Assessing the Impact of Energy Poverty on CO_2 Emission in Pakistan

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Candidate of **Master of Philosophy** at the National University of Modern Languages do hereby declare that the thesis **Assessing the Impact of Energy Poverty on CO_2 Emission in Pakistan** submitted by me in partial fulfillment of MPhil degree, is my original work, and has not been submitted or published earlier. I also solemnly declare that it shall not, in future, be submitted by me for obtaining any other degree from this or any other university or institution.

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Abstract

Energy poverty as an issue was raised in the late 20th century at global level then policymakers, international organizations, and researchers focused on it. The accessibility as well as affordability to clean energy services are the key factors towards sustainable economic growth. If a society has no access to clean energy sources, then there may be supply constraints. On the other hand, if a society is unable to afford clean energy sources, then there may be constraints on the demand side. In a nutshell constraint on demand and supply sides create energy poverty. In the same vein, present study tries to estimate energy poverty by utilizing various demand and supply side indicators in a multidimensional index approach. Further, three dimensions and fourteen indicators to measure energy poverty are used. Energy poverty dimensions are namely, energy services, clean energy, and energy affordability and uses equal weight strategy for three dimensions. The value of energy poverty index shows that overall energy situation improves and experienced a reduction in energy poverty in the entire period. At the second stage, study finds the impact of energy poverty and economic output on the CO_2 emissions in the Pakistan economy over the period of 1990s to 2019. On the basis of unit root tests Johansen Cointegration technique is used to find the long run dynamic relationship. The results of Johansen Cointegration show a statistically significant long run relationship between energy poverty and CO_2 emissions and does not hold the same relationship in the short run. Moreover, present study also uses GDP and GDP square terms in the model along with energy poverty to confirm the Environmental Kuznets Curve (EKC). EKC is basically a long run phenomenon so, in the short run GDP and square term of GDP are not statically significant. The government must give attention to increase the share of renewable energy in total energy mix.

Keywords: CO_2, Energy Poverty, Multidimensional Index, Gross Domestic Product, EKC, Johansen Cointegration, ADF

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CHAPTER 01

1.1 Introduction

Poverty is a common problem that exist all over the World but it is a challenging issue for a developing and developed nations (IEA., (2019). There are various forms of poverty like energy, economic, political, food and lack of natural resources etc. These all types are interlinked with each other and convert into web of ill-beings for a society. Political poverty effects the energy poverty in a sense that when there is political instability, lack of governance, lack of political maturity and no proper planning in developing project in the country. When government fails to start new energy projects in energy sector with increasing demand of energy services leads the country to energy poverty. Energy poverty is a situation where a household has no access to basic energy services (like space-cooling, lighting and heating), cooking facilities, modern appliances and information technology at affordable prices for social and material needs (Bouzarovski., 2017). Energy poverty is a broader concept; it varies from region to region and society to society. In developed nations energy poverty is a situation when a household or firm is unable to attain the energy services due to high cost of energy. Energy poverty in developing nation is quite different from the developed nation. The energy poverty in developing nations is combination of lack of accessibility, affordability, and poor energy governance. Day et al., (2016), explain the concept of energy poverty is the inability to attain the energy services as the safe, reliable and affordable energy services. Traditionally energy poverty is defined as the lack of access to basic traditional biomasses (firewood for warming, cooling and cooking purposes, chips, dungs and cakes etc.). The definition of energy poverty is not so sample but a complex phenomenon. There is difference between energy poverty and fuel poverty. Bouzarovski & Petrova., (2015) gives the definition of energy poverty on the biases of capabilities approach.

Energy is a basic need for quality life and plays an important role in achieving socio-economic wellbeing. The socio-economic well-being of an individual and society is closely related to the energy services. The quality of life cannot be attained without proper energy services because energy has connected to all daily needs of a person, from education to health, transport, lighting and cooking purposes, (Bouzarovski & Petrova, 2015). Energy has a crucial role in the development of any country, those countries who are energy rich, their economic growth accelerates, and low levels of economic growth are noticed in the developing nations due to limited supply of energy services. It improves the education and health sector of the country. Energy helps societies to move from one development stage to another development stage. Without the accessibility of energy services moving from one stage to another stage is difficult. Energy poverty became a serious issue for policymakers, academia, and among the researchers after the work done by (Boardman., 1991) in the field of energy.

Energy poverty at individual level is the situation when a person spends less than 10 percent of his income on energy services or unable to get utilities from energy services, but at aggregate level energy poverty refers to the lack of energy availability, affordability and governance of energy services. A household is in the state of energy poverty, when he/she has no access to basic energy services and depends on the traditional biomass for lighting, heating and cooling purposes. A firm is in a state of energy poverty, when it is unable to perform its services due to availability, affordability and governance of energy services.

Poverty in developing nations is caused by the less availability of electricity, LPG, and other clean energy services. Most populations in developing nations are highly energy poor and this high rates of energy poverty lead to severe poverty because all of the physical and human capital works on energy and fosters economic growth. The availability of energy services leads to overcome the poverty. Energy speeds up economic growth, provides new job opportunities to people in every sector of the economy and it is necessary to put the economy of any nation on the right path and sustain human development. Agricultural sector is the backbone of developing nations and energy has a positive effect on agricultural productivity. Modern sources of energy enable the peasants to use advanced technologies at time of growth and cultivation and also provide the water through pumps. The countries who are less energy poor, have a well-equipped energy sector and provide energy services to their citizens at affordable cost have achieved stages of economic development and transit from agriculture to industrialized based sectors, becoming capital intensive. Energy is the backbone for all sectors like health, education, transportation, construction, and industrialization. In the present time it is very difficult to perform an activity without energy and energy is considered a dire need of daily life (Editor., 2012).

Worldwide, 759 million population have no electricity and 2.6 billion people have deprived of clean cooking facilities respectively, (IEA., 2019). Sub-continent Africa are highly energy poor in terms of lighting and cooking. Four countries from Asia (Pakistan, India, Bangladesh, and Indonesia) and six countries from Sub Saharan Africa account 63 percent of households have no access to electricity. The most vulnerable situation prevails in the Sub Saharan Africa and has the largest energy deficit where only 17% of people out of total population enjoy clean sources of energy for cooking. Households having low income, mostly depends on the use of solid biomass, kerosene oil, coal and firewood. (González-Eguino, 2015; IEA, IRENA, UNSD, WB, 2019).

The availability of energy services is relatively better in Pakistan as compared to African countries, here about 46.3% of population have access to energy services for heating and cooking purposes (IEA., 2018) which is still very low. But when we compare the present situation of Pakistan with some developed nations, its condition is not in an ideal stage because half of the population is still deprived of clean energy for cooking purposes. The availability of electricity is relatively better in the urban areas of the country but this situation is much worse in the rural areas. On the other side, energy consumption per capita in terms of oil in Kg of Pakistan is 460 kg and 51 million people have no access to electricity (IEA., 2016).

Although the situation of energy consumption per capita and availability of electricity are improving overtime, but still we belong to an energy poor state because of low accessibility to clean cooking facility and low electrification rate in rural areas of the country and high cost of energy services preventing the people to consume the required level of energy. Energy poverty is a multidimensional concept which may vary from state to state as per their geographic, economic and availability of energy sources.

There is a different definition given by the different researchers because it is a broad concept and cannot be easily defined. There is complexity in defining energy poverty due to the broadness of energy poverty. There are different concepts regarding the definition of energy poverty in developing and developed nations but the same understanding exists about the concept energy poverty. It is tough to reach consciences about unified definition. Energy poverty in developing nations is just the lack of basic energy services for lightening, heating, cooling and cooking purposes, (Sokołowski et al., 2020). The energy poverty in developed nations is different from the developing nation and it is consider as not meeting the threshold level of share of income that is not consumed on energy related goods and services (Buzar, 2007).

There is debate among the academia, applied researchers and social activist about the energy poverty situation in the world but the real issue is on the side of quantification of energy poverty in both developing and developed nations. Analytical work and policy implications are coupled with the definition and measurement of energy poverty. It is tough to reach on a conscience about the common definition of energy poverty. One may think different questions regarding the energy poverty definitions relying on the geographical and climate of the nations. The questions may be like: is the energy poverty like income poverty? Whether the energy poverty is based on the lack of access to energy services like clean cooking and lighting? Or simply the consumption of energy products that people used in daily life. Someone may be called energy poor if he or she at least have lack to: (a) If he or she has at least 35 kg liquid petroleum gas per capita per year or the improved supply of solid biomass and clean cooking stoves. (b) If the person lack to 120KWH electricity supply per year is energy poor (Awan et al., 2013).

Energy poverty is also defined as the situation, when households are unable to attain energy related utilities. This concept of energy utilities is related to the cost of energy and it is mainly applicable to developed nations, where there is no issue in terms of availability of energy services and it is not suit to apply it in developing nations, where people have lack of access to electricity and energy for cooking purposes, (Smyth., 2020). Low energy demand and poverty are closely related to each other and go hand to hand. Low energy demand leads to poverty or vice versa (Pachauri & Spreng., 2003).

Energy poverty is the concern for the United Nations (UN), Greenpeace, many international organizations, and environmental related non-governmental organizations (NGOs). The economic growth and availability of energy are interlinked with each other (Editor., 2012). The country like Pakistan who is energy poor and millions of residents confronted with limited supply of energy due to inadequate planning and investment in the energy sector. This limited supply of energy effects individual life at micro level and also effect the productivity of all sectors of economy at macro level. Access to modern energy services improves the quality of life. The situation is very worse in rural economy of Pakistan and especially for the small farmers and home businesses of the Baluchistan, interior Sindh and South Punjab that are living in the state of energy poverty.

At a micro level, energy consumption is positively linked with the standard of living of a household. It enhances the livelihood of the households because it provides new job opportunities at micro and macro level. Energy services provide warmth and cooling to households. Efficient and clean energy are required for the life of humans and reduced indoor air pollution, as well as for this planet. Economic poverty leads energy poverty as affordability of energy is compromised then both types of poverty have negative effects for the environment. So, the life of future generations will be compromised. In simple words, when households are deprived of electricity and depend on the traditional biomass which emits much carbon dioxide and other particles.

There are different approaches to measure energy poverty like; expenditure approach, energy access based approach, accessibility and affordability of energy at micro and aggregate level. Expenditure approach is supposed to rank according to the threshold level of expenditure on energy items. If somebody or a society is unable to achieve that certain level of expenditures, then that will be categorized as energy poor. Different proportions of income to energy services are used to identify who are energy poor and who are not energy poor. Haleem et al., (2017) also measured the energy poverty at household level through expenditure approach, while using the fixed ten percent rule (TPR).

The other approach is energy access based approach that is also used by many researchers in their studies. This approach is binary in nature. The data for this type of research is collected through having/ not having access to energy services (Nathan & Hari, 2020).

The third approach is accessibility and affordability of energy in the country and it is generally used in developing countries. This approach works on the Alkire and Foster methodology, (Alkire & Foster., 2011). Sadath & Acharya., (2017) also used this approach to measure energy poverty.

Energy poverty is a broader concept and has many determinants like trade openness, foreign direct investment, population growth, energy consumption of non-renewable energy sources etc., or low share of green energy into the energy mix. It is beyond the scope of present study to discuss all these determinants of energy poverty. Present study tries to assess the macro level effect of energy poverty on CO_2 emission.

1.1.1 Energy and Economic Poverty

Energy poverty affects the production sector and limits the potential of economic growth. Access to energy services and modern technologies for commercial and all economic activities creates employment opportunities for people and also helps to fight against poverty. Full access to energy can combat hunger by increasing productivity of all sectors of the economy and reducing the loss of post-harvest. The access of modern energy services is important for the long-distance transit airplane and rails for goods and passengers, and it reduce the travel costs and time. Health is closely associated with modern energy services. Electricity is necessary for ultrasound, ECG, ECO, blood tests and all other medical equipment's run with electricity. Electricity provides medical services at night in rural areas (Editor., 2012). The agriculture sector in the poor countries depend on the animal and labor input because they are energy poor due to which overall productivity remains low while developed countries use high level of energy input (machinery and fuel) in the production that accelerates and increase the productivity and saves time. Nitrogen based fertilizer accounts 45% of all energy input in the production process while the labor just accounts for 3% in the production process in the USA. In a country like Pakistan where both the industrial and agriculture sector is deprived of energy services, they have no access to energy services the whole day, month or year, affect their productivity. Energy poverty leads to economic poverty in developing countries because energy is the main source of development in any country, (González-Eguino, 2015).

In a developing country the demand for energy is less due to low investment because the people are unable to purchase or expenditures on basic energy services remain low. Low investment leads to low income that is the cause of country's trap in the energy poverty. Energy poverty from the supply side occurs when there are less energy services because the income of people is not enough to buy the basic energy service, so the demand for energy services remains low. When the income remains low, it leads to low saving. The investment on energy services remains low that leads to not generate more electricity and clean energy projects in the country

1.2 Relationship between Energy Poverty and CO2

Energy poverty got attention in late of 20^{th} century in all over the world. Energy consumption is considered as source of carbon emissions into the atmosphere. The use and production of energy causes 70% of total emissions of GHG at global level due to high rate of dirty energy into the total energy mix. The access to electric services and expansion in other energy services result in climate change (Pereira et al., 2018). Developing nations largely depends on obtaining energy from coal and traditional biomasses like as firewood, coal, kerosene oil, dung and plants waste. Biomass is largely obtained from the agriculture sector and large populations live without basic energy services. These nonrenewable energy (dirty energy) sources are producing more carbon dioxide (CO_2) and other hazardous gasses into environment. CO_2 contributes major share in greenhouse gases (GHGs). CO_2 generally emit from the consumption of wood for burning and heating purposes, animal dungs, coal and other fossil fuels (Pervez et al, 2010. The share of fossil fuel is about 85 percent of total mix of energy, and it emits huge amount of CO_2. Energy is mostly produce in the world from non-renewable sources, it releases the waste gasses into atmosphere, CO_2 is in huge amount in that waste gasses, which is also known as greenhouse gas. CO_2 traps the heat and not letting it to the outer space of atmosphere. To check the environmental or socio economic effect of energy poverty, particularly on the CO_2 emission become important research for the scholars. Energy poverty is a serious issue to environment and it causes the severe environmental degradation (Reyes et al., 2019). Some studies find that there is a causality between energy poverty and CO_2 emission. It is very important to check the dynamic effect of poverty on CO_2 emission in case of Pakistan because Pakistan is developing and semi-industrialized country. Pakistan is highly energy poor as compared to the rest of the world and largely depends on dirty energy which is the main reason for the emission of greenhouse gasses into the atmosphere. As CO_2 emissions in Pakistan in 2019 was 223.6 million tones. Which increased from 17.7 to 223.6 million from the year 1970 to 2019 (Pakistan environment).

