all these contributions from individual countries and experts and constructs a global stable database, which is completely recognized and available for public and up-gradation. The GTAP 9database comprises distinct input-output tables for 120 individual countries showing 98% GDP & 92% world population and also includes 20 combined regions of small economies. The main data source of macroeconomic indicators applied in GTAP database 9 is the World Bank World Development Indicators (Aguiar et al., 2016).

2.8 CGE Models Application

Numerous authors have applied CGE models to developing and less developing countries in the world to analyze the impacts on macroeconomic variables of any external shock in the economy.

Naqvi (1998) applied CGE model and used the Social Accounting Matrix (SAM) for the base year 1983-84 as a dataset to analyze the impacts of energy policies on the economy of Pakistan. The results after simulations showed that variation in energy tax has diverse impacts on all goods and services. It also showed that by applying natural gas tax shows negative impacts on consumption of households. It further revealed that by removing tax distortions will raise the real GDP and also bring constructive impacts on balance trade.

Siddiqui and Iqbal (2001) applied CGE model to examine the impacts of tariff reduction on income distribution of households on Pakistan economy. They have used Social Accounting Matrix (SAM) for the 1989-90 year for database simulations, which provides a complete picture of Pakistan economy. The results showed an increase in real income of households because of the drop in

prices. An increase in the share of labor in GDP has been observed due to tariff reduction which depicts a rise in regional household's income. This also implies that production has a welfare impact on households.

Gosh (2004) established a CGE model using GTAP 4[16] to analyze the impacts of transport infrastructure on Pakistan economy. He suggested a multi-regional CGE model examine the impacts of new road infrastructure networks between Peshawar and Karachi. The results after simulation showed a positive impact of the new road network on industrial sectors of Punjab, NWFP and Khyber Pakhtunkhwa province of Pakistan. This highway network will rise real household income for consumption which will lead to increase in utility of both provinces. The road networks will cause an increase in income of households that will result in an increase in the utility levels in dual provinces. The results also showed a 16% increase in GDP of the economy due to this road infrastructure network development.

Butt (2006) applied CGE model in Pakistan to estimate the impacts of tariff reduction on regional differences, employment, production & exports of the country. The study established database by using the I-O table of the year 1990-91 formed by Federal Bureau Statistics (FBS 2001).The results showed positive impacts of trade liberalization on all areas of Pakistan by an increase in output,

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[16] The GTAP 4 database comprises complete bilateral trade, protection data and transport describing economic ties between regions, combined together with separate country input-output databases which are responsible for inter sectoral bonds between **50** sectors within every   45 regions**.**

employment, and exports. The results also revealed positive linkage among trade liberalization & regional differences in military rules and negative for the case of democratic government.

Siddiqui & Kemal (2006) analyzed the impacts of trade liberalization and drop in remittances on welfare and poverty for Pakistan economy. They have applied a CGE model with a database of SAM for the year 1989-90.The study conducted two sets of simulations for the desired objectives. The results revealed tariff cut has a positive impact on welfare and poverty reduction and trade liberalization is no reason for poverty rise in Pakistan in the 1990s.While a drop in remittances causes a decrease in benefits of trade liberalization. Thus, the positive effect of trade liberalization is dominated by the negative impact of the decline in remittance in urban areas. Thus, it shows that remittance decline is a major factor in the rise of poverty in Pakistan in the 1990s.

Ahmed and O' Donoghue (2008) applied CGE model to capture impacts of policy simulations on Pakistan economy. They used SAM as a database GAMS software used for the model application. They included 16 industrial sector, 12 agricultural sector, and 6 services sector. Households were divided into rural & urban households. The rural households were further classified into 17 classes. The study was done by trade simulations of trade liberalization. Results recommended that change in external oil prices have great potential to affect the economy of Pakistan. Increase in FDI will reduce poverty in the country. It was also revealed that one major cause of poverty is the increase in import prices.

Hussain (2010) used CGE model by using SAM   (2002) to analyze the financial severity and the trade liberalization impacts on the wellbeing of household and inequity. The study revealed two major effects of export tax and tariffs. They decrease the trade capacities on both exports and imports. They also execute economic costs by enforcing resources misallocation. Thus, if taxes for trade will be reduced, the economy will escape through production and consumption falsifications.

It is a well-known fact that free trade results in improved proficiency. The results further revealed that for small countries i.e. Pakistan, imposing tariffs does not influence world prices.

Dorosh and Rashid (2013) applied CGE model to analyze modern trade rules for agriculture sector by linking it to the industrial sectors of Pakistan from the year of 2000 to 2010 and also evaluate the impacts of income tax on agriculture sector to the economy of Pakistan by using SAM 2002. The results revealed an increase of 5% and 10% in the government income on imposing of agricultural tax. The results also showed that processing and imports of the country flourished while construction and export sectors showed a decline. The labor demand in non - agriculture sector rose, while the demand in agriculture sector decreased due to rise in agriculture income tax.

(Siddig et .al, 2014) studied the socioeconomic impacts of policies for reducing fuel subsidies by using nationwide framework My GTAP[17] model in Nigeria The model integrated country- specific information into 12 households groups to observe domestic policies. The study included 13 regions & 21 commodities. My GTAP integrated government revenues in two fragments; income & expenditure. It is believed that by dropping fuel prices followed by a low standard of living cost can be the result of subsidies integrated into the imported fuel goods. The study maintained a decrease in fuel subsidy policy because it has positive impacts on the income of poor households which will lead to lessening poverty in Nigeria.

Kuiper and Shutes (2014) used MyGTAP database to examine the impacts of food security on many households of Ghana. The study included multiple households to analyze the effects of food policies on the weakest part of the society and assisting the government to plan interventions for

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[17] MyGTAP is the extended version of GTAP which includes new structures and data which analyze regional impacts of international trade policies on governments and households.(mygtap.org/)

providing help to poor households of the society. The study incorporated 9 households & 19 commodities. In this study, three methods were applied to include household's data in GTAP database. First, user weights were allocated to households and merged into GTAP. Secondly, the study incorporated household data by using national SAM. Thirdly, they entered the household survey data in GTAP model for analysis. The results showed by removing export subsidies will be helpful for the poor people of Ghana.

Khan et al. (2015) applied CGE model to examine impacts of agricultural trade liberalization of agricultural trade on income equity of Pakistan. The study used the advanced MyGTAP[18] model which is established by Walmsley & Minor (2013). The model used two sets of the database for simulations: SAM 2007-08 and GTAP. The study has thoroughly examined impacts of agricultural trade liberalization of agricultural trade on household's level. This study included 18 households, 37 sectors & 12 regions. The results liberalization of agricultural trade revealed that income variation in Pakistan is enlarged by 0.49% from starting point. Moderate and large households are helped, and there is a minor rise in the real incomes of intermediate and big farmers.

We are using CGE models in our study due to several reasons. Firstly, these models have been extensively used in the analysis of economic impacts of power and climate change- related policies. CGE models are also used to assess a wide range of policies of welfare. The theoretical basis of these models help in the interpretation of simulations in the form of consumers and firms in the economy. These models can also analyze the flow of and factors of production in the

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[18] MyGTAP is a group   of GEMPACK programs (Harrison and Pearson, 1996) aimed to restructure and modify the   GTAP database into several households and   production factors to aid the examination of CGE framework.

economy to their relative prices (Cai & Arora, 2015).Therefore, from the above studies, I have found CGE model more suitable to analyze the economy-wide impacts of CPEC coal investment in Pakistan. I have applied this model to analyze the macroeconomic impacts of these coal power plants on Pakistan economy.

CHAPTER-III

DATA AND RESEARCH METHODOLOGY

3.1 Study Area

The current study comprised of three provinces of Pakistan. There are seven coal power plants included in CPEC early harvest projects. Sindh includes three coal power plants each with 1320 MW (Port Qasim Electric Coal Power Plant and two Engro Thar Coal projects in Tharparkar district).Two projects with 1320MW capacity are included in Punjab province i.e., Sahiwal Coal-Fired Power Plant and Rahimyar Khan Coal Power Project. Baluchistan province also includes two coal power plants i.e., Gwadar Coal Power Project (300MW) & HUBCO Coal Power Project (1320MW) at Hub, Baluchistan. (Ministry of Planning, Development & Reforms).The exact locations of these coal power plants are shown below:
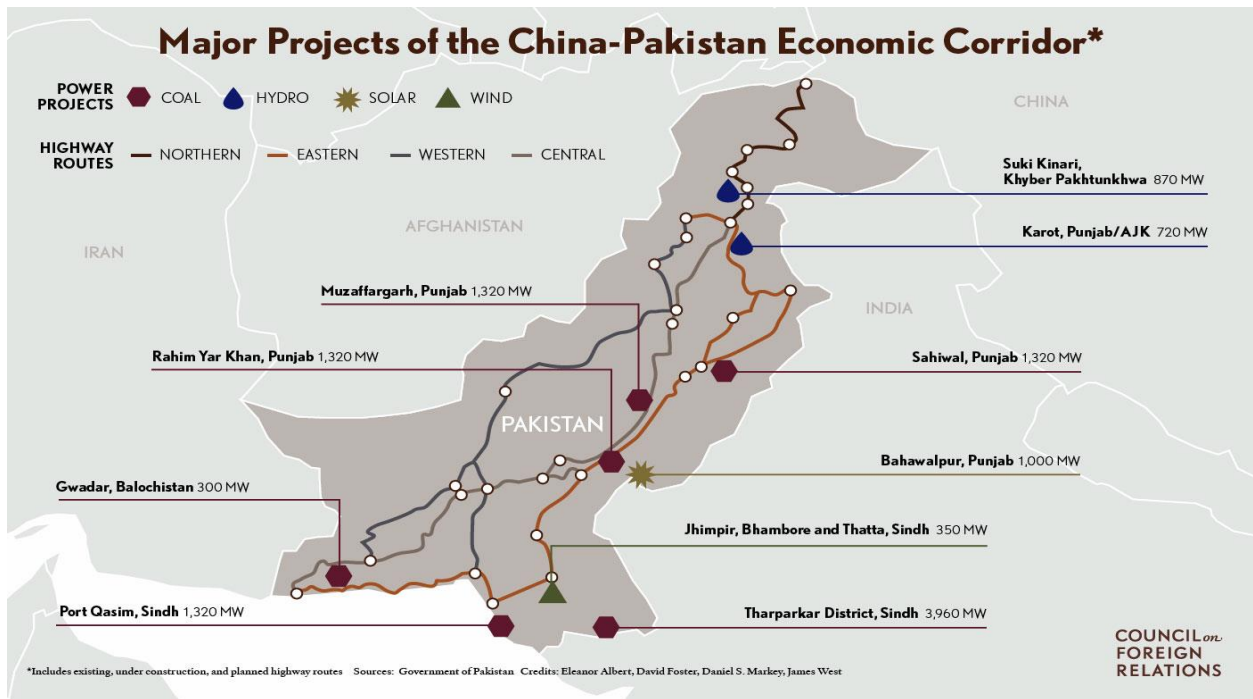
Figure 3.1 Map of CPEC Coal Power Plants
(Source: google.com.pk/map of CPEC Coal Power Plants)

Table 3.1: Details of coal power plants under CPEC

Sr. No	Project Name	Capacity (MW)	Estimated Cost (US$ M)
1	Port Qasim Electric Company Coal Fired, 2X660, Sindh	1320	1980
2	Sahiwal 2X660 MW Coal-fired Power Plant, Punjab	1320	1600
3	• Engro Thar 4X330 MW Coal-Fired, Thar, Sindh • Surface mine in block 2 of Thar Coalfield, 6.5 mtpa, Thar Sindh	1320	2000 1470
4	Gwadar Coal Power Project, Gwadar Baluchistan	300	360
5	HUBCO Coal Power Plant, Hub Baluchistan	1320	970
6	Rahimyar Khan Coal Power Project, Punjab	1320	1600
7	• SSRL Thar Coal Block 1-6.5mtpa Thar, Sindh • SSRL 2X660 MW Mine Mouth Power Plant,	1320	1300 2000
Total		8220	13,280

(Source: Ministry of Planning Development & Reform, Government of Pakistan)

3.2 CPEC Coal Projects Details:

I) Sahiwal Coal Power Plant (1,320MW)

The Sahiwal coal power plant covers an area of 15 kilometers to the northeast Sahiwal in Punjab province. The power plant consists of two 660MW plants for power generation capacity of 1,320 MW in the initial phase, and it will be followed by a second phase which will include two 1,000MW plants. The plants will use super-critical technology for power generation. It will be sponsored by a Chinese company, Huaneng Shandong Rui Group.The plant will be powered by sub-bituminous coal imported from Indonesia and South Africa. The efficiency of the plant will be 42.11% for the production of complete electricity[19].The 95% civil work on the plant site has been completed. The plant inauguration is expected in October 2017 and plant will be commercially operational on 25Dec, 2017(cpec.gov.pk).

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[19] http://www.cpec.gov.pk/project-details/2

II) HUBCO Coal Power Plant (1320 MW)

Hub Power Company Limited (HUBCO) is placed at Hub in the district Lasbela, Baluchistan. The HUBCO is a large, private power company with a capacity of 1,320 MW plant, located 60 km away from Karachi in Hub. This project has also become the part of CPEC energy priority projects. The power plant will be financed by China Power Hub Generation Company. This project will also use super-critical technology and imported sub-bituminous coal for power generation. The plant will be commercially operational till 2018/2019(cpec.gov.pk).This power plant has socio-economic importance besides power generation in Hub. It will generate employment opportunities for the local population of the remote area of Hub[20].

