A study on the Sustainability of Renewable Energy

Thesis

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By

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Candidate's Declaration

I, hereby, certify that the thesis titled "**A study on the sustainability of Renewable Energy**" and submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy is an authentic record of my research work carried out under the guidance of Prof. Nand Kumar.

The matter presented in this thesis has not been submitted elsewhere in part or fully to any other university or institute for the award of any degree.

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Certificate

This is to certify that the thesis titled "**A study on the sustainability of Renewable Energy**" submitted by **Shweta Kumari (2K19/PHDHUM/503)** in fulfilment of the requirements for the award of the degree of Doctor of Philosophy is an authentic research work carried out by her under my guidance and supervision. The contents embodied in this thesis had not been submitted by her earlier to any institution or organization for any degree or diploma to the best of my knowledge and belief**.**

Prof. Nand Kumar
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...It is impossible to start....

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For any error or inadequacy that may remain in this work, the responsibility is, of course, solely mine.

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ABSTRACT

Renewable energy sources and associated technologies are regarded as clean resources since they minimise negative environmental effects and generate little secondary waste when used to their full potential. In addition, these sources can be maintained in light of present and foreseeable socioeconomic needs. The major environmental issues brought on by the rising commercial energy demand have sparked interest in the study of renewable energy sources. Energy available from the sun and wind are not only inexhaustible, but also environment friendly. The Hydropower, Geothermal and Biomass also help to reducing the environmental pollution. The nuclear energy is the most feasible energy source because it is low carbon pollution high thermal energy generation at low waste technology.

Therefore, various renewable energy sources are likely to play a key role in meeting in carbon mitigation to achieve UN net zero carbon emission by 2050.

In this regards the environmental Kuznets curve (EKC) , Fourier ADF, Fourier GLS, Fourier LM, Fourier KPSS, vector auto regression (VAR), Fourier bootstrap Toda-Yamamoto causality test, like Dynamic ordinary least square (DOLS), Fully modified ordinary least squares and wavelet coherence methods have been used.

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Nomenclature

Nomenclature:

α	Deterministic term	n	Time index
β	Estimated parameter	R	Real part of complex variables
γ	Slope Coefficient	S	Smoothing operator
ϑ	Coefficient	S_t	Partial sum of OLS residuals
ε	Error terms	s	Scale
ε_t	Stationary disturbance with variance	t	Time
ω	Estimator	u_t	Stationary error term with variance
C	Cointegration	W	Wavelet
k	Single frequency selected for the approximation	y	Casualty

Acronyms

GDP	Gross development product	CIS	Commonwealth of Independent States
ARDL	Autoregressive Distributed Lag	FMOLS	Fully modified ordinary least squares
FBTY	Fourier Bootstrap Toda-Yamamoto	ECM	Error correction model

EKC	Environmental Kuznets Curve	QLF	Quadratic functional *form*
LPG	liquefied petroleum gas	VECM	Vector error correction model
BRICS	Brazil, Russia, India, China, and South Africa	DOLS	Dynamic ordinary least square
OECD	Organization for Economic Co-operation and Development	OLS	Ordinary least squares
GCC	Gulf Cooperation Council	LM	Lagrange Multiplier
NE	Nuclear Energy	TYGC	Toda-Yamamoto Granger Causality
KPSS	Kwiatkowski–Phillips–Schmidt–Shin	AMG	Classical algebraic multigrid
VAR	Vector Auto Regression	ECM	Error correction model
SO_2	Sulphur dioxide	NOx	Nitrous Oxide
CO2	Carbon dioxide	ADF	Augmented Dickey–Fuller test
GLS	Generalized least squares		

CHAPTER 1

INTRODUCTION

1.1 The idea of Renewable Energy

Sustainable development is described as "development that meets present needs without compromising future generations' ability to meet their own." Sustainable development and sustainable energy are concepts that are inextricably linked. (UN, 1987). To be sustainable, development must be treated holistically, taking into account its social, economic, and environmental components. As a result, in addition to the consequences on the environment, it is critical to address the larger socioeconomic implications of sustainable energy. In a 2019 research, the International Renewable Energy Agency (IRENA) defined sustainable energy as "energy that is produced and consumed in a way that meets the needs of the present without compromising future generations' ability to meet their own needs." This definition underlines the critical importance of balancing energy output and consumption with environmental and natural resource protection for future generations. According to the International Energy Agency (IEA), "sustainable energy is essential for meeting all of the world's energy needs while reducing greenhouse gas emissions and mitigating the effects of climate change." According to the International Energy Agency, "sustainable energy is critical for achieving sustainable development, providing modern energy services for all, reducing air pollution and improving public health, as well as enhancing energy security and resilience." (IEA, 2020).

Energy sustainability is defined by its reliance on clean, renewable energy sources such as solar, wind, hydro, geothermal, and biomass. These energy sources are abundant, widely distributed, and may be used without releasing harmful pollutants or greenhouse gases into the atmosphere. According to a European Commission (2020) assessment, wind and solar energy are the least expensive forms of new electricity generation in most places of the world. Renewable energy relies heavily on energy efficiency. Improving energy efficiency can help us use less energy to meet our demands, reducing the need for new energy generation and lowering greenhouse gas emissions. According to a study published in the Journal of Cleaner Production, "energy efficiency is the most important measure for achieving sustainable energy because it reduces energy consumption, which reduces carbon emissions and other environmental impacts." He and Lu (2019). Another method is to increase energy efficiency. Energy efficiency is the use of technology and other tactics to reduce the amount of energy required to meet human needs. Improving energy efficiency can reduce the requirement for new energy generation and help to reduce greenhouse gas emissions. According to researchers in a study published in the journal Nature Energy, "energy efficiency is a critical component of sustainable energy systems and can significantly contribute to reducing greenhouse gas emissions." Meyers et al. (2020).

Despite this, there are difficulties in implementing renewable energy. Incorporating substantial amounts of renewable energy into the grid, for instance, can necessitate significant changes to the infrastructure and regulatory frameworks that are currently in place, according to a National Renewable Energy Laboratory study published in 2019. According to a study that was published in the journal Energy Policy, "the lack of access to finance and technology, frail institutions, and ineffective policies are major barriers to achieving sustainable energy in developing countries." (Kemausuor et al., 2020). Further challenges to achieving sustainable energy include the need for energy storage solutions to address the intermittent nature of some renewable energy sources, improved grid infrastructure to support the integration of renewable energy sources into the energy system, and increased public awareness and education about the advantages of sustainable energy. All things considered, the idea of sustainable energy is a complicated and multifaceted subject that necessitates careful evaluation of the environmental, financial, and social ramifications of energy production and consumption. We can build a more resilient, just, and sustainable future for ourselves and subsequent generations by adopting sustainable energy.

1.2 The need for the transitions to Renewable Energy

The International Energy Agency (IEA) claims that in order to achieve the Paris Agreement's objectives, which include keeping global warming well below 2°C above pre-industrial levels, a worldwide shift to renewable energy is necessary. To accomplish this goal, renewable energy sources must supply at least 70% of global electricity consumption by 2040, according to the IEA. Researchers, policymakers, and corporate leaders all across the world have publicly recognised the varied and complex need for renewable energy transition. Here are a few of the main arguments in favour of switching to green energy sources:

- **Climate Change**: The use of fossil fuels as the main source of energy, such as coal, oil, and gas, has led to a substantial rise in greenhouse gas emissions, especially carbon dioxide. (CO_2). These emissions are to blame for climate change, which is having disastrous effects on the globe, including rising sea levels, an increase in the frequency and severity of natural disasters, and modifications to weather patterns. Reducing greenhouse gas pollution and mitigating the effects of climate change require a shift to renewable energy.
- **Energy Security**: Access to affordable energy is a key component of both national and economic security. However, relying on fossil fuels for energy output makes nations susceptible to changes in the price of crude, interruptions in supply, and geopolitical unrest.

Countries can lessen their reliance on foreign fossil fuels and increase their energy security by switching to renewable energy sources.

- **Effects on Public Health and the Ecosystem:** The use of fossil fuels has detrimental effects on both the ecosystem and public health. Along with CO2, hazardous pollutants like sulphur dioxide, nitrogen oxides, and particulate matter are also released when fossil fuels are burned. These pollutants have been linked to cancer, heart disease, and respiratory issues. The extraction and transportation of fossil fuels can also hurt wildlife, pollute water supplies, and affect ecosystems. These detrimental effects on human health and the ecosystem can be reduced by switching to renewable energy.
- **Technological Innovation:** The development and application of renewable energy technologies can promote technological advancement, the creation of employment, and economic expansion. The growth of new markets, industries, and technologies, as well as new business models, can all result from investing in renewable energy technologies.

1.2.1 Climate Change

The use of fossil fuels as the dominant source of energy has contributed significantly to the rise in greenhouse gas emissions, particularly carbon dioxide, resulting in global warming and climate change. Climate change has far-reaching and destructive impacts, ranging from rising sea levels to increasing frequency and severity of natural disasters to changes in weather patterns. Transitioning to renewable energy is critical for mitigating these effects. The combustion of fossil fuels emits significant volumes of CO_2 and other greenhouse gases into the atmosphere, trapping heat and contributing to the greenhouse effect. This effect causes global warming, which has a wide range of environmental consequences, including melting polar ice caps, increasing sea levels, and more frequent and severe weather events. These changes have already had a significant influence on natural systems and human cultures all across the world, and the consequences are expected to worsen in the next decades.

Renewable energy sources such as solar, wind, hydro, and geothermal power provide a more environmentally friendly and sustainable alternative to fossil fuels. Renewable energy sources, unlike fossil fuels, create no greenhouse gas emissions and have a significantly lower environmental imprint. Furthermore, renewable energy sources are more reliable and less susceptible to supply disruptions than fossil fuels, making them a more secure and robust energy source. Transitioning to renewable energy is a complex and difficult task, but it is also critical. It necessitates a multifaceted approach that includes improvements in energy policy, infrastructure, and technology. Governments, organizations, and individuals all play a part in this shift, and international cooperation and coordination are required to handle this global issue. To summarize, the transition to renewable energy is critical for reducing the consequences of climate change and guaranteeing a sustainable future for future generations. This transformation is critical, and action at all levels of society is required to make it a reality.

1.2.2 Energy Security

Energy security is defined as the continuous availability of energy at a reasonable price, which is critical for national and economic security. Oil, coal, and natural gas have long been the principal sources of energy for many countries across the world. These fuels, however, are finite resources vulnerable to price fluctuation and geopolitical turmoil. Countries that rely significantly on them are therefore exposed to economic shocks and supply interruptions. According to the International Energy Agency (IEA), worldwide energy consumption is expected to rise by about 50% by 2050, with fossil fuels continuing to supply the majority of the world's energy. As a result, governments must urgently shift to more sustainable and reliable energy sources in order to attain energy security.

Solar, wind, hydropower, and geothermal energy are all reliable and sustainable alternatives to fossil fuels. They are also becoming more cost-effective, making them an appealing choice for countries seeking to improve their energy security. According to the IEA, renewable energy sources accounted for roughly 72% of new power capacity additions globally in 2019. Renewable energy sources offer a variety of other advantages in addition to being a stable source of energy. They can, for example, aid in the reduction of air pollution, the mitigation of climate change, and the creation of new job opportunities in the clean energy sector. According to an IRENA analysis, the renewable energy sector employed approximately 11 million people globally in 2018, with the potential to create millions more employment in the coming years.

Countries that have made large investments in renewable energy have experienced significant gains in terms of energy security. Denmark, for example, has become one of the world's most energy-secure countries as a result of significant expenditures in wind energy. According to IRENA, renewable energy accounted for over 70% of the country's electricity consumption in 2018. Similarly, Germany has made tremendous headway in recent years in shifting to renewable energy sources. The country has set a goal of eliminating nuclear power by 2050 and reducing greenhouse gas emissions by 80-95%. Renewable energy sources will account for roughly 44% of the country's overall electricity consumption in 2020, according to the Federal Ministry of Economic Affairs and Energy.

Finally, energy security is an important component of both national and economic security. Countries whose energy output is primarily reliant on fossil fuels are prone to price volatility, supply disruptions, and geopolitical turmoil. Countries can minimise their dependency on imported fossil fuels and improve their energy security by shifting to renewable energy sources. Renewable energy sources, in addition to providing a steady source of electricity, provide a number of other advantages, including job development and reduced environmental effect. The transition to renewable energy sources is a worldwide priority that governments must undertake as soon as possible.

1.2.3 Effects on Public Health and the Ecosystem

The burning of fossil fuels has major adverse effects on both public health and the environment. The combustion of fossil fuels emits a variety of damaging pollutants into the atmosphere, including carbon dioxide (CO2), sulphur dioxide (SO2), nitrogen oxides (NOx), and particulate matter. These contaminants can have major health repercussions, such as respiratory issues, heart disease, and cancer. According to the World Health Organization (WHO), outdoor air pollution causes around 4.2 million deaths worldwide each year. Furthermore, a Harvard University study indicated that exposure to air pollution from fossil fuel combustion was responsible for an estimated 8.7 million premature deaths worldwide in 2018. Besides from serious health repercussions, the production and transportation of fossil fuels can have substantial environmental consequences. The extraction of fossil fuels frequently requires the use of heavy machinery and chemicals, which can degrade ecosystems, pollute water resources, and endanger species.

Transportation of fossil fuels can potentially harm the environment. Oil spills from tanker accidents or pipeline breaks, for example, can have severe consequences on marine and coastal ecosystems. In 2010, for example, the Deepwater Horizon oil disaster in the Gulf of Mexico dumped roughly 4.9 million barrels of oil into the ocean, causing extensive environmental damage and wildlife deaths. These detrimental health and environmental effects can be mitigated by shifting to renewable energy sources. Renewable energy sources like sun, wind, hydropower, and geothermal do not emit hazardous pollutants into the atmosphere and do not necessitate the same amount of resource exploitation as fossil fuels. As a result, renewable energy can help reduce air and water pollution, protect ecosystems, and lessen wildlife suffering.

According to a study conducted by the National Renewable Energy Laboratory, switching to renewable energy could have considerable health benefits in the United States. According to the report, reducing fossil fuel emissions by half by 2050 might avert 175,000 premature deaths, 1.6 million asthma episodes, and 90,000 emergency room visits per year. Transitioning to renewable energy can offer considerable economic benefits in addition to health benefits. According to a research conducted by the International Renewable Energy Agency (IRENA), the renewable energy sector might provide up to 28 million new employment globally by 2050. To summarize, the usage of fossil fuels has serious consequences for both human health and the environment. These effects can be mitigated by switching to renewable energy sources, resulting in better public health and environmental results. The transition to renewable energy is required not only to combat climate change, but also to improve the health and well-being of communities worldwide.

1.2.4 Technological Innovation

Renewable energy technology development and use have the ability to accelerate technological innovation, create new job opportunities, and support economic growth. Renewable energy sources, such as solar, wind, and geothermal, are becoming increasingly cost-competitive with fossil fuels, and their scale and deployment are fast expanding. Renewable energy technologies outperform traditional fossil fuel technology in various ways. They are, for example, often cleaner and more sustainable, have lower running costs, and rely less on finite resources. As a result, renewable energy technologies are spawning new markets, industries, and business models, propelling technological innovation and economic growth.

Energy storage is one area of innovation being driven by renewable energy technology. Energy storage technologies such as batteries and pumped hydro storage are becoming more essential as the proportion of renewable energy in electricity generation grows. Energy storage can assist overcome renewable energy sources' intermittent nature, making them more reliable and effective. The creation of smart grids is another area of innovation. Smart grids improve the efficiency, reliability, and flexibility of electrical networks by utilising modern sensors, communication technology, and control systems. They can also aid in the integration of renewable energy sources into the grid, making supply and demand easier to regulate and balance.

Renewable energy technology are also spurring economic growth and creating new job possibilities. The International Renewable Energy Agency (IRENA) reported that the renewable energy sector employed 11 million people worldwide in 2018, with the potential to produce up to 28 million more jobs by 2050. According to the analysis, renewable energy adoption could enhance global GDP by up to 2.5% by 2050. Renewable energy technologies can drive economic growth by establishing new industries and markets, in addition to employment creation. For example, as the solar sector has grown, new business models have emerged, such as solar leasing and community solar programmes. These business models have made solar energy more accessible and cheap for families and companies, propelling the sector forward and opening up new avenues for investment and innovation.

The advancement of renewable energy technologies is also fuelling innovation in other industries such as transportation and agriculture. As renewable energy grows more economical and accessible, electric vehicles, for example, are becoming increasingly widespread. Renewable energy technologies are also being used to power irrigation systems and other agricultural activities, reducing farmers' reliance on fossil fuels. To summarize, the development and deployment of renewable energy technology drives technological innovation, creates new job opportunities, and promotes economic growth. Investing in renewable energy technology can lead to the development of new markets, industries, and technologies, as well as new business models. Renewable energy expansion is required not only to combat climate change, but also to promote technological advancement, economic expansion, and job creation.

1.3 Indian Energy Scenario

The goal of the Electricity Act 2003, which went into effect on June 15, 2003, is to increase competition, safeguard consumer interests, and provide access to electricity for all. The Act includes provisions for the National Electricity Policy, rural electrification, open access in transmission, phased open access in distribution, mandatory SERCs, license-free generation and distribution, power trading, mandatory metering, and harsh penalties for electricity theft. The Electricity (Amendment) Act of 2003 and the Electricity (Amendment) Act of 2007 each altered the Electricity Act of 2003 twice. In order to enable the States and the Centre to act in harmony and collaboration, it is intended to propel the sector onto a trajectory of solid commercial growth. According to the above act the energy is the primary need to supply for Indian citizen of rural and urban both areas.

Figure 1.1 shows the total power generation year wise from 2009 to 2021 and it expressed the growth of power generation also.

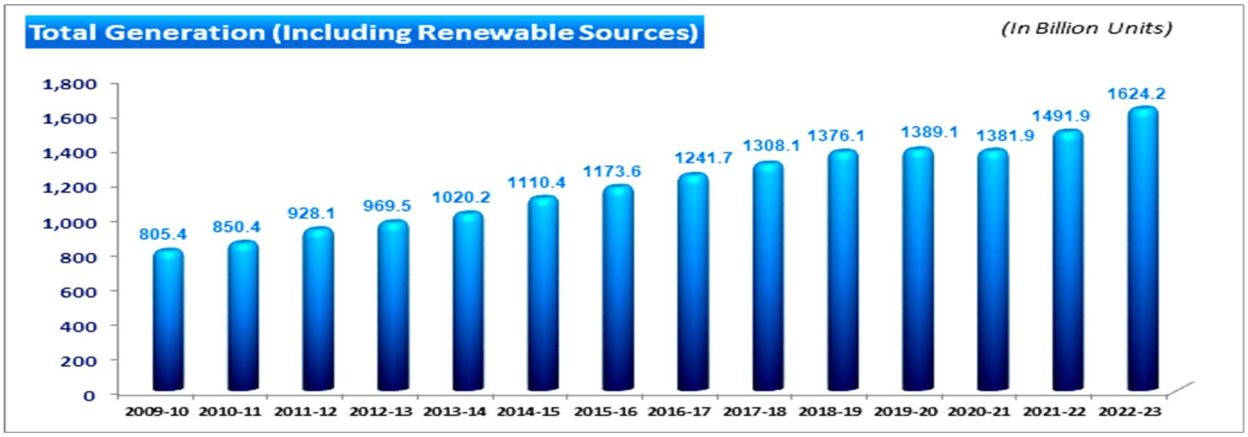
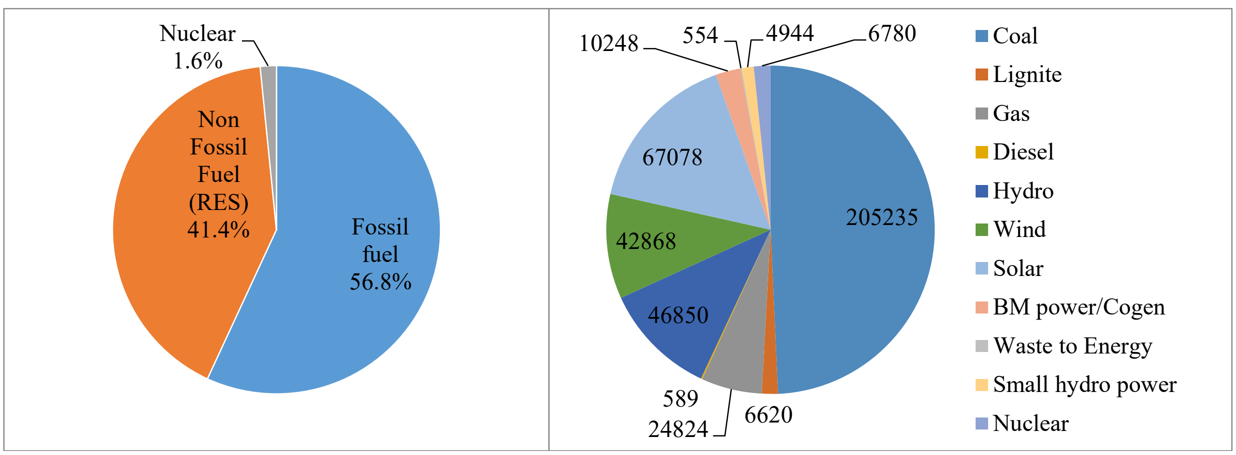


Figure 1.1: Total generation from 2009-10 to 2022-23 [Sources: World Bank]

The electrical power installed generation capacity is shown in figure 1.2 and observed that the 56.8% of total electricity generation have been generated through fossil fuel, 41.4% is generated through non fossil fuel (RES) and 1.6% power is generated through nuclear fuel.