1.3 Environmental Kuznets Curve (EKC)

The environmental Kuznets Curve is based on the concept of the Simon Kuznets curve. Grossman and Krueger gave this hypothesis in the year of 1991. The environmental Kuznets curve predicts that initially an economic development destroys the environment to some certain level, but when a certain economic growth is achieved then the society relationship improves with the environment and environmental degradation starts reducing. In simple words it says that economic development leads to a friendly environment. The relationship of environment and income per capita gives a U-shaped curve, (Alstine & Neumayer., 2010).

Environmental degradation has the endless discussion among policymakers, researchers and environmental organizations to protect the environment against rapid economic development. The economist gave serious attention between the linkage of environmental degradation and income. This enables the policy makers to adopt good policies to protect the environment. When a rapid industrialization occurs in the economy, it needs more energy to operate and more emission of greenhouse gases (GHG) and also low income economies have limited technology and bad infrastructure that further leads to environmental destruction but at a certain level of income this environmental destruction decreases, (Mosconi et al., 2020).

1.4 Problem of Statement

Pakistan is a developing and semi-industrialized country and among the most vulnerable countries of the world. On one side Pakistan is facing serious threats of environmental degradation while on the other side Pakistan is an energy poor state and heavily depends on acquire energy services from dirty sources. Interestingly in the given situation, there is a negative relationship between energy poverty (if pro-green energy sources otherwise the direction of the relationship will reverse) and GHG. The only way out from energy poverty and reduction in CO_2 emission, for Pakistan is to increase its renewable energy sources into total energy mix. Pakistan relying on the consumption of fossil fuel (coal, wood, dungs and waste straw) which emits huge amount of greenhouse gasses. In Balochistan and Khyber Pakhtunkhwa firewood accounts for half the carbon emission which is due to unavailability of electricity and clean energy for cooking purposes, (Hassan., 2017). The main problem is to access energy poverty in the country and its impact on carbon emissions.

1.5 Research Gap

In empirical literature, hardly find a single study that estimates the impact of energy poverty on environmental degradation. Qurat-ul-Ann & Mirza., (2014) and (Mahmood & Shah., 2017) conduct studies and measure energy poverty at micro level by using household data of Pakistan. They conclude that on average 26.4 percent of households are energy poor. Mirza & Szirmai., (2010) estimate the intra energy poverty in Punjab, Pakistan. The results show that 91.7% of households are highly energy poor in rural areas. Amna Haleem et al.,(2017) check the relationship in the reduction of energy poverty with the environment and finds that 69.67 percent of people are deprived of clean fuel energy for cooking and 9.04 households have no access to electricity. There is no single study available who investigates the relationship of energy poverty at macro level with CO_2 emission. A Contemporary study is going to estimate energy poverty of Pakistan at macro level by using the multi-dimensional energy poverty index. Then check the dynamic impact of energy poverty reduction on CO_2 emissions in Pakistan.

1.6 Research Objectives

- To measure energy poverty by using a multidimensional approach in Pakistan.
- To evaluate how energy poverty reduction effect on CO_2 emissions in Pakistan.

1.7 Research Questions

What is the energy poverty status in Pakistan?

What is the relationship between energy poverty and CO_2 emission?

1.8 Significance of Study

The findings of the present study are important for policy makers as Pakistan is confronted with the issue of environmental degradation and the ongoing energy crises in the country. The reduction in energy poverty will be beneficial for environment in Pakistan. When more people access to energy services and clean cooking facilities, it will help the households emit less carbon dioxide. The findings of this study will help the researchers and policymakers to better understand energy poverty status in Pakistan. This study helps the policy makers in the implementation of an effective energy poverty policy to decrease the energy poverty that may help in the decrease of carbon dioxide in the country. The outcome of this paper contributes to the literature on the assessment of energy poverty for the developing nations.

1.9 Organization of the study

The chapter 2 is literature review that focuses on the different approaches for the measurement of energy poverty and discusses literature on the CO_2 emission and Environmental Kuznets Curve. Chapter 3 of the study first goes into details of the theoretical framework of the study and econometric model. The next section of the chapter tries to explain the methodology for the contemporaneous study, sources of the data and discuss the dimensions of energy poverty. The end section of the chapter tries to assess energy poverty and discusses the methodological and measurement issues of energy poverty. Chapter 4 of the study comprises on the result and discussion section of the study. The last chapter consists of the conclusion and policy recommendations.

CHAPTER 02

Review of Literature

2.1 Introduction

Review of literature is a summary of previous studies, or it is synthesizing the ideas of existing literature which helps to identify the research gap and research framework of the study. Moreover, review of literature helps the researcher to adopt new strategies in model, data and analysis for the selected area. Moreover, it is very important for defining a research problem.

This chapter also provides the insights for theoretical framework and evolution of theories which are necessary for the new avenues of research. This chapter helps in selecting the suitable methodology for research by analyzing the weaknesses and strengths of methodologies used in the previous studies and the most appropriate technique for data analysis.

This chapter briefly discusses the relevant literature on the assessment of multidimensional energy poverty and the impact of energy poverty on environmental degradation. Although there is very limited literature available on the relationship between energy poverty and environmental degradation.

The first segment of this chapter explain the importance of literature review in research and different categories of energy poverty and in 2.2.1 section of the chapter discusses the expenditure approach to alleviate energy poverty line with fixed ten percent rule and different threshold, and the issues related in the application of this approach because it underestimates the energy poverty condition. While Section 2.2.2. discusses the human development index to measure energy poverty. The next section 2.2.3. of this chapter briefly explain the literature on the access based-approach. The section 2.2.4 discusses the energy affordability approach. The last section 2.2.5. discusses the most appropriate use approach multi-dimensional index which takes several dimensions of energy poverty. The section 2.3 discusses the literature on nexus between energy poverty and CO_2 emission and also discusses the hypothesis of environmental Kuznets curve.

2.2 Energy Poverty measurement

The literature on assessing the energy poverty in developing nations is considerably increasing but it is still in the transitional phase. This section reviews the different measures of energy poverty that are used in empirical analysis so far. Energy poverty as a topic gets attention especially in measurement to formulate better decisions for society and it gets attention among policymakers by employing the implication of energy poverty measures to formulate better decisions for local society as well as the global community. Measurement of energy poverty is coupled with definition, data, geographic conditions, and methodology. These factors made it a complex phenomenon. Due to such complexities, there is no predefined exact yardstick to measure energy poverty, (Thomson et al., 2017). The simplest and common method to measure energy poverty is drawing the energy poverty line with some threshold level or benchmark of energy but still there are various aspects that need to be explored.

It is clear that there is no universal method or approach that measures energy poverty precisely. Appropriate approach for the measurement of energy poverty and selection of appropriate dimensions and indicators are dire need of the present time due to energy crises and environmental degradation. At micro level knowing the energy poor and energy rich households are prerequisite for the policy makers. As energy poverty is complex phenomenon and it is caused by several factors, so it needs more attention to be measured. There are many differences in energy poverty situation both in developing and developed nations. The energy poverty in developed nations is just in terms of energy affordability and not in the form of accessibility but the situation is worse in developing nations and they are confronted energy poverty in terms of energy affordability and energy accessibility. There are three categories that have been used for the assessment of energy poverty that are availability, quality and demand of energy services, (Zhao et al., 2021).

Energy demand is the minimum level of energy requirement that fulfills the consumption of energy services. There is a huge imbalance in access to energy services and demand for energy services today. The energy demand increases globally due to rapid development, (Chakravarty & Tavoni, 2013).

Energy service availability includes indicators such as access to traditional biomass, share of population to electricity for cooling, lighting and heating purposes, cooking facilities and mechanical power. The accessibility of Energy service is the key factor in the reduction of economic poverty and maintains sustainable development. People lies in an energy poverty state struck in the life of poverty. Energy service availability is the priority in MDGs agenda. More resources are required to fulfill the requirements of energy access and huge investment in developing economies due to the high rate of energy poverty, (Practical Action., 2010).

The energy service quality is related to income of the households and the cost of energy services which restricts the households to avail the basic energy services. The ratio of expenditures to income is used for energy quality and suggests that access to electricity is more efficient than using alternative energy services which helps in affordability of energy services in developing nations, (Foster et al., 2000).

2.2.1. Expenditure Approach

This approach considers the expenditure on energy services by households and takes the expenditure indicators. It derives the information from the expenditure indicators on energy services. This approach compares the threshold of indicators and assesses the energy poverty whether a household is below or above the threshold level. Different researchers propose different thresholds to assess energy poverty. Threshold remains below or above the expenditure matric, (Charlier & Legendre., 2018). This approach explores the ratio of expenditure on energy to income of household or firm, (Thomson et al., 2017). This approach uses mainly relative and absolute expenditure approach. A household or firm is considered energy poor if the expenditure on energy services is too high above the threshold level or too low the certain threshold level. The expenditure based indicators contain.

Energy Poverty Line or Ten percent rule

Low income, High cost Indicators

Energy Poverty Line

This is the most used economic approach that is based on the conventional poverty line. It simply assesses energy poverty by calculating the consumption of energy at households' level on energy services. The premise of this approach is that households remain energy poor if they spend beyond the threshold of their income to acquire adequate energy services.

Foster et al., (2000) use the ten percent energy poverty threshold to alleviate energy poverty. In simple words, households are said to be energy poor if they spend beyond ten percent of their income (Ten Percent Rule, (TPR)) on energy items. Low income and high costs of energy services restricts the consumption of required energy services below the specified line. The study estimates that household is energy poor if per capita consumption of energy services lies below 10 percent of income.

Khandker et al., (2012) use relative threshold instead of using fixed 10 percent line to measure energy poverty, and point out a threshold point, as income level of family increases, so they consume more of energy services and give an argument of correlation of income with energy services. The study further points out that a small increase in low income does not immediately increase energy consumption and also points out that when a certain level of income threshold is achieved, it leads to increase the consumption of energy services below that threshold point the families are called energy poor. Authors estimate energy poverty for both rural and urban areas of India and use cross-sectional data of 2005 household's survey. The study estimates that 43 percent of households lack of access to energy while 22 % of people are poor in terms of income. Energy and income poverty is 28% and 20% respectively in urban area of India. The result shows that income poverty is highly correlated in urban areas but there is no such a strong relationship exists in rural areas of India. The study also focuses on determining whether the energy poor is also income poor, and it reveals that an energy poor household is also suffered from income poverty.

Another study Mahmood & Shah., (2017), estimates the decreasing trend of energy poverty in recent years in Pakistan following the framework of relative threshold and determine this line by assuming that a households are energy poor if the deprivation count for households below the threshold and non-energy poor if they lies above the deprivation count for the certain threshold. The study alleviates the energy poverty for all provinces in Pakistan and national level, using the multi-dimensional index. The data takes from the PSLM survey for the year 2010 to 2011 and 2008/09. The results show that still half of the population are living in the state of energy poverty. The energy poverty decreases in urban areas due to availability and affordability of energy services but the energy poverty situation in rural areas are worse and overall 76 percent households are energy poor as compared to urban areas, (Awan et al., 2013)

Churchill & Smyth., (2020), use proportion of income to energy expenditures using different cut off ratios of 5%, 15% and 20% and also examine the influence of ethnic diversity on the energy poverty situation in Australia. The study uses the secondary data for the period of 2005 to 2016. Neighborhood trust and income are used as a channel through which the ethnic diversity affects energy poverty. Ethnic diversity shows differences among different groups belonging from different groups in a society and measure the energy poverty through budget shares or expenditures on energy services and ethnic diversity measure through neighborhood level and also examines the effect of ethnic diversity on energy poverty situation and expenditures of households on energy services. The result shows that there is positive relationship between energy poverty and ethnic diversity in Australia.

Villalobos et al., (2021) identify the energy poor population, using fixed ten percent rule to measure energy poverty in Chile. The study takes the data of 3500 households from the national survey of public perception for the period of 1992 to 2017. The result obtains through ten percent rule indicated that 15.5 percent of population have deprived of energy services and 16 percent of people have monetarily poor. The study further points out that affordability of energy services plays a key role in the accessibility of modern energy sources, lighting, reliability of services and quality of energy services.

Low income and High-Cost Indicators

Low income and high cost (LIHC) indicators consider a household's energy poor if after attaining energy services push them below poverty threshold due to high cost of energy services. This framework focuses on the cost threshold of energy services and also on income threshold. Hills., (2012) criticizes the fixed ten percent rule (TPR) because under the cut of ratio, income and prices do not remain same but change continuously and one does not precisely estimate who is energy poor and who is energy rich due changing trends in income and efficiency related to energy appliances. Further taking equal costs and income for varying family size leads to biased estimation in energy poverty. Under this approach household is considered energy poor if equalized disposable income remains low then median disposable income or the expenditure (equalized) on energy services is greater than required median expenditure on energy services.

From the above literature, it is clear that income expenditure approach (budget shares) is straight forward but it is far from the perfect estimation of energy poverty because it does not capture all dynamics of the energy use for poor and rich populations living in different climates or it provides insights of single dimension of energy poverty but energy poverty has need a broader dimensions to measure and critically analyze the multi-dimensional approach in the measurement of energy poverty. These researches estimate the energy poverty, just relating it to the energy services, by distinguishing the use of energy services of households such as heating, lighting and basic cooking facilities (Pelz et al., 2018).

2.2.2 Human development index

International Energy Agency., (2005) formulated an energy development index for the human development index (HDI) which comprises of several dimensions to energy access. This measurement does not capture the energy inequality within the country and percentage of energy poor people in the country but takes the broader measurement of energy poverty.

Krugmann & Goldemberg., (1983), attempt to estimate the energy requirements for satisfaction of households for three different regions of the world Latin America, Asia and Africa. Assess the energy poverty in terms of energy consumption per capita related to GDP per capita through broader measures such as HDI or index of quality life. This approach is the same as the energy poverty line.

Horta et al., (2019) study the vulnerability and energy poverty in Portugal and assess the regional condition of energy poverty by constructing the composite index of energy poverty that combine climate, energy performance in dwelling stock and energy consumption, using the secondary data of municipal statistics of energy department and interview from 100 households across the country in urban and rural areas. The result indicates that extent but variable and vulnerability in energy poverty throughout the country.

2.2.3 Access based approach

Alam et al., (1998) assesses the energy poverty through availability of energy services and presents a statistical model that measures the wellbeing of households energy consumption per capita and estimates per capita consumption of energy for 112 countries. The wellbeing of households in any society or community directly measures by the total use of energy per capita.

The dwelling of households in less developed nations depends on the access to electricity and basic cooking facilities. The authors quantify the energy consumptions of households, using cooking and density of population.