III) The Port Qasim Electric Company, Coal Plant (1,320 MW)

The Port Qasim coal project comes in rank first among the energy priority projects under CPEC. The project is situated in the Port Qasim Industrial Park, which is 37 km southeast of Karachi. It consists of two units with whole power generation capacity of 1320MW.It will be fueled by 4.66million tons of imported sub-bituminous coal annually. This coal will be imported by Indonesia & South Africa. The plant will be financed by Port Qasim Electric Company private limited. The project is using super-critical technology for power generation. The 65% civil work on plant site has been completed. The plant energization will be expected to be in Oct 2017.The plant will be commercially operational in June, 2018(cpec.gov.pk).

IV) Engro, Thar Block II Coal -Fired Power Plant (1,320 MW)

In December 2014, Engro Thar coal power plant 660 megawatts was listed among the energy priority projects of CPEC .The project is planned to be completed by the second quarter of 2018.

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[20] defence.pk/pdf/threads/hubco-coal-power-plant-1320-mw-balochistan.484817/

A further 660 MW unit is proposed to be completed in the second phase of the project. Thar coal field is enriched with lignite reserves of coal. The coal used for power generation is used from Thar Block II coal fields. It requires 3.8 million tons of lignite annually. (ESIA block II)

The project site is located at Thar block II coal fields with a latitude: 24º 43' 38" – 24º 50' 18" and longitude: 70 º17' 36" – 70 º26' 16"), in the District of Tharparkar and east of Sindh province. Block II has total 2 billion tons of lignite reserves which have power generation capacity of 100,000MW electricity for 200 years. It is located at 20 Km from Islamkot city, which is near Singharo-Bitra village. The reliability of this energy project makes it sustainable energy source which will help in reducing energy crisis of the country. (Thar Mining & Power Project Information Pack Sindh Engro coal mining Co).The power plant will be commercially operational till 2018/2019(cpec.gov.pk).

V) SSRL Thar Coal Block 1-6.5mtpa Thar, Sindh

Sino-Sindh Resource Private Limited (SSRL) has got mining lease in Block-I of Thar coalfields on 24th Sep, 2012.SSRL is going to begin an open-pit coal mine for 6.5 mtpa in block –I of Thar coal-fields and two mine- mouth 2 x 330 MW energy plants will be driven on indigenous lignite coal reserves. This project is also included in the energy priority projects of China Pakistan Economic Corridor (CPEC). An agreement had been signed between Sino-Sindh Resources (SSRL) and Shanghai Electric Group Co., Ltd (SEC), in which SSR will supply the extracted coal from the block I of Thar coalfields to SEC for the power generation of 2 x 660MW mine mouth power plants. Environmental Social Impact Assessment (ESIA) has been completed for the project. The power plant will use sub-critical technology for power generation. The project commercial production is expected to be in 2018/2019(Thar Coal Energy Board Government of Sindh).

VI) Rahimyar Khan Coal Power Project, Punjab

Rahimyar Khan power plant is a project of 1,320 MW coal power plant located in Punjab, province of Pakistan. A Chinese company, Huaneng Shandong Power signed an agreement with Punjab government for the construction of Rahimyar Khan Coal Power Plant in February, 2016.The project cost was set at $2 billion. This project has also become the part of CPEC energy priority projects. Sub-bituminous coal will be imported as the fuel source for power generation[21].The project will use super-critical technology for power generation. The power plant is still under scrutiny.

VII) Gwadar Coal Power Project, Gwadar

The major projects Of CPEC in Gwadar city include: construction of Gwadar port and a new international Gwadar airport which would be functional by the end of December 2017.A new 300 -bed hospital will also be included in the CPEC projects. The further development in Gwadar will include the establishment of 300MW coal power plant. Sub-bituminous coal will be imported from South Africa for the production of this power plant. The power plant will be financed by China Communication Construction Company (CCCC).The project is still in the documentation phase. (cpec.gov.pk).

To achieve our desired objectives, our study is divided into two components:

- ➢ Calculation of carbon emissions of CPEC Coal Power Plants
- ➢ Use of GTAP database to study the economy- wide impacts of CPEC Coal Projects

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[21] http://www.sourcewatch.org/index.php/Rahim_Yar_Khan_power_station

3.3 Calculation of Carbon Emissions of CPEC Coal Power Plants

To achieve our first objective, the following study has been conducted for the estimation of the carbon emissions.

After discussing multiple number carbon emission estimation methods in chapter II, the following formula proposed by Van Dijk et al., 2011 was applied for the estimation of carbon emissions of CPEC coal power plants:

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

3.3.1 Data

All CPEC energy projects come under the power generation sector, so secondary data for these coal projects were obtained from different power sector organizations mainly Board of Investment (BOI), Ministry of Planning, Development & Reforms, Private Power Infrastructure Board (PPIB) & National Electric Power Regulation Authority (NEPRA).In order to achieve our proposed objectives, three parameters are required: Type of coal, amount of coal burning (million tons of coal) and amount of GHGs emitted (tons of CO2). With these parameters, the carbon emissions of coal power plants will be calculated by using formula proposed by Van Dijk et al. 2011.

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

The details of the above parameters are given below:

1) Amount of coal required per annum:

This is the coal amount required per annum by a power plant for the generation of specific plant capacity. This value was obtained from different government power sector organizations published

reports i.e., BOI, PPIB, NEPRA and different ESIA (Environmental &Social Impact Assessment) reports of the given projects.

2) Coal Type:

Different types of coal are available in the world. The main types of coal are given below:

Table 3.2 Types of Coal with their Percentage Carbon Content

Rank	Type of Coal	Percentage Carbon Content
#1	Anthracite	87%
#2	Bituminous	77-87%
#3	Sub-bituminous	71-77%
#4	Lignite	60-70%

(Source: http://geology.com/rocks/coal.shtml)

The information of the type of coal used in the power plants for power generation is also obtained from the ESIA reports and government reports of the projects. Thar power plants have used indigenous lignite reserves of coal for power generation while rest of the plants have used imported sub-bituminous coals from Indonesia, South Africa, and Australia.

3) Carbon emissions equivalent with respect to % Carbon content in Coal:

As one molecule of carbon dioxide produces (Atomic weight of Carbon=12, Atomic weight of Oxygen= 16, molecular weight of CO_2 =44) carbon emissions: (12/44= 0.2727, 1 /0.2727 =3.667).Therefore, by multiplying the factor 3.667 with the percentage of given amount of coal required for power generation, carbon emission factor of a given power plant can be calculated.

4) Methane Factor:

As both carbon dioxide (CO_2) & methane (CH_4) are considered as GHGs according to Kyoto Protocol. We mostly consider carbon dioxide and ignore methane, although greenhouse effect of methane is 21 times the greenhouse effect of CO_2. Therefore, in final calculations, methane factor is also included. Therefore, with the amount of CO_2 released 0.3% CH_4 is also added to its Global Warming Potential (GWP) of 21[22] (Dijk et al., 2011).

3.3.2 Calculations

Following formula is used for the calculation of carbon emission equivalents:

Carbon emission (eq) = Amount of Coal× CO_2 emissions +Amount of Coal (0.3% ×CO_2emissions×GWP for CH_4 of 21)

1) Sahiwal 2X660 MW Coal-fired Power Plant, Punjab

Amount of Coal required=6million tons (Board of Investment Report)

Type of Coal=Sub-bituminous

Percentage carbon content=71-77%

Carbon emission factor=2.71 tons

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=6,000,000×2.71+6,000,000(0.003×2.71×21)$$

(1 kg of CH_4=21 kg of CO_2 equivalent; (IPCC 2006)

$$=16260000+1024380$$

$$=17{,}284{,}380 \text{ tons of } CO_2 \text{ equivalents}$$

2) Engro Thar 4X330 MW Coal-Fired Power plant

Amount of Coal required=3.8 million tons (Thar Coal Energy Board, Government of Sindh)[23]

Type of Coal=Lignite

Percentage carbon content=60-70%

Carbon emission factor=2.38 tons

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=3{,}800{,}000\times2.38+3{,}800{,}000(0.003\times2.38\times21)$$

$$= 9044000+569772$$

$$=9{,}613{,}772 \text{ tons of } CO_2 \text{ equivalents}$$

3) Port Qasim Electric Company Coal Plant, 2X660, Sindh

Amount of Coal required=5.61 million tons (PPIB)

Type of Coal=Sub-bituminous

Percentage carbon content=71-77%

Carbon emission factor=2.71 tons

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[23] http://sindhcoal.gos.pk/

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of   Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=5,610,000×2.71+5,610,000(0.003×2.71×21)$$

$$=15203100+957795.3$$

$$=16,160,895.3 \text{ tons of } CO_2 \text{ equivalents}$$

4) Gwadar Coal Power Project, Gwadar 300MW

Amount of Coal required=1.275million tons (PPIB)[24]

Type of Coal=Sub-bituminous

Percentage carbon content=71-7%

Carbon emission factor=2.71 tons

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of   Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=1,275,000×2.71+1,275,000(0.003×2.71×21)$$

$$=3455250+217680.75$$

$$=3,672,930.75 \text{ tons of } CO_2 \text{ equivalents}$$

5) HUBCO Coal power plant, Hub Baluchistan, 1320 MW

Amount of Coal required=5.61 million tons (PPIB)

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[24] http://www.ppib.gov.pk/N_upcoming_coal.htm

Type of Coal=Sub-bituminous

Percentage carbon content=71-77%

Carbon emission factor=2.71 tons

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=5,610,000 \times 2.71 + 5,610,000(0.003 \times 2.71 \times 21)$$

$$=15203100 + 957795.3$$

$$=16,160,895.3 \text{ tons of } CO_2 \text{ equivalents}$$

6) Rahimyar Khan Coal Power Project, Punjab 1320MW

Amount of Coal required=5.61 million tons (PPIB)

Type of Coal=Sub-bituminous

Percentage carbon content=71-77%

Carbon emission factor=2.71 tons

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=5,610,000 \times 2.71 + 5,610,000(0.003 \times 2.71 \times 21)$$

$$=15203100 + 957795.3$$

$$=16,160,895.3 \text{ tons of } CO_2 \text{ equivalents}$$

7) SSRL Thar Coal Block 1-6.5mpta Thar, Sindh, 1320MW

Amount of Coal required=5.61 million tons (PPIB)

Type of Coal=Lignite

Percentage carbon content=60-70%

Carbon emission factor=2.38 tons

Carbon emission (eq) =Amount of Coal× CO2 emissions +Amount of   Coal (0.3% ×CO2emissions×GWP for CH4 of 21)

$$=5,610,000 \times 2.38 + 5,610,000(0.003 \times 2.38 \times 21)$$

$$=13351800 + 841163.4$$

$$= 14,192,963.4 \text{tons of } CO_2 \text{ equivalent}$$

Total CO_2 equivalents emissions from all Coal Power Plants=75,979,636.43tons of CO_2 equivalent

3.4 Economy-Wide Impact Analysis of Coal Projects under CPEC

After discussing various multiple economic analysis methods, global GTAP model known as CGE model has been selected for the macroeconomic analysis of CPEC coal power plants. As GTAP provides a complete global database including full bilateral trade information of 140 regions of the world, which help in the analysis of global economic issues. Thus, CPEC is also a mega project of commerce among Pakistan and China. Therefore, GTAP database model will help in the analysis of macroeconomic indicators due to the investment of China on coal power plants in Pakistan under CPEC.A major reason for choosing this model is the wide applications of the model for

trade analysis issues in the world. Assessing the macroeconomic indicators i.e. GDP, sectoral imports & exports would give a broader picture of the economic viability of the CPEC coal power plants in Pakistan.

3.4.1 Use of GTAP database for the Economy-Wide Impact Analysis of CPEC Coal Power Plants

To study the coal component of CPEC, we used the latest global GTAP Power Database 9 for the base year 2011. The database is composed of 140 regions and 68 sectors. As we already know the status of Pakistan economy, and in order to simplify calculations, the total number of regions were aggregated to 10 regions & the number of commodities or sectors to 23 from total 68 GTAP sectors (Peters, 2016).

The newly available comprehensive GTAP Power database 9.0, which is the predominant database for global CGE (Computable General Equilibrium) analysis, disaggregates the electricity sector into the following new sectors: transmission & distribution, coal, gas, nuclear, oil, hydroelectric, solar, wind and other different power technologies. Gas, oil, & hydroelectric powers are further distinguished by load type: base and peak (designated by "BL" and "P" suffixes, respectively). The levelized input costs for every technology are evaluated to be same as possible to the original data, but homogeneous with the original GTAP 9 Database (Peter, 16).
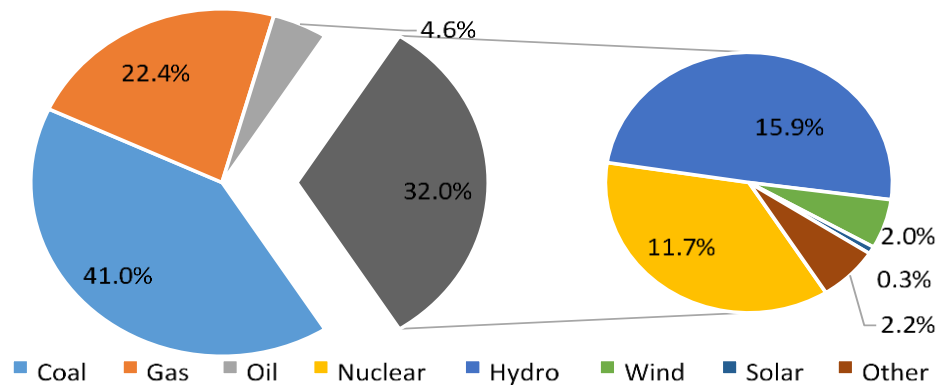
Figure 3.2: Global electricity generation shares by technologies in 2011.
(Source: Peters, 2016)

3.4.2 GTAP Model:

Changes in prices of goods or production of any product can have significant impacts on employment, incomes, and output of other different industries, government income and consumption, thereby underscoring the significance of catching critical connections amongst products and markets. Due to this reason, CGE models are most suitable for economy-wide analysis. CGE models mostly focus on the links between products & factor markets on prices & output production through complete input-output linkages & equations, that model links macroeconomic variables i.e., investment & savings (Minor and Mureverwi 2013). This study has applied a global computable general equilibrium model named as GTAP model. GTAP model is a relative stationary model which is mainly constructed on neoclassical concepts. It's a linearized model which uses the global database for the economy-wide analysis for countries. The model assumes, that all markets are perfectly competitive, all manufacturing & trade activities show constant returns to scale, industries and household's exhibit profit & utility maximization behavior. The model is simulated using a software called GEMPACK[25] (Harrison and Pearson, 1996).