(a) In % of total generation (b) In MW of electricity generation [Sources: World Bank]

Figure 1.2: Installed generation capacity (Fuel wise) as on 30-05-2023

India presently has 168.96 GW of total renewable energy capacity (as of February 28, 2023), with approximately 82 GW of that capacity being implemented at various phases and over 41 GW being in the tendering stage. This includes 42.02 GW of wind power, 10.77 GW of Bio power, 64.38 GW of solar power and 51.79 GW of hydropower. For the five financial year 2023–2024 to the financial year 2027–2028, the government of India has decided to invite the bids for 50 GW of renewable energy capacity yearly. To reduce the dependence on fossil fuel there is required to increase the capacity of RES which helps to reduce the pollution also.

1.4 The Impact of Traditional or Conventional Energy Sources

The traditional or conventional energy sources are most common energy sources and which are responsible for increasing the pollution due to this increasing the global warming and other changes occurs in the climate as follows:

- **Climate Change:** The use of fossil fuels not only adds to global warming, but also has additional climate-related consequences, such as rising sea levels and more frequent and severe weather occurrences.
- **Air Pollution:** The health consequences of air pollution can be severe, especially for vulnerable groups like children and the elderly. Furthermore, air pollution can have an influence on ecosystems, such as acid rain, which harms forests and lakes.
- **Water Contamination:** The extraction and transportation of fossil fuels can cause water pollution, which can have both acute and chronic effects on aquatic life and human health.
- **Land Use:** The exploitation of fossil fuels can result in habitat degradation and fragmentation, reducing biodiversity and ecosystem services. Furthermore, the development and maintenance of energy infrastructure can have an impact on land usage and wildlife populations.
- **Waste Generation:** Waste generated by traditional energy sources can represent major environmental problems, especially if improperly managed. Coal ash, for example, can contain heavy metals and other pollutants that flow into streams.

- **Socioeconomic Effects:** Traditional energy sources have social and economic consequences in addition to environmental consequences. Communities near fossil fuel extraction sites, for example, may suffer significant effects on their health, livelihoods, and cultural heritage.

1.4.1 Climate Change due to Conventional Energy Sources

The combustion of fossil fuels emits huge volumes of greenhouse gases into the atmosphere, including carbon dioxide, methane, and nitrous oxide. These gases trap heat from the sun, causing the Earth's atmosphere to warm, a phenomenon known as global warming or climate change. However, the consequences of climate change are not restricted to higher temperatures. Here are some instances of how climate change affects the environment:

- **Rising sea levels:** As global temperatures rise, so will sea levels. This is due to the expansion of the ocean caused by melting glaciers and ice sheets, as well as thermal expansion of saltwater. As a result, during the pre-industrial era, sea levels have risen by around 8 inches (20 cm). Rising sea levels are a major issue for coastal areas because they can cause floods, erosion, and saltwater intrusion into freshwater sources.
- **More frequent and severe weather events:** Hurricanes, heatwaves, droughts, and wildfires are becoming more often and severe as a result of climate change. This is due to increased evaporation caused by warmer temperatures, which can result in more heavy rains in certain locations and more severe droughts in others. Warmer temperatures can also result in more frequent and severe heatwaves, which can be fatal to vulnerable populations.
- **Changes in precipitation patterns:** Climate change is causing changes in precipitation patterns all across the planet. Some locations have more frequent and strong rains, while others have more frequent and severe droughts. These changes have the potential to have a large influence on agriculture, water availability, and natural ecosystems.

- **Ocean acidification:** Because the oceans absorb around 30% of the carbon dioxide released by human activities, the pH of seawater is decreasing. This process, known as ocean acidification, can have serious consequences for marine life because it makes it more difficult for species like corals and shellfish to create shells or skeletons.

1.4.2 Air Pollution due to conventional energy sources

The air pollution increases due to the fossil fuel applications in energy generation and the pollution will affect the human beings in so many ways which are given as follows:

- **Respiratory issues:** Air pollution can lead to a variety of respiratory issues, such as coughing, wheezing, shortness of breath, and asthma episodes. These symptoms might be especially severe in patients who already have respiratory diseases such chronic obstructive pulmonary disease (COPD).
- **Cardiovascular disease:** Air pollution exposure has also been related to an increased risk of cardiovascular illness, such as heart attacks, strokes, and high blood pressure.
- **Cancer:** Certain air pollutants, such as benzene and diesel exhaust, have been linked to an increased risk of cancer.
- **Neurological effects:** There is evidence that air pollution can impair cognitive function and brain development, especially in youngsters.

The air pollution may have a considerable influence on ecosystems in addition to having a detrimental impact on human health. Acid rain, for example, can harm forests, lakes, and other ecosystems due to the release of sulphur dioxide and nitrogen oxides into the atmosphere. Acid rain can make soil more acidic, making it difficult for plants to absorb nutrients. It can also increase the acidity of lakes and rivers, which can kill fish and other aquatic species. Overall, air pollution is a major environmental concern with far-reaching consequences for human health and ecosystems. Policies and practises that limit emissions from sources such as transportation, industry, and energy generation are critical for reducing air pollution.

1.4.3 Water Contamination due to conventional energy sources

Traditional energy sources, such as oil and natural gas, can cause water contamination, which can have both immediate and long-term effects on aquatic ecosystems and human health.

- **Immediate effects on aquatic life:** Transportation accidents or oil spills during extraction can release enormous amounts of oil and other contaminants into waterways. This can have rapid and severe consequences for aquatic life, such as fish kills, habitat destruction, and decreased populations of aquatic plants and animals. Oil spills, for example, can damage fish gills, making it difficult for them to breathe and potentially leading to suffocation.
- **Long-term effects on aquatic life:** Even trace amounts of oil and pollutants can have long-term effects on aquatic life. These contaminants can build up in the food chain, causing bioaccumulation and bio-magnification, which can harm the health of fish and other aquatic species, as well as humans who consume them.
- **Human health consequences:** Water pollution from fossil fuel extraction and transportation can have serious consequences for human health. The use of fracking chemicals in natural gas extraction, for example, has been linked to groundwater contamination as well as increased rates of cancer and other health issues in adjacent towns. Furthermore, oil spills can contaminate drinking water supplies, resulting in illness and disease.

In order to tackle the environmental effects of traditional energy sources' water contamination, rules and best practises have been put in place to decrease the possibility of accidents and spills. These initiatives include the deployment of safer technologies, stricter safety requirements, and improved monitoring and oversight. However, given the inherent hazards of fossil fuel extraction and transportation, shifting to cleaner, more sustainable energy sources is a crucial step towards protecting aquatic ecosystems and human health.

1.4.4 Land Use effect due to conventional energy sources

- **Destruction of habitat and fragmentation:** The extraction of fossil fuels frequently necessitates the removal of huge tracts of land to make room for mining or drilling operations. This can lead to the loss of key habitat for plant and animal species, with potentially disastrous consequences for ecosystems. Furthermore, the building of pipelines, roads, and other infrastructure linked with fossil fuel extraction can fragment habitats, making species movement difficult and contributing to further biodiversity loss.
- **Impacts on ecosystem services:** Ecosystem services are the advantages that humans gain from natural ecosystems, such as clean air and water, carbon storage, and recreational activities. The destruction and fragmentation of habitats caused by fossil fuel extraction can result in the loss of these services, which can have serious consequences for human health and well-being. The loss of wetlands and other natural habitats, for example, can limit ecosystems' ability to absorb and filter water, resulting to increased flooding and water pollution.
- **Wildlife population impacts:** The building and maintenance of energy infrastructure can have an impact on wildlife populations. Wind turbines and electricity lines, for example, can kill birds and bats, while oil and gas development can alter wildlife travel patterns and mating habits. The loss of habitat caused by fossil fuel extraction can also lead to population decreases of endangered and threatened species.

Governments and organisations have implemented a variety of strategies to address the impacts of fossil fuel extraction on land use and biodiversity, including regulations on land use and biodiversity conservation, as well as efforts to promote renewable energy sources and reduce demand for fossil fuels. These initiatives are crucial for preserving natural ecosystems as well as the benefits they bring to human societies.

1.4.5 Waste generation

The creation of waste is a significant issue when using conventional energy sources like coal, oil, and natural gas. For millennia, these energy sources have provided the majority of the world's energy needs, yet they have also posed serious environmental dangers. This problem is especially important when improper waste management results in land, water, and air contamination. One example of a waste product produced by the combustion of coal is coal ash. The by-product of burning coal, coal ash is made up of a variety of minerals and trace elements, including heavy metals like arsenic, lead, and mercury. Coal ash can leak into neighbouring rivers if it is not adequately managed, poisoning the water supply and endangering aquatic life.

Oil and gas drilling operations can produce a lot of garbage in addition to coal ash. Large amounts of water, chemicals, and sand are frequently injected into the ground during the extraction of oil and gas in order to fracture the rock and release the oil or gas. Hydraulic fracturing, sometimes known as "fracking," produces a large amount of wastewater that may contain radioactive elements and heavy metals among other contaminants. To reduce the environmental concerns connected to these industries, waste produced by conventional energy sources must be managed properly. This can involve taking steps like making sure coal ash is kept in lined landfills to stop it from seeping into nearby waterways, treating wastewater produced by oil and gas operations to remove contaminants, and enacting strict regulations to make sure waste is handled and disposed of properly.

Overall, waste creation is a serious environmental issue connected to conventional energy sources, and it is crucial that researchers keep looking into and creating creative solutions to address this problem. By doing this, we can contribute to ensuring the sustainability of our energy systems and reducing the negative effects on the environment and public health.

1.4.6 Socio-economic impacts

Traditional energy sources have several socioeconomic repercussions that can have a big impact on the local communities that are close to fossil fuel extraction sites. These effects can be detrimental and far-reaching, impacting anything from a person's health to an entire community's cultural heritage. Public health is one of the most important socioeconomic effects of traditional energy sources. A number of pollutants, including particulate matter, sulphur dioxide, nitrogen oxides, and volatile organic compounds, can be produced during the extraction, processing, and use of fossil fuels and have a detrimental effect on human health. Particularly for susceptible groups like children, the elderly, and those with pre-existing medical disorders, these pollutants can cause respiratory troubles, heart disease, and other health concerns.

Traditional energy sources can have a big impact on regional economy. While the exploitation of fossil fuel reserves may increase employment and economic prospects in a region, it may also result in the abolition of long-standing ways of life and the upheaval of regional economies. The boom-and-bust cycles connected to the extractive industries can also result in a lack of stability and uncertainty in the local economy. The development of fossil fuel resources may also have an impact on local communities' cultural heritage. For instance, the installation of pipelines and other infrastructure may interfere with traditional cultural practises like hunting, fishing, and gathering. Furthermore, as younger generations are urged to follow more "modern" professional pathways, the expansion of fossil fuel resources may result in the loss of old knowledge and cultural practises.

Last but not least, concerns of justice and equity are frequently strongly related to the socioeconomic effects of traditional energy sources. The negative effects of fossil fuel extraction and consumption frequently have a disproportionately unfavourable impact on low-income and minority communities. These communities might not have enough resources to address the negative effects of fossil fuel extraction on human health and the environment, and they might be more susceptible to eviction and other economic disturbances.

It is crucial that academics and decision-makers take into account traditional energy sources' social and economic effects in addition to their environmental effects in order to address these concerns. This may entail taking steps to give impacted communities a voice in decisions regarding energy development in their region, compensating victims financially, and funding sustainable development projects like renewable energy that can create jobs for impacted communities. As a result, communities near fossil fuel extraction sites may experience substantial changes in their health, way of life, and cultural heritage as a result of the socioeconomic repercussions of traditional energy sources, which are intricate and multidimensional. It is crucial that doctoral candidates and researchers keep looking into these effects and creating solutions that cater to the requirements of impacted populations.

1.5 Analysing various types of renewable energy

The term "renewable energy" refers to energy sources including solar, wind, hydro, geothermal and biomass power that are continuously renewed by nature. Compared to conventional fossil fuels, these energy sources are seen as being more environmentally friendly because they don't release greenhouse gases and aren't prone to depletion. Recent years have seen a rise in the use of renewable energy as concerns about climate change and the depletion of fossil resources have grown. The use of renewable energy is essential for combating climate change and lessening its harmful effects on the environment. Because of growing worries about the effects of climate change and the depletion of fossil fuels, the usage of renewable energy sources has been more popular recently. The utilisation of renewable energy sources is crucial to attempts to lower greenhouse gas emissions and keep global warming to less than 1.5°C over pre-industrial levels, according to the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2021). The main cause of greenhouse gas emissions, which trap heat in the atmosphere and cause global warming, is the burning of fossil fuels for energy.

In comparison to conventional fossil fuels, renewable energy sources like solar and wind power are carbon-free and have a smaller negative impact on the environment. The usage of renewable energy technology might reduce greenhouse gas emissions by up to 70% by 2050, according to a study by the International Energy Agency (IEA) (IEA, 2018). The usage of renewable energy has various environmental advantages in addition to reducing climate change. For instance, the use of hydropower lowers the amount of water required for the production of electricity from fossil fuels, while the use of solar and wind power lowers the amount of air pollution caused by the burning of fossil fuels (IRENA, 2021). Finally, it cannot be emphasised how crucial renewable energy is to halting global warming and minimising its damaging effects on the environment. For a sustainable energy future to be realised and for the reduction of greenhouse gas emissions, renewable energy technologies must be deployed.

1.5.1 Solar Energy

Solar photovoltaic (PV) panels and concentrated solar power (CSP) systems are two examples of the many technologies that may be used to capture solar energy, which is the energy that the sun produces. Sunlight, infrared, and ultraviolet radiation are just a few of the many types of electromagnetic radiation that the sun releases. It is a strong energy source. Through a variety of solar technologies, this energy can be gathered and transformed into usable forms of energy. The most popular type of solar technology used to capture solar energy is solar PV panels. These solar-powered panels are comprised of silicon or other semiconductor-based photovoltaic cells, which transform light into electricity. Photovoltaic cells are made up of layers of various materials that are intended to absorb and transform solar radiation into useful electricity.

The solar cells produce electricity when sunlight hits them by igniting electrons in the semiconductor substance. Solar-generated electricity can be used immediately to power buildings and other devices, or it can be stored in batteries for later use. The capacity of solar panels to produce electricity is influenced by a number of variables, such as their size and efficiency, the amount of sunlight available, and their orientation with respect to the sun. Contrarily, CSP systems employ mirrors or lenses to focus sunlight onto a tiny area, creating heat that may be converted into energy. The heated fluid, such as water, is heated by concentrated sunlight, creating steam that powers a turbine and creates energy.

Solar power is a clean, renewable energy source that doesn't release any greenhouse gases that contribute to global warming. Because solar technologies are becoming more affordable and solar cells are becoming more efficient, it is anticipated that the use of solar energy will increase. Solar energy, which is the fastest-growing renewable energy source, is predicted to have a substantial impact on the world's energy mix, according to the International Renewable Energy Agency (IRENA). As a result of its many benefits, such as its capacity to lower greenhouse gas emissions and its cost-competitiveness with conventional fossil fuels, solar energy is a viable renewable energy source that has grown in popularity recently. Solar technology needs to continue to be researched and developed in order to reduce costs and increase efficiency, which will make solar energy more widely used in the coming years.

1.5.1.1 The LCOE of Solar Energy

In recent years, solar energy's LCOE has been dropping quickly, making it more competitive with conventional fossil fuels. The International Renewable Energy Agency (IRENA) reports that between 2010 and 2020, the global LCOE of solar PV decreased by 82%, making it one of the least expensive sources of power in many regions of the world. The location and size of the solar plant, the effectiveness of the solar panels, the cost of financing and construction, and other elements can all affect the levelized cost of energy (LCOE) of solar energy. Generally speaking, nations with lots of sunshine and supportive policies and incentives for the development of solar energy tend to have lower LCOEs for solar energy.

According to the National Renewable Energy Laboratory (NREL), the LCOE of utility-scale solar PV in the United States varied in 2020 from $29 to $42 per MWh, depending on location and other variables. Natural gas-fired power stations have an LCOE that varied from $36 to $46 per MWh in comparison. As reported by IRENA, the LCOE of solar PV was predicted to be around $32 per MWh in 2020 in China, which is the world's largest producer of solar panels and a significant player in the growth of solar energy. The LCOE of solar PV was predicted to be roughly $38 per MWh in 2020 in India, a market for solar energy that is expanding quickly.

The LCOE of solar energy has already fallen below that of conventional fossil fuels in several regions of the world, making it a viable option for generating power. For instance, according to IRENA, the LCOE of solar PV was predicted to be lower than the LCOE of natural gas-fired power plants in some regions of Chile in 2020, at about $20 per MWh. Overall, the decreasing solar energy LCOE is encouraging for the development of renewable energy. Solar energy is becoming a more competitive source of electricity in many regions of the world as the cost of solar technology continues to fall and efficiency rises. This development could be crucial in the transition to a low-carbon economy.

1.5.1.2 The Disadvantages of Solar Energy

Although solar energy is a promising and quickly expanding renewable energy source, there are a number of possible drawbacks and difficulties that could arise from its utilisation. The following are some of the biggest drawbacks of solar power:

- **Weather-dependent:** Solar energy's need on sunshine to produce power makes it one of the largest obstacles because it is weather-dependent. Weather factors, especially the amount of sunlight, have a significant impact on solar energy. Several variables, including as the time of day, season, latitude, cloud cover, and atmospheric conditions, can affect how much solar radiation reaches the Earth's surface. The sun power can be a very dependable source of electricity in regions with high levels of sun radiation and few cloudy days. Solar energy can, however, be less dependable and trickier to incorporate into the grid in places with less regular sunlight or more frequent cloud cover. Additionally, temperature can have an impact on the output of solar panels, with greater temperatures resulting in a reduction in efficiency. This can be particularly difficult in hotter regions where there is a high demand for air cooling, which increases the need for electricity at periods when solar panels can be less effective. Utilizing energy storage technology like batteries is one way to alleviate the problem of weather dependence. Energy storage can contribute to the maintenance of a more steady and dependable supply of power by storing extra solar energy during periods of peak sunlight and utilising it during periods of low sunlight or high demand. Energy storage devices, however, can be costly and have restrictions on their capacity and duration, which can make them less effective. Overall, even though solar energy's reliance on the weather is a potential drawback, current developments in solar panel and energy storage technologies are working to overcome this issue and make solar energy more dependable and available.

- **Upfront expenses:** Another issue with solar energy is that it frequently entails high upfront expenses for installation and equipment. The high initial expenses of solar energy's equipment and installation are one of its main obstacles. For individuals, companies, and governments wishing to transition to renewable energy sources, the cost of solar panels, inverters, batteries, and other related components can be a significant hurdle. Solar energy systems are typically made to produce electricity for at least 25 to 30 years. However, the significant installation expenses up front may discourage others from utilising the technology. The International Energy Agency (IEA) reported that the average upfront cost of solar PV systems in industrialised nations in 2020 was $1.16 per watt, while it was $0.73 per watt in underdeveloped countries. The high initial costs of solar energy are caused by a number of variables. A sizeable amount of the entire cost goes towards the price of solar panels, which are comprised of photovoltaic cells that turn sunlight into power. Inverters, which transform the DC electricity generated by solar panels into AC electricity usable in homes and businesses, can also be very expensive. The upfront expenses of solar energy systems are also increased by batteries, which are frequently used to store excess energy generated by solar panels.
- **Land Use:** Large-scale solar projects can necessitate enormous tracts of land, which can be difficult to come by in locations with limited accessible space. A 1 MW solar power plant,

for example, normally takes 4-5 acres of land, but larger projects can require hundreds or thousands of acres. This land use can clash with other purposes, such as agriculture or conservation, particularly in locations where land is scarce. One of the primary issues about solar energy's land use is the possibility of land-use change. Solar projects may be built on previously undeveloped land, such as farmland, forests, or other natural regions, in some situations. This land-use shift has the potential to result in the loss of critical habitats and biodiversity, as well as the relocation of local communities that rely on them. Another issue with solar energy's land use is the possibility of competition from other land uses. In some areas, solar projects may compete for fertile land with agriculture, or with conservation initiatives to safeguard endangered species or natural environments. This can result in confrontations between various groups and interests, as well as economic consequences for local communities.