Another study evaluates energy poverty conditions in Pakistan, using the PSLM survey for the year of 2007/008. The study evaluates the energy poverty situation in rural and urban regions of the country, taking five dimensions. The study reveals that the availability of electricity improves with passage of time in urban areas and clean energy for cooking facilities while the situation of energy in terms of lighting and fuel in rural areas does not improve. Most of the population living in rural areas are energy poor in terms of fuel cooking, 45% of households' access to fuel cooking. Collectively 81 percent have access to electricity services in Pakistan, which shows improvement in this field in recent decades. The worst situation prevails in terms of home appliances and only 15 percent households have access to modern home appliances and 85 percent people are deprived of this facility which is too much low and they just depend on the use of traditional cock stoves and other homemade appliances which is not environment friendly and produce more indoor air pollution, (Sher et al., 2014).

Access to energy services is the most essential determinant for any society's welfare and one cannot think of attaining a quality life without energy access. Modern energy services are very important in economic development. This approach is linked with access to energy sources. At a micro level, when electricity or other energy sources for cooling and heating purposes are available to households then it is not an energy poor household. Different researchers calculate energy poverty through energy access approach by calculating the ratio of households who has access to energy sources to total households. This explain energy poverty through access and consumption of energy services, (Mirza & Szirmai., 2010).

Nussbaumer et al., (2012) present a study on the measurement of energy poverty and development, following the same framework by exceeding the deprivations from cooking and lighting to deprivations in modern appliances, entertainment and include the telecommunication services and critically analyze the previous instruments of energy poverty. The study discusses the unidimensional approach or income expenditure approach which has been widely used in previous literature and shows the narrow picture of the issues. single dimension does not well capture all dimensions of the energy poverty, but the energy poverty has a broad phenomenon and it lacks the different insight into the overall state of affairs. Energy poverty is best estimated by the composite index because it is the best index for measuring the different facets of problems involving. The same multidimensional index based on the methodology of multi-dimensional poverty index, which estimates incidence of energy poverty and intensity. The study collects the data from the demographic and health surveys (DHS) and assigns equal weights to all indicators. Household are energy-poor if energy poverty goes beyond certain minimum level of deprivation recognizes the energy poverty as the foundation for sustainable development. The results show that energy poverty has an inverse relationship with human capital development.

Bersisa & Heshmati, (2016) tries to assess the accessibility of energy and issues related to measuring energy poverty. The study uses the Alkire-Foster method by constructing the multi-dimensional index which includes 4 dimensions and five indicators. The study uses data from the socioeconomic survey of Ethiopia for the year 2011 to 2014. The study analyzes the energy poverty in urban and rural regions of Ethiopia. The results reveal that severe energy poverty exists in the rural areas of Ethiopia and only 26 percent households provides energy services. The effects of energy poverty are examined by using logit model. The study further check that large size families were more multi-dimensional poor.

Energy access metric is binary in nature and due to binary in nature it is used for data collection like having/ not having access to electricity or fuel. The first component of energy accessibility is access to electricity (% of household’s access to an electric network). Second is the access to modern cooking services like LPG, electricity and biomass cook stoves. Energy access is easy and simple in measuring energy poverty because the energy access includes only households that are using energy. It does not include the use of electricity in the industrial sector, enterprises, street lighting and electricity used in buildings are not part of energy access. Energy access does not take the usage of energy outside households, (Culver., 2017).

The concept EP receives attention in policy making in India which is compulsory to attain the society’s welfare. The availability of energy services such as electricity and modern cooking facilities are essential in affecting health, climate change and other social hazards. Following the same approach, (Sadath & Acharya., 2017) assess the multi-dimensional energy poverty in India by aggregating households deprivation to lighting and cooking facilities. The findings of this study shows that more people are energy poor in rural areas of India where most of the residents are deprived of energy services and depend on the traditional biofuels and the situation is relatively better in the urban areas.

Njiru., (2018), estimated the energy poverty in Nigeria and further check its effect on the living standard of Nigerian people. The study shows that sever energy poverty prevails in most parts of Nigeria. Access to electricity remains low that directly affect the consumption of foods and other related goods in daily life. The low availability of energy services to most of the population compel the people to heavily rely on the use of traditional biomasses. This excessive use of traditional biomasses leads to produce more CO_2 emission which effect the health of people and causes many diseases. Secondly the low availability of energy services full the prices of electricity, due to high cost of energy services the large factories depends on to acquire the energy needs from traditional biomasses.

Mendoza et al., (2019) assessed energy poverty at household level in 80 provinces of Philippines'. The study uses seven indictors namely, communication, education, space cooling, telecommunication means, refrigeration, lighting and modern cooking appliances to capture the energy poverty deprivation at household level. The energy poverty situation improves at those regions where economic performance improved and high rate of energy poverty notices at low economic performance regions. Findings of the study suggest that the overall situation of energy poverty improves as compared to neighboring developing nations of Asia but a large gap prevails across different regions of the country. Access to education and communication indicators contributes 90 percent to energy poverty among all of the indicators of the study. It means that 90 out of 100 families are deprived of the appliances related to communication and education. The Luzon region of Philippines experienced the lower rate of energy poverty while other regions experienced the moderate rate of energy poverty.

Nathan & Hari., (2020) reviewed different approaches in the energy poverty measurement and tries to assess the energy poverty in urban areas of India. They measured energy poverty through an access-based approach and distributed the energy poor people into three categories: high energy poor, moderate level of energy poor and transitional level of energy poor and calculated the severity and depth of energy poverty just for people living in the state of energy poverty and not for the whole population. The study focuses on modern lighting and clean cooking facilities to household. The result shows that 30 percent of population in 15 states of India is deprived of clean cooking facilities and more than 5 percent of population have lack of access to lighting facilities. The study further found that 3.2 percent of the population has been living in an extreme energy poverty state, 26.3 percent of the population has been living in the moderate level of energy poverty and 26.1 percent have been living in the transitional level of energy poverty. The overall 44 percent of the population have access to lighting and cooking facilities.

The availability of electricity and other energy services improves in the last decades in Sri Lanka. Jayasinghe et al., (2021) alleviate energy poverty in Sri Lanka. The study uses the latest data from the income and expenditure survey department of Sri Lanka and tries to examine the inequality, intensity, and energy poverty determinants in Sri Lanka. They use the multi-dimensional approach by using several indicators to alleviate the energy poverty and give equal weights to all indicators by applying principal component analysis (PCA). The results reveal that 57 percent of people are living in a state of severe energy poverty in terms of modern cooking facilities and overall 43 percent people have been deprived of energy.

2.2.4. Energy Affordability Approach

Energy affordability is also considered the main issue in developing nations due to limited income and high prices. Some scholars use the prices or cost of energy to measure energy poverty and some researchers measure energy poverty subjectively, like as “feeling” the deprivation when households are unable to warmth room, cooling, heating and other basic energy services which give satisfaction to households during cold season. Energy prices are economically, statistically related to the wellbeing of households. As prices of electricity, fuel, and other energy services increases, it leads to decrease the demand of energy services, and affect the wellbeing of consumers at micro level and also affect the consumption of energy services at macro level and the consumer remains energy poor. Affordability of energy services is necessary to maintain quality of life, (Thomson et al., (2017).

Churchill et al., (2020) examines the influence of fuel on the comfort of Australians, employing different measures of fuel poverty. Three indicators (ability to pay to keep the room warm, overdue on utility bills, damp walls) were used to measure fuel poverty in European countries. The estimates revealed that energy and income poverty go hand in hand and fuel poverty negatively affects the wellbeing of people.

2.2.5 Multidimensional indices

Latterly the measurement of energy poverty shifts from a unidimensional approach that is based on the concept of income expenditure approach or budget shares of income on energy services to a broader concept multidimensional approach. The unidimensional approach defines energy poverty through a single dimension, but only one dimension does not best describe energy poverty because energy poverty has multiple dimensions and a broad concept to be measured. Multidimensional energy index consists of several indicators and covers most of the dimensions of energy. Multidimensional approach has been used widely, especially in the developing nations. This approach takes both the subjective and objective measures. It takes various aspects of energy poverty, and these aspects are not discussed in the unidimensional approach. This approach incorporates multidimensional energy poverty like cooking, lighting, cooling, heating, and other basic energy services. It takes both incidence of energy poverty and intensity of energy poverty, (Nussbaumer et al., 2012).

Pachauri et al., (2004) provide review of different approaches that were used by many researchers from 1990s to 2005 and give a novel concept to measure the energy poverty that consists of different services of energy and the level of consumption. The authors measure energy poverty at household level in India. The study uses the secondary data from the year 19983 to 1999 by constructing the approach of multi-dimensional index and does not consider the old income approach which just estimates the single dimension of energy poverty and applies the consumption matrix. The results show a reduction in the energy poverty at household level in India that most have only access to kerosene oil and other traditional biomass.

Some researchers comprehensively study energy poverty and find evidence of decreasing energy poverty. Recently, (Wang et al., 2015) analyze the energy poverty situation of thirty provinces and some economic regions in China for the year 2000 to 2013, and review the measurement of energy poverty that have been used in many studies. This study analyzes different indicators and measurement of energy poverty and its application from availability and suitability of data and constructs the comprehensive index for elevation of energy poverty at national level. The recent development, improvement in social infrastructure, and wellbeing of households improves, energy poverty shows a decreasing trend in China. This is mostly because of improvement in the affordability, accessibility and efficiency in energy services. The study also reveals that some households of some regions of China are still in an energy poverty state as compared to regions which are not economically poor.

Nagothu., (2016) also constructs the multidimensional index based on the work of Nussbaumer., (2011) uses several dimensions. The study uses the household level data from 2011 to 2012 of national sample survey (NSS). The study uses three dimensions' energy services, modern cooking facility, and modern lighting facility. The unequal weighted strategy is used in the entire study while the energy services are given more weight. The result reveals that a high rate of energy poverty exists in the Northern state and low energy poverty prevails in the Southern states in India and overall 31 percent people live in the state of energy poverty. The study further compares the result to African countries and shows that there is a lower level of energy poverty prevalent in India than African countries.

Akinbo et al., (2018) tries to assess energy poverty in South Africa based on the methodology of Nussbaumer et al. (2012) using multi dimensions. The study uses the data of national income dynamic surveys of 10801 households. The results revealed that low income households both living in rural and urban areas of the country faced an intermediate rate of energy poverty. Overall 95 percent of the people have lack of access to cooking fuel and the situation in terms of lighting is better and 65 percent deprived of lighting. The study further pointed out that the income poor population both in rural and urban areas of the country are 90 percent lacking access to modern appliances, entertainment and telecommunication.

Rafi et al., (2021) in the same way construct the multidimensional index which covers both accessibility and affordability of energy poverty. The study uses micro level data from household Indian Human Development (IHDS), surveys in India, which focuses on the impact of poor energy conditions of households on leading indicators of human development, covering both accessibility and energy affordability. The study reveals an inverse relationship of energy poverty with children's health and severely affects the studies of students because having no proper light at night for study affects the learning capacity of students.

The contemporaneous study constructs the multi-dimensional index combining both accessibility and affordability of energy services and gives equal weights to all dimensions. Follow the sample method of equal weights because the study gives equal importance to all dimensions.

2.3 Studies on the Determinants of CO2 Emission

Climate change is considered as one of the main issues in today's world. The large emission of greenhouse gasses specifically, the CO_2, nitrous oxide (N_2O), methane (CH_4) and other hazardous gasses into the atmosphere causes climate change. The CO_2 has the largest share to climate change because developing economies heavily rely on fossil fuels, inefficient transportation, excessive deforestation for agriculture and rehabilitation purposes, (Hu et al., 2019). The CO_2 emission and its determinants can reduce the carbon emission targets. Previous studies find the relationship of energy poverty with environmental degradation.

González-Eguino., (2015) extensively analyzes the impact of energy poverty on health, economic growth and environmental degradation. This situation is very worse in regards to access to clean cooking facilities and approximately 75% of the population of these two continents are highly energy poor in terms of clean energy for cooking. Most of the people in these regions depend on the traditional biomass for heating and cooking. The use of firewood for heating facilities aggravates the air pollution and the inadequate use of biomass causes indoor pollution in low-income regions. The low-income regions where people have access to meet their needs of energy services have difficulty in affording the basic energy services and mostly rely on the consumption of firewood or other traditional alternative for use.

Reyes et al., (2019) estimates the energy poverty for the capital city Valdivia of Chili. Authors propose that firewood is the most usable source of heating by the residents of Valdivia. The survey by Air pollution management plan (PDA) shows that 90 percent of air pollution is only produce by the burning of firewood for heating purposes, especially in the winter season by the residents in Valdivia city of Chili and only 10 percent air is polluted by the transportation which is too much low as compared to the combustion of firewood. This excessive use of traditional biomass is due to lack of adequate thermal appliances and just using the old traditional cook stoves by the residents for heating and this excessive use produces more indoor pollution.

Oliveira & Graff., (2019) analyze the effect of safe provision of electricity and its effect on the CO_2 emission in rural areas of Brazil. The study points out that the rural areas of the country are not connected with electric grids and also deprived of other clean energy resources and most of the population in rural areas depend on obtaining energy services through traditional biomasses such as wood, animal waste, dungs etc. that is the main cause of CO_2 emission. The study further shows that an increase in the share of clean energy in the overall energy mix may bring environmental benefits in society and a reduction in CO_2 emission. The study observes that access of electricity to rural populations enables the people to use more efficient energy appliances and consumption in real terms but reduces the intensity of CO_2 emission. The study indicates a strong association of energy poverty with CO_2 emission.

Zhao et al., (2021), estimates the energy poverty and then checks its dynamic effects on CO_2 emission in different regions of China. The study uses the data for the year 2002 to 2018, using the GMM method to find the reduction effect of energy poverty on Carbon Dioxide emissions. The results show unidirectional causality in those regions where energy poverty is less and a bidirectional causality in those regions where energy poverty is high. The total energy poverty shows a downward trend in the period from 2002 to 2018. The authors further estimate the heterogeneous and asymmetric effects of energy poverty on CO_2 emission, using the quantile approach of regression.

Ahmed & Long., (2012) investigates the long run relationship among carbon dioxide emission, economic growth, trade liberalization and energy consumption to test the hypothesis of environmental Kuznets curve (EKC) in Pakistan for the year 1971 to 2008. They applied the ARDL model to test the short run and long run relation among the variables to verify the environmental Kuznets curve (EKC). The result reveals the existence of a long run relationship among the CO_2 emission, gross domestic product, trade liberalization and use of energy, and shows no significant relationship among the CO_2 emission and gross domestic product, trade liberalization and energy use.