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[25] GEMPACK (General Equilibrium Modelling PACKage) is an economic modelling software. It is mostly suitable for computable general equilibrium (CGE) models, but it can control a wide range of economic behaviors.

In the GTAP model, every region has a single representative household, known as the regional household. The regional household's income is produced through factor payments[26] and tax returns (export and import taxes) net of subsidies. The regional household distributes expenses over private household expenditure, government expenditure, and savings according to a Cobb Douglas per capita utility function. Thus, each element of final demand continues a constant share of total regional income.

The study under consideration requires the impacts of Chinese real investment in coal projects on the overall economy of Pakistan. The global CGE model used GTAP 9 database for base year 2011to analyze the macroeconomic impacts of this coal investment shock on Pakistan economy. The main macroeconomic indicators which were analyzed in this study include real GDP, real imports, and exports of Pakistan.

3.4.3 Model Closure

The standard Commutable General Equilibrium model used in this study assumes full employment of endowment commodities (land, labor, and capital), perfect competition (zero economic profits), mobile factors (except land which moves sluggishly between uses), a flexible trade balance and mobile capital between regions (which responds to variations in rates of return on capital).

3.4.4 Behavioral Parameters in the GTAP Model

The following table represents the description of all the parameters used in the equations of the GTAP model.

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[26] A wage, rent, interest and profit payments for the services of limited resources, the factors of production (labor, capital, land & entrepreneurship), in return for productive services. Factor payments are usually classified according to the productive services of resources.

Table 3.4: Behavioral Parameters of Equations in the GTAP Model

Parameters	Set Index	Description
σ_D ESUBD(i)	i∈ TRAD_COMM	Elasticity of substitution among domestic & imported goods in the Armington aggregation structure for all agents in all regions.
σ_D ESUBD(i)	i∈ TRAD_COMM	Elasticity of substitution among domestic & imported goods in the Armington aggregation structure for all agents in all regions.
σ_{VA} ESUBVA(j)	j∈ PROD_COMM	Elasticity of substitution between primary factors of production of commodity j
ESUBT(j)	j∈ PROD_COMM	Elasticity of substitution among composite intermediate inputs & value-added in the production of commodity j
σ_T ETRAE(i)	i∈ ENDWS_COMM	Elasticity of transformation for sluggish primary factor of endowments.
SLUG		Sluggish-mobile switch parameter
RORFLEX(r)	r∈ REG	Flexibility of expected net rate of return of capital stock in region r, with respect to investment
RORDELTA		Binary switch coefficient which determines the mechanism of allocating Investment funds across all regions.
β SUBPAR(i,r)	i∈ TRAD_COMM r∈ REG	The substitution parameter in the CDE minimum expenditure function
γ INCPAR(i,r)	i∈ TRAD_COMM r∈ REG	The expansion parameter in the CDE minimum expenditure function

(Source: Hertal et al, 2016)

1. Source Substitution Elasticities

The GTAP Database comprises two sets of source substitution elasticities. One includes the substitution between domestic products & imports while the other includes substitution between imports from different regions. In the model, the source substitution elasticities are explained separately for all representative agents within each region rather than discussing to a single economy- wide demand behavior, unlike other models. For cross-regional behavior, the GTAP model assumes that for each commodity, all agents in all regions exhibit the same substitution of elasticities. The source substitution elasticities utilized in former versions of the GTAP Database were taken from the SALTER model (Jomini *et al.* 1991).

2. Factor Substitution Elasticities

The whole elasticity of substitution between primary factors governs the potential of the economy to adjust its output mix in response to variations in relative prices, or changes in the endowments of these factors. These parameters also play an essential role in determining the sectoral supply response in the presence of sector-specific and sluggish factors of production. For example, with the fixed supply of agricultural land in the model, the capacity to expand output of farm area can be directly connected to the ease of substitution between land & labor and land & capital. The third column of above table provides the assumed values for σ_{VA} for each of the GTAP sectors.

3 Factor Transformation Elasticities

The third type of behavioral parameters in GTAP database defines the extent of movement of primary factors among the sectors. The model differentiates the perfectly mobile factors and sluggish factors through productive sectors within each region. In the default setting of GTAP database, skilled & unskilled labor are considered perfectly mobile while natural resources and land as sluggish factors of production.

4 Investment Flexibility Parameters

Investment flexibility parameters are referred to the extent of flexibility of regional investment. In the GTAP model, if the user selects to allow the allocation of global investment to regional economies to be responsive to region-specific rates of return on capital (parameter *RORDELTA* is 1), then the parameter *RORFLEX*(r) > 0 must be properly specified [equation (58) of table 2.15 in chapter 2 of Hertel and Tsigas

(1997)]. The smaller the value of *RORFLEX(r)*, (a positive flexibility parameter) the greater the responsiveness of international investment to a change in the rate of return in region *r.*

5. Consumer Demand Elasticities

GTAP uses the constant difference of elasticities (CDE) functional form in the description of private household demands. The CDE was introduced by Hanoch (1975).It can be classified as near to the nonhomothetic & CES and more flexible functional forms. It is based on the assumption of implicit additivity and allows for a richer representation of income effects on the demand system.

6 CDE Calibration Procedure

The calibration problem comprises choosing the values of the substitution parameter, $\beta(i,r)$ or SUBPAR(i,r), to replicate the desired compensated, own-price elasticities of demand, then choosing the expansion parameters, $\gamma(i,r)$ or INCPAR(i,r) to repeat the targeted income elasticities of demand. The calibration of the CDE parameters for GTAP 7 follows the procedure used in the GTAP 4 database which is discussed more fully in Liu, et al. (1998). The procedure is a modification of Surry's (1997) approach which uses *maximum entropy* to calibrate a non-homothetic CDE expenditure function with subsistence quantities for three goods. Surry's procedure was modified to accommodate a larger number of goods with widely varying budget shares (Hertal et al, 2016)

3.4.5 Research Simulations

This study has used a standard global CGE model known as GTAP Model to study the economy-wide impact of coal investment under CPEC. With this backdrop, we have applied shock "qo" variable in the model to increase the output of coal to 5000 Megawatt (MW).

3.4.6 Simulation Steps

1) First, we use the GTAPAgg [27] software in order to develop a dataset in the form of SAM for our simulations. This software helps in the aggregation of our all database.

2) Run the software RunGTAP[28] in the GEMPACK to upload the datasets aggregated and saved for simulations.

3) We can do this by clicking on FILE →version archive →Load archive→then select aggregations (in the zip file), we have done with GTAPAgg.

4) In order to check our simulations, we can test our simulations by clicking on the shock.

5) Now, the shock variable option Q_o=output shock for coal technology to 5,000MW, in order to analyze the change in macroeconomic indicators of Pakistan economy from 17MW to 5,000MW coal shock.

6) After running the experiments of simulations, save the results.

7) Results are now ready for analysis.

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[27] GTAPAgg is a software established by Mark Horridge at the policy center studies center, used for the aggregation of databases from the complete GTAP database.
[28] RunGTAP is a visual display to many GEMPACK programs. RunGTAP helps the users to run simulations in a window by applying GTAP model.

CHAPTER IV

RESULTS AND DISCUSSION

The methodology for the current study has been mentioned in the last chapter, which is subdivided into two components. This chapter will now include detail analysis of the results which are deduced by using the devised methodologies in the previous chapter.

The first objective of our study is to calculate the carbon emissions generated by the installation of coal power plants under the CPEC projects. There are seven coal energy projects in the CPEC mentioned in the list of energy priority projects of CPEC (Ministry of Planning & Development, Government of Pakistan).Therefore, these projects will generate the humongous amount of carbon emissions which are the main drivers of global warming. This global warming would ultimately lead to climate change, which is the global externality of 21st century.

Therefore, the current study aims to quantify the carbon emissions that would be generated from the CPEC coal power plants.

The second objective of our study is to analyze the impacts of CPEC coal projects on Pakistan economy. As the total investment of CPEC on energy projects includes U.S$34 billion, and the majority of the projects are coal projects (Ministry of Planning & Development, Government of Pakistan). This huge investment will have significant impacts on Pakistan economy, which resolve the current energy crisis of Pakistan. Therefore, the current study aims to study the macroeconomic impacts of these coal power plants on Pakistan economy.

4.1 Data for the 1st Component of Study

As these all coal projects come under the power generation sector, so secondary data for these coal projects have been obtained from different power sector organizations mainly Board of Investment (BOI), Ministry of Planning, Development & Reforms, PPIB and NEPRA.

4.1.1 Results
Table 4.1 gives the results of the calculations of the carbon emission equivalents of CPEC coal power plants.

Table 4.1 Carbon Emissions Equivalents Released from CPEC Coal Power Plants

Sr. No.	Power Plant	Power Capacity (MW)	Amount of Coal required (m tons)	Type of Coal	Percentage of Carbon Content%	Carbon emission factor (tons)	CO$_2$ equivalents released(tons)
1	Sahiwal 2X660 MW Coal-fired Power Plant, Punjab	1320	6	Sub-bituminous	71-77	2.71	17,284.380
2	Engro Thar 4X330 MW Coal-Fired, Thar, Sindh	1320	3.8	Lignite	60-70	2.38	9,613,772
3	Port Qasim Electric Company Coal Fired, 2X660, Sindh	1320	5.61	Sub-bituminous	71-77	2.71	16,160,895.3
4	Gwadar Coal Power Project	300	1.275	Sub-bituminous	71-77	2.71	3,672,930.75
5	HUBCO Coal power plant, Hub Baluchistan	1320	5.61	Sub-Bituminous	71-77	2.71	16,160,895.3
6	Rahimyar Khan Coal Power Project, Punjab	1320	5.61	Sub-bituminous	71-77	2.71	16,160,895.3
7	SSRL Thar Coal Block 1-6.5mpta Thar, Sindh	1320	5.61	Lignite	60-70	2.38	14,192,963.4
	Net Carbon Emissions						75,979,636.43

(Researcher's simulations)

The results show that total amount of carbon emissions that would emit from the installation of these coal power plants will be 75,979,636.43 tons, which is a quite large value. The estimated results of carbon emissions show direct relationship of percentage of carbon content present in the coal with released carbon emissions. As the percentage of carbon content increases in the fuel used for power generation, the number of carbon emissions released from these power plants are also increased. Results also showed that Sub-bituminous coal is imported for power generation of these power plants has a higher percentage of carbon content (71-77%).While the Thar power plants are using indigenous Lignite reserves of coal which have less percentage of carbon content (60-70%).

Therefore, lignite coal has less carbon emission factor i.e. 2.38 tons as compared to imported Sub-bituminous coal, which has higher carbon emission factor i.e. 2.71tons.Thus, Sub-bituminous coal power plants will emit higher carbon emissions than lignite coal power plants. As table 4.1 shows that same amount of coal is used in Rahimyar khan power plant and in SSRL Thar Block I power plant, but there is a huge difference in their carbon emissions equivalent values i.e. 16,160,895.3tons and 14,192,963.4tons respectively. This difference arises due to the difference in the type of coals used in both power plants.
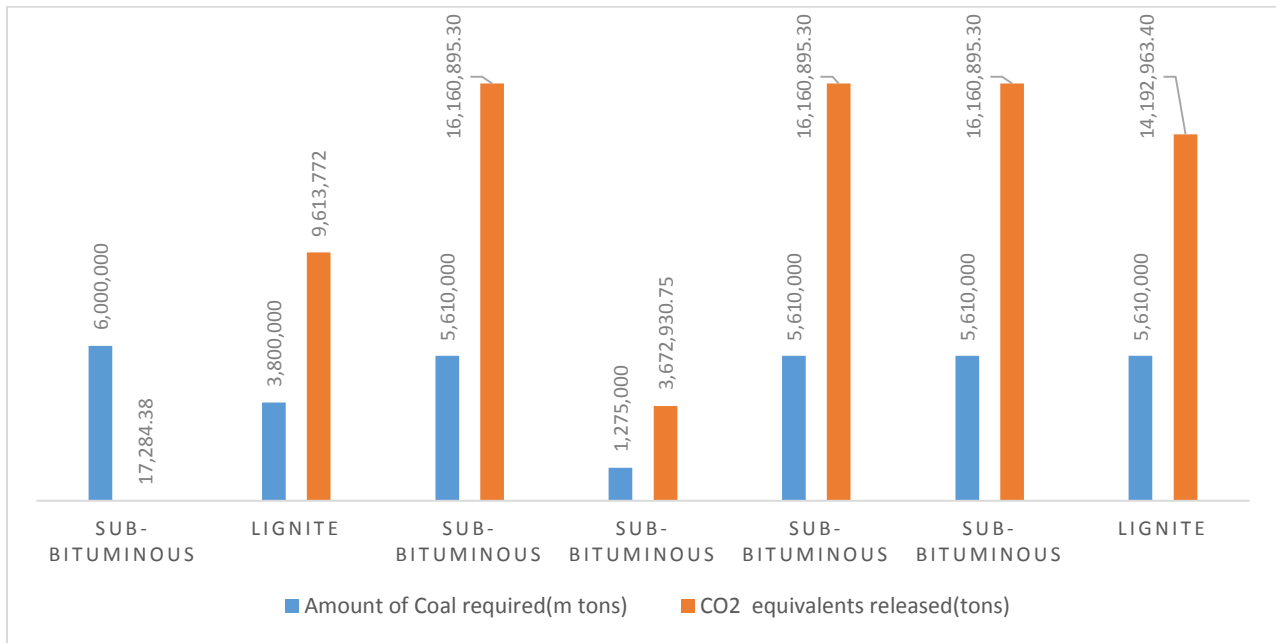
Fig 4.1: Relationship of Carbon Emissions with Type of Coal

Figure 4.1 shows how the value of carbon emissions changes by changing the type of coal for power generation in the power plants. We have already discussed that two types of coal are used in coal power plants for energy production i.e. lignite and Sub-bituminous coal. Sub-bituminous coal produces higher carbon emissions as compared to Lignite due to its greater carbon emission factor i.e. 2.71 tons. Thus in the figure with same amount of coal i.e. 5,610,000 million tons used for lignite and sub-bituminous coal produce a huge difference in the release of carbon emissions i.e. 14,192,693.40 tons & 16,160,895.30 tons respectively. Thus, it shows that sub-bituminous coal is more hazardous and produce higher carbon emissions than lignite coal reserves.