Here are some cases of land use issues in large-scale solar projects:

I. Ivanpah Solar Electric Generating System, California, and United States of America: This is a large-scale solar thermal power facility that spans more than 5 square miles of Mojave Desert. It has been chastised for having a negative impact on the local desert tortoise population and for destroying delicate desert environment.

II. Blythe Solar Power Project by Solar Millennium, California, and USA: This project planned the construction of a 9.3 square mile solar thermal power plant on public land near Joshua Tree National Park. Concerns about the project's impact on wildlife and the local environment led to its cancellation.

III. Solar Park at Neuhardenberg, Germany: This 162-hectare solar park was built on former agricultural land. While the project was effective in producing renewable energy, it was also criticised for its effects on the surrounding ecosystem and the loss of important farmland.

IV. Solar power plant in Rajasthan, India: The Bhadla Solar Park in Rajasthan has been criticism for its impact on local communities and displacement of residents.

These examples demonstrate the potential conflicts that might arise between large-scale solar projects and other land uses such as conservation, agriculture, and residential areas. It emphasises the significance of thorough planning and consideration of potential environmental and community implications when developing renewable energy projects.

- **Environmental impacts:** Solar energy is commonly recognised as a clean and sustainable energy source because it emits no detrimental greenhouse gas emissions when in use. Although solar energy is a clean and renewable source of electricity, the manufacturing, installation, and removal of solar panels can have an impact on the environment. Solar panels are manufactured using scarce and precious elements such as silicon, cadmium, and silver, which need energy-intensive extraction and refining processes. Furthermore, the manufacturing process can produce waste and pollutants such as greenhouse gases and harmful substances.

  According to a JRC (Joint Research Centre) report on "Life-cycle environmental impacts of solar photovoltaic systems," the fabrication of solar panels can have substantial environmental consequences such as acidification, eutrophication, and photochemical oxidant generation. The study also discovered that the environmental impact of solar panels was mostly determined by their location and manufacturing method.

If solar panels are not properly disposed of, they might have negative environmental consequences. When solar panels reach the end of their useful life, they must be recycled or disposed of correctly to avoid environmental damage. Improper disposal of solar panels can result in the release of harmful compounds and heavy metals into the environment, such as lead and cadmium, which can harm wildlife and humans. A study on "End-of-Life Management for Solar Photovoltaic Panels" conducted by the National Renewable Energy Laboratory (NREL) discovered that recycling solar panels can assist recover important materials while reducing the environmental impact of solar panel manufacture. However, the process of recycling solar panels can be time-consuming and costly. To reduce the environmental impact of solar panels, the full life cycle of the panels, from production to disposal, must be considered. Efforts can be taken to lessen the environmental effect of solar panel production by employing more sustainable manufacturing procedures, such as using recycled materials or inventing more efficient and resource-efficient manufacturing methods. Furthermore, appropriate solar panel removal and recycling can help prevent the discharge of harmful compounds and heavy metals in the environment.

- **Energy storage limitation:** Energy storage technologies, particularly batteries, are increasingly viewed as a critical answer to the intermittent nature of solar energy. However, because to the limits of energy storage technologies, such as their high cost, limited capacity, and short lifespan, solar energy may need to be augmented with other energy sources to provide reliable electricity supply. The capacity of energy storage devices is one of its key limitations. Batteries can only store so much energy, and their capacity is restricted by factors such as size, weight, and cost. According to an IRENA report on "Renewable Energy Statistics 2021," the global installed capacity of battery storage systems for renewable energy was at 31 GW in 2020, a relatively tiny fraction of the total installed capacity. Energy storage devices have a limited lifespan in addition to capacity constraints. Battery performance and efficiency deteriorate over time, and they must eventually be replaced. This can be both expensive and time-consuming, especially for large-scale energy storage systems.

According to the IRENA analysis, the lifespan of batteries used for energy storage typically runs from five to fifteen years, depending on the kind and use case. Another key constraint is the high cost of energy storage devices, notably batteries. According to a Bloomberg NEF report on "Battery Prices and Market Forecast," the cost of lithium-ion batteries, the most commonly used battery technology for energy storage, has decreased significantly in recent years, but they remain relatively expensive when compared to other forms of energy storage. The high cost of energy storage solutions for solar energy systems is a significant obstacle to wider implementation. As a result of these restrictions, solar energy may still need to be augmented with other energy sources in order to generate reliable electricity. In some circumstances, this may imply using energy from other sources, such as natural gas or hydroelectric power, to meet electrical demand during periods of low or high sunshine.

1.5.2 Wind Energy

Wind energy is the energy created by the movement of the wind and turned into electricity by wind turbines. Wind turbines catch the kinetic energy of the wind and convert it into mechanical energy, which is then transferred into electricity by a generator. Because wind is a natural resource that is constantly renewed by the sun's heating of the earth's atmosphere, it is a renewable energy source. Wind energy is a clean and sustainable alternative to traditional fossil fuel-based energy sources, and it is becoming a more popular source of power in many parts of the world.

Wind energy utilises wind turbines to transform the kinetic energy of the wind into electrical energy. Several steps are involved in the process:

- With its enormous blades, the wind turbine harnesses the kinetic energy of the wind. The blades are typically composed of lightweight materials such as fibreglass or carbon fibre and are aerodynamic in order to efficiently catch wind energy.
- When the wind blows, the blades are attached to a rotor, which revolves. The rotor is linked to a main shaft, which is linked to a generator.
- The rotor spins the generator, which generates power. The wind turbine generates electricity in the form of three-phase alternating current (AC).
- The electricity is then sent to a transformer, which raises the voltage to the required level for transmission to the power system.
- Finally, electricity is distributed to homes and businesses via the power grid, where it can be used for a variety of reasons.

Wind energy has applications on both large and small scales. Large-scale wind farms are made up of many wind turbines that are linked to the electricity grid, whilst small-scale wind turbines can be utilised to power individual homes or businesses.

1.5.2.1 The LCOE of Wind Energy

Wind energy's levelized cost of energy (LCOE) refers to the average cost of producing one unit of electricity over the lifetime of a wind turbine. The LCOE considers the original investment cost, maintenance costs, fuel costs (no fuel costs in wind energy), and the estimated lifetime of the wind turbine. Due to the higher construction and maintenance costs involved with offshore wind turbines, the LCOE of offshore wind power is often higher than that of onshore wind power. However, the LCOE of offshore wind generation has dramatically fallen in recent years, making it a more competitive source of electricity. The LCOE of wind energy varies based on factors such as wind resources, site location, turbine size, and financing costs. Despite this variability, wind energy is increasingly competitive with traditional fossil fuel-based electricity sources in many parts of the world.

The International Renewable Energy Agency (IRENA) estimates that the global weighted average LCOE of onshore wind power in 2020 will be around 6.5 cents per kilowatt-hour (kWh). This makes it one of the most affordable sources of electricity. However, depending on factors such as wind resources, site location, turbine size, and financing costs, the LCOE of wind energy might vary. In the United States, for example, the LCOE of wind energy has declined dramatically in recent years. According to the US Energy Information Administration (EIA), the LCOE of onshore wind energy in the United States in 2019 varied from 4 to 6 cents per kWh. Because of the higher construction and maintenance costs involved with offshore wind turbines, the LCOE of offshore wind energy is often higher than that of onshore wind energy. According to the National Renewable Energy Laboratory (NREL), the first offshore wind farm in the United States, the Block Island Wind Farm off the coast of Rhode Island, has an estimated LCOE of 24.4 cents per kWh.

Wind energy's LCOE has also reduced dramatically in Europe in recent years. According to a European Wind Energy Association (EWEA) research, the LCOE of onshore wind energy in Europe in 2013 ranged from 4 to 10 cents per kWh. The LCOE of offshore wind energy in

Europe ranged from 10 to 18 cents per kWh in the same year. These costs, however, have continued to fall in recent years, making wind energy more competitive with traditional fossil fuel-based electricity sources. The LCOE of wind energy varies based on factors such as wind resources, site location, turbine size, and financing costs. Despite this variability, wind energy is increasingly competitive with traditional fossil fuel-based electricity sources in many parts of the world.

1.5.2.2 The Disadvantages of Wind Energy

Wind energy is a renewable energy source that has been gaining popularity in recent years due to its environmental friendliness and minimal carbon footprint. However, as with all energy sources, it has significant drawbacks that must be addressed.

- **Intermittency of Wind Energy:**

Wind energy output is determined by the availability and strength of the wind, which can change dramatically over time. Because power demand must be fulfilled in real time, this variability and unpredictability can pose problems for system stability and reliability. When wind energy output unexpectedly reduces owing to changes in wind speed or direction, additional sources of electricity must be available to make up the shortfall and keep the grid stable. This can be accomplished via energy storage technology such as batteries or by having backup power plants on hand. However, these solutions can be costly, and balancing supply and demand in real time can be problematic. As a result, wind energy is generally mixed in with other energy sources, such as fossil fuels and other renewables to ensure a reliable and consistent energy supply.

Wind energy intermittency is a well-known issue in the renewable energy business, and it has been thoroughly researched by researchers and specialists in the field. In 2020, a study published in the journal Renewable and Sustainable Energy Reviews examined the impact of wind power intermittency on power system stability and dependability. According to the study, the variability of wind energy can cause huge swings in power output, making it difficult to maintain a stable grid. Energy storage devices such as batteries and pumped hydro can help minimise the consequences of wind intermittency, according to the scientists, but these solutions can be costly and may not be available in all places.

Another 2019 study published in the journal Energy Policy looked at the obstacles of integrating wind energy into India's electricity infrastructure. The study discovered that wind power's intermittent nature can pose problems to grid stability and reliability, particularly in areas with limited transmission infrastructure. Energy storage systems and other grid management technologies, according to the authors, can assist address these difficulties, but they may require considerable expenditures and legislative support.

- **Noise pollution due to wind power plants:**

Wind turbines can cause noise pollution, which is seen as one of the drawbacks of wind energy. While modern wind turbines have become quieter over time, they still emit some noise that can be annoying to individuals who live near wind farms. Wind turbines generate noise from a variety of causes, including the mechanical operation of the turbine, the blade passing by the tower, and the flow of air over the blades. The intensity of the noise varies based on parameters such as wind speed, turbine size, and distance from the turbine. Wind turbine noise is typically in the 40-50 decibel (db) range at a distance of 300-500 metres from the turbine, according to studies. The noise is often considered to be no louder than normal conversation at this level. However, at a distance of 50-100 metres, the noise level can rise to 60-70 db, which some people may find annoying. Wind turbines are often situated distant from residential areas to reduce noise pollution. Regulations and standards are frequently in place by governments and wind energy firms to control the amount of noise produced by wind turbines and to ensure that the noise level is below acceptable limits for local communities.

- **Wind Turbines Impacts on Birds**

Wind turbines can be dangerous to birds and bats, especially during migration. Collisions with turbines can result in damage or death, and certain species are especially vulnerable. Wind turbines' impact on bird and bat populations is still being studied and debated. Several studies have been carried out to investigate the dangers of bird and bat collisions with wind turbines, as well as the possible influence on populations. (Winkelman et al 2019) did a review of 166 research on bird and bat collisions with wind turbines. The study discovered that collisions with turbines have caused considerable decreases in some bird populations, particularly raptors and other large birds, although the overall impact on bird populations is thought to be minor. Another study (Cryan et al 2014) evaluated 60 studies on bat collisions with wind turbines. The study discovered that bat fatalities were more common than bird fatalities, and that specific bat species, such as the hoary bat, were especially vulnerable to accidents with wind turbines.

A study (Buler et al 2018) explored how wind turbines affect bird migration patterns. Wind turbines, according to the study, can interrupt the migration patterns of some bird species, especially those that rely on visual cues for navigation. Wind farm developers may adopt a variety of mitigation methods to reduce the likelihood of bird and bat collisions with wind turbines. A study by (Baerwald et al, 2009) discovered that utilising radar to identify bird and bat behaviour near wind turbines can prevent collisions by up to 60%. Another study (Briscoe et al, 2012) found that situating wind turbines away from migratory routes and utilising illumination to boost visibility can help decrease collisions. Overall, the evidence demonstrates that bird and bat accidents with wind turbines can cause severe harm to individual animals and communities, especially endangered species.

- **Upfront Cost of wind Turbines**

The initial expenses of erecting wind turbines and associated infrastructure can be a substantial barrier to wind energy adoption, especially for people and communities with low financial resources. These expenses include the purchase and installation of turbines, as well as the construction of transmission lines to connect the turbines to the grid. (Jacobson et al, 2018) examined the cost of wind energy in several nations and discovered that the cost of wind energy has been lowering over time, making it more competitive with other energy sources. The report did caution, however, that the upfront expenses of wind energy can still be a substantial obstacle, especially in developing nations where finance for renewable energy projects may be limited. To tackle this issue, governments and organisations have put in place a variety of policies and programmes to give financial assistance for wind energy projects. For example, the United States provides a production tax credit for wind energy, which provides a financial incentive for wind energy development. Furthermore, some organisations provide subsidies and loans for wind energy installations, particularly in low-income communities.

Community wind projects are another way to reduce the initial expenses of wind energy. These projects involve the installation of wind turbines by a group of people or a community, with the energy generated being used to meet the community's energy demands. Community wind projects can deliver significant long-term cost savings, as well as additional benefits such as enhanced energy independence and lower carbon emissions. While the upfront costs of wind energy can be a substantial obstacle to adoption, numerous policies, programmes, and community-based initiatives have been devised to address this issue and support the expansion of wind energy as a viable source of renewable energy.

1.5.3 Hydropower

A sustainable energy source known as hydro energy, also known as hydropower or hydroelectric power, produces electricity by harnessing the energy of moving water. It has a long history of effective use across the globe and is one of the oldest and most popular types of renewable energy. The energy of moving or falling water is used to produce hydroelectricity, often known as hydroelectric power or hydropower. Building a sizable dam across a river or diverting water from another natural water source to create a reservoir are the first steps in the process. This dam or reservoir functions as a facility for storing large amounts of water with potential energy. The gates or valves at the dam's intake are opened to let the water held there flow into a penstock when power has to be produced. The water is directed through a big pipe or tunnel known as a penstock. The turbine, which is either at the foot of the dam or in a powerhouse next to the dam, is propelled by the force of the flowing water.

The water pressure that strikes the turbine's blades causes them to spin. The generator is coupled to the shaft that the turbine blades are attached to as they rotate. Electricity is produced through electromagnetic induction when the generator's coil rotates within a stationary magnetic field as a result of the turbine's shaft's rotational movement. Alternating current (AC) is the most common form in which energy is generated. A high voltage is used to carry electricity from the generator to the electrical grid, where it is distributed to end users. Homes, businesses, factories, and a variety of other uses for the electricity are all possible.

The system's design determines whether the water is sent back to the reservoir or discharged into the river downstream after passing through the turbine. The water can either be re-used in a run-of-river system, where it continues to flow downriver, or it can be retained in the reservoir for future use in a storage-based system. Harnessing hydropower involves a number of steps and parts, including:

- Dam or Water Intake: A dam or water intake construction is usually built to produce a reservoir or to divert water from a river or waterfall. The dam aids in controlling water flow and levels as well as storing potential energy as stored in raised water.
- Water is transported to the turbine by the penstock, a sizable pipe or conduit, from a reservoir or other water source. The water may keep its potential energy because it has a method to go via pressure.
- A hydroelectric power plant's turbine is its beating heart. The turbine spins as a result of the turbine's blades being struck by high-pressure water from the penstock. The turbine transforms the mechanical energy contained in the kinetic energy of moving water.
- Turbine Types: Pelton, Francis, and Kaplan turbines are just a few of the different types of turbines that are utilised in hydroelectric power plants. The head and water flow rate are two important considerations when choosing a turbine type.
- Generator: A generator, which is essentially an electrical machine, is coupled to the revolving turbine shaft. The generator's rotor, which is enclosed by a stationary stator, revolves as the turbine spins. Through electromagnetic induction, this rotation causes the passage of electrons in the stator windings, producing power.
- Power Distribution: The alternating current (AC) that the generator generally produces is used to distribute power. To enable effective transmission across long distances, transformers are utilised to scale up the voltage. Power lines are then used to provide the electricity to consumers' homes, places of business, and industries.

1.5.3.1 The LCOE of Hydropower Plant

The average cost of generating electricity from a hydroelectric power plant over the course of its lifetime, stated per unit of energy produced, is known as the levelized cost of electricity (LCOE) for hydroelectric power. This cost is commonly expressed in dollars per kilowatt-hour, or $/kWh. The LCOE is a widely used tool to evaluate the economic viability of various energy sources. Hydroelectric power's levelized cost of energy (LCOE) can change based on a number of variables, such as the particular project's characteristics, its location, size, construction and operating expenses, financing terms, and the facility's lifespan. Several important factors that influence the LCOE of hydroelectric electricity are listed below:

- **Costs of construction:** A large portion of the LCOE is made up of the initial capital expenditure needed to develop a hydroelectric power station. Construction costs can be influenced by elements such the kind of dam, turbine technology, civil engineering specifications, transmission infrastructure, and site-specific variables.
- **Costs of Operation and Maintenance:** The hydroelectric facility's continuing operational and maintenance costs have an effect on the LCOE. This covers the costs associated with staffing, monitoring, turbine and electrical equipment maintenance, sediment control, and environmental monitoring. These expenditures can be reduced by efficient maintenance and operation procedures.
- **Project Lifespan:** The LCOE calculation is impacted by a hydroelectric power plant's operating lifespan, which can last more than 50 years with good upkeep and improvements. In order to minimise the annualised costs and possibly the LCOE, a longer lifespan enables the original capital costs to be dispersed over a greater number of years.

- **Interest Rates and Financing:** The cost of capital, which includes interest rates and financing arrangements, significantly affects the LCOE. Lowering the total expenses and, as a result, the LCOE, can be accomplished by lower interest rates or more benevolent financing terms. Grants, tax breaks, and government subsidies may also have an impact on the project's finances.
- **Energy Production and Capacity Factor:** The hydroelectric plant's capacity factor—the proportion of actual electricity produced to the maximum possible production—affects the LCOE. The installed capacity is used more effectively with a higher capacity factor, potentially lowering the LCOE.
- **Reservoir management** expenditures, such as those associated with silt removal or environmental mitigation measures, can raise overall costs and have an effect on the LCOE. Additional funding might be needed to ensure environmental standards are followed and to address the project's social and environmental repercussions.

Depending to a variety of factors, such as geographic conditions, project scale, local labour costs, funding conditions, regulatory frameworks, and more, the LCOE of hydroelectric electricity might change across different countries. Based on information currently available and broad trends, the following are rough ranges of LCOE for hydroelectric electricity in various nations:

i. Norway: Hydroelectric power accounts for an important percentage of Norway's electricity production. Norway's hydroelectric projects are expected to have LCOEs of between $30 and $60 per megawatt-hour (MWh).

ii. Canada: This nation also has a wealth of hydropower resources. With respect to project size and location, the LCOE for hydro power in Canada usually varies from $30 to $80 per MWh.

iii. Brazil: The Itaipu Dam is only one of the significant hydroelectric projects that Brazil is renowned for. Brazil's hydroelectric power's LCOE is predicted to be between $30 and $70 per MWh.

iv. China: China possesses a adequate installed hydroelectric power capability. The LCOE for hydroelectricity projects in China might be as low as $40 per MWh or as high as $80 per MWh, depending on the size of the project.

v. United States: The LCOE for hydroelectricity varies across various locations in the United States. Larger-scale hydro projects can have lower LCOE values, often between $30 and $70 per MWh, whereas smaller hydro projects can have higher LCOE values, ranging from $50 to $100 per MWh.

vi. Switzerland: The country has a long history of using hydroelectric electricity. According to estimates, the LCOE for hydroelectricity projects in Switzerland will range between $60 and $90 per MWh.

vii. India: The LCOE for hydroelectric electricity in India might change based on the size, location, and particulars of the project. Per megawatt-hour (MWh), the LCOE for hydroelectric power in India typically ranges from $40 to $80.

viii. France: The Alps and Pyrenees areas of France have a substantial hydroelectric power capability. In France, the LCOE for hydroelectric plants typically ranges from $40 to $80 per MWh.

ix. Japan: Due to its geographical limitations and restricted land availability, hydroelectric power projects in Japan may be more expensive. Due to issues like the country's hilly geography and seismic considerations, the LCOE for hydroelectric electricity in Japan normally ranges from $60 to $100 per MWh.