Cil., (2019) examines the effects of energy consumption and per capita income on CO_2 emissions in Turkey. The study uses secondary time series data, collected from the information analysis of carbon dioxide center, Maddison's site and world development indicators (WDI) for the year 1960 to 2007. The findings of study show that there exists both long run and short run relationship between the energy consumption and CO_2 emissions for the selected period using the Cointegration test (Greggory-Hansen test), and also verifies the environmental Kuznets curve (EKC) hypothesis for both period 1960 to 1979 and the next period from 1979 to 2007. The author gives the policy implication that a Turkish government must use those resources which produce more clean energy to reduce the CO_2 emissions in the country.

Zhang et al., (2020) test the hypothesis EKC to economic growth, square of economic growth and energy efficiency. The study uses the panel data for developing countries for the period of 1990 to 2013. The study uses the ARDL model to test the hypothesis of EKC and data enveloping analysis (DEA). The result shows 0.26 convergence to long run equilibrium. The study verified inverted U-shaped environmental Kuznets curve for the developing economies as the square of gross domestic product is significant and negative. This trajectory and speed of the environmental Kuznets curve rely on economic growth addition of renewable energy that emits less amount of CO_2 emission. The DEA result shows that all of the emerging economies are confronted to reduce the intensity of energy, increase efficiency and try to sustain economic development.

Filippidis et al., (2021) test EKC hypothesis by focusing on gross domestic product, energy consumption, electricity production and income inequality. The study uses the panel data for the year 2000 to 2019 for 200 countries. The study emphasizes to test it globally as well as in low- and high-income countries to observe the heterogeneous responses. The result first shows a positive relationship between the economic growth and renewable energy and negative relationship with consumption of fossil fuel. Further economic growth positively related to the production of renewable electricity and negatively related with the production of electricity produced by coal. The result of the study supports the validity of the EKC hypothesis. Both renewable and non-renewable energy sources is supportive to economic growth and increasing renewable energy requires government regulations to enlarge the renewable energy sector and further trade openness promote the production of renewable energy.

CHAPTER 03

Theoretical Framework, Model, and Methods

3.1 Introduction

The aim of this chapter is to define the theoretical framework, model, and methods that are going to apply in present study. Methods and models are important for any research process, and it mainly contains research design, model of the study and all statistical procedures that are used in ongoing research. The first section of this chapter is about the importance of models and methods. The section 3.2 discusses the theoretical framework that provides the theoretical support to the contemporaneous study. While section 3.3 differentiates the economic and econometric model of the study. While section 3.4 section describes the data collection process and description of the variables. The section 3.5 discusses the issues related to the measurement of energy poverty. The 3.6 section of the chapter confers about the dimensions of energy poverty. The section 3.7 of the chapter debates on the assessment of energy poverty and compares the dimensions of energy poverty with energy poverty for the specified period to analyze the trend of dimensions with energy poverty. The section 3.8 discusses the normalization process of the data for energy poverty index. The section 3.9 discusses the weight distribution to indicators and dimensions of index. The most important section 3.10 comprises the methods used in the research. The section 3.11 discusses the unit root test of stationarity of time series data. The section 3.12 discusses the concept and role of correlation analysis between the variables of the model. The last section 3.13 contains the procedure of Johansen Cointegration test for multivariate analysis and other related issues e.g., vector error correction model etc.

3.2 Theoretical Framework

Energy got attention among researchers in the late 1970s due to the oil shock. In early empirical attempts, researchers estimated the relationship between energy and other macroeconomic and social indicators (Kraft., 1978). Then later on, the direction of research moves toward the directional relationship between energy consumption and economic growth (unidirectional causality, or bidirectional causality etc.,). The causality exists from energy consumption towards economic growth, (Razzaqi et al., 2011). The causal relationship of energy use towards economic growth, (Stern., 1993). Hereafter, many researchers tried to investigate the relationship (nexus) among energy, economy, and environment.

In recent times, many studies try to investigate the relationship between energy poverty and economic growth (Ullah et al., 2021). But energy poverty has many issues like definition, various dimensions of energy poverty, upstream and downstream energy poverty. Lack of accessibility accompanied by affordability of energy services creating energy poverty in developing nations. Boardman., (1991) is the first who works and measures fuel poverty in the United Kingdom. Boardman measures fuel poverty at household level. Later on many other researchers work in this area. Pakistan is a developing economy and confronted with the issue of energy poverty that further leads to environmental degradation in the country. Nasir et al., (2022), checks the mitigating role of energy security and energy poverty and reveals that applying appropriate energy security policy in the long run has strong association with energy poverty and plays a vital role in decreasing energy poverty. Haleem et al., (2020), finds that bringing the improvement in the energy poverty (security) substantially reduces the emission of CO_2. Yadav et al., (2019) bringing improvement in the availability and affordability of electricity and other energy services and improvement in conservation of energy reduces the energy poverty and reduction in CO_2 emission.

The relationship between energy poverty and CO_2 is the point of interest among researchers and policy makers because CO_2 is the main source of the environmental degradation in the world, (Jessel et al., 2019; Sattler., 2017). Moreover, due to lack of availability of clean energy services in the world, high growth rate of urbanization and deforestation have contributed more to this regard. The low rate of electrification, low share of clean energy sources into the overall energy mix and less affordability due to the developing stature of the economy leads to more consumption of traditional biomasses and woods at micro and macro level to meet the needs of energy services. These are producing more pollution and more carbon dioxide emission from the consumption of traditional resources which is the main cause of severe environmental degradation in the world. (Day et al., 2016). Zhao et al., (2021) assess the energy poverty and its impact on CO_2 emission in China where, the study finds that a decrease in energy poverty leads to a reduction the emission of CO_2 in China. From the above literature it is clear that in some cases a decrease in energy poverty reduces the CO_2 emission while some studies give the opposite result that a decrease in energy poverty increases the CO_2 emission.

3.3 Model

Model represents the simplified version of the reality and allows the researchers to understand and observe the behavior of the study and makes predictions about the future. The objective of the model is to take some complex or real-world situations to solve them through some simplified version of the equation. A well-designed model helps the researcher to solve and analyze the problem in a better way. Models may be in the form of diagrams, statistical equations, charts, flow Charts and graphs depending upon the nature of the study. It shows the relationship among dependent and explanatory variables of the study and it is also used for forecasting and helps in prediction of future in policy making, (Shalabh., 2018).

Models are a significant part of economics, without models the economics is incomplete. Economists define the model as a framework which explains every aspects of reality. Model is simplified the complicated reality or system in an easy way and economics proceeds models of social phenomena, (Varian., 2010).

The model of this study contains $CO_{2,}$ Energy Poverty (EP), and log of gross domestic product. The model of the study is so easy and simple. The log with gross is taken only due to checking the environmental Kuznets curve (EKC). Acheampong., (2018) also uses CO_2 emission and economic growth in his study. Zou & Zhang., (2020) also use CO_2 emission, energy consumption and economic growth in their study.

3.3.1 Econometric model

Econometric models are used to show the statistical relationship that is believed to be held between two or more economic indicators. It provides a quantitative explanation of the behavior of economic variables. The econometric model may be defined as the set of equations that represents the economic behavior of the economy, (Mayer., 2006).

This study investigates the impact of energy poverty reduction on CO_2 emissions. The dependent variable of the study is CO_2 emission, while energy poverty is the independent variable. This study also uses a control variable like national income. The econometric model for this study is constructed as:

$$CO_2t = \alpha_0 + \alpha_1 EP_t + \alpha_2 logy_t + \alpha_3 logy_t^2 + \varepsilon_t \qquad (3.1)$$

Here the subscript t represents the time periods (years) of the study, α_0 represents the intercept of the equation and ε_t is the disturbance term, which is independently and identically distributed and α_i (i >0) refers to the estimated coefficients. The carbon dioxide CO_2 is the dependent variable. The log of gross domestic product and log of gross domestic product square are the control variables of this study, and EP represents the energy poverty index which comprises three dimensions and fourteen indicators. When initially income increases and the industrialization process starts in the economy, it demands more energy to work that leads to more emission of CO_2, and after a certain level of income is achieved, the environmental destruction is reduced due to the addition of new technology and better infrastructure.

No doubt there are many other potential control variables that can be added to the model but adding more control variables to the model causes a loss of degree of freedom. As study uses small data set for analysis due to no availability of data of energy poverty related indicators. Secondly, the main objective of the study is to check the impact of energy poverty on CO_2 emission and just adding economic growth to the model is enough to explain the effect of energy poverty and economic growth on CO_2 emission.

3.4 Description of Variables and Data sources

The CO_2 is the dependent variable of the study, and its data is collected for the year 1990s to 2019 from the World Development Indicator (WDI) and it is measured in kilotons, while the data of energy poverty (EP) variable is generated through an index and data of various variables that are used in index are collected from the International Energy Agency (IEA), Pakistan Bureau of Statistics (PBS), Pakistan Energy Book various editions (PEB) and World Development Indicator (WDI). This study also uses some control variables such as gross domestic product (GDP) and square of gross domestic product data collected from the world development indicators (WDI) and measured in the current US dollar. In the following table 3.1 description, measurement scale, and data sources of variables of our model are discussed.

Table. 3.1: Description of Variables

Variables	Variables Name	Symbol of variables	Measurement	Data Sources
Dependent Variables	Carbon dioxide	CO_2	Kilotons	World Development indicator (WDI)
Independent Variables	Energy poverty	EP	Measure through an index	WDI, IEA, PEB and PBS
Control Variables	Gross domestic product	Log (y)	Current (US$)	World Development Indicator (WDI)

From the above table one can find energy poverty, it is a broad concept; it needs serious attention to measure. Energy poverty has several dimensions and indicators, which cannot be directly measured. For this purpose, many researchers try to construct the index which comprises several dimensions. Alkire & Foster., (2011) construct the multidimensional index to measure the energy poverty. Sadath & Acharya,, (2017), also uses the same approach, constructing the multidimensional index.

3.5 Measurement Issues of Energy Poverty

Energy poverty is not a single indicator. It contains several dimensions. Some researchers measured energy poverty through a single proxy variable which does not explain the overall situation of energy poverty. There is no unified measure of energy poverty that captures all dimensions of energy poverty because energy poverty is a complex and diverse phenomenon. Alkire & Foster, (2011) developed a technique for measuring multidimensional poverty which captures several dimensions of poverty. Later on (Nussbaumer et al., 2012) used this technique to estimate energy poverty .

The unavailability of data is the basic problem in accessing the energy poverty in developing countries because of non-availability of survey departments in all parts of the country. The classification, assessment and methodological issues are faced by many researchers in measuring the energy poverty in any territory. There are no specific indicators that can be treated as the best measures of energy poverty in the world because there are a variety of indicators that vary from society to society. Energy poverty varies over time and place which cannot be precisely measured. The self-assessment approach to measure energy poverty has limitations. Appropriate indicators for the measurement of energy poverty are also one of the hurdles in the measurement. In the following sections, study discusses the various dimensions and indicators of energy poverty with special focus on Pakistan.

3.6 Dimensions of Energy Poverty

Energy poverty is a broad concept and needs much attention regarding the selection of indicators and dimensions of energy that are the best source to explain the overall energy situation in the country. This study uses three dimensions and fourteen indicators to construct an energy poverty index that will explain the overall energy situation of Pakistan. The explanation and importance of three dimensions of the study are discussed in below sub-sections, sequentially.

3.6.1 Energy Services Availability

The availability of energy services is considered as the most important dimension of energy poverty index (EP) which comprises of several indicators. The availability of energy services to the whole population is the main issue to tackle in developing countries due to inadequate resources and less investment in the energy sector. It is also considered a key cause to sustain economic development and reduce the carbon dioxide production and other hazardous gasses production, as more people transit from traditional biomasses to electricity and other alternative resources for energy. To achieve the target of Millennium Development Goals in the developing countries is impossible without access to energy services because the lack of access to basic energy services are the key contributor towards economic poverty especially in developing nations, (Karekezi & McDade., 2018). Bersisa., (2016) assesses the energy poverty in Ethiopia and finds out the accessibility of energy services as the main issue towards economic development in Ethiopia. The estimation shows that 75 percent of the population still have no access to basic energy services which is a very alarming situation for the country to sustain its economic growth and reduce the emission of greenhouse gasses (GHG). Considering the case of Pakistan Shahbaz., (2015) tries to examine the effect of electricity shortage on the different sectors of the country, such as agriculture, manufacturing, and industrial sector of the economy while using OLS method. The results obtained through the OLS method shows that the shortfall of electricity badly affects all sectors of the economy and further shows that the shortfall of energy services reduces the economic growth by 2 percent of Pakistan from the year 1990 to 2013. The energy service availability is used in many studies to estimate energy poverty in European countries, (Bouzarovski, 2017; Schuessler, 2014). The IEA., (2004).; Practical Action., (2010) describe energy poverty as the lack of access to basic energy services in their report.

The dimension of energy service availability includes five important indicators. Some of the indicators are taken from the supply side such as access to electricity in rural and urban areas, domestic crude oil production and total energy supply by all sources. Mahmood & Shah., (2017) analyzes the overall energy situation of Pakistan. The results show that the overall 26 percent of the population have a lack of access to energy services. This situation is much worse in rural areas where more than half of the population still have no access to electricity and other basic energy services. Haleem et al., (2020) also accessed the energy poverty situation of Pakistan. The findings of the study show that only 9 percent of the population still have no access to lighting facilities, and further finds out that when production capacity of crude oil increases within the country then the country will import less oil from abroad that will decrease energy poverty.

3.6.2 Clean Energy

Clean energy is considered as the most useful source of energy services in developing and developed nations because it does not contain the carbohydrate which releases carbon dioxide CO_2 into the atmosphere. Clean energy is mostly produced from the solar panels, nuclear plants, geothermal and other clean resources which are renewable and produce less amount of CO_2 emission, (Wan., 2013). The annual report released by the International Energy Agency (IEA) figures out that the overall 2.7 billion people have no access to clean energy services in the world, (IEA., 2011). The consumption of energy poverty is strongly related with consumption of energy services. When the production capacity increases then the industrial sector demands more energy to meet their needs which means that emission of more hazard gasses into the atmosphere and the environment will be more degraded in future. It is very necessary that a reduction in energy poverty will only reduce the reduction in carbon dioxide (CO_2) emission when the share of clean energy increases in the total mix of energy then a reduction in energy poverty contributes to reduced carbon dioxide (CO_2) emission, (Chakravarty & Tavoni, 2013).

Clean energy is the second dimension of the study in the construction of energy poverty index (EP). This dimension of index includes five indicators which are very important to transit from non-renewable energy (dirty energy) to clean energy (renewable energy) to meet the needs of energy services and help in the reduction of (CO_2) emission. (Zhao et al., 2021) explain the performance of clean energy over time in energy poverty reduction of China and also check the dynamic effect of energy poverty reduction in carbon dioxide (CO_2) reduction in those regions where energy poverty is reduced. Pakistan is a semi industrialized country and also facing the huge shortfall of electricity and lack of other energy resources at the same time. The growing economy of the country needs energy services to accelerate the economic growth and most needs of energy services are fulfilled from fossil fuel due to the shortfall of electricity and gas to the industrial sector and residential sector which releases the harmful gasses into the atmosphere. Looking at all of these factors, provision of clean energy service is the key in energy poverty reduction and also in the reduction of carbon dioxide (CO_2) emission.