4.1.2 Monetary Cost of Carbon Emissions

Let's assume that all the coal power projects under CPEC will be completed till 2025. By assuming this scenario, monetary cost of the carbon emissions is estimated based on the carbon price trajectories drawn in (Luckow et al, 2013).

Our results show that 65% of the CPEC coal power plants will become operational in 2020, while the remaining 35% power plants will become operational till 2025 as mentioned in the CPEC energy project (cpec.gov.pk). Based upon this data and the carbon price standards described in the Luckow study:

As the business-as –usual continues, till 2020 the monetary cost of 65% power plants will be $15 per ton of carbon emissions. Similarly, the results also represent that the price of carbon emissions of the remaining 35% coal projects will rise to $18 during the period of 2020-25. This shows, the $14 per ton levelized price for the whole period till 2025.

4.2 Data for 2nd Objective of the Study

To achieve the second objective of the study, GTAP database 9 for the base year 2011 was used to study the impact of applying the shock of coal investment under CPEC on macroeconomic indicators of Pakistan economy. We applied global GTAP database known as CGE model to analyze these macroeconomic indicators i.e., real GDP, imports and exports of Pakistan economy.

4.2.1 Impact on Real GDP

The results of simulations of the second objective of the study are given below.

Table 4.2: Percent changes in GDP of Pakistan

Variables	Base Value Million USD, 2011	Sim-I	Net Effects(USD)Millions
Real GDP	213686.2	0.74714	1,581.27

(Source: Researcher's simulations)

The results after simulations show a positive change in real GDP of Pakistan due to an increase of 5,000MW coal output production. The current GDP of Pakistan is about 5.28%, will rise to further 0.74% due to Chinese investment in coal power plants under the mega project of CPEC. The net GDP effects due to coal investment shock give an enormous value i.e., US$1,581.27 million which

will have a significant impact on Pakistan economy. This increase in GDP will further increase our trade with other countries. Therefore, the Chinese investment in coal power plants has significant positive impacts on Pakistan economy. This investment will improve the growth and economy of Pakistan in a better way.

4.2.2 Impact on Trade

The following table gives us the net impacts on trade variables of coal investment shock of CPEC coal power on Pakistan Economy.

Table 4.3: Percent changes in trade variables of Pakistan

Variables	Base Value Million USD, 2011	Sim-I	Net Effects(USD)Millions
Real Exports	30933.12	0.12349	37.11
Real Imports	56862.29	0.15026	85.2

(Researcher's simulations)

The above table shows a remarkable increase in the imports and exports of Pakistan economy. Both indicators of trade are increasing due to coal investment shock of Pakistan. Results indicate that the rate of imports is greater than the rate of exports. The increase in imports is not so alarming due to many reasons: The major imports of Pakistan include raw materials of our exports i.e. machinery, oil, metals etc. The increase in imports of machinery will have a multiplier effect on the economy. The other main reason for fewer exports of Pakistan is to meet the rising domestic demand of commodities production in the economy. In order to fulfill this domestic demand, our imports are higher. This increase in imports of raw materials for industries will ultimately increase our exports in the long run.

Table 4.4: Percent Changes in Sectoral Exports

Variables	Base Value Million USD,2011	Sim-I	Monetary Value(U.S$)Million
Grains, Crops	3580.09	-0.21231	-7.51
Vegetables, Fruits	657.3	0.32574	2.1
Meat Livestock	182.87	-2.7887	-5.08
Extraction	346.65	3.1941	10.7
Processed Food	1391.39	-0.85012	11.8
Leather	631.66	2.31324	14.5
WAP	3678.59	2.61741	96.0
Textile	10759.88	2.3984	257.1
Light Manufacturing	1320.95	1.72242	22.7
Heavy Manufacturing	3326.3	3.68622	122.4
Utility Consumption	90.79	0.59678	0.53
Transport Communication	1605.86	-0.9171	-14.61
Financial Services	143.89	-1.79117	-2.57
Bus Services	659.71	-0.36918	-2.37
Other Services	2272.02	0.28076	6.3

Source: Researcher's simulations

Table 4.3 shows the results after simulations of GTAP model. Overall a positive increase in all sectoral exports of Pakistan has been observed due to the huge investment of US$ 13,280millions under CPEC on coal power plants in Pakistan. Pakistan is an energy- scarce country and this power crisis in the country is the main source of a hindrance in economic growth of Pakistan (Mufti et al., 2016). The huge deficit of power is mainly due to high dependence on imported fuels which is becoming the main obstacles in the socioeconomic development of Pakistan. The current energy deficit between demand and production of electricity in Pakistan is nearly about 5000-8000MW with a continual increase rise of 6-8% per annum(Raheem et al.,2016).Thus, with the increase of 5000MW coal output , energy deficit of Pakistan will be overcome to some extent.

Therefore this will enhance the performance and output production of different industrial sectors of Pakistan. Thus, efficiency and output production of industries will increase the exports of Pakistan. As we know that major exports of Pakistan are cotton, leather, and rice. Thus, table 2 shows a remarkable increase in export values in leather, WAP, textile and heavy manufacturing

industries due to CPEC investments in coal power plants in Pakistan. These all industries are highly dependent on electricity for output production.
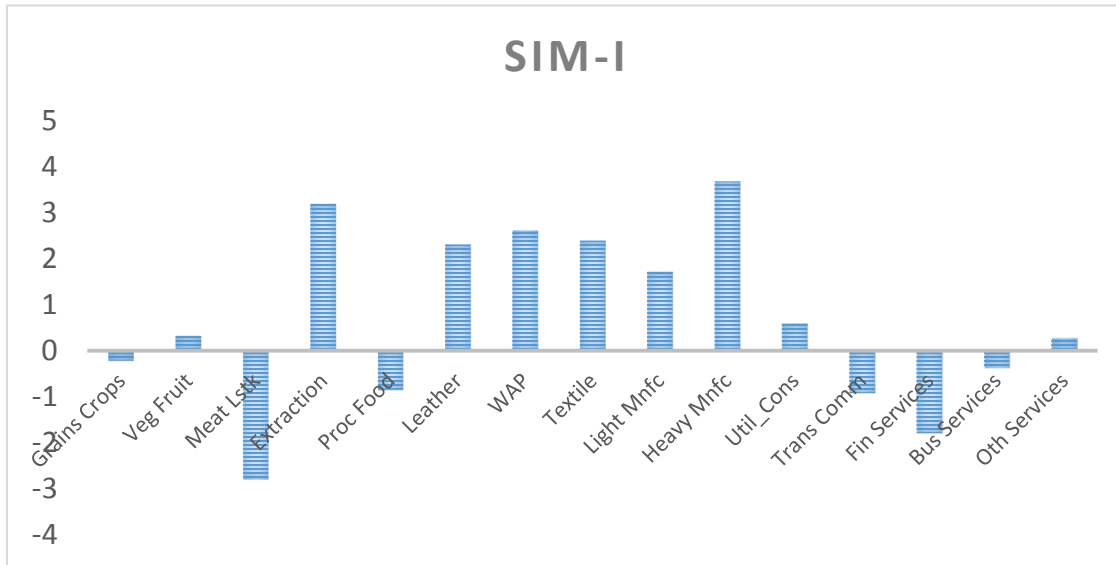
Figure4.2: Simulation Results of Sectoral Exports of Pakistan

Figure 4.2 shows the results of simulations of coal shock on different sectors of exports of Pakistan. As the graph shows a maximum increase in exports in heavy manufacturing, leather industry, textile industry, WAP, light manufacturing sectors due to increase in energy production of Pakistan. These sectors require huge amount of energy for their production. Thus, after overcoming energy deficit by coal investment shock, the exports of these industries will be increased to great extent. While grain crops, vegetable fruits, bus services do not require as much energy as compare to industrial sectors, so their exports remain slightly unaffected due to coal investment shock in Pakistan.

Table 4.5: Percent Changes in Sectoral Imports

Variables	Base Value Million USD,2011	Sim-I	Monetary Value(U.S$)Million
Grains, Crops	2306.1	0.4975	11.2
Vegetables, Fruits	767.23	0.39036	2.99
Meat Livestock	171.56	1.63051	2.79
Extraction	5362.84	0.40602	21.4
Processed Food	3357.91	1.06937	35.5
Leather	301.68	1.73265	5.21
WAP	163.31	0.94351	1.53
Textile	2774.49	0.72373	19.9
Light Manufacturing	4875.62	-0.06425	-2.92
Heavy Manufacturing	26139.44	-0.2967	75.8
Utility Consumption	112.26	-0.03064	0.03
Transport Communication	1975.94	1.08442	21.3
Financial Services	510.5	0.90413	4.5
Bus Services	3987.93	0.75565	29.9
Other Services	1049.93	0.70131	7.3

(Source: Researcher's simulations)

Table 4.4 shows a gradual increase in imports due to increase in GDP production. As GDP rises due to increasing industrial growth, the imports flow will also rise due to increasing demand for foreign raw materials i.e. new machinery and subsequent higher costs of many imports. As we see a remarkable increase in the imports of raw materials meat livestock, processed food, leather

products (jackets, shoes etc.) in Pakistan. Thus, results after simulations of coal shock investment show a positive impact on imports of Pakistan.
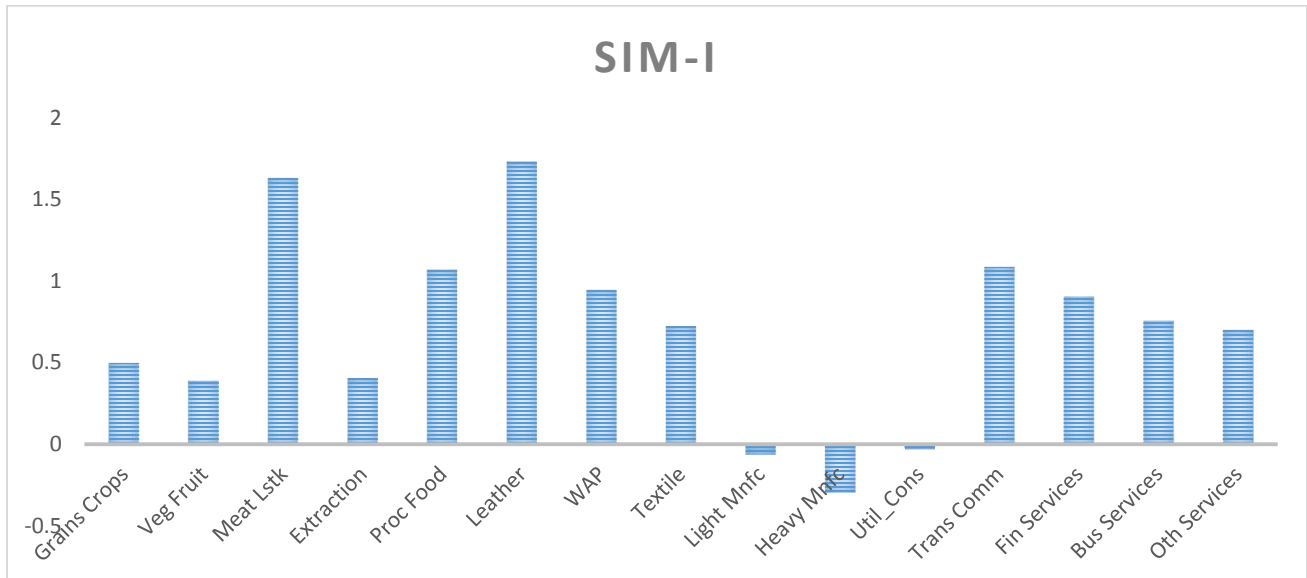
Figure 4.3: Simulation Results of Sectoral Imports of Pakistan

 Figure 4.3 also shows a great increase in the imports of Pakistan. As GDP rises due to overcoming of energy deficit by the investment on coal projects, the demand for raw materials for industrial production also rises which to increase in the imports of Pakistan. As the graph shows a greater increase in imports in the leather industry for the raw materials, processed food, transport sector of Pakistan. While heavy manufacturing and light manufacturing sectors show negative values of imports because of their increase in exports rates. Thus, the above graph shows an overall increase in sectoral imports of Pakistan due to overcoming of the energy crisis of Pakistan which will lead to increase in the economy of Pakistan.

4.2.3 Sensitivity Analysis
We have conducted a sensitivity analysis to test some of the important modeling assumptions to see its impact on overall results. The results of this study are based on full employment assumption. However, with a high unemployment rate in Pakistan, we test the assumption of unemployment of unskilled labor and review changes in the assumption regarding the trade balance.