1.5.3.2 The advantages and Disadvantages of Hydropower

The various advantages have been observed of hydropower generation, these are describes as follows:

- Hydro energy is renewable since it depends on the ongoing water cycle that is heated by the sun. It is also environmentally friendly. It doesn't use up or diminish the water supply. As opposed to fossil fuels, it doesn't release greenhouse gas emissions, which helps to reduce air pollution and slow down climate change.
- Power that is Consistent and Reliable: Hydropower plants can produce power that is consistent and reliable as long as there is a steady supply of water. Since they may run constantly or be dispatched as needed, they are useful for base load power, which offers a steady supply of electricity.
- Water management: Building reservoirs, which have many uses, is a common step in the development of hydroelectric generating facilities. Reservoirs can manage floods, control water flow, supply irrigation, and establish areas for boating and fishing.
- Long Operational Lifespan: Hydroelectric power stations can operate for up to 50 years. For many years, they can generate electricity efficiently with the right upkeep and annual modifications.

The various disadvantages of Hydropower have also been observed along with the advantages, the following important disadvantages have been found:

- Impact on Environment: Dam and reservoir development for hydroelectric power plants may have a huge negative impact on the environment. The construction of reservoirs affects the native river ecosystems and may cause wildlife and habitats to be displaced. Fish populations and biodiversity may be harmed as a result of it altering fish migration patterns. Additionally, the creation of reservoirs may result in the build-up of sediment, which could harm ecosystems downstream. Prior to the start of a project, environmental studies are done to reduce these effects, and interventions like fish passageways and sediment control procedures are used.

- Displacement: Large-scale hydropower projects frequently necessitate the purchase of land, and they may include the relocation of populations residing in the project region. This may result in the eviction of native populations, the destruction of livelihoods, and the upheaval of neighbourhood communities. Providing adequate compensation, alternate means of subsistence, and involving affected people in decision-making processes are essential. Plans for resettlement should place a high priority on social protection, cultural preservation, and the welfare of populations that have been displaced.
- Limitations: There aren't many ideal sites for large-scale hydroelectric projects available, especially in developed areas where many of the best places have already been taken. Identifying potential locations for new projects necessitates thorough feasibility assessments that take environmental, hydrological, and geological issues into account. Conflicts may also result from competing land uses like agriculture, tourism, or conservation. As a result, there is limited room for hydro energy to grow further, hence it could be necessary to look into alternate renewable energy sources.
- Impact of Climate Change: The hydro energy industry faces issues as a result of climate change. Water supply can be impacted by altered precipitation patterns and decreased snowmelt, which can change river flows and reservoir levels. Aquatic ecosystems and

fisheries may be impacted by changes in river temperatures and water chemistry. Extreme weather conditions, such as lengthy dry spells or heavy rain, can also have an impact on the consistency and predictability of water resources. Sustainable hydro energy production depends heavily on managing water supplies and modifying hydroelectric infrastructure to these shifting conditions.

- Maintenance: functioning and maintenance are essential for the effective and dependable functioning of hydroelectric power plants. This include controlling the water flow, maintaining the turbines, and maintaining the electrical apparatus. Reservoir sedimentation can also lower storage capacity and impact the effectiveness of a facility. To keep everything running as efficiently as possible, regular dredging or sediment flushing may be required.
- International and Transboundary Problems: Since many rivers and water basins are shared by several nations, the construction of hydroelectric plants may result in transboundary conflicts. International collaboration and diplomacy are needed to resolve issues including water allocation, downstream effects, and power sharing agreements. To solve these complex issues and guarantee the equitable and long-term use of shared water resources, collaborative frameworks and methods are crucial.

1.5.4 The Nuclear Energy

Nuclear reactions, more precisely nuclear fusion or fission, produce a particular sort of energy known as nuclear energy. It involves the release of energy from atomic nuclei splitting or merging, which generates enormous amounts of heat. Following that, various processes employ this heat to produce electricity. The main elements and procedures of nuclear energy are as follows:

i. The splitting of an atom's nucleus into two or more smaller nuclei, known as nuclear fission, results in the release of a considerable quantity of energy. Neutron bombardment of heavy atomic nuclei like uranium-235 or plutonium-239 is the conventional way to start this process. These nuclei become unstable after absorbing a neutron and break apart into smaller pieces, releasing more energy and neutrons.

ii. A nuclear reactor is a structure where controlled nuclear fission reactions take place. The fuel rods, control rods, coolant, moderator, and reactor core are some of its important parts. The nuclear fuel, such as enriched uranium or plutonium, is contained in the fuel rods and undergoes fission reactions. Control rods are used to absorb extra neutrons and control the nuclear reaction; they are often constructed of materials like boron or cadmium.

iii. Heat Production: A tremendous amount of heat is produced during the nuclear fission process. This heat is transferred to the coolant, which circulates around the reactor core and can be either liquid metal, gas, or water. The thermal energy is absorbed and carried away from the reactor by the coolant.

iv. The heat that is transmitted to the coolant is utilised to generate steam. The coolant is typically carried through a heat exchanger in nuclear power plants, where it transmits heat to a different water loop that produces steam. A turbine receives the steam, which is being used at high pressure and temperature.

v. Heat exchanger high-pressure steam is fed into a turbine to produce electricity. The steam expands through the turbine blades, speeding up the rotation of the turbine. The rotating turbine is coupled to a generator, which uses electromagnetic induction to transform mechanical energy into electrical energy. The electricity produced is then sent to the electrical system to be distributed to homes, businesses, and other users.

1.5.4.1 The LCOE of Nuclear Energy

A number of variables, such as the particular project, location, reactor type, building costs, operating and maintenance expenses, financing terms, and regulatory environment, can affect the Levelized Cost of Electricity (LCOE) for nuclear energy. The levelized cost of energy (LCOE) for nuclear energy typically ranges from \$50 to \$100 per megawatt-hour (MWh) in developed nations with established nuclear power infrastructure and seasoned regulatory frameworks. The LCOE, however, can occasionally be greater, particularly for new projects or those dealing with particular difficulties. While the levelized cost of energy (LCOE) for nuclear energy can vary significantly in developing countries where nuclear power is being introduced or developed based on factors including knowledge transfer, local labour costs, and funding terms. In underdeveloped nations, the LCOE for nuclear energy typically ranges from \$60 to \$120 per MWh.

I. United States: Depending on the exact project and region, the LCOE for nuclear energy varies in the United States. For existing nuclear facilities, estimates place the typical LCOE in the \$50–\$90 per megawatt-hour (MWh) range. However, because of higher construction costs and regulatory constraints, the LCOE for new nuclear plants, especially advanced reactors, may be higher.

II. France: The country is well known for its heavy reliance on nuclear power. In France, the LCOE for nuclear energy is predicted to be between \$60 and \$90 per MWh. Standardised reactor designs and a well-established nuclear sector benefit the nation and aid in cost and efficiency management.

III. United Kingdom: In the United Kingdom, the LCOE for nuclear energy can vary from \$80 to \$110 per MWh. The UK has started building the Hinkley Point C nuclear power facility, however there have been issues with finance and construction costs, raising the LCOE for that particular project.

IV. South Korea: The nuclear energy industry in South Korea is noteworthy. According to estimates, South Korea's LCOE for nuclear energy is between $70 and $100 per MWh. The nation has prioritised efficiency and standardisation in reactor designs, which has helped to keep costs down compared to certain other nations.

V. China: China has been investing in both local and foreign nuclear projects, and its nuclear power industry is expanding. Nuclear energy's LCOE varies in China depending on project scale and technology, among other things. The estimated price range for new nuclear projects in China is between $60 and $100 per MWh.

VI. Russia: Exporting nuclear technology to other nations, Russia has a long history of producing nuclear energy. In Russia, the LCOE for nuclear energy is predicted to be between $60 and $90 per MWh. A well-established nuclear industry and standardised reactor designs are advantageous to the nation.

VII. India: The levelized cost of energy (LCOE) for nuclear energy in India might differ depending on the particular project, reactor type, building costs, financing arrangements, and other factors. Estimates indicate that the LCOE for new nuclear projects in India could range from $60 to $90 per megawatt-hour (MWh), despite the fact that precise data might not be easily accessible. It's important to note that India has been looking at developing cutting-edge nuclear technology, such thorium-based reactors, which may have an effect on the LCOE in the future.

VIII. Japan: Depending on project-specific variables and the particular circumstances of the nation, the LCOE for nuclear energy can also differ in Japan. Japan's nuclear energy policy and regulations have undergone substantial modifications as a result of the Fukushima Daiichi nuclear disaster in 2011. Estimates show that the LCOE for new nuclear projects in Japan will vary from $80 to $120 per MWh, notwithstanding the fact that precise data might not always be accessible. The greater LCOE range is caused by a variety of elements, including heightened safety regulations and the expense of decommissioning older plants.

1.5.4.2 The advantages and disadvantages of Nuclear energy

The following advantages have been observed of Nuclear energy:

- High Energy Density: Nuclear energy has a very high energy density, which translates to the production of a considerable amount of energy from a small amount of nuclear fuel. As a result, nuclear power plants can produce a lot of electricity with only a small amount of fuel.
- Nuclear power plants produce baseload power, which entails that they are able to run constantly and offer a steady supply of electricity. They are dependable sources of energy since they are not reliant on outside variables like the weather.
- Low Greenhouse Gas Emissions: During regular operations, nuclear energy does not directly emit greenhouse gases like carbon dioxide. As a result, it is a low-carbon energy source that can slow global warming.
- Energy Security: By varying the energy mix and lowering dependency on imported fossil fuels, nuclear power plants can improve energy security. Countries with large nuclear power capacities can lessen their reliance on imported energy.

The following disadvantages have been observed of utilization of Nuclear energy for power generation:

- Nuclear Waste Management: The handling and disposal of radioactive waste is one of the major problems with nuclear energy. Spent fuel rods and other leftovers from nuclear reactors are radioactive for thousands of years. To stop any potential release of radiation into the environment, safe methods of storage and disposal are crucial. To safely bury nuclear waste, long-term repositories like deep geological repositories are being designed, however their construction may be hampered by political obstacles and public opposition.
- Safety issues: It is crucial to ensure the safety of nuclear power facilities. Despite the high level of safety associated with nuclear energy, catastrophes like Chernobyl and Fukushima have brought attention to the dangers. These mishaps had negative effects on both the environment and people, which prompted more scrutiny and stringent safety rules. To reduce dangers and preserve public confidence, ongoing investments in safety research, strict maintenance practises, and efficient emergency response plans are essential.
- Security and non-proliferation: Nuclear technology can be abused to create nuclear weapons. Strict international safeguards and non-proliferation agreements, like the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), are in place to stop the spread of nuclear weapons. Security precautions are required to guard against potential terrorist threats and prevent unauthorised access to nuclear materials.
- Significant Upfront Capital Costs: Due to their complexity and strict safety standards, nuclear power facilities have significant initial capital costs. The expenses cover infrastructure for waste management, safety measures, and reactor building as well as site preparation. The project developers may face financial difficulties as a result of these

high capital expenditures, which may also hurt nuclear energy's ability to compete with other methods of energy production.

- Nuclear fuel, such as uranium and plutonium, are readily available in large numbers, but there are only a small number of conveniently accessible, high-grade resources. The development of new fuel cycles, such as breeder reactors and thorium reactors, or the deployment of enhanced fuel enrichment and reprocessing technologies to maximise fuel utilisation, are therefore necessary for the long-term sustainability of nuclear energy.
- Public Perception and Acceptance: Because of worries about safety, waste management, and the possibility of accidents, the public has a difficult time accepting nuclear energy. For nuclear energy projects to be developed and expanded, public support is essential. It's crucial to address these issues through open communication, outreach, and stakeholder involvement to win over the public's trust and win its support.
- Decommissioning is necessary as nuclear power reactors get older and reach the end of their useful lives. Decommissioning entails properly closing down the plant, removing and discarding radioactive parts, and cleaning up the area. Decommissioning can be a difficult, expensive procedure that needs to be carefully planned out and done in accordance with all applicable regulations.

1.5.5 Biomass Energy

A renewable energy source that has received a lot of attention is biomass energy, which has the potential to lessen greenhouse gas emissions and rely less on fossil fuels. It entails transforming organic resources into forms of useful energy, such heat, electricity, or biofuels. Specific energy crops like switchgrass and miscanthus, agricultural waste products like maize stalks or rice husks, forestry waste products like wood chips or sawdust, and even organic waste products like food scraps or manure can be utilised as organic materials for biomass energy. These biomass feedstocks contain carbon molecules that represent stored energy that can be released and utilised through various conversion procedures.

Combustion is a typical technique for converting biomass into energy, in which the organic material is burned to create heat in dedicated facilities. Direct application of this heat to industrial operations is possible, as is the creation of steam for the purpose of powering turbines. Buildings, both residential and commercial, can use biomass combustion for heating. Biochemical conversion is a different type of conversion that uses bacteria, enzymes, or microorganisms to break down biomass and turn it into biofuels like ethanol or biodiesel. Typically, fermentation is utilised in this process, which turns sugars from biomass feedstocks into alcohol or other fuels that can be used for heating or transportation.

Another method is known as thermochemical conversion, which uses heat and chemical reactions to transform biomass into energy. This can be done by using techniques like pyrolysis, gasification, or liquefaction, which result in a variety of energy-rich byproducts such solid biochar, bio-oil, and syngas (a mixture of hydrogen and carbon monoxide). These goods can be refined further and utilised as feedstocks for the chemical industry, to produce heat or energy, or both.

The utilisation of biomass energy has a number of benefits. First off, because plants absorb carbon dioxide (CO2) as they develop, the carbon dioxide (CO2) released during the burning or conversion of biomass is regarded to be neutral. By doing so, greenhouse gas emissions are reduced and climate change is fought. Additionally, biomass energy can boost regional agriculture, generate employment along the biomass supply chain, and lessen reliance on foreign imports of fossil fuels.

Depending on the biomass conversion technology selected, the process of converting biomass into energy requires a number of processes. The main steps in converting biomass into energy are summarised in the following general manner:

I. Collection & Preparation of Biomass: Biomass feedstocks are gathered and transported to the biomass conversion facility. These feedstocks can be organic waste, forestry residues, energy crops, or agricultural residues. For the purpose of improving its physical characteristics and raising its energy density, the biomass may go through preprocessing procedures including shredding, grinding, or drying.

II. Biomass Conversion:

- Combustion: To provide heat energy, prepared biomass is burned in a combustion chamber or boiler during biomass combustion. This heat can be utilised immediately to heat rooms, power industrial processes, or create steam to turn a turbine and generate electricity.
- Gasification: In a regulated atmosphere with a limited amount of oxygen, biomass is partially burned. Syngas (synthesis gas) is a gas combination created by heating biomass at high temperatures, often between 700 and 1,200 degrees Celsius. Carbon monoxide (CO), hydrogen (H2), and a trace quantity of methane (CH4) make up the majority of syngas. Syngas can be processed further to create chemicals or biofuels, or it can be utilised as a fuel for electricity generation.
- Pyrolysis: The degradation of biomass into three primary products, including biochar, bio-oil, and syngas, occurs when biomass is heated in the absence of oxygen. Solid carbon-rich material called biochar is used as a fuel or to modify soil. A mixture of liquids called bio-oil can be used as fuel or as a raw material for making biofuel. The syngas created by the

pyrolysis of biomass can be used for numerous purposes, including the production of heat and power.

- Anaerobic Digestion: By using anaerobic digestion, biomass feedstocks like animal dung, food scraps, or crop residues can be transformed into biogas. In an atmosphere devoid of oxygen, microorganisms break down the biomass to create a methane-rich biogas. This biogas can be utilised to fuel vehicles or to generate heat and power. A nutrient-rich digestate that can be used as fertiliser is also produced by anaerobic digestion.
- Energy Conversion and Utilisation: Depending on the particular application, the energy generated during the biomass conversion process is used in a variety of ways. It can be applied to industrial operations, district heating systems, or heating applications in buildings. It can also be utilised to produce energy using internal combustion engines or steam turbines. For use in vehicles, biomass energy can also be transformed into biofuels like ethanol or biodiesel.
- Residue Management: Various residues, like as ash from combustion or biochar from pyrolysis, are formed as a result of the biomass energy conversion process. Sustainability of the environment depends on the handling of these wastes. Ash can be utilised as a soil amendment or properly disposed of, whereas biochar can be used to enhance soil or produce energy.

1.5.5.1 The LCOE of Biomass

A statistic called Levelized Cost of Energy (LCOE) is used to evaluate how cost-competitive various energy sources, including biomass energy, are. It reflects the typical cost of producing a unit of electricity during the course of a power plant, accounting for initial construction expenditures, operational expenses, fuel costs, and other elements. Due to changes in the availability of technology, governmental frameworks, and local market conditions, the Levelized Cost of Energy (LCOE) of biomass energy might differ dramatically from one country to the next. Here are the approximations of the LCOE for biomass energy in several nations:

i. United States: Depending on variables including feedstock availability, project scale, and geographical differences, the lifetime cost of energy (LCOE) for biomass energy in the United States typically ranges from \$0.06 to \$0.12 per kilowatt-hour (kWh).

ii. Germany: The LCOE for biomass energy in Germany is reportedly between \$0.07 and \$0.14 per kWh. Based on feedstock costs, conversion technologies, and support mechanisms like feed-in tariffs and renewable energy subsidies, the precise values may change.

iii. Sweden: Sweden has been a leader in the use of biomass energy. According to estimates, Sweden's biomass energy costs between \$0.05 and \$0.10 per kWh. Sweden benefits from a long history of using biomass for the generation of heat and power, supporting policies, and a well-developed biomass supply chain.

iv. Brazil: A large portion of Brazil's energy mix comes from biomass, especially sugarcane bagasse and other agricultural waste. Brazil's LCOE for biomass energy is predicted to be between \$0.06 and \$0.10 per kWh due to the availability of cheap biomass feedstocks and tried-and-true conversion techniques.

v. India: In India, the cost of producing one kilowatt-hour (kWh) of biomass energy typically ranges from \$0.06 to \$0.12. Depending on variables including feedstock accessibility, project size, technological effectiveness, and legislative support, the precise values may change.

vi. Japan: As a component of its renewable energy portfolio, biomass energy has been extensively promoted in Japan. In Japan, the LCOE for biomass energy is predicted to be between \$0.08 and \$0.14 per kWh. The price of feedstock, the choice of technology, the scope of the project, and government incentives are some of the variables that affect this range.

vii. Canada: The biomass energy sector is expanding and the country has a wealth of biomass resources. In Canada, the LCOE of biomass energy typically runs between $0.06 and $0.12 per kWh. The precise values rely on variables including the availability of biomass as a feedstock, regional variances, technological developments, and governmental policies.

viii. France: A sizable portion of France's renewable energy mix comes from biomass energy. In France, the LCOE of biomass energy is predicted to be between $0.07 and $0.13 per kWh. Feedstock costs, conversion technology, project size, and governmental incentives are some of the variables affecting this range.

1.5.5.2 The advantages and disadvantages of Biomass

The following advantages have been observed by using of biomass:

- Renewable and Sustainable: Biomass is made from organic elements that are continually renewed by natural processes, such as plants, agricultural waste, and organic waste residues. Biomass is seen as a renewable energy source as opposed to fossil fuels, which have limited reserves. By managing biomass resources responsibly and assuring their availability over the long term, biomass energy production may be sustained.
- Reduction of Greenhouse Gas Emissions: The carbon dioxide (CO_2) released during the combustion of biomass is balanced by the CO_2 absorbed by plants during their growth, making biomass energy considered carbon-neutral. This closed carbon cycle reduces net CO_2 emissions and aids in climate change mitigation. Compared to energy sources based on fossil fuels, biomass energy can significantly reduce greenhouse gas emissions.