3.6.3 Energy Affordability

Energy affordability is the last dimension of the energy poverty index (EPI) of our study. Foster et al., (2000) discuss the concept of energy affordability in developing countries and point out that a reduction in prices of energy services helps in the reduction of energy poverty and people can afford more energy services. (Shonali Pachauri & Spreng, 2011) analyzes different approaches to energy poverty and explains energy affordability as a situation when households are unable to fulfill their energy needs due to insufficient budget and inefficient energy appliances. More specifically, the energy affordability situation is much worse in rural areas of developing nations due low income, inefficient energy appliances and high cost of energy services.

Another study takes the energy affordability as an important dimension to alleviate the energy poverty in China. The result shows an improvement in terms of affordability in the last two decades in those regions where the energy poverty situation was not up to the level. The existing literature measures the energy affordability through different thresholds of income to energy services, (Wang et al., (2015). Some authors measure energy affordability at micro level, taking the share income spend by households on energy services and Some authors in recent time measure the energy affordability through macro based approach at aggregate level to best measure the overall energy poverty while using principal component analysis for assigning weights to all dimensions on the basis of importance (Jayasinghe et al., 2021).

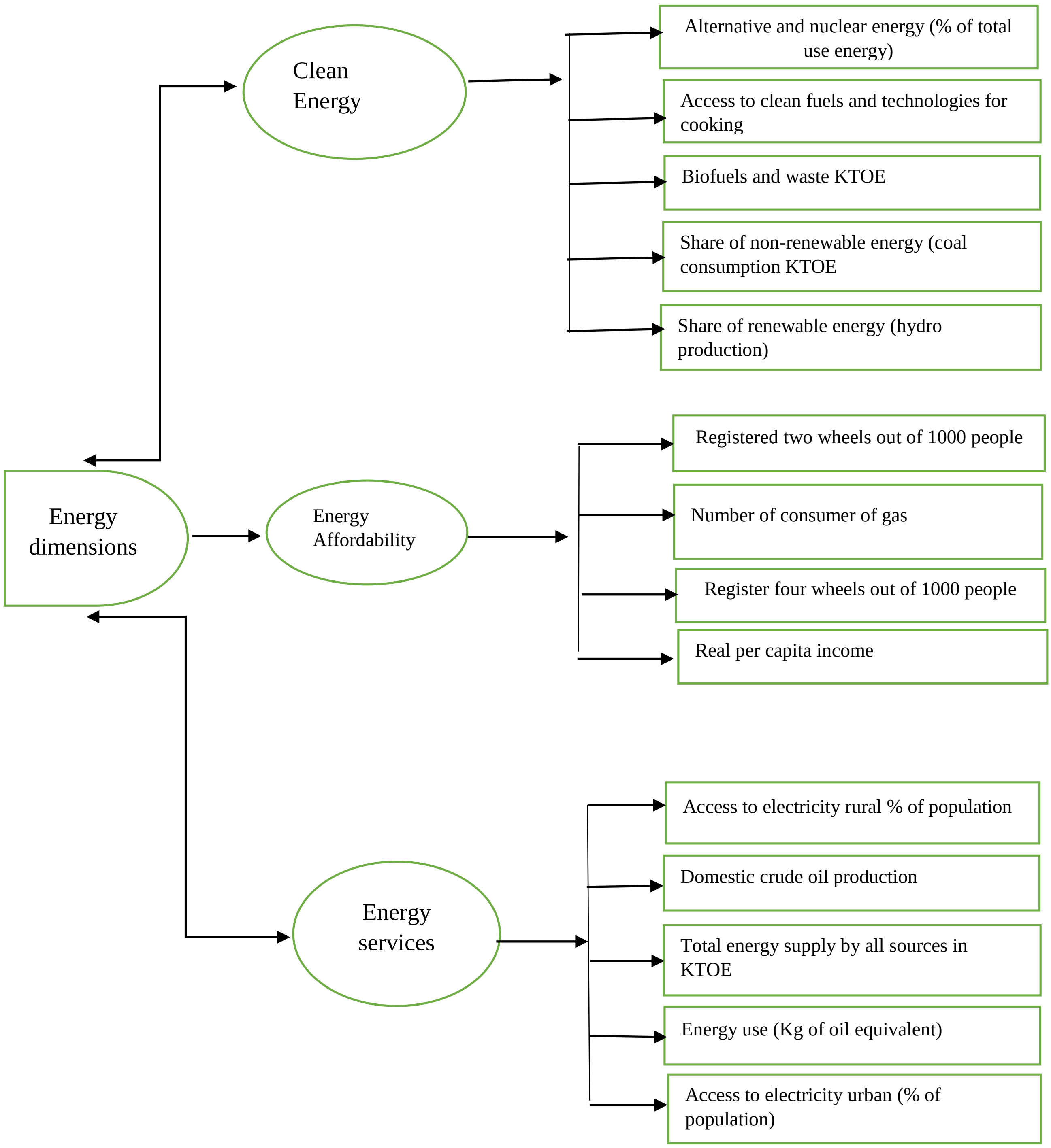
This study follows the second approach for the assessment of energy affordability in the energy poverty index. Energy affordability dimension consists of four indicators. The first two indicators of the dimension show the motorization rate out of 1000 inhabitants. The first indicator is the registration of four wheels and the second indicator represents two wheels' registration passenger cars out of 1000 people. Taking the case of Pakistan, the motorization rate is very low in Pakistan because Pakistan is a developing country where most of the people have less access to personal cars and railcars. The highest rate of motorization shows that more people afford energy services and also the development of the country. The motorization rate in Pakistan is very low as compared to European countries and other developed nations. The third indicator of energy affordability index is the number of consumers of gas. As the number of consumers of gas increases, energy poverty reduces. The last indicator of this dimension is the real income per capita. When income per capita increases, the households afford to consume more energy services and reduce energy poverty. The real income per capita in Pakistan is very low as compared to developed nations.

The details of all dimensions and their indicators are shown in the below table 3.2 and it is also presented in the flow chart 1.

Table 3.2 Multidimensional Energy Poverty Index (EP)

	Dimensions	Indicators	Data Sources
Energy Poverty Index	Energy Services	Access to electricity, rural (% of population)	WDI*
		Domestic crude oil production (TOE)	WDI*
		Total Energy supply by all sources in KTOE	IEA*
		Energy use (Kg of oil equivalent)	WDI*
		Access to electricity urban (% of population)	WDI*
	Clean Energy	Alternative and nuclear energy (% of total energy use)	PEB*
		Access to clean fuels and technologies for cooking (% of population)	WDI*
		Share of renewable energy (hydro production)	IEA*
		Share of non-renewable energy (coal consumption KTOE)	IEA*
		Biofuels and waste KTOE	IEA*
	Energy Affordability	Registered four wheels out of 1000 people	PBS*
		Registered two wheels for 1000 people	PBS*
		Number of consumer of gas	PEB
		Per capita real income $	WDI*

3.2.1: Schematic Chart of Energy Poverty Index (EPI)



3.7 Energy Poverty Assessment

The present study uses an equal weights strategy and assigns equal weights to all indicators and dimensions. The study uses three dimensions, energy service availability, clean energy, and energy affordability, and each dimension further comprises on several indicators. The aim of assigning equal weights to all dimensions means that each dimension of the present study contributes equally to energy poverty and has equal importance. The first dimension of the study is energy services which includes further five indicators. The (.20) weight is given to all indicators of energy services. The second-dimension clean energy also includes five indicators. The (.20) weights are also given to all indicators of this dimension. The last dimension energy affordability includes four indicators and (.25) weight is given to each indicator of this dimension. The developed index compares and analyzes the situation of energy poverty in Pakistan over a specified period from 1990s to 2019. Each dimension of the study explains some aspects of the energy poverty over time in Pakistan.

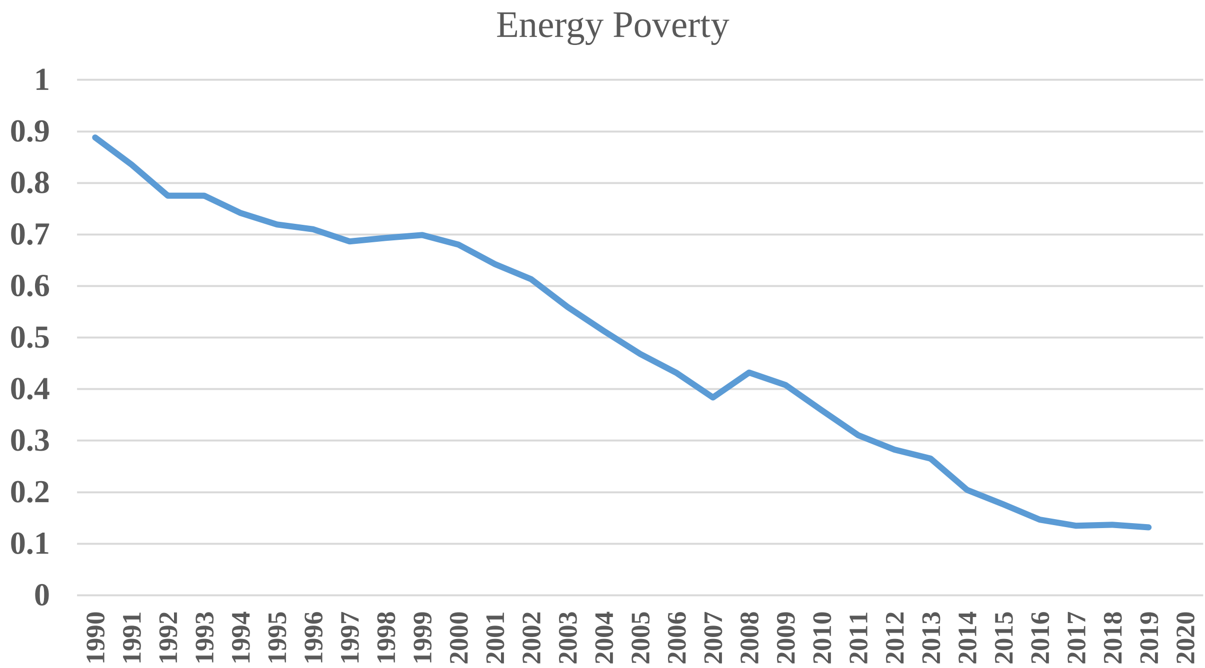
Zhao et al., (2021) measured energy poverty while using energy affordability, accessibility and clean energy in China. Jayasinghe et al., (2021) also measure energy poverty using seven indicators and multidimensions, and assign the weights through PCA analysis in Sri Lanka. Mahmood & Shah., (2017) calculate energy poverty at household level using multidimensions and equal weight strategy in case of Pakistan. Ullah et al., (2021) also measure energy poverty using multidimensions in their study.

The energy poverty index is measured mathematically by the following equation and assigns equal weight to all dimensions of the study.

$$EPt = \frac{1}{3}\{(ES)t + (CE)t + (EA)t\} \qquad (3.2)$$

The energy poverty is estimated by taking the above three normalized dimensions and assigning equal weights to all of the dimensions. The value of energy poverty lies between (0) and 1. The low value indicates a reduction in energy poverty (EP) over time and large the value is the indication of high energy poverty. The energy poverty shown in Figure 3 over time in Pakistan. There is experienced improvement in the reduction of energy poverty in Pakistan over time, but the reduction of energy poverty is not quite quick but experienced slow reduction in energy poverty over time. There is no serious attention given to the energy sector from 1990s to 1999s in the country due to political instability in this period and there were weak democratic governments in the country and no one government's able to complete his/her tenure. During this period the country experienced a worse performance in all macroeconomic indicators including the worse performance in the energy sector and energy poverty didn't reduce quite well. In 1999 that time's Army Chief general Pervez Musharraf dismissed that time elected government due to political instability and took charge of the government and the temporary political stability restored in the country. From the year of 1999 to 2007 there was political instability in the country, but the law-and-order situation started deteriorating due to America's alliance in the Afghan war. This alliance affects the law-and-order situation in Pakistan. Pakistan confronted the threat of terrorist activities in the country and also from the Afghan's border and the governments decided to give more attention towards the defense side and starts working to stabilize the deteriorated law-and-order condition of the country and due to all of these developments the governments took resources from development side towards defense side. Once again energy poverty increased in this period. Aftab., (2014) analyzed the energy crises which started worsening on words 2007 and the country experienced a huge shortfall of electricity due to a sharp increase in the oil prices in the international market and the imported oil bill increased by 36% that affects the generation of electricity in the country. when a general election was held in 2008 and people's party government came to power in the country and Musharraf's regime finished. After all these developments the energy poverty alleviation improved in the country but the reduction in energy poverty is quite low. The 2008 financial crises and increase in oil prices affect the improvement in energy poverty.

Figure 3. Energy Poverty



The weights of all indicators and dimensions are presented in Table 3.3 below. The relationship of energy poverty index with energy dimension is measured by the correlation analysis. The coefficient value of energy services with energy poverty index is 0.95, which shows a very strong association between energy poverty and energy services. The coefficient value of clean energy and energy poverty is 0.93 that is the indication of strong association between the clean energy and energy poverty. The coefficient value of energy affordability and energy poverty index obtained through correlation analysis is 0.96, which shows a strong linear association between energy poverty index and energy affordability. The last column of the following table contains the Cronbach Alpha for dimension and indicators of energy poverty. The value of Cronbach Alpha of dimensions and indicators are respectively equal to 0.913 and 0.63 which indicates a strong consistency and reliability among the dimensions and indicators of energy poverty.