Table 4.5 Macroeconomic Results for Sensitivity Analysis (Percent Change in US $ Million)

Variables	Base Value Million USD, 2011	Full employment Assumption	Unemployment of unskilled labor
Real GDP	213686.2	0.74714	0.75120
Real Exports	30933.12	0.12349	0.1269
Real Imports	56862.29	0.15026	0.15672

(Researcher's simulations)

As discussed in closure and reported above, the results are based on full employment assumption i.e., labor inputs cannot easily be increased in response to increased demand. We assume the unskilled labor to be unemployed in the model and then examine the extent to which this assumption impacts the results. The results as illustrated in Table … show that unemployment of unskilled labor has more positive impact on Pakistan's real GDP, total export and imports compared to full employment assumption. This confirms the fact that power sector involves more skilled labor compared to unskilled so with more demand for skilled labor will have an overall positive impact on Pakistan macroeconomic variable.

Level of Shocks

Sensitivity analysis is usually based on the size of shocks and can be undertaken in many ways. One can alter the shocks to reflect alternative views about the size of the shock or another method of systematic sensitivity analysis (SSA) can be employed. In systematic sensitivity analysis (SSA) number of simulations are carried out with a sampling distribution of the shocks employed in the model. The goal is to identify any critical points in which the shocks values may result in significantly different results. We find that doubling the shocks, more than doubles the gains to real GDP.

4.2.4 Welfare Gains Due To Increase in Output Production

The following table shows the welfare decomposition as a result of coal investment in Pakistan under CPEC

Table 4.5: Welfare Decomposition Due to Increase in Output Production

Allocative Efficiency Effect (Million USD)	Change in Terms of Trade(Million USD)	Technological Change (Million USD)	Total Welfare (Million USD)
243.0	567.14	3224.2	4190

(Source: Researcher's Simulation)

Table 4.4 shows a welfare decomposition due to increase in energy production, which will enhance the output of the industrial sector of the country. The total welfare gains resulted includes a huge amount of U.S$4190 million. It is decomposed further into allocative efficiency i.e., U.S$243.0 million, change in terms of trade i.e., U.S$567.14million and a huge amount of technological change i.e., U.S$3224.2 million respectively. Thus, a huge amount of welfare gain is observed in terms of trade and technological change sector due to increase in output production which would play a significant role in the economy of Pakistan.

CHAPTER V

CONCLUSION AND POLICY RECOMMENDATIONS

5.1 Conclusion

CPEC is a multibillion-dollar mega project starting from Kashgar province of China and passing through southwestern Gwadar port of Pakistan. It is a US$46 billion mega project by China with a major investment of US$34billiuon on energy projects and the remaining investment of US$12 billion dollars on transport infrastructure services of Pakistan (Irshad et al, 2015).As the majority of the energy projects include coal power plants which would result in environmental and socioeconomic impacts on Pakistan.

Therefore, the current study has been conducted to analyze the environmental and economic impacts of CPEC coal power plants. Total seven plants are included in the CPEC early harvest projects which would emit a huge number of carbon emissions and affect the climate of Pakistan. The study has calculated carbon emission equivalents of these coal power plants using formula proposed by Van Dijk et al. 2011.The results indicate a huge increase in the carbon emissions i.e. 75,979,636.43 tons from these power plants. The current carbon emissions of Pakistan has been recorded approx. 175,677,000million tonnes. When the emissions from CPEC coal power plants will be added to the current carbon emissions, they will accelerate to 2.312% which will magnify the magnitude of global warming potential in the atmosphere of Pakistan. The results also illustrate that sub-bituminous coal (imported) has a higher percentage of carbon content (71-77%) as compared to indigenous lignite coal reserves (60-70%) in Pakistan. This means that it is economically and environmentally judicious to use indigenous lignite coal reserves instead of importing bad quality Sub-bituminous coal from South Africa, Indonesia to run these coal-fired projects in Pakistan. The value of monetary cost which is calculated for the carbon emissions of CPEC projects until their completion is $14.Thus, the levelized cost of carbon emissions per ton is $14 for the whole period till 2025.So, the total cost of carbon emissions from these power plants will be $1,063,714,910 billion .This humongous value of carbon price will affect Pakistan economy.

To analyze the economy-wide impacts of CPEC coal power plants, a global GTAP database model known as CGE model was applied. The global GTAP model has used the latest available SAM of

the base year (2011).The results of descriptive analysis of our simulations of GTAP model reveal a general increase in the GDP of Pakistan. Thus, 0.74% increase in the current GDP of Pakistan i.e., 5.28% has been observed. This, increase in GDP will increase the industrial production, which will lead to an increase in the trade of the country. The results also indicates that the rate of imports has increased to a higher magnitude as compared to the export rate of Pakistan. The simulations result also show a tremendous increase in different sectoral exports i.e., the heavy manufacturing, textile exports and leather exports i.e., 3.68%, 2.39% & 2.31% respectively. With the increase in the revenue due to large exports rate of Pakistan, imports of Pakistan will also an increase of 0.15% in the Pakistan economy. Thus, the simulation results indicate a positive increase in all the four indicators i.e., real GDP, imports, exports and & welfare of Pakistan which will boost its economy. Therefore, in order to run these coal power plants environmentally and economically viable, the Chinese government should use indigenous lignite coal reserves and also include green efficient technologies in order to remove moisture content of coal and tackle the global threat of climate change and also set their power tariffs at an acceptable rate in order make them feasible for the Pakistan economy.

5.2 Policy Recommendations

- As the air quality will be highly affected by fugitive dust emissions from the construction activity for infrastructure development and coal power plants under CPEC. Therefore, infrastructure companies should use Electrostatic precipitators (EP) and bag filters in order to settle dust and & reduction of dust in the atmosphere.

- Desert ecosystems support a wide range of wild fauna i.e., Great Indian Bustard, Blackbuck, Chinkara, desert fox, short-toed eagle, Asian desert cat, some snake species. While, most of the CPEC coal power plants are constructing in desert areas. Ecological corridors must be established due to habitat fragmentation of these wildlife species due to the construction of coal power plants in order to restore these wildlife species of desert ecosystems.

- As the carbon price calculated for the carbon emissions show a humungous amount i.e. $1,063,714,910 to curb these carbon emissions. This will affect Pakistan economy adversely. Thus, Ministry of Finance should take serious consideration about this huge billion dollars carbon price before approving these coal projects.

- Pakistan is the 8th most vulnerable country of climate change, and CPEC the coal projects will emit a humongous number of carbon emissions i.e., 75,979,636.43 tons which increase to 2.312% to current emissions of Pakistan, which are the main drivers of extreme climate events. Thus, Ministry of Climate Change should negotiate with the Chinese government to include more renewable energy projects than coal-based energy projects in order to curb these prodigious carbon emissions for Pakistan.

- As coal energy projects will resolve our current energy crisis of Pakistan, which will enhance Pakistan economy .There is need to use indigenous coal reserves of Tharparkar district & Chamalung district of Baluchistan Pakistan rather than importing sub – bituminous coal from other countries. Pakistan has large amount of 185.175billion tons of coal reserves in Pakistan, which have high potential for power generation .IPPs should make serious consideration for introducing new advanced technologies   like WTA (Wirbelschicht-Trocknungmit interne Abwärmenutzung) and Briqetting for the removal of moisture content from coal and pulverization of coal for efficient power production.

- With the fixation of energy crisis of Pakistan with coal power plants, industrial production will be enhanced which would lead to increase our GDP to 0.74 from 5.2% and also increase the imports and exports of the country. The results a show a greater increase in imports ($85.2million)   than exports ($37.1 million) which will increase the exports of the country in longer run. Therefore, these coal projects must be included in the CPEC early harvest projects in order to foster the Pakistan economy.

- As CPEC investment on coal power plants will boost up mining industry of Pakistan. This will generate employment opportunities to the people Pakistan. Therefore, Chinese companies should also include to the local people near plant sites to improve the living standards of the affected people due to plant construction.

5.3 Limitations of the Study

The study has been conducted on limited scale because of following constraints

- Numerous studies have been conducted for the calculation of carbon emissions of different coal projects including Life Cycle Assessment (LCA) for a thorough comparison of

different technologies, however it was not possible in this study due to unavailability of data.

- Due to time constraint social impact analysis was not possible for the CPEC coal power plants.

5.4 Recommendation for Future Research

- Research on different aspects of CPEC is still in its initial phase this includes different projects of energy and infrastructure development. As most of the energy projects in CPEC include coal-based projects rather than renewables which are the main drivers of global climate change. And the infrastructure development routes from Gilgit to Gwadar have many adverse social and environmental impacts, which mainly include: air pollution, groundwater pollution, biodiversity loss due to habitat destruction. With the raising awareness of various environmental issues and different environmental organizations in Pakistan in environmental degradation, it is highly needed to quantify the environmental costs of different projects under CPEC and help to minimize these environmental damages. This would bring endorsement and simplification to the perception of environmental impacts of CPEC projects.

- Comparison can also be made among renewable and coal-based energy projects by using different parameters of analysis i.e., cost benefit ratio, net present value (NPV), payback time etc.

- After the completion of first early harvest projects of CPEC, data availability issue will be resolved by formation of CPEC data centers, many new research ideas can be evolved. After getting complete data sets of these CPEC projects, by application of different soft wares like (RETScreen), annual GHG reduction costs and life cycle cost analysis of these projects can calculated.

- As the current study has used macroeconomic indicators to assess economy wide impacts of CPEC coal power plants, after completion of the projects, other different microeconomic indicators of the economy can also be analyzed by using global GTAP database.

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GTAP MODEL EQUATIONS

Linearized version (model code)	Levels version

Linearized version (model code)

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!-------------------------------------------------------------------------------!
! See GTAP model documentation by Hertel and Tsigas for derivations and         !
! discussion of these equations.  Specific references to tables and equations   !
! refer to that document.                                                       !
!-------------------------------------------------------------------------------!
! The EQUATIONS in this model are organized in the same manner as the tables    !
! in the documentation by Hertel and Tsigas.  Therefore we begin with the       !
! accounting relationships, and the price linkage equations.  Due to Walras'    !
! Law we exclude the equilibrium condition that the supply of global capital    !
! goods equal the global demand for savings.  This offers a consistency check   !
! on the model under the usual, general equilibrium closure.  Next come the     !
! equations describing producer behavior.  Note that each sector combines       !
! imports with domestic goods and therefore faces a unique composite            !
! commodity price.  The next set of behavioral equations refer to the           !
! regional households.  In the normal closure, income in each region is         !
! distributed between private and government consumption and savings in         !
! constant proportions, as would be dictated by a Cobb Douglas aggregate        !
! utility function.  Tables 7 and 8 describe behavior of the sluggish primary   !
! factors of production and regional investment, respectively.  Finally we      !
! have the tables with equations for the global transport sector (table 8) and! 
! for the regional terms of trade.  In order to determine the change in a       !
! region's terms of trade, one simply deducts the change in the price index     !
! for goods purchased, at world prices, from the change in the price indexes    !
! for goods sold.  This includes all savings/investment transactions which are! 
! mediated on a global basis.                                                   !
!-------------------------------------------------------------------------------!


!-------------------------------------------------------------------------------!
! The accounting relationships in the model follow.  These correspond to        !
! the equations from Table 1 of the documentation.                             !
!-------------------------------------------------------------------------------!


!-------------------------------------------------------------------------------!
! Market clearing conditions follow                                            !
!-------------------------------------------------------------------------------!


!-------------------------------------------------------------------------------!
! The following equation enforces market clearing for all but one of the        !
! tradeable commodities, while checking for equilibrium in the final market     !
! (savings=investment).  Note that walraslack must be endogenous in the usual   !
! general equilibrium closure.  However, in any of the partial equilibrium      !
! closures it will be exogenous.                                               !
!-------------------------------------------------------------------------------!
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Levels version