- Waste Management and Resource Utilisation: Biomass energy can be made from a variety of organic wastes, including municipal and industrial organic waste, agricultural residues, and forestry residues. By transforming these waste products into electricity, biomass energy contributes to resource efficiency, the reduction of landfill waste, and the reduction of methane emissions from the breakdown of organic waste.
- Energy Independence and Security: By lowering reliance on imported fossil fuels, biomass energy production can increase energy independence. Due to the availability of biomass resources across a wide range of geographical locations, it provides a decentralised energy option. Using locally obtained biomass as feedstocks can improve energy security and foster community growth.
- Applications for Flexible Energy: Biomass energy can be transformed into a variety of forms, such as heat, electricity, and biofuels, enabling applications for flexible energy. Heat can be produced from burning biomass for domestic, industrial, and commercial uses. Electricity can be produced in biomass power plants, helping the grid. For use in transportation, biomass feedstocks can also be turned into biofuels like ethanol and biodiesel.
- Economic and job opportunities are created by biomass energy projects along the entire biomass supply chain, from biomass production and transportation to conversion and facility maintenance. These initiatives can help local economies, promote job growth in the agricultural, forestry, and renewable energy industries, as well as aid in the development of rural areas.
- Baseload and dispatchable power generation: Baseload power, or a steady supply of electricity, can be produced by biomass power plants. Biomass energy may be dispatched

and regulated in accordance with demand, providing stable and dependable power supply, unlike intermittent renewable sources like solar and wind.

The following disadvantages have been observed during utilisation of Biomass:

- Carbon Emissions and Air Pollution: The burning of biomass results in the release of carbon dioxide (CO2) into the atmosphere, which contributes to the emissions of greenhouse gases. The carbon cycle makes biomass carbon-neutral over the long run, but the immediate emissions can still cause local and regional air pollution. The production of pollutants such nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs), which can have a negative impact on the air quality and people's health, can result from inefficient or improperly managed combustion.
- Biomass feedstock production can have substantial environmental effects and can affect how land is used. If large-scale monoculture plantations for energy crops are not maintained responsibly, they may cause deforestation, biodiversity loss, soil erosion, and water pollution. Additionally, transforming natural ecosystems into places for the production of biomass might harm nearby habitats and restrict the amount of land available for other uses, such as food production and conservation.
- Intensity and Competition of Resources: The generation of biomass energy demands a substantial amount of land, water, and other resources. This might result in rivalry for resources between the production of biomass energy and other industries, including agriculture or the environment. Agricultural land, water resources, and fertiliser use may be under strain due to the rising demand for biomass feedstocks, which could result in unsustainable practises and resource depletion.

- Feedstock Availability and Seasonality: Seasonal fluctuations, weather patterns, and agricultural practises are some examples of the factors that can limit the supply of biomass feedstock. Depending on particular feedstocks, it could be difficult to provide a steady and dependable supply all year long. The stability and predictability of biomass energy output may be impacted by this seasonality, potentially causing disruptions in the energy supply.
- Technical difficulties and performance consistency: Biomass energy conversion systems can be complicated and need thorough optimisation to reach high efficiency. The efficient conversion of biomass into energy may be hampered by the diversity in feedstock properties. The complexity and cost of biomass energy projects may also increase due to the need for sophisticated machinery and experienced operators during some conversion processes, such as gasification and pyrolysis.
- Transportation and logistics: Compared to fossil fuels, biomass feedstocks frequently have a poor energy density. It can be expensive and logistically difficult to transport biomass across large distances, particularly in isolated places. It is vital to build biomass energy facilities close to biomass sources since transporting biomass might result in increased costs, energy use, and environmental effects.
- Water Consumption: Steam turbines, one type of biomass energy conversion method, need a lot of water to cool down. Particularly in areas with scarce water supplies or conflicting demands for water, water scarcity and competition for water resources can limit the scalability and sustainability of biomass energy generation.
- Financial viability and reliance on subsidies: Compared to other renewable energy sources, biomass energy projects can have greater capital costs and frequently require significant upfront investments. Various elements, including the availability of feedstock, the cost of the

technology, the state of the energy market, and governmental regulations, can affect how economically viable biomass energy is. Relying on incentives or subsidies to make biomass energy commercially viable can raise concerns about a project's long-term viability.

1.5.6 Geothermal energy

A renewable energy source called geothermal energy is created from the heat that the Earth's crust stores. It makes use of the thermal energy that the Earth's core naturally generates, as well as the warmth left over from the planet's birth and the radioactive decay of materials in the crust. Direct heating and cooling systems and the production of electricity are just a few uses for this energy. The core of the Earth reaches temperatures of several thousand degrees Celsius, making it an extraordinarily hot place. Through conduction and convection processes, this heat energy steadily flows towards the surface. By utilising this heat transfer, geothermal energy is able to access the Earth's natural heat reserves and transform them into useful energy. The sources of geothermal energy are as follows:

I. Hydrothermal systems: When water comes into touch with heated rocks in the Earth's crust, hydrothermal systems are created. Geothermal reservoirs of hot water or steam are produced when heat from the rocks is transferred to the water. The most prevalent and economically viable source of geothermal energy is through hydrothermal systems.

II. Geo-pressured Systems: In deep sedimentary basins, where high-pressure hot water with dissolved methane is trapped, geo-pressured systems are present. The majority of these systems are found in coastal areas.

III. EGS stands for Enhanced Geothermal Systems, a method that increases the productivity of geothermal resources in regions with limited natural heat and permeability. It entails injecting water into warm, low-permeability rock formations and extracting the heated fluid through production wells to create designed geothermal reservoirs.

The geothermal energy can be harnessed in various ways:

- Geothermal power plants use heat energy extracted from geothermal resources to create electricity. To do this, hot water or steam is drawn out of underground reservoirs and used to power turbines that are connected to electricity generators. The type of power plant technology used, such as flash steam, binary cycle, or dry steam systems, depends on the temperature of the geothermal fluid.
- Applications for Direct Use: Geothermal energy can be utilised directly to heat and cool buildings. Hot water or steam is used directly for space heating in homes, buildings, industrial processes, greenhouses, and district heating systems in regions where geothermal resources are close to the surface. To draw heat from the earth for space heating and cooling, geothermal heat pumps are also used.

Accessing the geothermal resource and turning the heat into electricity are just several steps in the process of producing geothermal energy. An explanation of the procedure is provided below in detail:

i. Exploration and identification: The first phase is to locate possible geothermal resources using exploration methods such as geological surveys, satellite imaging, and others. In order to identify regions with a high geothermal potential, surface characteristics, rock formations, and temperature gradients must be examined.

ii. Drilling of wells: Wells are dug into the geothermal reservoir when a promising site has been found. The properties of the resource, such as temperature, permeability, and fluid content, determine the depth and construction of the wells. Two types of wells are often employed:

(a) Production Wells: These wells are used to remove steam or hot water from a reservoir. To reach the geothermal resource, they are frequently dug vertically or at an angle.

(b) Reinjection Wells: Following energy extraction, cooled fluid (such as water or condensed steam) is pumped back into the reservoir using reinjection wells. This keeps the reservoir under pressure and extends the life of the resource.

iii. Fluid Extraction: Through the production wells, hot water or steam is drawn from the geothermal reservoir. In low-temperature systems, the fluid's temperature might be as low as a few tens of degrees Celsius or as high as several hundred degrees Celsius.

iv. Energy Conversion: The hot water or steam that was retrieved is sent to a geothermal power plant to be converted into electricity. The procedure changes according on the fluid's composition and temperature:

a) A binary cycle power plant is utilised in systems with lower operating temperatures (below 150 °C). A heat exchanger transfers the heat from the hot geothermal fluid to a working fluid with a lower boiling point, such isobutane or isopentane. The vaporisation and expansion of the working fluid propels a turbine that is coupled to a generator, which generates energy.

b) Flash Steam Power Plants: These are used in systems with moderate to high temperatures (over 150°C). A flash tank is used to quickly lower the pressure of the high-pressure geothermal fluid. The fluid subsequently turns into steam as a result of this, which is utilised to power a turbine that is attached to a generator.

v. Power Generation and Transmission: The generator transforms the mechanical energy from the turbine into electrical energy. After that, the electricity is transferred via a grid system to supply homes, companies, factories, and other electrical customers with power.

vi. Monitoring and Maintenance: To guarantee maximum performance and lifetime, geothermal power facilities need to be regularly inspected and maintained. Monitoring fluid flow rates, pressure, temperature, and other operational characteristics fall under this category. For effective and dependable operation, wells, turbines, generators, and other equipment must be properly maintained.

1.5.6.1 The LOCE of Geothermal Energy

The average cost of generating electricity from a geothermal power plant during its lifespan, including all expenses related with planning, building, operation, and maintenance, is referred to as the Levelized Cost of Electricity (LOCE) of geothermal energy. The overall lifespan expenses are divided by the total quantity of power produced during the plant's lifetime to determine the LOCE. The following cost elements have an impact on geothermal energy's LOCE:

- Resource Assessment, Exploration, and Development: The first phase of a geothermal project entails drilling to locate and access the geothermal resource. The costs of the entire project may be greatly influenced by these actions.
- Plant Construction: The creation of the infrastructure for a geothermal power plant, including well drilling, the installation of power producing equipment, and grid connectivity, is part of the construction phase. The cost of labour, materials, and engineering during this phase can significantly affect the LOCE.

- Operation and maintenance: To maintain effective and dependable operation, geothermal power plants need frequent operation and maintenance activities. This include maintaining fluid reinjection systems, monitoring the wells, and power producing machinery. Depending on the scale of the facility, the technology utilised, and the characteristics of the resource, the cost of operation and maintenance can change.
- Electricity Production: The geothermal power plant's lifetime output of electricity has an impact on the LOCE. The cost per unit of electricity produced can be decreased by increasing power generation in order to spread out the initial development and building costs over a greater output.
- Finance and Policy Support: The LOCE of geothermal energy can be affected by the cost and availability of funding. Project expenses might be decreased with the use of lower interest rates and favourable financing arrangements. Additionally, by lessening the financial burden on geothermal projects, supportive policies like feed-in tariffs, tax incentives, or grants can also have an impact on the LOCE.

A number of variables, such as the quality of the geothermal resource, the size of the project, technological developments, regulatory backing, and local market conditions, can affect the Levelized Cost of Electricity (LOCE) of geothermal energy in different nations. Here are several countries' approximations of the LOCE for geothermal energy:

i. Iceland: Iceland is renowned for its plentiful geothermal resources and has had great success producing electricity from them. Iceland's LOCE for geothermal energy, which ranges between 4 and 7 US cents per kilowatt-hour (kWh), is thought to be among the lowest in the world. The country's favourable geology, good resource quality, and well-established geothermal sector are responsible for this low cost.

ii. United States: Depending on the particular project and resource quality, the LOCE of geothermal energy varies in the United States. In general, the LOCE for traditional hydrothermal geothermal plants is between 5 and 10 US cents per kWh. The LOCE, however, may be higher in some areas with deeper and more difficult resources. Reducing costs and boosting competitiveness are significantly aided by technological improvements and supportive policies.

iii. Kenya: Kenya is a major generator of geothermal energy in Africa and has made considerable investments in the field. Geothermal energy in Kenya is thought to have a LOCE of 7 to 10 US cents per kWh. Utilising the rich resources found in the Rift Valley, the nation has established a successful geothermal programme that has attracted foreign investment.

iv. Another nation with significant geothermal potential is Indonesia. Depending on the project and resource quality, geothermal energy's LOCE varies in Indonesia. It is predicted to be between 6 and 10 US cents per kWh. In order to encourage investments in geothermal power generation and wean the nation off fossil fuels, the government has put supportive laws and incentives in place.

v. New Zealand: A major portion of New Zealand's electricity is produced from geothermal energy. Depending on the project and resource parameters, the LOCE of geothermal energy in New Zealand is predicted to range between 6 and 12 US cents per kWh. The nation's advantageous geothermal resources and a thriving geothermal sector help to keep costs down.

vi. India: Geothermal energy is still in its infancy in India, and the LOCE can change based on the particular project and resource circumstances. However, it is predicted that the LOCE for geothermal energy in India will fall between 7 and 12 US cents per kilowatt-hour (kWh). In areas like the Himalayas, the Western Ghats, and some of the north-eastern provinces, India has tremendous geothermal potential.

vii. France: Despite having few high-temperature geothermal resources, France has been spending money on low-temperature geothermal heating and cooling systems. Depending on the particular project and technology employed, geothermal energy's LOCE varies in France. The LOCE can cost between 8 and 15 US cents per kWh for deep geothermal projects, although it can be lower for shallow geothermal operations.

viii. Italy: Historically, mostly in the Tuscany region, Italy has used geothermal energy. The unique project and resource conditions determine the LOCE of geothermal energy in Italy. The LOCE for traditional hydrothermal geothermal power facilities is predicted to be between 6 and 12 US cents per kWh. Italy has been developing its enhanced geothermal systems (EGS) and increasing its geothermal capacity.

ix. Turkey: Turkey is currently constructing geothermal power projects and has large geothermal resources. Depending on the particular project and resource conditions, geothermal energy's LOCE varies in Turkey. The LOCE is typically predicted to be in the 6–12 US cents per kWh range, while cost may be lower for projects with advantageous resource characteristics.

x. Portugal: Portugal has fewer geothermal resources than some other nations, but it has been looking into how to use them. The unique project and resource conditions determine the LOCE of geothermal energy in Portugal. According to estimates, costs vary based on the depth and temperature of the geothermal resource, falling between 8 and 15 US cents per kWh.

xi. Australia: The country is home to both high-temperature and low-temperature geothermal systems. Depending on the particular project and resource conditions, the LOCE of geothermal energy in Australia can change. The LOCE for typical hydrothermal projects is predicted to fall between 7 and 15 US cents per kWh. However, due to the difficulty of drilling and reservoir engineering, deep geothermal projects or enhanced geothermal systems (EGS) may have higher costs.

1.5.6.2 The advantages and disadvantages of Geothermal Energy

- Geothermal energy comes from the heat produced inside the Earth, which is continually supplied by natural processes, making it renewable and sustainable. It is a renewable energy source that can be used indefinitely without running out. Geothermal energy will be accessible for as long as the Earth's core is hot.
- Low Emissions: When compared to fossil fuel-based power plants, geothermal power plants emit relatively little in the way of greenhouse gases and air pollutants. Low levels of carbon dioxide (CO2), nitrogen oxides (NOx), and sulphur dioxide (SO2) are released during the energy generation process. Geothermal energy is regarded as a clean energy source that helps combat climate change by lowering greenhouse gas emissions.
- Baseload Power: Due to their ability to run constantly in all kinds of weather, geothermal power plants offer a steady and dependable supply of electricity. They are able to offer baseload power, which is crucial for supplying towns and businesses with electricity on a continuous basis. Geothermal energy can offer a reliable and predictable supply of power, in contrast to other intermittent renewable energy sources like solar or wind.

- Geothermal energy resources can support local economic development and energy independence because they are frequently localised. Geothermal project development can boost the local economy and lead to job possibilities. Additionally, geothermal power promotes energy security by lowering reliance on imported fossil fuels and susceptibility to price volatility in global energy markets.
- In comparison to fossil fuel-based power generation, geothermal energy offers long-term cost stability. Since geothermal energy derives from the heat of the Earth and does not require a constant supply of fuel, fuel costs are comparatively inexpensive once a geothermal power plant is constructed and operating. This consistency can offer protection from shifting fuel prices and a more stable environment for energy pricing.
- Geothermal energy has several uses beyond just producing electricity. In a variety of applications, such as district heating systems, industrial processes, greenhouses, and space heating in homes and buildings, it can be used directly for heating and cooling. Geothermal heat pumps are able to efficiently and sustainably collect ground-source heat for room heating and cooling.
- Geothermal power facilities have the potential to be developed as combined heat and power (CHP) systems, commonly referred to as cogeneration. The overall effectiveness and value of geothermal energy are further increased by CHP systems, which capture the waste heat generated during the power generating process and utilise it for a variety of heating purposes.

The following disadvantages of geothermal energy have been observed:

- Limitations of the Site: Geothermal energy is site-specific and can only be used in locations with favourable geological characteristics, such as hot springs, geysers, or regions with strong subsurface heat flow. Geothermal energy cannot be used everywhere because to these geographical constraints, which limits its potential for widespread application.

- High upfront costs: Building geothermal power facilities can be quite expensive. Significant investments are needed for resource appraisal, power plant building, and exploratory drilling. Particularly for smaller-scale initiatives or in regions with limited access to financing, these high entrance costs may act as a barrier to entry.
- Exploration and Resource Uncertainty: To ascertain the resource potential and quality prior to investing in a geothermal project, extensive exploration and assessment efforts are required. This procedure calls for digging wells and doing in-depth geoscientific research, both of which can be time-consuming, difficult, and expensive. A project's viability may also be at danger due to the ongoing degree of uncertainty surrounding the size and productivity of geothermal reservoirs.
- Environmental Impact: Geothermal energy still has some environmental effects even if it is thought to be more environmentally friendly than fossil fuels. Hydrogen sulphide (H2S), ammonia (NH3), and trace elements can be released during the extraction of geothermal fluids from subterranean sources. Potential dangers to nearby ecosystems and water resources, as well as the correct management and mitigation of these emissions, are crucial.
- Deep digging into the Earth's crust is required for geothermal energy, which presents hazards and technical difficulties. Unexpected geological formations, extreme temperatures, and corrosive fluids that might harm equipment can all be encountered during drilling operations. To guarantee a project is implemented safely and effectively, due to the complexity of subsurface activities, knowledge and careful management are needed.

- Baseload electricity can be produced using geothermal energy, but its scalability is constrained by the lack of sufficient geothermal resources. It can be difficult to increase geothermal capacity outside of established resource locations, and it may be necessary to make substantial investments in infrastructure construction, drilling, and exploration. This constraint limits the potential for geothermal energy to be widely used.
- Water Use and Potential Depletion: Some geothermal power plants use a lot of water to produce steam and extract heat. In particular in locations of water scarcity, the extraction and reinjection of geothermal fluids may have an effect on local water supplies. Without proper management, excessive geothermal fluid extraction might deplete geothermal reservoirs or change the local hydrological system.
- Geographical Restrictions: Because geothermal energy is location-specific, it may not be accessible or economically feasible in some areas, especially those that are far from geothermal resources. This restriction lessens the geographic diversity of available energy sources and may impede the development of geothermal energy in regions with high energy demand but low geothermal potential.
- Surface Effects and Land Use: Infrastructure for geothermal power plants, such as power plants, pipelines, and access roads, need land. The local ecosystems, habitats, and land use patterns may be impacted by these land requirements. To reduce surface impacts, geothermal project development must take into account land use planning, environmental studies, and community involvement.

1.6 Motivation of the study

The urgent need for a transition towards a more sustainable and clean energy system drives the study of the sustainability renewable energy. The need to research alternative energy sources is becoming more pressing as the negative effects of fossil fuel use, such as climate change, air pollution, and resource depletion, become more and more obvious. A viable alternative is provided by renewable energy, which makes use of resources like sunshine, wind, water, and biomass that are plentiful and naturally replenishable.

In order to make sure that the use and deployment of renewable energy are in line with long-term environmental, social, and economic objectives, it is crucial to understand how sustainable it is. By carrying out research in this area, we can evaluate the potential trade-offs, resource needs, and environmental effects of various renewable energy systems. Our ability to maximise the benefits of renewable energy while minimising any potential negatives is made possible by this knowledge. We can then build plans based on this information.

Furthermore, researching the long-term viability of renewable energy aids in improving the effectiveness and efficiency of these systems. This entails boosting grid integration and energy storage systems, streamlining the processes for converting energy, lowering the energy inputs needed for production and installation, and promoting environmentally friendly behaviours across the whole life cycle of renewable energy infrastructure. The overall sustainability and feasibility of renewable energy solutions can be improved by identifying the areas for development.

Moreover, for a successful energy transition, it is essential to comprehend the social and economic aspects of renewable energy. Research in this field examines the possibilities for decentralised energy systems as well as issues like job development, community involvement, equal access to energy, and more. By taking into account these variables, we can make sure that the use of renewable energy not only addresses environmental issues but also fosters socioeconomic growth and an equitable and inclusive energy transition.

Finally, the impetus for researching renewable energy sustainability stems from our collective desire for a cleaner, more robust, and sustainable energy future. We can speed the transition to a renewable energy-based society by increasing our expertise and knowledge in this subject. This will help to influence policy, direct investment decisions, and stimulate innovation. This study also enables us to address potential obstacles, manage risks, and embrace opportunities for sustainable development, paving the path for future generations to enjoy a more sustainable and affluent future.