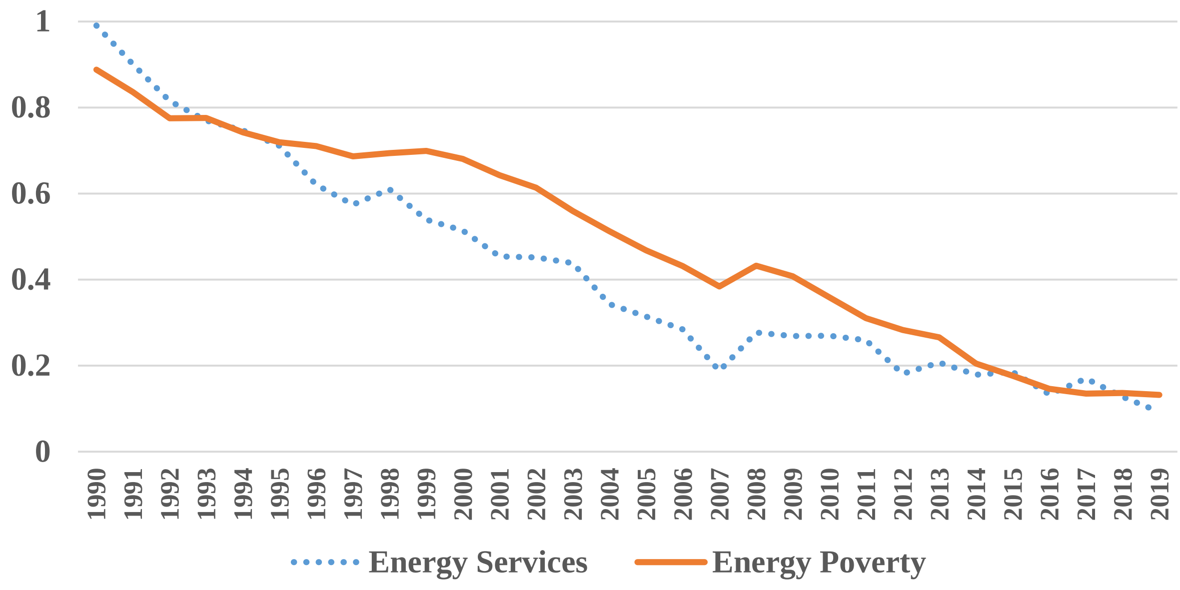
Table 3.3 Weight distribution and Correlation Results

Dimensions	Indicators	Correlation between EP and Dimension	Cronbach Alpha of dimension and Indicators
1/3 (Energy Services)	0.2 (Access to electricity rural (% of population))	0.95	0.913
	0.2 (Access to electricity urban, % of total pop)		
	0.2 (Domestic crude oil production TOE)		
	0.2 (Total energy supply by all sources KTOE)		
	0.2 (Energy use of oil kg equivalent)		
1/3 (Clean Energy)	0.2 (Alternative and nuclear energy (% of total energy use)	0.94	0.63
	0.2 (Access to clean fuels and technologies for cooking (% of total population)		
	0.2 (Share of non-renewable energy (coal))		
	0.2 (share of renewable energy (hydro production))		
	0.2 (biofuels and waste KTOE)		
1/3 (Energy Affordability)	0.25 (Registered four wheels out of 1000 people)	0.96	
	0.25 (Registered two wheels out of 1000 people)		
	0.25 (Number of gas consumers) 0.25 (Real income per capita)		

3.7.1 Energy Services and Energy Poverty

The provision of energy services to whole population is the challenging task for any government. The availability of energy services is the key to sustainable development in developing and developed nations and providing energy services at affordable prices in developing nations is another issue due to low income per capita and inefficient appliances of energy services. The welfare of society is related to the easily availability of energy services while unmaintainable availability of energy services for daily use at micro and macro level effects the living standard of people and also affects the economic growth of the nation, (Latief et al., 2020). The relationship of energy poverty to energy services is depicted in Figure 3.1. The energy situation of Pakistan is not up to the level as compared to other South Asian countries and developed nations due to less investment in the energy sector from the 1990s up to now due to political instability and less resources for the production of new projects. The trend can be observed from the above figure 3.2 but the reduction process is very slow because non-government was stable and there persist high level of political instability in the country from time to time. There was no mega project started from the year 1991 to 1999. All of the macroeconomic indicators experienced worse downward trend in this decade and along with it badly affects the energy sector of economy and most of the rural areas of the country was deprived from the basic lighting and heating facility. When the Nawaz Sharif government was not letting to complete its tenure due to prevailing political instability in the country and that times Army Chief, General Musharraf imposed the emergency in the country on 14th October 1999. The country experienced the political instability from 1991 to 2005 but the country law and order situation start deteriorating on wards and the country victimized of terrorism onwards. At the same time inadequate investment in the energy sector leads to increase the energy poverty in the country. The country confronted the threat of terrorism from the outside and within the country. The governments gave less attention towards the energy sector and diverted the budget from the development projects towards the defense side and from that time the shortfall of energy increased over time. In 2014 the Prime minister Nawaz Sharif inaugurated the Thar Coal Project to meet the needs of energy services. This project approximately adds 660-megawatt (MW) electricity to the national electricity grid. The trend shows very strong correlation in the last two decades of energy poverty with energy services and contributes towards a reduction in energy poverty.

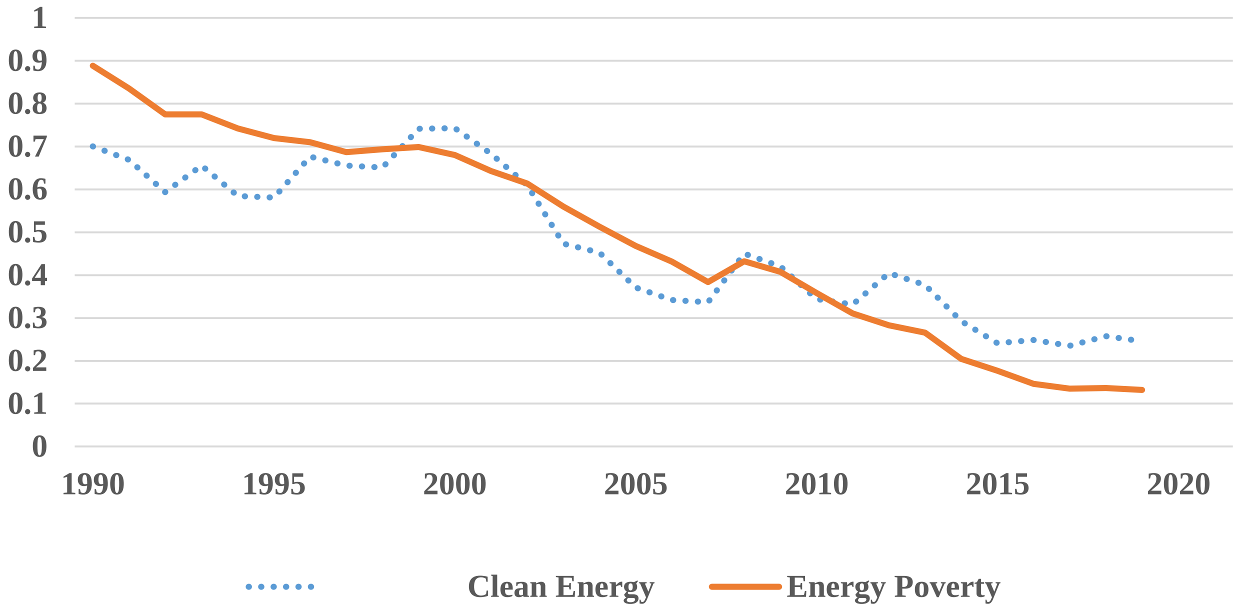
Figure 3.1 Energy Services and Energy Poverty



3.7.2 Clean Energy and Energy Poverty

The provision of clean energy is considered as the key factor in reducing the CO_2 emission and also helps in meeting the needs of energy. Clean energy is the most suitable source of energy in developed nations, and they are still working to produce more clean energy to reduce the environmental degradation in the world. There has been tremendous work done in the sector of clean energy in European and other developed nations in the world, but the situation is quite opposite in developing nation because first the developing nation has lack of access to energy services, and secondly if they have some energy in the national grid, most of them are produced from the fossil fuels (dirty energy). It is considered essential in today's world to produce more clean energy to fulfill the demands of energy due to severe environmental degradation by the emission of greenhouse gasses (GHG). Taking the case of Pakistan, the Figure 3.2 shows a relationship of clean energy with energy poverty which shows that in the last two decades a serious attention has been given to clean energy. The depicted graph of two variables presents a satisfactory behavior since 2008. The increasing demand of energy services in the last two decades compelled the concerned authorities to heavily rely on the national and international independent production (IPPs) to meet the dire need of energy to decrease the shortfall of energy services and did not work to add more energy in long term and only tries to minimize the energy shortage in the short run. All of the IPPs produce electricity from imported oil which severely degrades the environment and all of the people in rural areas of Pakistan are relying on the biomass for lighting and use wood and cow dung for cooking purposes. The fossil fuel share in electricity generation is almost 50 % of the total generation and the share of renewable energy (nuclear and other clean energy sources) sources is very low, Abbasi et al., (2020). The cost of wrong policies severely damaging the environment and more addition of greenhouse gases (GHG) into the atmosphere. The trend in environmental degradation started when the government started the projects of energy that were the part of China Pakistan Economic Corridor (CPEC) and energy produce from these projects mostly relying on imported oils and coal. The addition of clean energy into the total energy mix is the key to sustainable development for the economy in Pakistan.

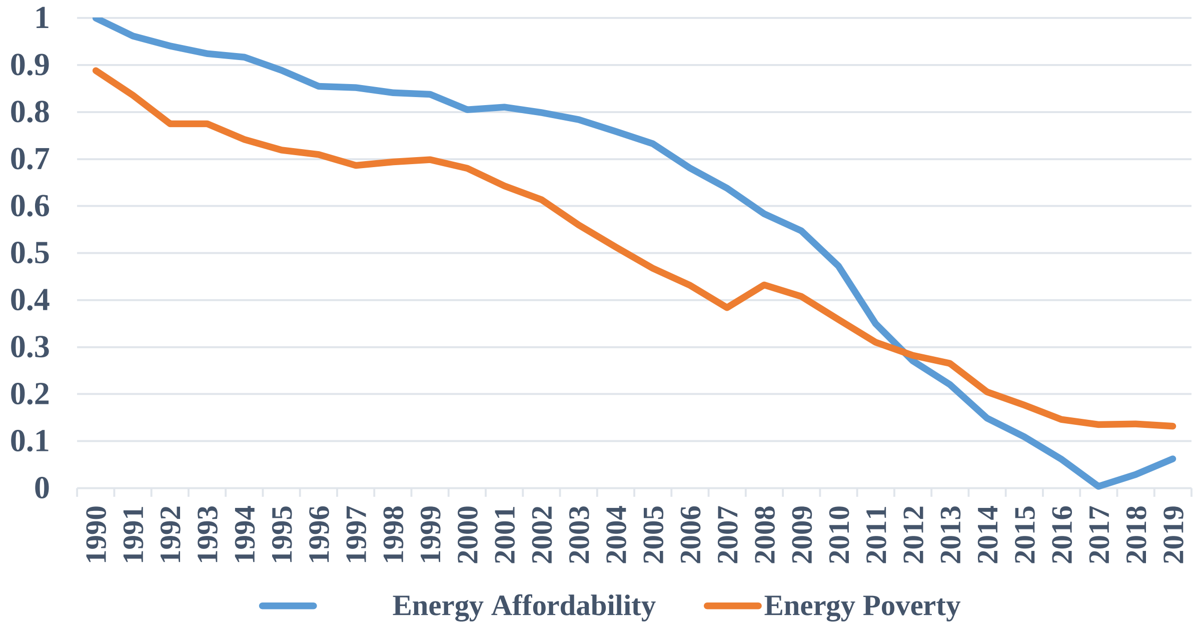
Figure 3.2 Clean Energy and Energy Poverty



3.7.3 Energy Affordability and Energy Poverty

The last dimension of the index is energy affordability relationship with energy poverty is depicted in Figure 3.3. This dimension shows an improvement over time since 1990s to 2019. This improvement is due to an increase in the demand for two wheels and four wheels, better roads, efficient cars, improvement in the standard of living and high population growth.

Figure 3.3. Energy Affordability and Energy Poverty



3.8 Data normalization

Normalization is a process through which the range of data is set between 0 and 1 or it may be set between -1 to 1. The normalization is applied to the data having different features and it gives better results when there is no outlier in the data, Ali., (2012). This study uses time series data from the year 1990 to 2019. The study estimates energy poverty, using three dimensions and 14 indicators. All indicators are not of the same scale and all of the indicators have a large set of data. To reduce the dimensionality of the large data set to smaller one and homogenous scale, data normalization is applied to all dimensions. The following two formulas are used for normalization of data, (Ullah et al., 2021); Wang et al., 2015).

$$\text{Benefit: } X_t^i = \text{Max}x_t^i\text{-}x_t^i \text{ / Max}x_t^i\text{- Min}x_t^{i*}$$

$$\text{Cost: } X_t^i = x_t^i \text{ - Min}x_t^i \text{ / Max}x_t^i\text{- Min}x_t^{i*}$$

Where the X_t^i is normalized value and small x_t^i is the actual value in the date set of x variable and i* represent the indicators (i*= 1,2,3,…..2019). The value obtained after normalization is free scale and homogenous. The value of normalized date lies between zero and one ($0 \leq X_t^i \leq 1$).

3.9 Weight Distribution

The next task after normalization of all indicators is assigning the weight distribution to all indicators of each dimension and the next stage is to assign weight to each dimension. There is enormous literature on the weight distribution to each indicator and dimensions. Further the weight distribution depends on the objective measurement of the index. Mahmood & Shah., (2017) estimates energy poverty in Pakistan, the study uses unequal weighted methods to each dimension on the basis of importance. Awaworyi Churchill & Smyth., (2020) follows the framework of Alkire equal weights to all indicators of objective measure of energy poverty. Jayasinghe et al., (2021) estimate energy poverty in Sri Lanka following first equal weighted method and secondly adopting the principal component analysis (PCA) to allot weights on the bases of importance itself by the technique. Greco et al., (2019) use the equal weights to all indicators and the next step after assigning the weights is to get index value by the aggregation method.

Study uses equal weights for three dimensions of energy poverty index. Equal weights show the unbiasedness towards any specific dimension. Moreover, weight based composite indexing approach is widely used in time series data like, UNDP is continuously using weight strategy in case of HDI. Principal component analysis and factor analysis are generally used in cross sectional data and these two approaches are dependent on the nature of data set.

3.10 Research Methodology

Research methodology is referred to the process or procedure that is used in research conducting. It helps in identifying the research process and overall information regarding the research issue. It helps to solve research problems in a systematic way and confirms overall reliability and validity of research issues. It more specifically prescribes the methods through which research is conducted and further comprises of the techniques followed in analyzing data and interpretation of the data. There are usually two approaches, quantitative and qualitative approach that are used in research conducting, Gounder., (2012). Kothaari., (2008) explains research methodology in his book named research methodology as the systematic way, through which a researcher solves and understands the research problem and discusses that a methodology is wider than research method.

There are mainly two methods in the research process which are quantitative methods and qualitative methods.