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Note:
The indexes used in this section are:
r - region
s - region (destination)
n - non-savings commodities
d - demanded commodities
p - produced commodities
t - traded commodities
e - endowment commodities
em - mobile endowment commodities
es - sluggish endowment commodities
ec - capital endowment commoditiy
c - capital goods
```

1. EQUATION MKTCLTRD
! This equation assures market clearing in the traded goods markets. (HT#1)!
(all,i,TRAD_COMM)(all,r,REG)
VOM(i,r) * qo(i,r) = VDM(i,r) * qds(i,r)
                + VST(i,r) * qst(i,r)
                + sum(s,REG, VXMD(i,r,s) * qxs(i,r,s))
                + VOM(i,r) * tradslack(i,r) ;
	$$QO_{t,r} = QDM_{t,r} + QST_{t,r} + \sum_s QXMD_{t,r,s}$$

2. EQUATION MKTCLIMP
! this equation assures market clearing for the tradeable commodities entering
  each region (HT#2)!
(all,i,TRAD_COMM)(all,r,REG)
qim(i,r) = sum(j,PROD_COMM, SHRIFM(i,j,r) * qfm(i,j,r))
               + SHRIPM(i,r) * qpm(i,r) + SHRIGM(i,r) * qgm(i,r) ;
	$$QIM_{t,r} = \sum_r QIMS_{t,r,s} = \sum_p QIFM_{t,p,r} + QIPM_{t,r} + QIGM_{t,r}$$

3. EQUATION MKTCLDOM ! this equation assures market clearing for domestic output (HT#3)! (all,i,TRAD_COMM)(all,r,REG) qds(i,r) = sum(j,PROD_COMM, SHRDFM(i,j,r) * qfd(i,j,r)) + SHRDPM(i,r) * qpd(i,r) + SHRDGM(i,r) * qgd(i,r) ;	$$QDM_{t,r} = \sum_p QDFM_{t,p,r} + QDPM_{t,r} + QDGM_{t,r}$$

4. EQUATION MKTCLENDWM
! In each of the regions, this equation assures market clearing in the markets
  for endowment goods which are perfectly mobile among uses. (HT#4) !
(all,i,ENDWM_COMM)(all,r,REG)
VOM(i,r) * qo(i,r) = sum(j,PROD_COMM, VFM(i,j,r) * qfe(i,j,r))
               + VOM(i,r) * endwslack(i,r) ;
	$$QO_{e,r} = \sum_p QFM_{e,p,r}$$

5. EQUATION MKTCLENDWS ! In each of the regions, this equation assures market clearing in the markets for endowment goods which are imperfectly mobile among uses. (HT#5) ! (all,i,ENDWS_COMM)(all,j,PROD_COMM)(all,r,REG) qoes(i,j,r) = qfe(i,j,r);	Covered by equation above
!--! ! For Equation 6 (zero profits condition) see the Behavioral Equations for ! ! Producers below. ! !--! !--! ! Equation 7 generates a price index for transportation services based on ! ! zero profits. Refer to the Global Shipping Industry Equations below. ! !--!	

8. EQUATION PRIVATEXP
! This equation computes private household expenditure as household income
  less savings less government expenditures. (HT#8)!
(all,r,REG)
PRIVEXP(r) * yp(r) = INCOME(r) * y(r)
            - SAVE(r) * [psave + qsave(r)]
            - sum(i,TRAD_COMM, VGA(i,r) * [pg(i,r) + qg(i,r)]) ;
	$$PRIVEXP_r = INCOME_r - SAVE_r - \sum_t VGA_{t,r}$$
	Constant budget shares in standard closure

9. EQUATION REGIONALINCOME

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9. EQUATION REGIONALINCOME
! This equation computes regional income as the sum of primary factor payments
  and tax receipts. (HT#9)  The first term computes the change in endowment
  income, net of depreciation.  The subsequent terms compute the change in
  tax receipts for various transactions taxes.  Note that in each of these
  terms the quantity change is common.  This defines the common transaction
  which is being taxed.  It is the prices which potentiall diverge.          !
(all,r,REG)
INCOME(r) * y(r) = sum(i,ENDW_COMM, VOA(i,r) * [ps(i,r) + qo(i,r)])
                                  - VDEP(r)   * [pcgds(r) + kb(r)]
 + sum(i,NSAV_COMM, {VOM(i,r) * [pm(i,r) + qo(i,r)]}
                  - {VOA(i,r) * [ps(i,r) + qo(i,r)]})
 + sum(i,ENDWM_COMM,sum(j,PROD_COMM,{VFA(i,j,r) * [pfe(i,j,r) + qfe(i,j,r)]}
                                  - {VFM(i,j,r) * [pm(i,r)   + qfe(i,j,r)]}))
 + sum(i,ENDWS_COMM,sum(j,PROD_COMM,{VFA(i,j,r) * [pfe(i,j,r) +  qfe(i,j,r)]}
                                  - {VFM(i,j,r) * [pmes(i,j,r) + qfe(i,j,r)]}))
 + sum(j,PROD_COMM, sum(i,TRAD_COMM,{VIFA(i,j,r) * [pfm(i,j,r) + qfm(i,j,r)]}
                                  - {VIFM(i,j,r) * [pim(i,r)   + qfm(i,j,r)]}))
 + sum(j,PROD_COMM, sum(i,TRAD_COMM,{VDFA(i,j,r) * [pfd(i,j,r) + qfd(i,j,r)]}
                                  - {VDFM(i,j,r) * [pm(i,r)     + qfd(i,j,r)]}))
 + sum(i,TRAD_COMM, {VIPA(i,r) * [ppm(i,r) + qpm(i,r)]}
                  - {VIPM(i,r) * [pim(i,r) + qpm(i,r)]})
 + sum(i,TRAD_COMM, {VDPA(i,r) * [ppd(i,r) + qpd(i,r)]}
                  - {VDPM(i,r) * [pm(i,r)   + qpd(i,r)]})
 + sum(i,TRAD_COMM, {VIGA(i,r) * [pgm(i,r) + qgm(i,r)]}
                  - {VIGM(i,r) * [pim(i,r) + qgm(i,r)]})
 + sum(i,TRAD_COMM, {VDGA(i,r) * [pgd(i,r) + qgd(i,r)]}
                  - {VDGM(i,r) * [pm(i,r) + qgd(i,r)]})
 + sum(i,TRAD_COMM, sum(s,REG,{VXWD(i,r,s) * [pfob(i,r,s) + qxs(i,r,s)]}
                            - {VXMD(i,r,s) * [pm(i,r)      + qxs(i,r,s)]}))
 + sum(i,TRAD_COMM, sum(s,REG,{VIMS(i,s,r) * [pms(i,s,r)   + qxs(i,s,r)]}
                            - {VIWS(i,s,r) * [pcif(i,s,r) + qxs(i,s,r)]}))
 + INCOME(r) * incomeslack(r);
```

$$INCOME_r = \sum_e PS \cdot QO_{e,r} - (1 - DEP_r) \cdot KB_r$$

$$+ \sum_a (1 - TO_{n,r}) \cdot PM_{n,r} \cdot QO_{n,r}$$

$$+ \sum_{em} \sum_p (TF_{em,p,r} - 1) \cdot PM_{em,p,r} \cdot QFE_{em,p,r}$$

$$+ \sum_{es} \sum_p (TF_{es,p,r} - 1) \cdot PMES_{es,p,r} \cdot QFE_{es,p,r}$$

$$+ \sum_t \sum_p (TFM_{t,p,r} - 1) \cdot PIM_{t,p,r} \cdot QFM_{t,p,r}$$

$$+ \sum_t \sum_p (TFD_{t,p,r} - 1) \cdot PM_{t,p,r} \cdot QFD_{t,p,r}$$

$$+ \sum_t (TPM_{t,r} - 1) \cdot PIM_{t,r} \cdot QPM_{t,r}$$

$$+ \sum_t (TPD_{t,r} - 1) \cdot PM_{t,r} \cdot QPD_{t,r}$$

$$+ \sum_t (TGM_{t,r} - 1) \cdot PIM_{t,r} \cdot QGM_{t,r}$$

$$+ \sum_t (TGD_{t,r} - 1) \cdot PM_{t,r} \cdot QGD_{t,r}$$

$$+ \sum_t \sum_s (2 - TX_{t,r} + TXS_{t,r,s}) \cdot PFOB_{t,r,s} \cdot QXS_{t,r,s}$$

$$+ \sum_t \sum_r (TM_{t,r} + TMS_{t,r,s} - 2) \cdot PCIF_{t,r,s} \cdot QXS_{t,r,s}$$

10. EQUATION KEND

```
10. EQUATION KEND
! Ending capital stock equals beginning stock plus net investment. (HT#10)!
(all, r, REG)
     ke(r) = INVKERATIO(r) * qcgds(r) +
          [1.0 - INVKERATIO(r)] * kb(r) ;
```

$$KE_r = (1 - DEP_r) \cdot KB_r + REGINV_r$$

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!-----------------------------------------------------------------------!
! Equation 11 computes changes in global investment.  Refer to Equation 11'  !
! in the Investment Equations section below.                            !
!-----------------------------------------------------------------------!
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$$\sum_r REGINV_r - (DEP_r \cdot KB_r) = \sum_r SAVE_r$$

This equation is not in the model, due to Walras'
Law, but the next equations check that it holds.

12. EQUATION WALRAS_S

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12. EQUATION WALRAS_S
! This is an extra equation which simply computes change in supply in the
  omitted market.  (HT#12)!
walras_sup = globalcgds;
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Original
$$WALRAS\_SUP = GLOBALCGDS$$

13. EQUATION WALRAS_D ! This is an extra equation which simply computes change in demand in the omitted market. (HT#13)! GLOBINV * walras_dem = sum(r,REG, SAVE(r) * qsave(r)) ;	$$WALRAS\_SUP = \sum_r SAVE_r$$
14. EQUATION WALRAS ! This equation checks Walras Law. The value of the endogenous slack variable should be zero. (HT#14)! walras_sup = walras_dem + walraslack ;	$$WALRASSLACK = WALRAS\_SUP - WALRAS\_DEM$$
!---! ! The following equations serve to link prices in different markets taking ! ! into account taxes/subsidies. There are 6 types of taxes in this model: ! ! import taxes, source-generic variable levies on inter-regional imports, ! ! output taxes, export taxes, destination-generic variable export subsidies on! ! inter-regional exports, income taxes, primary factor taxes on firms, and ! ! commodity taxes levied both on households and firms. These correspond to ! ! the Price Linkage Equations in Table 2 of the documentation. ! !---!	

15. EQUATION SUPPLYPRICES
! This equation links pre- and post-tax supply prices for all industries.
  This captures the effect of output taxes. TO(i,r) < 1 in the case of a
  tax. (HT#15)!
(all,i,NSAV_COMM)(all,r,REG)
ps(i,r) = to(i,r) + pm(i,r) ;
	$$PS_{n,r} = PM_{n,r} \cdot TO_{n,r}$$
	
	where *TO* is 1 - the tax rate
	TO < 1 in case of a tax

16. EQUATION MPFACTPRICE
! This equation links domestic and firm demand prices. It holds for Mobile
  endowment goods and captures the effect of taxation of firms' usage of
  primary factors. (HT#16)!
(all,i,ENDWM_COMM)(all,j,PROD_COMM)(all,r,REG)
pfe(i,j,r) = tf(i,j,r) + pm(i,r) ;
	$$PFE_{es,p,r} = PM_{es,p,r} \cdot TF_{es,p,r}$$
	
	where *TF* is 1 + the tax rate
	TF > 1 in case of a tax

17. EQUATION SPFACTPRICE
! This equation links domestic and firm demand prices. It holds for Sluggish
  endowment goods and captures the effect of taxation of firms' usage of
  primary factors. (HT#17)!
(all,i,ENDWS_COMM)(all,j,PROD_COMM)(all,r,REG)
pfe(i,j,r) = tf(i,j,r) + pmes(i,j,r) ;
	$$PFE_{es,p,r} = PMES_{es,p,r} \cdot TF_{es,p,r}$$
	
	where *TF* is 1 + the tax rate
	TFE > 1 in case of a tax

18. EQUATION PHHDPRICE
! This equation links domestic market and private household prices.It holds
  only for domestic goods and it captures the effect of commodity taxation of
  private households. (HT#18) !
(all,i,TRAD_COMM)(all,r,REG)
ppd(i,r) = tpd(i,r) + pm(i,r) ;
	$$PPD_{t,r} = PM_{t,r} \cdot TPD_{t,r}$$
	
	where *TPD* is 1 + the tax rate
	TPD > 1 in case of a tax

19. EQUATION GHHDPRICE
! This equation links domestic market and government household prices.
  It holds only for domestic goods and it captures the effect of commodity
  taxation of government households. (HT#19) !
(all,i,TRAD_COMM)(all,r,REG)
pgd(i,r) = tgd(i,r) + pm(i,r) ;
	$PGD_{t,r} = PM_{t,r} \cdot TGD_{t,r}$
	
	where *TGD* is 1 + the tax rate
	TGD > 1 in case of a tax

20. EQUATION DMNDDPRICE
! This equation links domestic market and firm prices.
  It holds only for domestic goods and it captures the effect of commodity
  taxation of firms. (HT#20)!
(all,i,TRAD_COMM)(all,j,PROD_COMM)(all,r,REG)
pfd(i,j,r) = tfd(i,j,r) + pm(i,r) ;
	$PFD_{t,p,r} = PM_{t,p,r} \cdot TFD_{t,p,r}$
	
	where *TFD* is 1 + the tax rate
	TFD > 1 in case of a tax

21. EQUATION PHHIPRICES
! This equation links domestic market and private household prices. It holds
  only for imports and it captures the effect of commodity taxation of private
  households. (HT#21)!
(all,i,TRAD_COMM)(all,r,REG)
ppm(i,r) = tpm(i,r) + pim(i,r) ;
	$PPM_{t,r} = PIM_{t,r} \cdot TPM_{t,r}$
	
	where *TPM* is 1 + the tax rate
	TPM > 1 in case of a tax

22. EQUATION GHHIPRICES
! This equation links domestic market and government household prices. It holds
  only for imports and it captures the effect of commodity taxation of
  government households. (HT#22)!
(all,i,TRAD_COMM)(all,r,REG)
pgm(i,r) = tgm(i,r) + pim(i,r) ;
	$PGM_{t,r} = PIM_{t,r} \cdot TGM_{t,r}$
	
	where *TGD* is 1 + the tax rate
	TGM > 1 in case of a tax

23. EQUATION DMNDIPRICES
! This equation links domestic market and firm prices. It holds only for
  imported goods and it captures the effect of commodity taxation of
  firms. (HT#23)!
(all,i,TRAD_COMM)(all,j,PROD_COMM)(all,r,REG)
pfm(i,j,r) = tfm(i,j,r) + pim(i,r) ;
	$PFM_{t,p,r} = PIM_{t,p,r} \cdot TFM_{t,p,r}$
	
	where *TFM* is 1 + the tax rate
	TFM > 1 in case of a tax

24. EQUATION MKTPRICES ! This equation links domestic and world prices. It includes a source-generic import levy. (HT#24)! (all,i,TRAD_COMM)(all,r,REG)(all,s,REG) pms(i,r,s) = tm(i,s) + tms(i,r,s) + pcif(i,r,s) ;	$PMS_{t,r,s} = PCIF_{t,r,s} \cdot TM_{t,r} \cdot TMS_{t,r,s}$ where *TMS* and *TM* is 1 + the tax rate *TMS* > 1 in case of a import tariff
!---! ! In order to implement a variable levy, it is necessary to define ! ! a domestic price target. This is the ratio of domestic to average ! ! imported goods' price. Note that the way this price ratio is defined, it ! ! includes intraregional imports as well. In most applications, regions will! ! represent groups of individual countries. In the case of the E_U, we have ! ! eliminated intraregional trade, so that this aspect is not relevant there. ! !---!	