The major driving forces for this research are as follows:

- **Energy Return on Investment (EROI):** Although renewable energy sources typically have a positive EROI, it's crucial to take into account the energy inputs necessary to produce, construct, and maintain renewable energy infrastructure. To ensure the long-term viability and overall energy efficiency of various renewable technologies, it is essential to comprehend and maximise their EROI. Through measuring the ratio of energy output to energy input over the course of a technology, the Energy Return on Investment (EROI) measure is used to analyse the effectiveness and sustainability of energy sources. It reveals how much energy is needed to create and maintain a certain energy source.

  The EROI analysis for renewable energy technologies considers a number of things, such as the energy used in equipment manufacturing, raw material extraction and processing, transportation, installation, operation, and maintenance. Even though the EROI of renewable energy sources is typically positive, it is crucial to comprehend and maximise this statistic to ensure long-term sustainability and total energy efficiency. The main features are broken down as follows:

- Manufacturing: Energy inputs are needed to produce renewable energy technology including solar panels, wind turbines, and batteries. These involve assembly, manufacturing procedures, and the extraction and processing of raw materials. The EROI of renewable technologies can be increased by streamlining production procedures, consuming less material, and boosting productivity.
- Infrastructure and Installation: Energy inputs are also needed for the infrastructure of renewable energy, such as the building of solar, wind, or hydroelectric power plants. This covers the installation process itself, equipment transportation, and site preparation. Higher EROI values may result from reducing energy-intensive installation methods and optimising logistics.
- Operation and maintenance: Energy is used during the operation of renewable energy systems for maintenance tasks and recurring equipment replacements. To guarantee optimum performance and longevity, regular inspections, repairs, and component replacements are required. By requiring less regular maintenance and replacements, increasing the dependability and durability of renewable technologies can increase their economic return on investment.
- Energy Storage and Grid Integration: For renewable energy systems to manage supply-demand imbalances and reduce intermittency, energy storage devices must be integrated into the grid. When calculating EROI, it is necessary to take into account the energy input needed for producing and maintaining energy storage devices, such as batteries or pumped hydro

storage. The overall EROI of renewable energy systems can be raised by optimising storage technology and investigating different storage options with higher efficiency.

- Life Cycle Assessment: A thorough life cycle assessment (LCA) is necessary to appropriately calculate the EROI of renewable energy sources. The whole life cycle of the technology, including the extraction of raw materials, production, transportation, installation, operation, maintenance, and end-of-life disposal, is taken into account by LCA. Researchers can find places where energy inputs can be minimised and strategies to increase overall EROI by taking into account all stages.

➢ **Resources and Land Requirements:** The installation of some renewable energy technologies, such as large-scale wind and solar farms, necessitates a sizable amount of land. Conflicts between land uses may result from this if it competes with areas used for agriculture, wildlife habitats, or other land uses. Furthermore, many renewable technologies could depend on particular components, such rare earth elements, whose extraction and processing might have an impact on the environment and society.

- Land Use Conflicts: The installation of large-scale renewable energy projects, such solar farms and wind parks, frequently necessitates the use of significant land tracts. Conflicts with other land uses, such as agriculture, conservation areas, or urban growth, may result from this. It is possible for renewable energy installations to be built on prime agricultural land in some circumstances, which could have an effect on local economy or food production. Planning carefully, including stakeholders, and taking into account land zoning and allocation are all necessary to strike a balance between the need for renewable energy production and other land uses.

- Environmental Impacts: The development of renewable energy infrastructure may have an impact on the environment, particularly when it results in the destruction of habitat or the conversion of land. For instance, the development of wind farms might alter bird migration routes or endanger nearby species. Similar to how large-scale hydropower projects can affect fish populations and change river ecosystems. To reduce these effects and guarantee the sustainability of renewable energy projects, extensive environmental impact studies and mitigation strategies must be put in place.
- Materials: Some renewable energy systems require particular materials, such as rare earth elements (REEs), which are crucial parts of solar panels, electric vehicle batteries, and wind turbines. Environmental and societal effects may result from the mining, processing, and disposal of these materials. For instance, mining practises that might lead to habitat loss, water pollution, and issues with human rights are frequently linked to REEs. These difficulties may be lessened by investigating alternate materials or by enhancing recycling and recovery methods.

➢ **Environmental Impacts:** Despite being usually regarded as being cleaner than fossil fuels, renewable energy sources do have some environmental effects. Large-scale hydroelectric projects, for instance, can modify river flows and disrupt ecosystems, which has an impact on aquatic biodiversity and habitats. Similar to that, improper management of the manufacturing and disposal of renewable energy infrastructure parts, such as solar panels and wind turbines, could have negative environmental effects.

- Solar panels are made of a variety of elements, including glass, aluminium, silicon, and trace amounts of lead and cadmium, and two potentially dangerous metals. Although solar panels have a lengthy lifespan (usually 25 to 30 years), it is still important to properly dispose of and recycle them in order to reduce their negative environmental effects. Most solar panels are not currently recycled, and different regions have different disposal practises. The environment and human health may be at danger if hazardous material releases during disposal or incineration are not properly controlled.

- Wind turbines: Typically lasting 20 to 30 years, wind turbines have a longer lifespan than solar panels. Due to their size and the materials they are made of, wind turbines' disposal can be challenging as they reach the end of their useful lives. The base, nacelle (which houses the generator and gearbox), and blades are the four main parts of a wind turbine. The recycling of wind turbines is still in its infancy, and many of them end up in landfills. Materials used in wind turbine manufacturing, such as steel, concrete, fibreglass, and rare earth magnets, must be handled using proper recycling and waste management procedures.
- Radioactive Waste: Low-level, intermediate-level, and high-level radioactive waste are all produced by nuclear power reactors. The most dangerous waste is high-level waste, which includes spent nuclear fuel. It needs long-term management and disposal. Highly radioactive compounds found in this garbage can be hazardous for a very long time. To make sure it doesn't endanger the environment or human health, proper disposal is required.

To address the pressing issues of climate change and create a sustainable energy future, it is crucial to do research on the switch from conventional energy to renewable energy. Traditional energy sources, which are largely based on fossil fuels, have historically been the main forces behind economic expansion. However, due to their extensive usage, alarming amounts of greenhouse gas emissions have been produced, accelerating the effects of global warming, including sea level rise, harsh weather, and damage to ecosystems and agriculture. We can drastically lower greenhouse gas emissions and slow the rate of climate change by funding research into renewable energy sources including solar, wind, hydro, geothermal, and biomass. Technologies utilising renewable energy generate little to no direct emissions while in use, providing a cleaner and more environmentally friendly alternative to fossil fuels. To effectively mitigate the worst effects of climate change and protect the welfare of future generations, it is crucial to understand how to harness and integrate these renewable energy sources into our energy systems.

By diversifying energy sources and decreasing reliance on imports of fossil fuels, switching to renewable energy also improves energy security by lowering the danger of resource-related geopolitical crises. Due to their widespread distribution, renewable energy sources give nations the chance to utilise their plentiful indigenous resources, promoting energy independence and supply-chain resilience. There are substantial economic advantages to the move as well. Researching and developing new renewable energy technologies fosters innovation and generates new employment opportunities across a range of industries, promoting economic growth and ensuring industries have a sustainable future. Furthermore, by offering decentralised energy solutions, renewable energy helps reduce social and economic inequalities in access to energy, particularly in rural and isolated areas. This transformation is mostly being driven by sustainability. Since fossil fuels are limited resources, their extraction results in habitat destruction, water pollution, and environmental deterioration. In contrast, renewable energy sources may be replenished and leave behind a significantly lower ecological footprint, protecting biodiversity and natural ecosystems for future generations.

Researching the switch from fossil fuels to renewable energy also spurs technological development. The efficiency and cost of renewable energy technologies are rising as we continue to research and develop them. This cost-effectiveness makes renewable energy more and more competitive with fossil fuels, hastening the switch and enabling it to be used by a larger number of people. The transition to renewable energy sources also plays a crucial role in enhancing public health. The reduction of harmful emissions and air pollutants from burning fossil fuels leads to cleaner air and water, which lowers the incidence of cardiovascular and respiratory ailments and eventually enhances people's quality of life. In conclusion, in-depth analysis of the switch from conventional to renewable energy is essential to combating climate change, enhancing energy security, fostering economic growth, and protecting the environment and public health. We can create a more sustainable and prosperous future for people and the world by putting a priority on renewable energy alternatives and funding their development.

The world is in the transition phase from traditional energy sources to renewable energy sources for achieving the United Nations net zero carbon emissions by 2050. Therefore it becomes utmost important to analyse the renewable energy system that can support sustainability without effecting the stability of energy supply to meet the increasing energy demands. Additionally forecasting plays a crucial role in informed decision making and risk mitigation that is involved in shifting to a new sources of energy. Renewable energy has recently been the main concern for every country due to its ability to reduce GHGs emissions.

In this research Fourier bootstrap ARDL, Fourier bootstrap Toda-Yamamoto, Wavelet coherence and the business usual analysis was used to study both the short run and long run relationship between the variables CO2 emissions, GDP and renewable energy. The future potential of renewable energy to reduce CO2 emissions by 2050 was estimated if the transition to renewable energy it carried out in the same pace. The study also analysed the total CO2, SO2 and NOx mitigated by the use of renewable energy.

1.7 Statement Problem

- It is necessary to create an energy mix that can lessen environmental effect while retaining the stability of the energy supplied.
- Clarity is required to decide which sustainable renewable energy and technology is better suited for a given nation.
- To determine whether the chosen renewable energy will be able to reduce CO2 emissions in order to achieve the UN's net zero carbon emissions goal by 2050.
- It is necessary to compare co-integration and business-as-usual analyses of renewable energy for both the short and long run of developed nations in order to make policy decisions.

1.8 Significance of the study

The significance of this study lies in recognising and addressing the challenges associated with the transition of energy system by highlighting the problems faced by the nations who have been using the alternative sources of energy for more than five decades. This will give the blue print and help solve the problems of the nations who are new to the transition phase.

1.9 Organization of the thesis

Section 1: Introduction provides an overview of the sustainable energy sources and key concepts.
Section 2: Literature Review conducts a review of the existing literature and identify gaps.
Section3: Methodology techniques to outperform the strategy

Section4: The impact of renewable energy on economy and environment

Section 5: The Environmental Kuznets curve hypothesis

Section 6: The sustainability of different renewable energy

Section 7: The future of the shift in energy transition and the United Nations net zero carbon emissions.

Section 8: Conclusion the study concludes by summarizing the key findings and contributions. It also discusses the limitations of the research and suggests areas for future exploration and improvement.

CHAPTER 2

LITERATURE REVIEW

For the past two decades, environmental concerns like climate change, air pollution, greenhouse gases and global warming are the major international agenda. Worldwide an action plan to reduce the environmental pollution was adopted by 178 nations in the 1992 Rio de Janeiro earth summit. Later, by signing the Kyoto Protocol and the UNFCCC, countries committed to participating in mitigating global climate change. In addition, the UN (2017) Sustainable Development Goals (UN-SDG) require signatory countries to take various initiatives to lessen the strain on nature. Greenhouse gases (GHG) are one of the most serious threats to the climate and the ecosystem. It is caused by extensive industrialization, urbanization, and deforestation from high fossil fuel-based energy consumption. The urbanization affects the country's economic growth and carbon dioxide. Trade openness (trade/GDP) is significantly increases the global exchanges of goods and services and economic expansion. It's still debatable point whether it has a good or bad impact on carbon dioxide emissions. Trade openness helps developing countries adopt advanced technologies that significantly reduce CO_2 emissions. It is also observed that the urban areas have a significant impact on energy use and emissions of carbon dioxide. Urbanization's consequences on the usage of fossil fuels have surely altered the atmosphere's carbon content, which is contributing to increase in global warming.

The scientists at the Intergovernmental Panel on Climate Change (I.P.C.C.) discovered in 2007 that the correlation between greenhouse gas emissions and the average global temperature exists. For example, greenhouse gas emissions have increased by about 1.6 percent per year, and fossil fuel carbon dioxide emissions by 1.9 percent for the last three decades, annually. Compared to developed nations, carbon dioxide emissions from energy consumption have dramatically grown during the 1990s. Concerns about global warming as well as climate change have indeed been voiced as a result of an alarming amount of environmental deterioration. Acknowledging environmental pollution's sources and how it affects economic growth has therefore grown more crucial in recent times.

2.1 The assessment of different sources of renewable energy

The research on the sustainability of renewable energy mainly focuses on the assessment of sustainability in energy system, economy, society, environment and technology. Campos-Guzmán et al. established a renewable energy sustainability assessment system based on environmental, economic and social dimensions, and verified that the combination of life cycle analysis and multi-criteria decision making is correct for the assessment of renewable energy system sustainability. (Harjanne and Korhonen, 2020) presented key issues in the concept of renewable energy in terms of sustainability, inconsistency, policy impact, decoy and conversion strategies, and general misleading; and proposed models for classifying energy production based on carbon content and combustion.

(Guen et al., 2018) used energy maps to qualitatively analyse the promising energy technologies in Swiss villages and improve energy sustainability in Swiss villages through building renovation and renewable energy integration. (Wang and Chen, 2010) analysed the role of the Clean Development Mechanism in promoting the sustainable development of renewable energy in China by reviewing CDM activities. (Chuang et al., 2019) assessed the sustainability of Taiwan's renewable energy sources and determined whether Taiwan's future electricity supply was stable.

(Böhringer et al., 2017) found that the amount of Internet subsidies had little direct impact on the sustainability of renewable energy technologies, but could lead to higher electricity prices and encourage technological innovation in renewable energy. (Maes et al., 2015) used the bio-refinery as a case to evaluate the EU Renewable Energy Directive Sustainability Guidelines, the results show that combining RED-based sustainability assessment with other more comprehensive assessments can more accurately understand the sustainability of the project. (Tareen et al., 2018) provided an insight into the potential of these resources in Pakistan to generate electricity for the national grid on a large scale, the results show that biomass is the most sustainable, available, implementable and environmentally friendly resource that can be used to reduce Pakistan's energy demand and supply gap.

2.2 The relationship between Economic Growth and Renewable Energy

(Inglesi-Lotz, 2016) used panel data to study the impact of renewable energy consumption on economic growth; the results show that the impact of renewable energy consumption on economic growth is positive, and promoting the development of renewable energy can promote the sustainability of economic growth. (Pierie et al., 2016) discussed an integrated system approach for determining the sustainability of biogas or green gas production pathways and demonstrates that this approach can be used as a sustainable solution for generating and identifying energy production pathways. (Maulidia et al., 2019) discussed Indonesia's current renewable energy policy and how to achieve sustainable development of renewable energy and its goals. (Sinha et al., 2018) analysed the causal relationship between economic growth, carbon emissions, fossil fuels and renewable energy consumption during the period 1990–2016; the results demonstrate that renewable energy is implemented to ensure sustainable economic growth by reducing carbon emissions and increasing energy supply.

2.3 Renewable Energy System and Sustainable Development

Based on the concept of sustainable development, (Zhao and Guo, 2015) established an evaluation index system for the sustainability of external benefits of renewable energy based on economic, social and environmental factors. Then they used the hybrid MCDM method to evaluate China's renewable energy sources, the results indicated that more policies to support photovoltaic power generation should be implemented to promote the sustainable development of the entire renewable energy industry. (Petinrin and Shaaban, 2015) discussed Malaysia's renewable energy policy and current energy implementation strategy, and evaluated the sustainability of renewable energy from 2000 to 2015; the results show that biomass and solar energy are the most potential energy sources. (Wang et al., 2018) used the Divisia index method to study the factors affecting the sustainable development of renewable energy in China, including supply structure, energy security, and carbon emissions and other factors. The results show that strong and sustainable renewable energy policies will help China's sustainable energy development. (Zhao and Chen, 2018) first identified 43 factors affecting the sustainable development of renewable energy in China through multi-facet content analysis; and then used questionnaires and relative importance index models to extract 33 key factors affecting the sustainable development of renewable energy within the context of China. In addition, the principal component analysis and driving force model were applied to determine the factors that have a greater impact on the sustainability of renewable energy.

2.4The Validity of EKC Hypothesis

The EKC is a variant of the Kuznets curve hypothesis put forward by Simon Kuznets (1955) in which the author postulated a nonlinear inverted-U shaped relationship between economic growth and income inequality. The difference between these two hypotheses is that the EKC hypothesis replaces income inequality in the Kuznets curve hypothesis and comments on the changing patterns of environmental quality, emissions of GHG in the context of this paper, along with rising national income level which is used to proxy for economic growth. The first empirical study that tested the validity of the EKC hypothesis for Mexico was pioneered by Grossman and Krueger (1991) in which the authors used sulfur and smoke emissions to quantify environmental quality within the EKC analysis. However, the findings condemned the existence of the EKC hypothesis in Mexico. (Dong et al, 2018) the authors employed annual natural gas consumption data to assess the CO2 emission-induced EKC hypothesis in the context of 14 Asia-Pacific economies. The results inferred that greater consumption of natural gas attributed to smaller volumes of CO2 emissions within these economies while empirical evidence of the existence of the EKC hypothesis was also confirmed. Similar findings were reported 4 The BRICS countries include Brazil, Russia, India, China, and South Africa. The study of (Nathaniel and Bekun, 2020) examined the association between urbanization and GDP in Nigeria covering the period from 1971 to 2014 by employing the Bayer and Hanck cointegration test, ARDL, FMOLS, DOLS, CCR, and VECM Granger causality. They found that urbanization negatively inhibits GDP, and there is a bidirectional link between urbanization and GDP. (Etokakpan et al., 2020) examined the association between gross capital accumulation and GDP in Malaysia covering the period 1980–2014, employing the Bayer and Hanck cointegration tests, ARDL, and Granger causality. The authors concluded that an increase in gross capital formation would increase GDP. (Adebayo S.T., 2020) also employed the ARDL and wavelet coherence methods to examine the long-run and causal relationship between CO_2 emissions and GDP in Mexico. The results showed a positive link between these variables. In terms of causality, they identified a two-way interaction between CO_2 emissions and GDP.