Quantitative research tries to investigate the observable phenomenon through numerical data collection or through some statistical and mathematical tools. It collects information about numerical numbers and logic and converts the gathered information to some numeric numbers. The quantitative research is mainly based on the paradigm of positivism. The quantitative research easily quantifies the data and generalizes the results of the sample to inference the whole population. This method tries to explain the relationship among the variables and their cause and effect with the usage of some statistical tools. The data gathered through this method is easily presented in the form of charts, tables and graphs and the nature of the data is measurable and comparable. It deals with hard facts and statistical data. The sample selects through random process from the population and uses the deductive reasoning to arrive at some conclusion. Quantitative research based on the objective approach. The quantitative research may be in the form of survey research, experimental research, and causal relationship, Apuke., (2017).

The qualitative research is concerned about obtaining non-numeric data from the respondents through questionnaires, interviews, diaries, and direct observations and analyzes the non-numerical data (text, audio and videos) to understand the nature of the data and purely qualitative phenomenon. Qualitative research tries to explore human behavior and measures it through a subjective approach. It deals, why and how the behaviors change or happens and uses inductive reasoning to arrive at some final conclusion, Mohajan., (2018). Busetto et al., (2020) define it as the qualitative phenomenon and the data comprises of words rather than some numeric number and the information that is gathered are recorded into procedures while using the qualitative management software for coding of the data.

The research process is usually based on the common assumptions about the complete data collection process. This research study uses the quantitative method. More specifically studying the effect of energy poverty on carbon dioxide (CO_2) emission, the quantitative method is considered as the most effective method from the statistical point of view, where world development indicators (WDI), Pakistan bureau of statistics (PBS), and international energy agency (IEA) have open access for data collection.

3.11 Unit Root Tests

In statistics, the unit root test is basically used for checking the statistical properties of a variable, whether a variable is nonstationary (unit root) in a time series data or stationary. The mean, and variance of non-stationary data varies over time, and one does not predict the behavior of the data while the mean and variance of the stationary data does not change over time but remains constant over time. There are different tests that are used to test the unit root of the variables. Dicky fuller, Augmented Dicky fuller test (ADF), and Philips Perron (PP) etc. are used to check the stationarity of data, Zhong., (2015). This study relies on the Augmented Dicky fuller (ADF), and Philips Perron (PP) test for checking the stationarity of the data.

3.11.1 Augmented Dicky Fuller Test

ADF test is used for testing the stationarity of time series data and it is the modification of the most used Dicky Fuller (DF) test. In 1984 the Dickey fuller test was modified, and it is used for more unknown orders. The ADF test eliminates auto correlation of the data by adding the extra lags of dependent variables and the lag length criterion is selected by Akaike Information Criterion (AIC) or Schwarz Information Criterion (SIC), Paparoditis & Politis., (2018).

ADF test mathematically can be expressed as

$$Y_t = \alpha + \delta Y_{t-1} + \mu_t \qquad (3.3)$$

$$\mu_t \sim^{iid} N(0, \sigma^2)$$

The above equation is AR(1) model, where Y_t is dependent variable, δ is the coefficient term which defines, whether a data has a unit root or not and μ_t is the error term. Subtracting Y_{t-1} from both side of equation 3.3.

$$Y_t - Y_{t-1} = \alpha + \delta Y_{t-1} - Y_{t-1} + \mu_t$$

$$\Delta Y_t = \alpha + (\delta - 1) Y_{t-1} + \mu_t$$

$$\Delta Y_t = \alpha + \rho Y_{t-1} + \mu_t \qquad (3.4)$$

The above equation (3.4) is the Dickey fuller model and expanding the orders of above equation gives Augmented Dicky Fuller (ADF) test. Testing the null hypothesis for the Dickey Fuller.

the null hypothesis H_o : ρ = 0 and alternative hypothesis H_o : ρ = 1 is the Dickey fuller unit root test.

$$\Delta Y_t = \alpha + \rho Y_{t-1} + \beta\Delta Y_{t-1} + \mu_t$$

$$\Delta Y_t = \alpha + \rho Y_{t-1} + \sum_{i=1}^{n} \beta\Delta Y_{t-1} + \mu_t \qquad (3.5)$$

The equation (3.5) is the Augmented Dickey fuller model. Further testing for the unit root if the ρ = 0 has a unit root (non-stationary) is the null hypothesis, the alternative hypothesis is that it has no unit root (stationary).

3.11.2 Philips Perron Test

Phillips Peron (PP) test is the statistical test that are used for testing the unit root of the data of time series and panel data. The name of this test is named after the work by Phillips and Peron in (1988). It is different from the ADF test in treating the heteroscedasticity and correlation in the disturbance term and ignores the correlation in regression. The Phillips Perron test selects the lag length without any specification, (Leybourne & Newbold, 1999; Phillips & Perron, 1988). The Philips Peron test equation is given below.

$$Y_t = \alpha + \rho y_{t-1} + \varepsilon_t \qquad (3.6)$$

Here some corrected form of t test, in order to correct the presence of serial correlation and heteroscedasticity in error terms. Just like the Augmented Dickey fuller test, and it is nonparametric in nature.

3.12 Correlation Analysis

The correlation analysis examines the relationship between two or more than two variables. It measures the degree of relationship between the variables that is under consideration. The correlation may be positive or negative depending upon the relationship between the variables. The coefficients obtained through correlation analysis provide the information about the relationship of two variables. The correlation values lie between 1 and -1. When the value of correlation analysis is -1, indicates a perfect negative link between the variables and +1 shows a perfect positive association between two variables. A coefficient value greater than zero shows positive association while less than 0 shows a negative association between two or more than two variables and when the value of correlation is equal to zero, it is the indication of no relationship between the variables. The value of correlation is calculated by dividing the covariance by its standard deviations, Schober & Schwarte., (2018). The correlation coefficient derivation is given below.

$$\text{Correlation} = r\,(x, y) = \frac{Cov\,(x,y)}{\sqrt{Cov(\,x,y)^2}}$$

$$r = \frac{\rho_{xy}}{2\sqrt{\rho_x \cdot \rho_y}}$$

$$r\,(x, y) = \frac{Cov}{S.D} \qquad (3.7)$$

The formula derived in equation (3.7) gives the coefficient value of correlation of two variables.

3.13 Johansen Cointegration Test

This is a multivariate generalized test that is based on the Ganger's test (1981), and named Johansson after these contributions by the Johansson Soren in (1991, 1992). Johansen proposed the two important tests, namely the Trace Statistics and Maximum Eigen-Value Statistics to test the long run relationship among the variables that are integrated of order one. Johansen Cointegration is useful for larger sample size to gives more reliable results. Johansen test starts with the VAR model and formulates the maximum likelihood and likelihood ratios for Cointegration of vectors and weights, (Johansen & Juselius, 1990). There is no big difference in the results obtained from the Trace Test and the Maximum Eigenvalue test but a trace test in some situations gives a better result in a low power situation. The Johansen cointegration test is helpful in the estimation of cointegrating vectors when the number variables are more than two, (Lütkepohl et al., 2001).

The Johansen Cointegration is used when all the variables are integrated of order 1, means all of the variables are stationary at first difference and does not apply, if any variable of the study is stationary at level. The null hypothesis is that there is no Cointegration equation, and the alternative hypothesis is that there is Cointegration, rejecting the null hypothesis at 5% critical value otherwise the null is accepted

Chapter 04

Results and Discussion

4.1 Introduction

Results and their discussion is the backbone of any research in real terms. On the basis of results, one can validate the theory or hypothesis. This chapter contains the empirical findings and discussion. Results start from descriptive analysis then move toward modern technique based on inferential analysis. The discussion is basically the interpretations of the findings of the study. The empirical results are obtained through the Johansen Cointegration technique. This chapter also revise the research question of the study. Result and discussion combine to give the brief detail of achieved results.

The first section 4.1 consists of the introduction of the chapter. The section 4.2 discusses the descriptive statistics of the data. The section 4.3 checks the unit root of the data through Augmented Dickey Fuller and Phillips Perron tests. The section 4.4 discusses the results of correlation matrix. The section 4.5 checks the lag length selection for the model. The section 4.6 discusses the result of the Johansen Cointegration test. The section 4.7 consists of the long run and short run results of the vector error correction model and also the verification of the Environmental Kuznets curve.

4.2 Descriptive Statistics

Descriptive statistics are selected statistical properties of the selected sample of the data that is used in the present study. The descriptive statistics gives a good quantitative description of the data and provides the information of the total population, from which the sample is selected. Descriptive statistics simply provides normalization of data, distribution of data, summarization of data, presentation and also analysis of the data. It is mainly used in non-experimental research. The descriptive statistics broadly deals with central tendency-dispersion of the data, and normality of the data. Mean and median show the center of the data. The dispersion is measured by the standard deviation and symmetry of the data is measured by the skewness and kurtosis, (Marshall & Jonker., (2010). Following Table 4.1 contains the descriptive statistics of the variables of the model of contemporaneous study.

Table 4.1 Descriptive Statistics

	CO_2 (Kilo tones)	EP (index)	GDP (Current US$)
Mean	123033.8	0.49	143000000000
Median	120160.0	0.49	11400000000
Minimum	218445.0	0.89	315000000000
Maximum	60310.00	0.13	40000000000
Std. Deviation	43219.10	0.24	90100000000
Skewness	0.5	1.7	0.54
Kurtosis	2.474059	2.2	1.86
Observations	30	30	30

The time span of data is 30 years. from the 1990s to 2019. The data of CO_2 and income is simply taken from WDI while the energy poverty is calculated through an index. The mean, median, minimum, maximum, standard deviation, skewness and kurtosis are presented for three variables of the study. The mean of CO_2 is 123033.8 kilo tones which shows the center of data and the value of standard deviation of carbon dioxide is 43219 kilo tones that shows the spread of the data from the mean. The skewness value of CO_2 is 0.5 kilo tons which confirms that the data behaves rightly skewed. The kurtosis value of CO_2 is 2.47 kilo tons means that the data is distributed at tails. While the mean and median values of energy poverty are 0.49 that shows the center of data and standard deviation 0.2388 which shows that there is less variability in the energy poverty from the mean over time. As the value of the index ranges from zero to one after normalization of all indicators of the index. So, in such circumstances, the value of standard deviation of energy poverty index may not have direct implications unless this reduction from value is deeply explored for each indicator. The value of skewness and kurtosis of energy poverty exhibit that the data has a symmetrical shape and normal distribution. The mean value of gross domestic product is 143000000000 $. The median value of gross domestic product is 11400000000 $. The standard deviation value of gross domestic product is 90100000000 $, which shows dispersion from the mean value in data. The maximum value of GDP is 40000000000 $ and minimum is 90100000000 $ and it shows how much change in total GDP over time. As it is anticipated that low level of GDP was in 1990 and the high level of GDP in 2019. The value of skewness is 0.54 $ that means the data which indicates that date is skewed moderately, and kurtosis specifies a normal distribution. The CO_2 emission is measured in kilo tons, gross domestic product is measured in current US dollar and energy poverty is measured through index.

Descriptive statistics deals with the behavior of single variable like; mean, standard deviation, range etc. So, the descriptive analysis does not explore the relationship between two variables. In the following section, correlation analysis is discussed. Coefficient of correlation tells the linear association between two variables and its magnitude vary from minus one to plus one. If both variables are independent, then correlation coefficient is simply zero. If the value of correlation is close to one, it shows a strong positive relationship between two variables. If the value is close to zero, it means no relationship between the two variables.

4.3 Correlation Matrix Analysis

Correlation matrix analysis has a very important role in multivariate analysis. It shows the relationship among the variables. When the value of coefficient is zero, it means no relationship between variables. When the coefficient value is equal to 1, it means perfect correlation between variables. If the coefficient value is negative, it shows the negative relationship. The positive coefficient value shows a positive relationship between the variables. The correlation depicts the relationship among variables pairwise in a table, (Gia & Choulakian., 2014). The pairwise results of Carbon dioxide, energy poverty, log of gross domestic product presented in the table 4.2. The value of coefficient of correlation between energy poverty and CO_2 emission is -0.96 which shows high negative relationship between the variables. The negative sign indicates that a decrease in energy poverty leads to increase in CO_2 emission in Pakistan because the total share of dirty energy is more than clean energy and mostly depends on the non-renewable energy. The coefficient value of gross domestic product is 0.95 shows a strong association with CO_2 emission.

Table 4.2 Correlation Analysis

	CO_2	EP	log(y)
CO_2	1.00		
EP	-0.96	1.00	
Log(y)	0.95	-0.99	1.00

It is clear from the descriptive statistics that all of the variables of the study show normal distribution and there is no outlier in the data that affect the outcomes of the study. Further the value of standard deviation indicates that the nature of data varies over time which indicates a trend in the data. The standard deviation indicates that data varies from the mean. Time series data contains four types of issues like seasonality, time trend, inertia and irregularities. While these four issues may be source of non-stationarity. The next task is to test the unit root. The next step after the descriptive statistics of all the variables is to check the unit root of the variables.

4.4 Unit Root Test

There are many test that are used to test stationarity of time series data like Dickey Fuller test (DF), Augmented Dicky Fuller (ADF), Philips Peron (PP), Schmidt-Phillips test and Elliott-Rothenberg-stock test but the present study uses ADF and, Phillips Perron (PP) tests are used to test the unit root of variables of model, (Schwert., 2002). In simple words, unit root test is observing the behavior of a series in the form of mean, variance, and standard deviation (Kim & Choi., 2017). If the mean and variance of the series are time invariant, then it is supposed to be a stationary series. On the other hand, if mean or variance or both vary with respect to time then such a series is considered to be non-stationary in nature. In the classical linear regression model, it is assumed that data of all the variables of model are stationary. If data is stationary, then simple Ordinary Least Square (OLS) provides best values of coefficients. If a single variable is found nonstationary then the value of the parameter will not qualify the test of BLUE. So, for this purpose, the present study applies the Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests to examine the unit root or stationary of the data. The results for unit root test of dependent, explanatory variable and control variable are reported in the below Tables.

4.4.1 Results of Augmented Dickey Fuller Test

Augmented Dickey Fuller (ADF) test is a statistical test that is used for testing the unit root in a series. ADF test is performing well in case of time series data, (Harris, 1992). The results of Augmented Dickey Fuller carbon dioxide (CO_2), explanatory variable energy poverty (EP), and gross domestic product (GDP) are presented in Table 4.3. EP contains the unit root al level that means a non-stationary. After that take the first difference and test the unit root again through ADF. At first difference EP becomes stationary at 1% level of significance. On the same vein CO_2 also contains the unit root at level and becomes stationary at first difference at 1% level of significance. The log of gross domestic product is also nonstationary, at level and becomes stationary at first difference at 1% level of significance. From the result of Augmented Dickey Fuller, it is clear that all of the variables of the model are stationary at first difference which gives the indication to apply the Johansen Cointegration test to test the long run relationship or cointegration among economy wide CO_2 emission, energy poverty, and income.

The next task is to test the unit root of the variables of the model through the Phillips Perron (PP) because this is useful in non-parametric and does not depend on the serial correlation, but the ADF requires the serial correlation. It also makes correction of t statistics to do heteroscedasticity and autocorrelation.