25. EQUATION PRICETGT ! This equation defines the target price ratio to be attained via the variable levy. (HT#25)! (all,i,TRAD_COMM)(all,s,REG) pr(i,s) = pm(i,s) - pim(i,s) ;	$$PR_{t,r} = \frac{PM_{t,r}}{PIM_{t,r}}$$ To insulate domestic producers from import competition (variable levy): *tm* endogenous and *pr* exogenous

!--!
! For Equation 26 refer to the equations on the Global Shipping Industry !
! given above. !
!--!
! The next equations pertain to export price linkage. Here, the option
  is available for applying a destination-generic export subsidy (tx) to
  maintain producer price levels. !	

27. EQUATION EXPRICES
! This equation links agent's and world prices. In addition to tx we have ts
  which embodies both production taxes (all s) and export taxes (r not equal
  to s) (HT#27)!
(all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
pfob(i,r,s) = pm(i,r) - tx(i,r) - txs(i,r,s) ;
	$$PFOB_{t,r,s} = \frac{PM_{t,r}}{TX_{t,r} \cdot TXS_{t,r,s}}$$
	where *TXS* and *TX* is 1 - the tax rate
	TXS < 1 in case of a tax
	To insulate domestic producers from export competition: *tx* endogenous and *go* exogenous

!--! ! Composite Imports Nest: Table 3 of Hertel and Tsigas ! !--!	
28. EQUATION DPRICEIMP ! Price for aggregate imports. (HT#28)! (all,i,TRAD_COMM)(all,s,REG) pim(i,s) = sum(k,REG, MSHRS(i,k,s) * pms(i,k,s));	$$PIM_{t,s} = \left(\sum_s MSHRS_{t,r,s} \cdot \left(PMS_{t,r,s} \right)^{1-ESUBM_t} \right)^{\frac{1}{1-ESUBM_t}}$$ where $$MSHRS_{t,r,s} = \frac{VIMS_{t,r,s}}{\sum_r VIMS_{t,r,s}}$$ if all import prices (*PMS*) are set equal to 1 in the base equilibrium.

29. EQUATION IMPORTDEMAND
! Regional demand for disaggregated imported commodities by source. (HT#29) !
(all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
    qxs(i,r,s) = D_VXWD(i,r,s) *
               [qim(i,s) - ESUBM(i) * [pms(i,r,s) - pim(i,s)]];
	$$QXS_{t,r,s} = QIM_{t,s} \cdot MSHRS_{t,r,s} \cdot \left(\frac{PMS_{t,r,s}}{PIM_{t,s}} \right)^{-ESUBM_t}$$

!--! ! We now turn to the behavioral equations for firms. The following picture ! ! describes factor demands. The first set of equations describe demands for ! ! primary factors. (See table 4 of the documentation.) ! !--! !--!	

! Composite Intermediates Nest ! !--!	
30. EQUATION ICOMPRICE ! Industry price for composite commodities. (HT#30) ! (all,i,TRAD_COMM)(all,j,PROD_COMM)(all,r,REG) pf(i,j,r) = FMSHR(i,j,r)*pfm(i,j,r) + [1 - FMSHR(i,j,r)]*pfd(i,j,r) ;	$$PF_{t,p,r} = \left(FMSHR_{t,p,r} \cdot \left(PFM_{t,p,r} \right)^{1-ESUBD_t} \right.$$ $$\left. + \left(1 - FMSHR_{t,p,r}\right) \cdot \left(PFD_{t,p,r} \right)^{1-ESUBD_t} \right)^{\frac{1}{1-ESUBD_t}}$$ where $$FMSHR_{t,p,r} = \frac{VIFA_{t,p,r}}{VFA_{t,p,r}}$$

31. EQUATION INDIMP
! Industry j demands for composite import i. (HT#31)!
(all,i,TRAD_COMM)(all,j,PROD_COMM)(all,s,REG)
      qfm(i,j,s) = qf(i,j,s)
          - ESUBD(i) * [pfm(i,j,s) - pf(i,j,s)];
	$$QFM_{t,p,r} = QF_{t,p,r} \cdot FMSHR_{t,p,r} \cdot \left(\frac{PFM_{t,p,r}}{PF_{t,p,r}} \right)^{-ESUBD_t}$$

32. EQUATION INDDOM
! Industry j demands for domestic good i. (HT#32)!
(all,i,TRAD_COMM)(all,j,PROD_COMM)(all,s,REG)
      qfd(i,j,s) = qf(i,j,s)
          - ESUBD(i) * [pfd(i,j,s) - pf(i,j,s)];
	$$QFD_{t,p,r} = QF_{t,p,r} \cdot (1-FMSHR_{t,p,r}) \cdot \left(\frac{PFD_{t,p,r}}{PF_{t,p,r}} \right)^{-ESUBD_t}$$

!--! ! Value-added Nest ! !--!	
33. EQUATION VAPRICE ! (Effective) price of primary factor composite in each sector/region.(HT#33)! (all,j,PROD_COMM)(all,r,REG) pva(j,r) = sum(k,ENDW_COMM, SVA(k,j,r) * [pfe(k,j,r) - afe(k,j,r)]);	$$PVA_{p,r} = \left(\sum_e SVA_{e,p,r} \cdot \left(\frac{PFE_{e,p,r}}{AFE_{e,p,r}} \right)^{1-ESUBVA_p} \right)^{\frac{1}{1-ESUBVA_p}}$$ where $$SVA_{e,p,r} = \frac{VFA_{e,p,r}}{\sum_e VFA_{e,p,r}}$$

34. EQUATION ENDWDEMAND
! Demands for endowment commodities (HT#34) !
(all,i,ENDW_COMM)(all,J,PROD_COMM)(all,r,REG)
      qfe(i,j,r) = D_EVFA(i,j,r) * [-afe(i,j,r) + qva(j,r)
          - ESUBVA(j) * [pfe(i,j,r) - afe(i,j,r) - pva(j,r)]] ;
	$$QFE_{e,p,r} = \frac{QVA_{p,r}}{AFE_{e,p,r}} \cdot SVA_{e,p,r} \cdot \left(\frac{PFE_{e,p,r}}{PVA_{p,r} \cdot AFE_{e,p,r}} \right)^{-ESUBVA_p}$$ CES. The technical change gives both a level effect and a substitution effect.

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!------------------------------------------------------------------!
! Total Output Nest                                                !
!------------------------------------------------------------------!
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35. EQUATION VADEMAND
! Sector demands for primary factor composite. (HT#35)!
(all,j,PROD_COMM)(all,r,REG)
      qva(j,r) + ava(j,r) = qo(j,r) - ao(j,r);
```

$$QVA_{p,r} = \frac{1}{\alpha_{p,r}^{va}} \cdot \frac{QO_{p,r}}{AVA_{p,r} \cdot AO_{p,r}}$$

Leontief. The parameter α is derived as the share of value added in output from the base data:

$$\alpha_{p,r}^{va} = \frac{VOA_{p,r}^0}{\sum_e VFA_{e,p,r}^0}$$

```
36. EQUATION INTDEMAND
! Industry demands for intermediate inputs, including cgds. (HT#36) !
(all,i,TRAD_COMM)(all,j,PROD_COMM)(all,r,REG)
      qf(i,j,r) = D_VFA(i,j,r) * [ - af(i,j,r) + qo(j,r) - ao(j,r) ];
```

$$QF_{t,p,r} = \frac{1}{\alpha_{t,p,r}^{f}} \cdot \frac{QO_{p,r}}{AF_{p,r} \cdot AO_{p,r}}$$

Leontief. The parameters α is derived as the shares of intermediate inputs in output from the base data:

$$\alpha_{t,p,r}^{f} = \frac{VOA_{p,r}^0}{VFA_{t,P,r}^0}$$

Note, there is no substitution between intermediates and value added but also no substitution between individual intermediates.

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!------------------------------------------------------------------!
! Next comes the zero profits equations                            !
!------------------------------------------------------------------!
```

```
6. EQUATION   ZEROPROFITS
! Industry zero pure profits condition. This condition permits us to
  determine the endogenous output level for each of the non-endowment sectors.
  The level of activity in the endowment sectors is exogenously
  determined. (HT#6)!
(all,j,PROD_COMM)(all,r,REG)
VOA(j,r) * [ps(j,r) + ao(j,r)] =
        sum(i,ENDW_COMM, VFA(i,j,r) * [pfe(i,j,r) - afe(i,j,r) - ava(j,r)])
      + sum(i,TRAD_COMM, VFA(i,j,r) * [pf(i,j,r)  - af(i,j,r)])
      + VOA(j,r) * profitslack(j,r);
```

$$PS_{p,r} \cdot QO_{p,r} =$$
$$\sum_e PFE_{e,p,r} \cdot QFE_{e,p,r} + \sum_t PF_{t,p,r} \cdot QF_{t,p,r}$$

```
!------------------------------------------------------------------!
! The household behavior equations follow.  This corresponds to Table 5. !
!------------------------------------------------------------------!
```

`!------------------------------------------------------------------!`
`! Aggregate Utility                                                !`
`!------------------------------------------------------------------!`	

37. EQUATION UTILITY
! computation of per capita regional utility (HT#37). Note that private
  utility has already been defined on a percapita basis. !
(all,r,REG)
INCOME(r) * u(r) = PRIVEXP(r) * up(r)
        + GOVEXP(r) * [ug(r) - pop(r)]
        + SAVE(r)   * [qsave(r) - pop(r)] ;
	$$U_r = UP_r^{\frac{PRIVEXP_r}{INCOME_r}} \cdot \left(\frac{UG_r}{POP_r}\right)^{\frac{GOVEXP_r}{INCOME_r}} \cdot \left(\frac{QSAVE_r}{POP_r}\right)^{\frac{SAVE_r}{INCOME_r}}$$
	where the value shares used as exponents are updated (but constant if the derived demands for government expenditure and savings are specified as Cobb-Douglas).

`!------------------------------------------------------------------!`
`! Regional Savings                                                 !`
`!------------------------------------------------------------------!`	

38. EQUATION SAVINGS ! regional demand for savings -- generated from aggregate Cobb-Douglas utility function where the pop(r) terms again cancel (HT#38)! (all,r,REG) qsave(r) = y(r) - psave + saveslack(r) ;	$$QSAVE_r = \frac{SAVE_r^0}{INCOME_r^0} \cdot \frac{INCOME_r}{PSAVE}$$ Cobb-Douglas. The value share is constant at the base level.

`!------------------------------------------------------------------!`
`! Government Purchases                                              !`
`!------------------------------------------------------------------!`	

39. EQUATION GOVERTU
! Computation of utility from regional government consumption. In
  some closures this index of gov't activity may be fixed, in which case
  govslack is endogenized. In this case the mix of regional expenditures
  changes and the aggregate utility index no longer applies. (HT#39)!
(all,r,REG)
ug(r) = y(r) - pgov(r) + govslack(r) ;
	$$UG_r = \frac{GOVEXP_r^0}{INCOME_r^0} \cdot \frac{INCOME_r}{PGOV_r}$$
	Cobb-Douglas. The value share is constant at the base level.

`!------------------------------------------------------------------!`
`! Demand for Composite Goods                                       !`
`!------------------------------------------------------------------!`	

40. EQUATION GPRICEINDEX ! definition of price index for aggregate gov't purchases (HT#40)! (all,r,REG) pgov(r) = sum(i,TRAD_COMM, [VGA(i,r)/GOVEXP(r)] * pg(i,r)) ;	$$PGOV_r = \prod_t PG_{t,r}^{\frac{VGA_{t,r}}{GOVEXP_r}}$$

41. EQUATION GOVDMNDS
! Government household demands for composite commodities. Note that the pop(r)
  argument in per capita income and that in per capita consumption cancel due
  to homotheticity. (HT#41)!
(all,i,TRAD_COMM)(all,r,REG)
qg(i,r) = ug(r) - [pg(i,r) - pgov(r)] ;
	$$QG_{t,r} = \frac{VGA_{t,r}^0}{GOVEXP_r^0} \frac{PGOV_r \cdot UG_r}{PG_{t,r}}$$
	Cobb-Douglas. Elasticity of substitution equal to 1
	$PGOV_r \cdot UG_r$ equals total government expenditure.

`!-----------------------------------------------------------------!`
`! Composite Tradeables                                             !`
`!-----------------------------------------------------------------!`	

`42. EQUATION GCOMPRICE`
`! Government household price for composite commodities (HT#42)!`
`(all,i,TRAD_COMM)(all,s,REG)`
`pg(i,s) =  GMSHR(i,s) * pgm(i,s) + [1 - GMSHR(i,s)] * pgd(i,s) ;`
	$$PG_{t,r} = \left(GMSHR_{t,r} \cdot \left(PGM_{t,r}\right)^{1-ESUBD_t} \right.$$ $$\left. + \left(1 - GMSHR_{t,r}\right)\left(PGD_{t,r}\right)^{1-ESUBD_t} \right)^{\frac{1}{1-ESUBD_t}}$$ where $$GMSHR_{t,r} = \frac{VIGA_{t,r}}{VGA_{t,r}}$$

`43. EQUATION GHHLDAGRIMP`
`! Government household demand for aggregate imports. (HT#43)!`
`(all,i,TRAD_COMM)(all,s,REG)`
`qgm(i,s) = qg(i,s) + ESUBD(i) * [pg(i,s) - pgm(i,s)] ;`
	$$QGM_{t,r} = QG_{t,r} \cdot GMSHR_{t,r} \cdot \left(\frac{PGM_{t,r}}{PG_{t,r}}\right)^{-ESUBD_t}$$

`44. EQUATION GHHLDDOM`
`! Government household demand for domestic goods. (HT#44)!`
`(all,i,TRAD_COMM)(all,s,REG)`
`qgd(i,s) = qg(i,s) + ESUBD(i) * (pg(i,s) - pgd(i,s)) ;`
	$$QGD_{t,r} = QG_{t,r} \cdot \left(1 - GMSHR_{t,r}\right) \cdot \left(\frac{PGD_{t,r}}{PG_{t,r}}\right)^{-ESUBD_t}$$

`!-----------------------------------------------------------------!`
`! Private Household Demands                                        !`
`!-----------------------------------------------------------------!`
	Total private household expenditure is determined from a per-capita Constant Difference of Elasticities implicit expenditure function. This function does not appear in the linearized version (where we do not use the level of expenditure): $$\sum_t B_{t,r} UP_r^{EP_{t,t,r} EY_{i,r}} \left(\frac{PP_{t,r}}{PRIVEXP_r / POP_r} \right)^{EP_{t,t,r}} \equiv 1$$ where $EP_{t,t,r} > 1$ governs the substitution and $EY_{t,r} > 0$ determines non-homothecity.