Table 2.1: Summary of the literature review

Name of the article	Author name, year of publication	Nations, time frame	Methodology Variables	Findings
CO2 emissions and financial development in an emerging economy: an augmented VAR approach	Abbasi and Riaz (2016)	Pakistan (1971–2011)	VECM, Granger, ARDL (FDI, CO2, FD, Stock market, GDP)	FDI ≠ CO2 GDP→ CO2 (+) Financial development does not aid in mitigating CO2 emissions rather it increases it. CO2 emissions rise as per capita income rises. Government should devise comprehensive and realistic mitigation strategies
How urbanization affects CO2 emissions in Malaysia? The application of STIRPAT model	Shahbaz et al. (2016)	Malaysia (1970Q1–2011Q4)	Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT), ARDL, VECM Granger causality (EC,GDP, URB, CO2, TO)	EC → CO2 (+) GDP→ CO2 (+) URB → CO2 (−) TO→CO2 (+) Economic growth is a major contributor to CO2 emissions. Energy consumption raises emissions intensity and capital stock boosts energy consumption. Trade openness increases CO2 emissions. The relationship between urbanization and CO2 emissions is Ushaped i.e. urbanization initially reduces CO2 emissions, but after a threshold level, it increases CO2 emissions.
The effects of financial development,	Shahbaz et al. (2013)	South Africa, (1965–2008)	ARDL, ECM (CC, EE, FDI, TO, CO2)	CC → CO2 (+) EE → CO2 (+) FD→ CO2 (−)

economic growth, coal consumption and trade openness on CO2 emissions in South Africa				Rise in economic growth increases energy emissions. Financial development lowers energy emissions. Coal consumption significantly deteriorate environment. Trade openness improves environmental quality. Existence of EKC is also found.
Impacts of urbanization and industrialization on energy consumption/CO2 emissions: does the level of development matter?	Li and Lin (2015)	Low, middle, and high-income countries (1971–2010)	Dynamic panel threshold regression models (Y, URB, EN, CO2)	In low-income nations Y → CO2 (+) EN → CO2 (+) URB → CO2 (+) In middle-income nations Y → CO2 (+) EN → CO2 (+) URB → CO2 (+) In high-income nations Y → CO2 (+) EN → CO2 (+) URB → CO2 (−)
Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: the case of Turkey	Ozatac et al. (2017)	Turkey (1960–2013)	ARDL, causality (Y, EN, TO, URB, FD, CO2)	EKC holds GDP → CO2(+) EN → CO2 (+) URB → CO2(+) TO→GDP(+)
Economic growth, financial development, urbanisation and electricity consumption nexus in UAE	Sbia et al. (2017)	UAE (1975–2011)	ARDL, VECM (Y, EC FD)	URB → EC (+) Y → EC (+) FD → EC (+) The relationship between urbanisation and electricity consumption is an inverted U-shaped. This implies that urbanisation increases electricity consumption initially and, after a threshold level of urbanisation,

				electricity demand falls.
CO2 emissions, energy consumption, economic growth, and financial development in GCC countries: Dynamic simultaneous equation models	Bekhet et al. (2017)	Gulf countries (1980–2011)	ARDL, causality (Y, ENE, FD, CO2)	CO2 → ENE in Saudi Arabia, UAE, and Qatar FD → CO2 in UAE, Oman, and Kuwait There is a existence of a long-term equilibrium relationship among CO2 and real GDP per capita, energy consumption, and financial development in all GCC countries except UAE.
The impact of income, trade, urbanization, and financial development on CO2 emissions in 19 emerging economies	Saidi and Mbarek (2017)	19 emerging economies (1990–2013)	GMM model Panel regression (Y, TO, URB, FD, CO2)	EKC is hold FD → CO2 (−) URB → CO2 (−) Financial development has a long-run negative impact on carbon emissions, implying that financial development minimizes environmental degradation. This means that financial development can be used as an implement to keep the degradation environmental clean by introducing financial reforms
The process of peak CO2 emissions in developed economies: a perspective of industrialization and urbanization.	Dong et al. (2019)	Developed economies (1960–2012)	threshold regression model (Y, URB, EN, CO2)	EN → CO2 (+) URB → CO2 (+) An assessment of the threshold effects of urbanization indicates that the effect of urbanization on carbon emissions differs at different urbanization levels.
Testing validity of the EKC hypothesis in South Korea: role of renewable energy and trade openness.	Koc and Bulus (2020)	South Korea (1971–2017)	ARDL (GDP, ENE, TO, CO2,REN)	N-shaped relationship GDP → CO2 (+) ENE → CO2 (+) TO→ CO2 (−) REN → CO2 (−) The N-shaped relationship

				between per capita CO2 emissions and GDP per capita implies that although some environmental gains will be achieved after the first turning point, an increase in environmental degradation may be seen from a second turning point.
Dynamic linkage among industrialisation, urbanisation, and CO2 emissions in APEC realms: evidence based on DSUR estimation.	Wang et al. (2020)	APEC nations (1990–2014)	Dynamic-unrelated seemingly regression (Y, IND, EN, CO2)	IND → CO2 (+) Y → CO2 (+) URB → CO2 (+)
Fresh insight into the EKC hypothesis in Nigeria: accounting for total natural resources rent.	Bekun et al. (2020)	Nigeria (1971–2015)	ARDL (Y, Y2, FDI, EC, CO2)	EKC is hold GDP → CO2 (+) EC → CO2 (+) FDI → CO2 (−)
The effects of energy consumption, economic growth and financial development on CO2 emissions in China: a VECM Approach. Sustainability	Jian et al. (2019)	China (1982–2017)	VECM, impulse response (Y, FD, EN, CO2)	FD → CO2 (+) Y → CO2 (−) EN → CO2 (+) EN → FD
The impact of energy intensity, urbanization, industrialization, and income on	Nondo and Kahsai (2020)	South Africa (1970–2016)	ARDL, VECM (Y, URB, ENE, IND)	URB → CO2 (+) ENE → CO2 (+) IND → CO2 (+)

CO2 emissions in South Africa: an ARDL bounds testing approach.				
The nexus between renewable energy, economic growth, trade, urbanization and environmental quality: a comparative study for Australia and Canada	Rahman and Vu (2020)	Australia and Canada (1960–2015)	ARDL, VECM causality (Y, EN, URB, CO_2)	In Australia Y →CO_2(+) In Canada Y → CO_2 (+) URB → CO_2 (+)
The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis:	Dogan and Inglesi-Lotz (2020)	European countries (1980–2014)	Panel OLS, FMOLS, FE (Y, EN, CO_2)	EKC does not hold GDP → CO_2 (−) The EKC hypothesis is not confirmed – but a U-shaped relationship is confirmed. The industrial share decreases emissions through the development and absorption of technologies that are energy efficient and environmental friendly. EKC hypothesis is confirmed when the aggregate GDP growth is considered, taking into account the improvement of the overall economic conditions of the countries regardless of the economic structure and role of industrialization
Testing the EKC hypothesis for the top six hydropower energy-consuming countries: evidence from Fourier bootstrap ARDL procedure	Pata and Aydin (2020)	Brazil, China, Canada, India, Norway and the USA (1965–2016)	Fourier bootstrap ARDL, Fourier TYGC (Y, EN, HEC, CO_2)	EKC hypothesis is not valid HEC → GDP in Brazil HEC ↔ GDP in China HEC alone is not sufficient to reduce EF in the six countries

Rediscovering the EKC hypothesis for the 20 highest CO2 emitters among OECD countries by level of globalization	Leal and Marques (2020)	OECD countries (1990–2014)	FMOLS, DOLS, AMG, CDS (Y, TO, CO)	EKC hypothesis is not valid OP→CO2 (+) REN → CO2 (+) Renewable energy consumption is ineffective for mitigating CO2 emissions in the long-run in the LGC (low globalized countries)
Dynamic relationship between oil price and inflation in oil exporting economy: empirical evidence from wavelet coherence technique	Adebayo et al. (2020)	Mint nations (1980–2018)	Pedroni, Westerlund Coint., PMG, CDS, panel causality (Y, TO, URB, EN, CO2)	GDP≠ CO2 TO→CO2 (−) TO→ENE (+) URB → CO2 (+)
International tourism, social distribution, and environmental Kuznets curve: evidence from a panel of G-7 countries	Anser et al. (2020)	G-7 countries (1995–2015)	Random effect, panel causality (CO2, ITR, FDI, GEE, HEXP, INEQ, EG)	ITR → CO2 (+) GDP → CO2 (+) FDI → CO2 (+) GEE → CO2 (+)
Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: new evidence from the BRICS economies	Khattak et al. (2020)	BRICS (1980–2016)	CCEMG technique (CO2, GDP, RE, YPC, YPC)	EKC hold YPC → CO2 (+) IN → CO2 (+) RE → CO2 (−)
The nexus between renewable energy, economic growth, trade, urbanization and	Rehman et al. (2020)	Australia and Canada (2000–2018)	GRA Model, Hurwicz method (CO2, EC, GDP, PG)	GDP → CO2 (+) EC → CO2 (+) PG → CO2 (+)

environmental quality: a comparative study for Australia and Canada				
Innovation, financial development, and transportation infrastructure matter for environmental sustainability in China?	Umar et al. (2020)	China (1971–2018)	Bayer-Hanck cointegration, wavelet coherence (CO2, IN, FD, TO, GDP)	IN → CO2 (+) FD → CO2 (−) TO→ CO2 (+)
An empirical analysis of the determinants of CO2 emissions in GCC countries.	Zmami and Ben-Salha (2020)	GCC countries (1980–2017)	STIRPAT model, PMG (CO2, GDP, EC, URB, TRA, FDI)	EKC valid EC → CO2 (+) FDI → CO2 (+)
Effect of foreign direct investment on CO 2 emission with the role of globalization, institutional quality with pooled mean group panel ARDL	Teng et al. (2020)	10 OECD economies (1985–2018)	PMG-ARDL	CO2 → GDP (+) FDI showed a negative relationship with CO2 i.e mean an increase in FDI will lead to decrease in CO2 emissions
Sustainability of the moderating role of financial development in the determinants of environmental degradation: evidence from Turkey	Rjoub et al. (2021)	Turkey (1960–2018)	FMOLS, DOLS	CO2 → GDP (+) The study also found the significant moderating role of “financial development” in the relationship between “economic growth” and carbon emissions, capital formation and carbon emissions, and urbanization and carbon emissions
Modeling CO 2	Zhang et al.	Malaysia	Cointegration,	GDP → CO2 (+)

emissions in Malaysia: an application of Maki cointegration and wavelet coherence tests	(2021)	(1960–2018)	wavelet, and gradual shift	GDP → CO_2 The Maki co-integration and ARDL bounds tests reveal evidence of cointegration among the variables. The ARDL test reveals that economic growth, gross capital formation, and urbanization exert a positive impact on CO_2 emissions.
Modeling CO_2 emissions in South Africa: empirical evidence from ARDL based bounds and wavelet coherence techniques	Odugbesan and Adebayo (2020)	South Africa (1971–2016)	ARDL & wavelet coherence	CO_2 → GDP (+) The ARDL long- and short-run estimates a positive and significant link between growth and CO_2 emissions.
Oil consumption, CO_2 emission and economic growth in MENA countries	Al-Mulali (2011)	Turkey (1980–2009)	Panel Granger causality	CO_2 ↔ GDP (+) oil consumption plays an important role in the economic growth of the MENA countries
The symmetrical and asymmetrical effects of foreign direct investment and financial development on carbon emission: evidence from Nigeria	Odugbesan and Adebayo (2020)	Nigeria (1980–2016)	ARDL, NARDL	CO_2 → GDP (+) The fndings for the linear (symmetric) efect shows that foreign direct investment (FDI), and energy consumption have a long-run relationship with CO_2 in Nigeria, while only FDI has a short-run linear relationship with CO_2.
Reinvestigating the determinants of environmental degradation in Nigeria	Ayobamiji and Kalmaz (2020)	Nigeria (1971–2015)	ARDL, FMOLS, DOLS, wavelet coherence	CO_2 → GDP (+)
An empirical investigation between CO_2 emission, energy	Wasti and Zaidi (2020)	Kuwait (1990–2014)	ARDL	CO_2 → GDP (+)

consumption, trade liberalization and economic growth: a case of Kuwait				
Effect of economic growth on CO2 emission in developing countries: evidence from a dynamic panel threshold model	Aye and Edoja (2017)	emerging nations	Panel techniques	CO2 → GDP (−)
Modeling CO 2 emissions in an emerging market: empirical finding from ARDL-based bounds and wavelet coherence approaches	Kalmaz and Kirikkaleli (2019)	Turkey	ARDL, FMOLS, DOLS, wavelet coherence	CO2 → GDP (+)
Do renewable energy consumption and financial development matter for environmental sustainability?	Kirikkaleli et al. (2020)	China	Maki cointegration, wavelet, and gradual shift	CO2 → GDP
CO2 emission and economic growth in Algeria	Bouznit & Pablo-Romero (2016)	Algeria	ARDL	CO2 → GDP (+)
Evaluating the role of renewable energy, economic	Aydoğan and Vardar (2020)	E-7 (1990–2014)	Panel VECM	CO2 → GDP

growth and agriculture on CO2 emission in E7 countries				
Decoupling analysis of world economic growth and CO2 emissions: a study comparing developed and developing countries	Wu et al. (2018)	World PRISMA (1995–2017)	ARDL	CO2 ↔ GDP
Natural resource abundance, technological innovation, and human capital nexus with financial development: a case study of China	Khan et al. (2020)	China (1987–2017)	GMM	CO2 → GDP (+)
Revisiting the EKC hypothesis in an emerging market: an application of ARDL-based bounds and wavelet coherence approaches	Adebayo (2020)	Mexico (1971–2016)	ARDL & wavelet coherence	CO2 ↔ GDP (+)
Energy consumption, emissions and economic growth in Bahrain	Jafari et al. (2015)	Bahrain (1980–2007)	TY causality	CO2 → GDP
Determinants of carbon emission in China: how good	Li et al. (2021)	20 provinces in China	Panel CSARDL	CO2 → GDP

is green investment?				
The effects of electricity consumption, economic growth, financial development, and foreign direct investment on CO2 emissions in Kuwait	Salahuddin et al. (2018)	South Africa (1980–2017)	ARDL	CO2 ≠ GDP
Determinants of CO 2 Emissions in Emerging Markets: An Empirical Evidence from MINT Economies	Awosusi et al. (2020)	MINT economies (1980–2018)		CO2 ≠ GDP
Investigating the causal linkage among economic growth, energy consumption and CO2 emissions in Thailand: an application of the wavelet coherence approach	Akinsola and Adebayo (2021)	Thailand (1971–2016)	ARDL & wavelet coherence, Granger and Toda-Yamamoto causality	CO2 → GDP (+) CO2 → GDP
Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: fresh insights from Maki Cointegration and causality tests	Ali et al. (2020)	Top 10 emitter countries (1990–2017)	Panel CSARDL	CO2 → GDP (+)

Does biomass energy consumption mitigate CO2 emissions? The role of economic growth and urbanization: evidence from developing Asia.	Gao and Zhang (2021)	13 Asian developing countries (1980–2010)	FMOLS and panel Granger causality tests	CO2 → GDP Energy consumption and economic growth
The energy consumption and economic growth nexus in top ten energy consuming countries: fresh evidence from using the quantile-on-quantile approach	Shahbaz et al. (2018)	Top 10 energy-consuming countries (1960Q1–2015Q4)	Quantile-on-quantile (QQ) approach	EC → GDP (+)
The relationship between energy consumption, economic growth and carbon dioxide emission: the case of South Africa	Khobai and Le Roux (2017)	South Africa	Johansen cointegration and VECM Granger causality tests	EC ↔ GDP
Revisiting the relationship between energy consumption and economic growth nexus in Vietnam: new evidence by asymmetric ARDL cointegration	Ha and Ngoc (2020)	Vietnam (1971–2017)	ARDL and Toda-Yamamoto causality	EC ↔ GDP
A disaggregated level analysis of the relationship among energy	Rahman et al. (2020)	China (1981–2016)	Hatemi-J and FMOLS	EC → GDP (+)

production, energy consumption and economic growth: Evidence from China				
Energy consumption and economic growth nexus: new evidence from Pakistan using asymmetric analysis	Baz et al. (2019)	Pakistan (1971–2014)	NARDL	EC → GDP (+)
Energy consumption, electricity, and GDP causality; the case of Russia, 1990-2011	Faisal et al. (2016)	Russia (1990–2011)	Toda-Yamamoto causality	No causal link
Energy consumption, carbon emissions, and economic growth in India: evidence from directed acyclic graphs	Yang and Zhao (2014)	India (1970–2008)	Granger causality and DAG	EC → GDP
A bootstrap panel Granger causality analysis of energy consumption and economic growth in the G7 countries	Mutascu (2016)	G7 economies (1970–2012)	Granger causality tests	EC ↔ GDP
Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and	Muhammad (2019)	Pakisthan (2001–2017)	ARDL	EC → GDP (−)

North Africa countries				
Electricity consumption, urbanization, and economic growth in Nigeria: new insights from combined cointegration amidst structural breaks	Nathaniel and Bekun (2020)	Nguyen and Nguyen (2018)	Bayer and Hanck cointegration tests, ARDL, FMOLS, DOLS, CCR, and VECM Granger causality	URB ↔ GDP (−)
The relationship between urbanization and economic growth	Nguyen and Nguyen (2018)	ASEAN (1971–2014)		URB → GDP (+)
International trade and environmental performance in top ten-emitters countries: the role of eco-innovation and renewable energy consumption	Ali et al. (2020)	Nigeria (1971–2014)	Maki cointegration, FMOLS, DOLS, CCR, and VECM Granger causality	URB → GDP (-)
Testing the EKC hypothesis in Indonesia: empirical evidence from the ARDL-based bounds and wavelet coherence approaches	Adebayo (2021)	Japan (1971–2015)	Wavelet coherence, ARDL, FMOLS, DOLS	URB → GDP (+)
An analysis of the implications of China's urbanization policy for	Yang et al. (2017)	China (2000–2010)	Pooled ordinary least squares (POLS), fixed effects (FE),	RE URB → GDP (+)

economic growth and energy consumption			and random effect	
Economic growth, urbanization and energy consumption—a provincial level analysis of China	Zheng and Walsh (2019)	29,provinces in China (2001–2012)	FE and sys-GMM estimated methods	URB → GDP (+) Gross capital formation and economic growth
Global evidence from the link between economic growth, natural resources, energy consumption, and gross capital formation	Topcu et al. (2020)	124 countries (1980–2018)	PVAR	GCF → GDP (+)
Modeling natural gas consumption, capital formation, globalization, CO2 emissions and economic growth nexus in Malaysia: fresh evidence from combined cointegration and causality analysis	Etokakpan et al. (2020)	Malaysia (1994-2020)	Bayer and Hanck cointegration tests, ARDL and Granger causality	GCF → GDP (+)
An analysis of the implications of China's urbanization policy for economic growth and energy consumption	Yang et al. (2017)	China (2000–2010)	Pooled ordinary least squares (POLS), fixed effects (FE), and random effect	RE URB → GDP (+)
Economic growth, urbanization and energy consumption—a	Zheng and Walsh (2019)	29,provinces in China (2001–2012)	FE and sys-GMM estimated methods	URB → GDP (+) Gross capital formation and economic growth

provincial level analysis of China				
Modeling natural gas consumption, capital formation, globalization, CO2 emissions and economic growth nexus in Malaysia: fresh evidence from combined cointegration and causality analysis	Etokakpan et al. (2020)	Malaysia (1980–2014)	Bayer and Hanck cointegration tests,ARDL	GCF → GDP (+)
Revisiting the relationship between energy consumption and economic growth nexus in Vietnam: new evidence by asymmetric ARDL cointegration	Hang et al. (2021)	Vietnam (1980–2014)	ARDL	URB → GDP (+)
Financial depth, gross fixed capital formation and economic growth: empirical analysis of 18 Asian economies	Boamah et al. (2018)	18 Asian nations (1990–2017)	POLS	GCF → GDP (+)
Scrutinizing the complex relationship between financial development gross fixed capital formation and economic growth in Africa by adopting CCEMG and AMG	Kong et al. (2020)	39 African countries (1997–2017)	AMG and CCEMG	Urban → GDP(+) Urban ↔ GDP (+)

estimation techniques				
Investigating the causal linkage among economic growth, energy consumption and CO2 emissions in Thailand: an application of the wavelet coherence approach	Akinsola and Adebayo (2021)	Thailand (1971–2016)	ARDL & wavelet coherence, Granger and Toda-Yamamoto causality	CO2 → GDP (+) CO2 → GDP
Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: fresh insights from Maki Cointegration and causality tests	Ali et al. (2020b)	Top 10 emitter countries (1990–2017)	Panel CSARDL	CO2 → GDP (+)
Does biomass energy consumption mitigate CO2 emissions? The role of economic growth and urbanization: evidence from developing Asia	Gao and Zhang (2021)	13 Asian developing countries (1980–2010)	FMOLS and panel Granger causality tests	CO2 → GDP Energy consumption and economic growth
The energy consumption and economic growth nexus in top ten energy consuming countries: fresh evidence from	Shahbaz et al. (2018)	Top 10 energy-consuming countries (1960Q1–2015Q4)	Quantile-on-quantile (QQ) approach	EC → GDP (+)

using the quantile-on quantile approach				
The relationship between energy consumption, economic growth and carbon dioxide emission: the case of South Africa	Khobai and Le Roux (2017)	South Africa (1988-2020)	Johansen cointegration and VECM Granger causality tests	EC ↔ GDP
Revisiting the relationship between energy consumption and economic growth nexus in Vietnam: new evidence by asymmetric ARDL cointegration	Ha and Ngoc (2020)	Vietnam (1971–2017)	ARDL and Toda-Yamamoto causality	EC ↔ GDP
A disaggregated level analysis of the relationship among energy production, energy consumption and economic growth: Evidence from China	Rahman et al. (2020)	China (1981–2016)	Hatemi-J and FMOLS	EC → GDP (+)
Energy consumption and economic growth nexus: new evidence from Pakistan using asymmetric analysis	Baz et al. (2019)	Pakistan (1971–2014)	Non linear ARDL	EC → GDP (+)
Assessing the sustainability of renewable energy:	Wang, Q. & Zhan, L. (2019)	18 European countries (2007-2016)	RAGA PP (total energy demand, energy taxes, carbon	The sustainability of renewable energy in Germany, the UK, France, and Italy is better than that the other. Whereas,

An empirical analysis of selected 18 European countries			dioxide emissions, sulfur oxides emissions, and nitrous oxides emissions)	Bulgaria, the Czech Republic, and Romania were the worst. The 17 indices selected by the 3E model the factors of total energy demand, energy taxes, carbon dioxide emissions, sulfur oxides emissions, and nitrous oxides emissions exert a stronger impact on the sustainability of renewable energy

2.5 Research Gap

- Over the last several years, economists and researchers have undertaken sincere efforts to study and analyse the impact of different energy on environment. The scopes of most of the existing studies are limited to the impact of human activity on natural environment. Limited studies have been done to study the level of optimal energy mix for different countries.