Table 4.3: Results of ADF Unit Root Test

Variables	Intercept		P-Value	Remarks
	Level	1^{st} difference		
Energy Poverty	-0.70	-4.42	0.0017	I(1)
Logy	-1.67	-4.75	0.0037	I(1)
$Logy^2$	-1.71	-4.67	0.0044	I(1)
CO_2	-1.66	-4.49	0.0016	I(1)

4.4.2 Results of Phillips Perron Test

The unit root of the variables is also checked by the Phillips Perron test, after applying the ADF test. The PP test is applied to all variables of the study. This test is used to test the unit root of time series analysis and correct the t statistics. The null hypothesis of this test hypothesized a unit root and alternative hypothesis reject the null hypothesis on the basis of P value, (Leybourne et al., 2016). The energy poverty has a unit root at level and rejected the null hypothesis at first difference at 1 percent level. The dependent variable carbon dioxide was not stationary at level and became stationary at 1 percent after applying the first difference. The log of gross domestic product was also non-stationary at level and became stationary at first different at 1 percent level. Similarly, the log of gross domestic product square was not stationary at level and became stationary at 1 percent level, after checking it at first difference. The results of the PP test for all the variables is shown in Table 4.4. The results of PP also reveal that all the variables are integrated of I (1) and from the result we conclude to use the Johansen Cointegration test to verify the long run relationship among the variables.

Table 4.4 Results of Phillips Perron Test

Variables	Intercept		P Values	Remarks
	Level	1st difference		
Energy Poverty	-0.701	-4.40	0.0018	I (1)
Logy	-1.67	-4.66	0.0045	I (1)
CO_2	1.357	-3.69	0.0100	I (1)

All variables of the model are integrated of I (1) that is a clear indication to use the Johnsen Cointegration test. The Johansen Cointegration test is applied when all the variables are stationary at first difference. The Johansen test shows the long run relationship among the variables.

4.5 Lag Length Selection Criterion

The selection of lag length is considered an important criterion in the process of Vector autoregressive (VAR), and auto regressive and distributed lag model (ARDL) in a time series analysis. Determination of lag length is a difficult process in the modeling and determination of lag length by itself reduces the precision of the result, (Asghar & Abid, 2007). The selection of lag length is mostly selected through Akaike's Information criterion (AIC), likelihood ratio

(LR) test statistics, final prediction error, Schwarz information criterion (SIC), and Hannan-Quinn information criterion.

Table 4.5 Lag Length Selection Criterion

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	-197.28	NA	20.61	14.37	14.56	14.43
1	-54.48	234.59*	0.002*	5.32*	6.27*	5.61*
2	-44.82	13.10	0.004	5.77	7.48	6.297

The Akaike information criterion (AIC), LR test statistics, final prediction error (FPE) and Hannan-Quinn information criterion, and Schwarz information criterion (SIC) suggest 1 lag order for the vector error correction model. The sign (*) indicates the suitable order of lag by the different test.

4.6 Johansen Cointegration Test

The variables of the study after applying the Augmented Dickey Fuller test and Phillips Peron test for unit root show that all of the variables of the study are stationary at first difference or integrated of order I (1) which is the prerequisite condition of applying Johansen Cointegration test. The Johansen Cointegration test is used for the analyzes of long run relationship among the variables, (Hjalmarsson & Osterholm., 2010). The vector auto regressive model (VAR) is estimated, and this model considers all the variables as endogenous. The lags are chosen after testing the lag order of variables through different criterions and most of them suggest taking one lag length for the analysis. The Johansen Cointegration has two test such as Trace Statistics and Maximum Eigenvalue test that test Cointegrating equation among variables. The result of both Trace statistics test and Maximum Eigen test are presented in Table 4.6 and Table 4.7 respectively.

Table 4.6 Trace Statistics

Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	0.05 Critical Value	p-value
None*	0.66	57.90	47.85	0.0043
At most 1	0.47	27.65	29.79	0.0866
At most 2	0.28	9.40	15.49	0.3291
At most 3	0.001	0.01	3.84	0.9535

The Trace statistics result indicates one cointegrating equations because at None* the trace statistics value is greater than at 0.05 percent critical value and its p-value is also 0.0043 and rejects the null hypothesis at 5 percent level which verifies the long run relationship of CO_2 emission, energy poverty, and gross domestic product. The next task is to verify it through Maximum Eigen-Value statistics.

Table 4.7 Maximum Eigenvalue

Hypothesized No. of CE (s)	Eigenvalue	Maximum Eigen Statistic	0.05 Critical Value	p-value
None*	0.66	30.24	27.58	0.0222
At most 1	0.47	18.24	22.13	0.1218
At most 2	0.28	9.40	14.26	0.2541
At most 3	0.001	0.003	3.84	0.9535

The Maximum Eigenvalue statistics also indicates one Cointegrating equation because the value of Maximum Eigen Statistic is greater than 0.05 critical value and p-value is also less than 0.05 so rejected the null hypothesis of no Cointegrating equation.

The findings of Trace Statistics and Maximum Eigenvalue Statistics tests confirm the long run relationship exists among the variables. The results propose the long relationship of carbon dioxide (CO_2) emission, energy poverty (EP), and log of gross domestic product support the result of, Haleem et al., 2020). On the basis of these results, the next task is to use the vector error correction model (VECM) to test both the long run and short run relationship among the variables.

4.7 Long Run and Short Run Results

The long run and short run results come after when the Johansen Cointegration relationship is established. The most important task after the establishment of Cointegration is to estimate the long run and short run effect of energy poverty (EP), log of gross domestic product (LGDP) and log of gross domestic product square $(LGDP)^2$ on the carbon dioxide (CO_2) emission for the period of 1990s to 2019. The long run result for the energy poverty, log of gross domestic product and square of log of gross domestic product are presented in the Table 4.8 below and the long run model is also given below.

$$CO_2 = 24.84 - 0.47EP + 3.9LGDP - 0.15LGDP^2$$

Table 4.8 Long Run Results

Dependent Variable CO_2	Coefficient	Standard error	t statistics
EP	-0.47	0.18	-2.61
LGDP	3.9	0.76	5.20
$LGDP^2$	-0.15	0.035	-4.33
R-Squared	0.932	**Adjusted R-Squared**	0.927
F-Statistics	12.99	Prob. 0.0010	
Obs* R-Square	29.17	Prob. 0.063	

The Breusch Godfrey LM test is used for the identification of serial correlation in the error terms. If serial correlation exists, then the model is not a good fit, having no serial correlation indicates that a model is good. The null hypothesis of this test is that there is no serial correlation. The value of p of observed R-Squared is greater than 0.05 that means there is no serial correlation. The results are presented in the below table 4.9.

The results of the long run are reported with reverse signs in the above Table 4.8 (Sims., 1980). There exists a long run relationship between energy poverty and GDP and GDP^2. Energy poverty has a very strong and negative relationship with CO_2 emission in Pakistan. The energy poverty coefficient indicates that a one-unit decrease in the normalized value of energy poverty leads to an increase in CO_2 emission by 0.47 kilotons. When there is one US$ increase in the gross domestic product leads to an increase of CO_2 emission by 3.6 kilotons. This number comes from the simultaneous effect of GDP and GDP^2. The findings of the study (Zhao et al., 2021) contradict with the current study which checked the impact of energy poverty on the CO_2 emission in China. Zhao et al., (2021) show that those regions of China where energy poverty rate is low, the CO_2 emission is low, and more emission is observed where energy poverty rate is high. From the result, it is clear that decreasing energy poverty overtime in Pakistan causes more carbon emissions. It means there is a major share of dirty energy into the energy mix of Pakistan. Pakistan is producing most of its energy from non-renewable resources which causes more CO_2 emission in the country. In recent, Pakistan has implant a new coal project to increase energy supply. On the other hand, most of the rural population depends on the traditional biomass that leads to increase the CO_2 emission.

The long run results verified the Environmental Kuznets Curve behavior between income and CO_2 emission for the Pakistan economy. The result shows that the growth of gross domestic product (GDP) has a positive effect on the CO_2 emission, supporting the result of (Khan et al., 2020). This means that an increase in economic growth increases the CO_2 emission. The confirmation of EKC is proved by the negative sign of coefficient of the gross domestic product square (GDP^2). The negative coefficient of economic growth square indicates a negative relationship of economic growth square with CO_2 emission. The results confirm an inverted U-shaped curve for the economy of Pakistan and support the result of, Dinda., (2004). Nazir et al., (2018) also verifies the environmental Kuznets and relationship energy consumption with CO_2 emission for the case of Pakistan. The study measures the environmental Kuznets curve (EKC) by looking at the emission of CO_2 with economic growth in the case of Pakistan and also finds that an increase in energy consumption accelerates the economic growth.

Table 4.10 Short Run Results

Dependent Variable CO_2	Coefficients	Standard error	t Statistics
ECM (-1)	-0.079	0.011	-7.18
D (CO_2 (-1))	-0.44	0.36	-0.12
D (EP (-1))	0.54	0.058	0.93
D (GDP (-1))	0.77	1.7	0.43
D (GDP^2 (-1))	-0.035	0.08	-0.43

The short run result is much different from the long run result of this study. The short run result of CO_2 emission, energy poverty, log of gross domestic product and log of gross domestic product square are statistically insignificant. The coefficient of error correction mechanism/term (ECM) is low magnitude which shows low adjustment towards the long run equilibrium after an exogenous shock in the short run. At the same time the error term is statistically significant. These results confirm that energy poverty does not affect the carbon dioxide emission in Pakistan in the short run. Similarly, the GDP of Pakistan does not affect the CO_2 emission in the short run. The short run analysis of the study estimated through error correction model (ECM) analysis. The ECM (-1) coefficient is equal to -0.079 that shows the speed of adjustment from short run to the long run equilibrium after an exogenous shock. The signs of coefficient of energy poverty confirms statistically insignificant but positive relationship between energy poverty and CO_2 emission in the short run. The short run result is not significant. The result shows that in the short run the economic growth has no influence on the carbon dioxide emission or environmental degradation as economic growth is the long run phenomena.

Chapter 05

01 Conclusion and Policy Recommendations

The accessibility to clean energy at affordable prices is key towards sustainable economic growth and climate change. According to (IEA, 2019) at global level still about 759 million have no access to electricity and about 2.6 billion people have no access to clean energy for cooking purposes. The situation of electrification and accessibility is very different among developed and developing nations. As in Pakistan 26.7% of the population have no access to electricity while 54% of the whole population are suffering from the lack of clean energy sources for cooking facilities (IEA, 2019). The accessibility to electricity and clean energy for cooking purposes are worse in the rural areas of Pakistan but the improvement is experienced in the urban areas of Pakistan. Low rate of affordability and accessibility to energy sources are signals of economic and energy poverty. In further investigation, economic poverty as well as energy poverty are relatively high in rural areas as compared to the urban areas in case of Pakistan.

Present study aims to assess energy poverty by using a multidimensional index approach in Pakistan. According to our best knowledge, empirical literature is lagging off in case of Pakistan in which energy poverty is measured and then investigates its impact on environmental degradation. It is an economy- wide time series data-based investigation in which data is used from 1990 to 2019. Many studies estimated the energy poverty at micro level and even a single study did not estimate the overall situation of energy poverty and environmental situation at macro level. The study examined energy poverty through via accessibility and affordability. The study further focuses to analyze the impact of energy poverty reduction on the emission of carbon dioxide (CO_2). Contemporaneous study selects three dimensions, energy service availability, clean energy, and energy affordability respectively, and fourteen indicators to assess the energy poverty. All of the indicators are made homogenous by data normalization process and further use the equal weight strategy to give equal importance to all dimensions of the study.

The study experienced a downward trend in the energy poverty from the 1990's to onwards with some fluctuation. The overall situation of energy improvement has been observed during this time period. The accessibility of energy services has improved in the selected period but the share of clean energy to total supply of energy is negligible, which is a serious threat to environmental quality. The energy affordability also improved in the entire period due to efficient appliances, increase in the demand of vehicles. The trend reverses in 2006 when energy poverty goes high in this time due to deteriorated law-and-order situation within the country and facing the external challenges at eastern and western borders of the country, compelled the government to reduce the development budget and estimated more amount to defense that leads to widen the gap between demand and supply of energy services. This situation is worsted in 2008 when the prices of oil increased in the international market due to increase in the bill of imported oil, then again from 2009 onward to 2012 experienced a downward trend in the energy poverty but in 2013 once again an upward trend observed in the energy poverty due to political development in the country and general election of 2013. From 2014 to 2018 the energy situation improved in this period because the government started new energy projects to enhance the energy supply in the country and some projects were part of China Pakistan Economic Corridor (CPEC).

CO_2 is the dependent variable, while energy poverty is an independent variable obtained through index and gross domestic product. The mean and standard deviation shows that a data has a variant nature and nonstationary behavior. Then the present study uses the ADF and PP test to test the unit root of variables of the model.

The R^2 explained the reliability of the model. The value of R^2 equals to 0.92 which indicates that CO_2 emission is best explained by explanatory variables. Serial correlation is tested by using Breusch Godfrey serial correlation LM test and no serial correlation found in the data.

The result of ADF and PP tests shows that all of the variable of the study are integrated of order one which prefers the use of Johansen Cointegration test for the confirmation of long run relationship among carbon dioxide CO_2, energy poverty (EP), log of gross domestic product (LGDP) and log of gross domestic product square ($LGDP^2$). After the confirmation of the long run relationship, applied the vector error correction (VEC) model. The long run result is statistically significant and has a negative relationship of carbon dioxide (CO_2) emission with energy poverty (EP). One-unit decrease in the normalized value of energy poverty (EP) leads to an increase in the emission of CO_2 by 0.47 kilotons. Similarly, one percent increase in the gross domestic product (GDP), increases the emission of CO_2 by 3.6 kilotons. The short result is not significant and short run equilibrium takes much time to deviate to the long run equilibrium. The study verifies the hypothesis of the environmental Kuznets curve (EKC). The sign of economic growth is positive and negative sign of the coefficient for economic growth square which confirms the environmental Kuznets curve.

There is need of policies that government and policy makers must adopt to rise the amount of clean energy in the overall mix of total energy and brings improvements at accessibility level by producing more clean energy through renewable resources and less the reliance of people at micro and macro level on the traditional biomass such as wood, coal and animals dungs etc. that may reduce the environmental air pollution. The renewable source of energy is the cheapest source of energy for developing nations in recent times. It is the dire need of time that the government must invest in the projects of renewable resources to produce cheap and environmentally friendly energy and reduce the carbon dioxide CO_2 emission. The government of Pakistan must provide electricity to remote rural areas and gas connection to reduce the environmental pollution.

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