`45. EQUATION PRIVATEU`
`! This equation determines private consumption utility for a representative`
`  household in region r, based on the per capita private expenditure`
`  function. (HT#45) !`
`(all,r,REG)`
`yp(r) = sum(i,TRAD_COMM, (CONSHR(i,r) * pp(i,r)))`
`      + sum(i,TRAD_COMM, (CONSHR(i,r) * INCPAR(i,r))) * up(r)`
`      + pop(r) ;`
	Derivation of total expenditure is subject to the budget constraint: $$PRIVEXP_r = \frac{PRIVEXP_r^0}{INCOME_r^0} \cdot INCOME_r$$ If the Cobb-Douglas total utility function is enforced (see equation 8 for the general specification).

`!-----------------------------------------------------------------!`
`! Composite Demands                                                !`
`!-----------------------------------------------------------------!`	

46. EQUATION PRIVDMNDS
! Private household demands for composite commodities. Demand system is on a
  per capita basis. Here, yp(r) - pop(r) is % change in per capita
  income. (HT#46)!
(all,i,TRAD_COMM)(all,r,REG)
qp(i,r) = sum(k,TRAD_COMM, EP(i,k,r) * pp(k,r))
        + EY(i,r) * [yp(r) - pop(r)]
        + pop(r) ;
	This leads to the derived demands
	
	$$QP_{t,r} = \frac{B_{t,r} \cdot EP_{t,t,r} \cdot UP_r^{EP_{t,t,r}EY_{T,r}} \left(\dfrac{PP_{t,r}}{PRIVEXP_r / POP_r} \right)^{EP_{t,t,r}-1}}{\sum\limits_t B_{t,r} \cdot EP_{t,t,r} \cdot UP_r^{EP_{t,t,r}EY_{T,r}} \left(\dfrac{PP_{t,r}}{PRIVEXP_r / POP_r} \right)^{EP_{t,t,r}}}$$

!---! ! Composite Tradeables ! !---!	
47. EQUATION PCOMPRICE ! Private household price for composite commodities (HT#47)! (all,i,TRAD_COMM)(all,s,REG) pp(i,s) = PMSHR(i,s) * ppm(i,s) + [1 - PMSHR(i,s)] * ppd(i,s) ;	$$PP_{t,r} = \left(PMSHR_{t,r} \cdot \left(PPM_{t,r} \right)^{1-ESUBD_t} \right.$$ $$\left. + \left(1 - PMSHR_{t,r} \right) \left(PPD_{t,r} \right)^{1-ESUBD_t} \right)^{\frac{1}{1-ESUBD_t}}$$ where $$PMSHR_{t,r} = \frac{VIPA_{t,r}}{VPA_{t,r}}$$
48. EQUATION PHHLDDOM ! Private household demand for domestic goods. (HT#48)! (all,i,TRAD_COMM)(all,s,REG) qpd(i,s) = qp(i,s) + ESUBD(i) * [pp(i,s) - ppd(i,s)] ;	$$QPD_{t,r} = QP_{t,r} \cdot \left(1 - PMSHR_{t,r} \right) \cdot \left(\frac{PPD_{t,r}}{PP_{t,r}} \right)^{-ESUBD_t}$$
49. EQUATION PHHLDAGRIMP ! Private household demand for aggregate imports. (HT#49)! (all,i,TRAD_COMM)(all,s,REG) qpm(i,s) = qp(i,s) + ESUBD(i) * [pp(i,s) - ppm(i,s)] ;	$$QPM_{t,r} = QP_{t,r} \cdot PMSHR_{t,r} \cdot \left(\frac{PPM_{t,r}}{PP_{t,r}} \right)^{-ESUBD_t}$$
!---! ! We continue with determination of supplies and composite price for sluggish ! ! primary factors corresponding to the equations in Table 7 of documentation. ! ! (Table 6 reports the formulae for calculating the CDE elasticities.) ! !---!	
50. EQUATION ENDW_PRICE ! This equation generates the composite price for sluggish endowments.(HT#50)! (all,i,ENDWS_COMM)(all,r,REG) pm(i,r) = sum(k,PROD_COMM, REVSHR(i,k,r) * pmes(i,k,r)) ;	$$PM_{es,r} = \left(REVSHR_{es,p,r} \cdot \left(PMES_{es,p,r} \right)^{1-ETRAE} \right)^{\frac{1}{1-ETRAE}}$$
51. EQUATION ENDW_SUPPLY ! This equation distributes the sluggish endowments across sectors. (HT#51)! (all,i,ENDWS_COMM)(all,j,PROD_COMM)(all,r,REG) qoes(i,j,r) = qo(i,r) + endwslack(i,r) + ETRAE(i) * [pm(i,r) - pmes(i,j,r)] ;	$$QOES_{es,p,r} = QO_{es,r} \cdot REVSHR_{es,p,r} \cdot \left(\frac{PMES_{es,p,r}}{PM_{es,r}} \right)^{-ETRAE}$$

!--! ! Capital stock and rate of return equations follow. They correspond ! ! to the Investment Equations of Table 8 in the documentation ! !--!	

52. EQUATION KAPSVCES
! This equation defines a variable for capital services, for convenience.
  (There is really only one capital services item.) (HT#52)!
(all,r,REG)
     ksvces(r) =
 sum(h,ENDWC_COMM, [VOA(h,r) / sum(k,ENDWC_COMM, VOA(k,r))] * qo(h,r)) ;
	$$KSVCES_r = \sum_{ec} QO_{ec,r}$$

53. EQUATION KAPRENTAL ! This equation defines a variable for capital rental rate. (HT#53)! (all,r,REG) rental(r) = sum(h,ENDWC_COMM, [VOA(h,r) / sum(k,ENDWC_COMM, VOA(k,r))] * ps(h,r)) ;	$$RENTAL_r = \prod_{ec} \left(PS_{ec,r} \right)^{\frac{VOA_{ec,r}}{\sum_{ec} VOA_{ec,r}}}$$

54. EQUATION CAPGOODS
! This equation defines a variable for gross investment, for convenience.
  There is really only one capital goods item.) (HT#54)!
(all,r,REG)
     qcgds(r) =
 sum(h,CGDS_COMM, [VOA(h,r) / REGINV(r)] * qo(h,r)) ;
	$$QCGDS_r = \sum_{c} QO_{c,r}$$

55. EQUATION PRCGOODS ! This equation defines the price of cgds for convenience. (HT#55)! (all,r,REG) pcgds(r) = sum(h,CGDS_COMM, [VOA(h,r) / REGINV(r)] * ps(h,r)) ;	$$PCGDS_r = \prod_{c} \left(PS_{c,r} \right)^{\frac{VOA_{c,r}}{REGINV_r}}$$

56. EQUATION KBEGINNING
! This equation associates any change in capital services during the
  period with a change in capital stock. Full capacity utilization is
  assumed. (HT#56)!
(all,r,REG)
     kb(r) = ksvces(r) ;
	$$KB_r = \frac{KB_r^0}{KSVCES_r^0} \cdot KSVCES_r$$

57. EQUATION RORCURRENT ! This generates the current rate of return on capital in region r.(HT#57)! (all, r, REG) rorc(r) = GRNETRATIO(r) * [rental(r) - pcgds(r)] ;	$$RORC_r = \frac{RENTAL_r}{PCGDS_r} - DEPR_r$$

58. EQUATION ROREXPECTED
! Expected rate of return depends on the current return and
  investment.(HT#58)!
(all, r, REG)
     rore(r) = rorc(r) - RORFLEX(r) * [ke(r) - kb(r)] ;
	$$RORE_r = RORC_r \cdot \left(\frac{KE_r}{KB_r} \right)^{-RORFLEX}$$

`!---------------------------------------------------------------!`
`! the following equations hold for the world as a whole         !`
`!---------------------------------------------------------------!`	

`59. EQUATION RORGLOBAL`
`! This equation computes alternatively the global supply of capital goods`
`  or the global rental rate on investment. (HT#59) !`
`(all,r,REG)`
`    RORDELTA*rore(r) +`
`[1 - RORDELTA] * {[REGINV(r)/NETINV(r)] * qcgds(r)`
`             - [VDEP(r)/NETINV(r)] * kb(r)}`
`  = RORDELTA * rorg + [1 - RORDELTA] * globalcgds + cgdslack(r) ;`
	RORDELTA = 0 (normal case):
	
	$$\frac{REGINV_r}{NETINV_r} \cdot qcgds_r - \frac{VDEP_r}{NETINV_r} \cdot kb = globalcgds$$
	
	RORDELTA = 1:
	
	$$RORE_r = RORG$$

`11'. EQUATION GLOBALINV`
`! This equation computes:`
`  either the change in global investment (when RORDELTA=1),`
`  or the change in the expected global rate of return on capital`
`  (when RORDELTA=0) (HT#11') !`
`RORDELTA * globalcgds + [1 - RORDELTA] * rorg =`
`RORDELTA * [ sum(r,REG, {REGINV(r)/GLOBINV} * qcgds(r)`
`              - {VDEP(r)/GLOBINV} * kb(r)) ]`
`+ [1 - RORDELTA] * [ sum(r,REG, {NETINV(r)/GLOBINV} * rore(r)) ];`
	RORDELTA = 0 (normal case):
	
	$$RORG = \prod_r \left(RORE_r\right)^{\frac{NETINV_r}{GLOBINV}}$$
	
	RORDELTA = 1:
	
	$$GLOBALCGDS = \sum_r (REGINV_r - VDEP_r) = \sum_r NETINV_r$$

`60. EQUATION PRICGDS`
`! This equation generates a price index for the aggregate`
`  global cgds composite. (HT#60) !`
`    psave = sum(r,REG, [ NETINV(r) / GLOBINV] * pcgds(r)) ;`
	$$PSAVE = \prod_r \left(PCGDS_r\right)^{\frac{NETINV_r}{GLOBINV_r}}$$

`!---------------------------------------------------------------!`
`! The following equations determine behavior in the global shipping industry.!`
`! This corresponds to Table 9 of the documentation.             !`
`!---------------------------------------------------------------!`
`!---------------------------------------------------------------!`
`! First we consider the "production function" for the composite transport    !`
`! services input.  This is Cobb Douglas in form, and is represented here      !`
`! by two equations.  In the first, the composite price index is computed.     !`
`! In the second, the derived demand for inputs from the various regions are   !`
`! generated.  Here the elasticity of substitution is zero.                    !`
`!---------------------------------------------------------------!`	

`7. EQUATION PTRANS`
`! This equation generates a price index for transportation services based on`
`  zero profits. (NOTE Sales to international transportation are not subject to`
`  export tax. This is why we base the costs to the transport sector on market`
`  prices of the goods sold to international transportation.) (HT#7)!`
`VT * pt = sum(i,TRAD_COMM, sum(r,REG, VST(i,r) * pm(i,r)));`
	$$QT \cdot PT = \sum_t \sum_r QST_{t,r} \cdot PM_{t,r}$$

61. EQUATION TRANSVCES
! This equation generates the demand for regional supply of global
  transportation services. It reflects a unitary elasticity of substitution
  between transportation services inputs from different regions. (HT#61)!
(all,i,TRAD_COMM)(all,r,REG)
     qst(i,r) = D_VST(i,r) * [qt + [pt - pm(i,r)]];
	$$QST_{t,r} = \frac{VST_{t,r}^0}{VT^0} \cdot \frac{VT}{PM_{t,r}}$$
	
	Cobb-Douglas

!---! ! Next we develop the equations describing the uses of the composite ! ! transport services QT. This composite input is used in fixed proportion ! ! to shipments along each route. It is here that we introduce the potential ! ! for input-augmenting technical change, atr(i,r,s), which is commodity and ! ! route specific. Thus, in the levels, ATR(i,r,s)*QTS(i,r,s) = QS(i,r,s), ! ! where QTS(i,r,s) is the amount of QT used along this route. Therefore, ! ! atr(i,r,s) > 0 reduces the composite input required along this route, and ! ! it also dampens the cost of shipping, thereby lowering the cif price ! ! implied by a given fob value. ! !---!	

62. EQUATION QTRANS
! This equation computes the global demand for international transportation
  services (i.e., variable qt). It reflects the fact that the demand for
  services along any particular route is proportional to the quantity of
  merchandise shipped [i.e., variable qxs(i,r,s)]. (HT#62)!
VT * qt = sum(i,TRAD_COMM, sum(r,REG,
     sum(s,REG, VTWR(i,r,s) * [qxs(i,r,s) - atr(i,r,s)]))) ;
	$$QT = \sum_t \sum_r \sum_s \frac{QXS_{t,r,s}}{ATR_{t,r,s}}$$

26'. EQUATION FOBCIF ! This equation links fob and cif prices for good i shipped from region r to s . (HT#26')! (all,i,TRAD_COMM)(all,r,REG)(all,s,REG) pcif(i,r,s) = FOBSHR(i,r,s) * pfob(i,r,s) + TRNSHR(i,r,s) * [pt - atr(i,r,s)];	$$PCIF_{t,r,s} = \left(PFOB_{t,r,s}\right)^{\frac{VXWD_{t,r,s}}{VIWS_{t,r,s}}} \left(\frac{PT}{ATR_{t,r,s}}\right)^{\frac{VIWS_{t,r,s}-VXWD_{t,r,s}}{VIWS_{t,r,s}}}$$