- Most of the literature on the sustainability of renewable energy mainly focuses on the assessment of sustainability in energy system, economy, society, environment and technology. Little research has been done on the sustainability of renewable energy itself.

- The existing evaluation process heavily relies on the multi decision criteria method which is not free from human error. How to conduct the evaluation of renewable energy sustainability without human error is another an open question.

- Given the indicators of renewable energy the data are non-normal and nonlinear data. How to effectively deal with these data remains an open question.

- As land and resources vary from country to country accordingly the means of raising investment and capacity to finance also vary from one another therefore implementation of single policy throughout the world is questionable.
- The existing literature heavily relies on greenhouse gas emission whereas limited research has been done on pollution through E-waste which play a vital role for renewable energy sustainability.

2.6 Research Question

Q1. What is the impact of renewable energy on economy and environment?

Q2. Does the Environmental Kuznets Curve Hypothesis holds true in the present scenario?

Q3. Are the different types of renewable energy sustainable?

Q4. What is the future of the shift in energy system, will it be able to meet the UN net zero carbon emission?

Q5. What are the policy measures that the government can take to become carbon neutral?

2.7 Objectives

- **RO1:** To analyze the impact of renewable energy on economy and environment
- **RO2:** To study the validity of environmental Kuznets curve hypothesis
- **RO3:** To study the sustainability of different renewable energy
- **RO4:** To estimate the future of energy transition
- **RO5:** To suggest policy measure to the government

CHAPTER 3

Methodology

3.1 Overview

The present study incorporates time series data and panel data of energy, environment and economy of under- developed, developing and developed countries. For which statistical, econometric and mathematical tools are used to achieve the objectives of the study. Simple statistical tools like Mean, Median, Mode, correlation, Stantard deviation, Skewness and Kurtosis are the few tools that will be incorporated in the study. Wheras, Fourier ADF, Fourier LM, Fourier GLS and Fourier KPSS will be used to check the stationarity of data. Further depending on the level of stationarity cointegration test like Fourier bootstrap ARDL will be applied and to check the causal linkage between the variables Fourier bootstrap Toda-Yamamoto test will be empolyed. Finally, to check the time and frequency dependency of the variables Wavelet Coherence will be used.

3.2 Data Collection

The period of study will be from 1965 onwards for the long-run analysis. Time series secondary data from various sources like World Bank and BP stats will be analysed through different tools. First the data's stationarity will be checked through the unit root test then the short-run and long-run cointegration test will be conducted to know the relationship. Further, diagnostic test will be performed like Jarque-Bera Normality Test, Ramsey RESET test, B.G serial Correlation LM test, Heteroskedasticity B.P.G.test and CUSUM test.

The Fourier flexible form will take all the multiple breaks into consideration that is associated while dealing long-run time series data. Whereas, the bootstrap will be solve the size and power problem as stated by Monte Carlo stimulation.

3.3 CO_2 Emissions

Carbon dioxide emission has been a major concern for both the developing and developed countries as it is the major contributor for global warming. The targets set by sustainable developmental goals (SDGs) for achieving net zero carbon emission by the year 2050 has been the centre of concern for the policy makers. There has been an unprecedented rise in the world greenhouse gases (GHG) emissions that has resulted in increasing the surface temperature globally and has resulted in the significant amount of climate change congesting the development prospect of the world economy (Ekwurzel et al, 2017). As estimated by the World Bank between the years 1980- 2012 the GHG emission has been magnified by 1.6 times (World Bank 2020). The GHG emissions were valued to be more by 27% than the obligatory level of 2^0C mark for achieving the targets of limiting the rise of global temperature (UNEP 2020). There were many international conference been organised to recognise pollution prevention measures such as Stockholm conference 1972 and the Rio conference 1992, the Kyoto protocol encouraged and promoted consumption of renewable energy for limiting GHG (Bildirici and Gokmenoglu, 2017). The main causes of GHG is the CO_2 increased in the environment due combustion of fossil fuel. The world energy production's approximately 55% depends on fossil fuels in the present era. China had the largest percentage in 2022 (32%), though it has started to decline significantly. The United States came in second with 14%, up 1.5% from 2021. India presently contributes 8% of the world's emissions, which are rising. The 27 countries that make up the European Union collectively represent 8% [ustodays.com]. The CO_2 emission by fuel and the CO_2 emission of selected four countries are shown in figure 3.1 and 3.2 respectively.

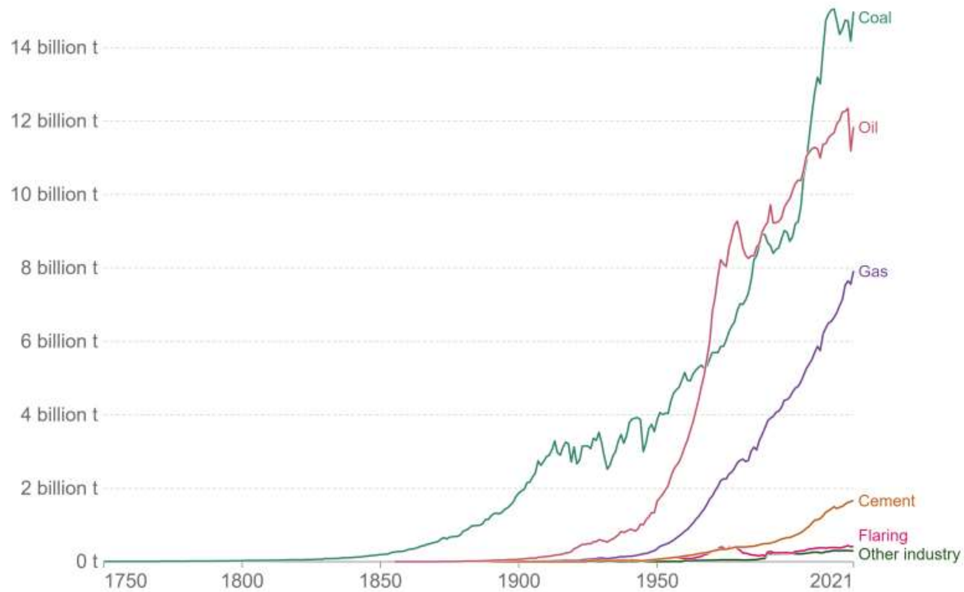


Figure 3.1: CO_2 emissions by fuels of world [https://www.iea.org/reports/co2-emissions-in-2022]

It is observed that the highest CO_2 is emitted by coal fuel because it is majorly used in thermal power plants and worlds approximately 60% electricity is produced from thermal power plants. The second is oil which is mainly used in transportation or in vehicles. The third fuel is Gas and remaining other fuels and cause of CO_2 emissions. The world's CO_2 emission during 2021 was 37.12 billion tonnes (BT) and the China, US, India and UK contributed 11.47BT, 5.01BT, 2.71BT, 346.77MT respectively [ustodays.com]. The figure 5.2 stated that in 2021 and 2022 China contributes more than 30% of global CO_2 emissions.

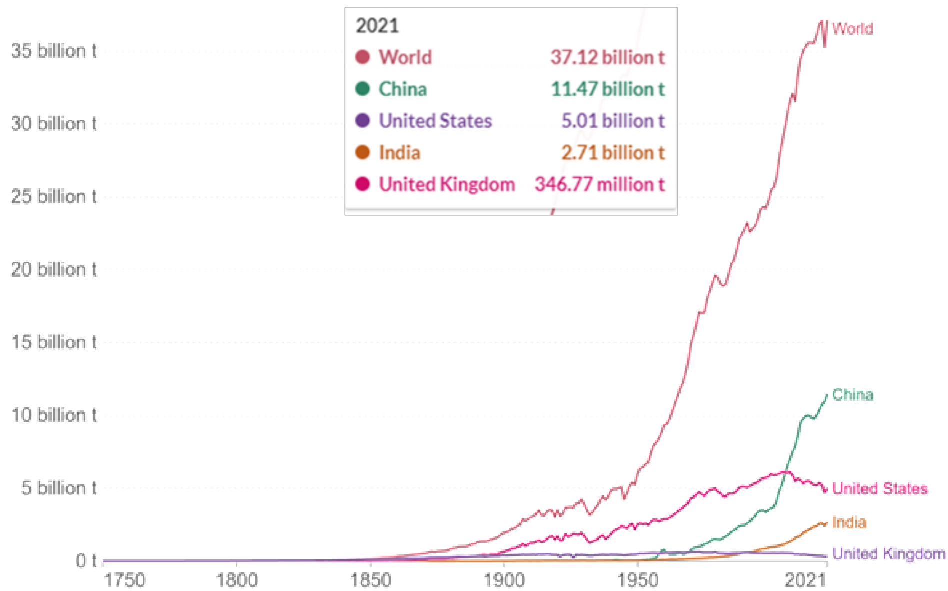


Figure 3.2: Annual CO2 emissions of China, US, India and UK from 1700 to 2021 [https://ourworldindata.org/co2-and-greenhouse-gas-emissions]

3.4 Carbon Capture

A relatively pure stream of carbon dioxide (CO2) from industrial sources is separated, processed, and transported to a long-term storage facility as part of the carbon capture and storage (CCS) process. The carbon dioxide stream, for instance, can be produced by burning biomass or fossil fuels. In most cases, CO2 is removed from significant point sources, such chemical or biomass plants, and then stored in a subterranean geological formation. Reduced greenhouse gas emissions will lessen the effects of climate change. A number of technologies, such as adsorption, chemical looping, membrane gas separation, or gas hydration, can be used to directly absorb CO2 from an industrial source, such as a cement kiln. About one thousandth of worldwide CO2 emissions will be absorbed by CCS by 2022, and the majority of projects will be for the processing of fossil fuels. The terms "carbon capture, utilisation, and sequestration" (CCUS) and "carbon capture and utilisation" (CCU) are sometimes used interchangeably. This is due to the fact that CCS is a rather expensive procedure that frequently results in products that are overly inexpensive.

3.5 Carbon Credit

At South Pole, we approach resolving climate change as a jigsaw, where each puzzle's solution consists of a number of interlocking components. It is vitally necessary to cut emissions and decarbonize economies, yet there isn't always the technology available and time is running out. Carbon credits come into play here. By purchasing carbon credits from verified activities that promote community development, safeguard ecosystems, or put in place effective technologies to lower or remove emissions from the atmosphere, businesses and people can make up for their unavoidable emissions. A quality carbon credit represents the reduction or removal of one tonne of carbon dioxide from the atmosphere. Companies can support initiatives that keep global climate targets within reach, such as maintaining and restoring irrecoverable natural carbon sinks, like forests or marine ecosystems, and scaling up emerging carbon removal technology, by purchasing carbon credits, which are transparent, quantifiable, and results-based.

Remaining emissions are compensated by carbon projects:

- Accelerates the transition to net zero in terms of climate action.
- Ensures businesses are assessing their footprint and assigning a cost to the harm they do,
- Attracts financing to worthy and qualified initiatives that contribute to sustainable development and significantly cut emissions.

CHAPTER 4

THE IMPACT OF RENEWABLE ENERGY ON ECONOMY AND ENVIRONMENT

4.1 Overview

In this study, the time series data of Canada from 1965 to 2021 for CO_2 emission, hydroelectricity, urbanization, oil and trade were analysed using ARDL and wavelet coherence. The results reveals that all the four variables have both short run and long run affluence on CO2 emissions. Wavelet coherence shows that in long run increasing hydroelectricity and urbanization reduces CO_2 emission that validates the EKC hypothesis. A percent growth in urbanization will reduce 0.26% CO_2. While oil consumption is highly significant to CO_2 emissions having a negative influence on environment as 1 % increase in oil consumption increases CO_2 emissions by 0.66%. Therefore the study suggests the use of biofuels should be promoted as the blending of conventional fuel with biofuels reduces the intensity of the fuel by which the environmental impacts can be lowered. The study proves that in long run with high economic growth the pollution decreases validating the EKC hypothesis.

4.2 Introduction

Hydropower is generally considered a low or zero carbon source of electricity generation, unlike fossil fuel-based electricity generation. Hydropower does not produce direct greenhouse emissions. However, land flooding after dam construction usually results in increased biogenic GHG emissions due to biomass decomposition in the newly created reservoir and reducing the forest. Canada deserves special consideration regarding the weather for a number of reasons, one of that is the third largest oil reserves in the world approximately 169.7 billion barrels (BP, 2020) after United States and Venezuela. It is one of the biggest power producer even though it produces 400TWh hydroelectric power in 2017 and its largest percentage is produced by fossil fuels result in more production of greenhouse gases (GHG) in comparison with the global carbon budget (GCB). (Qin et al. 2021) In 2018, Canada had the second highest per capita GHG emissions of the G7 after the US. In the year 2017, the hydroelectric power contribution was observed approximately 61 percent of the overall electrical production. That's why Canada comes in the list of top four hydropower generators worldwide, with China, Brazil, as well as the United States accounting for more than half of their total electricity production. Largest hydroelectric capacity is anticipated to rise dramatically over the next few decades as Canada works to minimize greenhouse gases from energy generation.

(Lau et al., 2016; Solarin, 2017 and Levasseur et al. 2021) investigated the environmental effects of hydroelectric energy consumption, CO2 emission as a measure of environmental pollution On the other hand, (Bello et al. 2018; Tiwari et al., 2022) investigated the effect of hydroelectric power consumption on environmental quality. Few studies in the literature, such as (Solarin and AlMulali, 2018; Isman et al., 2018) assess the role of economic growth in increasing the ecological footprint. Energy is the basic need of human life and so many econometric methods can be used to delegate the effect hydroelectric power to reduce CO2 emission. Such studies, which include renewable energy production and consumption in the EKC hypothesis analysis, are quite new. (Singh et al. 2022) used ARDL model and a vector error correction model (VECM) for time series data for the period 2007 to 2018. (Avik et al. 2018; He et al. 2010 and Sanu et al. 2019) tested the validity of EKC hypothesis and came to the conclusion that decreasing CO2 emissions by per capita power produced from renewable sources. (Boluk and Mert, 2014) studied 16 EU countries using a fixed effects panel model between 1990 and 2008.

It was revealed that the EKC hypothesis was not validated and that CO2 emissions were increased by per capita usage of renewable energy. (Farhani and Shahbaz,2014) examine 10 Middle East and North Africa (MENA) countries from 1980 to 2009 using FMOLS and dynamic least squares (DOLS) estimators, Granger panel causality test, and Perdon and Kao cointegration tests. They reported that the per capita use of renewable power increased the per capita CO2 emissions, proving the validity of the EKC hypothesis. (López-Menéndez et al., 2014) investigated the EKC hypothesis for 27 EU countries by using data between 1996 and 2010 on panel model. It revealed that the evidence supporting the EKC concept only for Cyprus, Greece, Slovenia, and Spain and it was found that for the remaining 23 nations the EKC did not validate. It expressed that the use of renewable energy per capita decreased CO2 emissions in long terms.

International business is frequently described in prior empirical research using the concept of trade openness, which is calculated as the ratio of total exports to imports to GDP. However, the composition of the global trade basket can significantly affect the quality of the environment apart from trade openness. So the trade openness has beneficial or a harmful effect on environmental quality is depending on a country's level of development and industrialization. (Charfeddine and Khediri 2016; Rej et al. 2022) expressed the bidirectional causation between EF and total foreign trade while examining the link between EF and Qatar's commercial openness. Solarin et al. 2021 observed that the trade openness hurt EF in the European region consequently improved environmental quality. Hu et al. 2008 revealed that the import and export favorably correlate with EF. The quality of exports dependent on the income levels of nations is also favored by urbanization, as per (Dogan et al., 2017) who also claimed that urbanization increased the environmental degradation in the upper level.

(Muhammad et al. 2013; Ayhan et al., 2021) illustrated the degree to which a country's economy is accessible to international commerce by its trade openness. This helps countries to increase exports, which intends to increase domestic production by increasing the scale of production, which leads to more pollution. (Al-Mulaliet al., 2015; Jun et al., 2020; Lin, 2017; Wen and Dai, 2020)There seems to be no consensus on the relationship between pollution and trade openness. In several countries, pollution levels increased with increasing trade openness. However, few believe that greater trade openness reduces pollution (Ghazouani et al., 2020; Kohler, 2013; Shahbaz et al., 2017). (Lantz and Feng, 2006) studied the EKC literature on Canada with a five-region panel data set from 1970 to 2000. Their findings demonstrate that CO2 emissions are more closely connected to technology and population than GDP.

However, panel data studies frequently include Canada. Canada often has an EKC in such circumstances. (Unruh and Moomaw, 1998) illustrate a few of the differences between Canada and other OECD nations. After 1973, Canada, and its neighbor, the United States, profited from technological progress after the oil crisis, and other OECD countries, only 2 countries contributed to the growth in CO2 emissions due to comparatively large oil reserves. Similarly, (Moomaw and Unruh, 1997) find evidence of EKC-type relationships in Canada, the United States and Luxembourg. (Dijkgraaf and Vollebergh, 2005) used panel and time series data methods, country-pair method and semi-parametric estimation and found evidence for CO2 EKC in Canada. The above literature shows a non-linear impact on CO2 emissions and the model employed doesn't reflects the one on one relationship with the variables. As Canada's 60% of the total electricity requirement is met by hydropower therefore it is of utmost importance to check the validity of EKC hypothesis. Also 81.65 % of the population lives in urban area so the study analyzed the magnitude of causal linkage between urbanization and CO2 emission which new to the existing literature. The study tried to highlight the short run, medium run and long run relation between oil consumption and CO2 emissions. It also measures the magnitude at which urbanization can help reduce CO2 emissions.

The current study answers of the following questions are required for analyses:

a) Can hydroelectricity solve the problem of increasing pollution by reducing CO2 emissions?
b) The impact of urbanization both in short run and long run.
c) Does increase in trade helps in reducing CO2 emissions and its magnitude?
d) The relationship between oil consumptions and CO2 emissions
e) Does the study validates the existence of EKC hypothesis?

4.3 Mathematical Methodology adopted

In this study, the relationships between carbon dioxide emissions, hydroelectricity, urban population, oil consumption, and export of goods and services in Canada from 1965 to 2021 are investigated. As the analyses was done on time series data of 56 years that were stationary at the combination of I(0) and I(1) hence autoregressive distributed lag (ARDL) was used. The variables employed are explained in table 4.1.

Table 4.1: Variables Specification.

Variables	Definition	Source
CO2	Carbon Dioxide Emission (Million Tonnes)	BP Statistical Review of World Energy
HYD	Hydroelectricity Consumption (Exajoules)	BP Statistical Review of World Energy
URB	Urban Population	World Development

		Indicators
OIL	Oil Consumption (Exajoules)	BP Statistical Review of World Energy
Trade	Exports of Goods and Services (constant 2015 US$)	World Development Indicators

While some of the selected variables were stationary at the certain level the others were stationary at the first difference, we found that the ARDL (Autoregressive distribution lag) model was the best suitable for our research.

The autoregressive distributed lag (ARDL) technique was popularized and used in the investigations by Pesaran et al. (2001). The ARDL model is considered one of the best econometric techniques in the case where the variables are either stationary at level I(0) or first difference I(0). It is considered a better model over other available models to examine the immediate long-term implications of distinct variables. The ARDL method uses the ordinary least square (OLS) method for cointegration of variables and is suitable for simultaneously calculating short-run and long-run elasticities for small sample sizes (Duasa 2007). The order of the variables' integration can be changed with ARDL. (Frimpong and Oteng , 2006) stated that the ARDL works well for independent variables that are I(0), I(1), or mutually cointegrated but fails when there is I(2) present in any variable. Additionally, the basic advantage of using the ARDL model is to provide empirical results that facilitates the examination of the heterogeneous effects of chosen independent variables from lower-order to higher-order quantiles.

The significance of time-changing variations in carbon dioxide emissions as defined by the consumption of renewable energy (hydroelectricity), urban population, oil consumption, and export of goods and services, respectively, would be further supported by this. Equation 1 is constructed to investigate the connection between emissions of carbon dioxide and the aforementioned variables throughout the perspective of Canada from 1965 to 2021.

$$\ln CO2 = f(\ln HYD,\ \ln URB,\ \ln OIL,\ \ln EGS) \ldots\ldots\ldots\ldots (1)$$

The natural log is used in the equation above, and table 1 gives explanations of the variables.

$$\Delta \ln CO2_t = a_0 + \Sigma_{i=1}^{n1} a_{1i} \Delta \ln HYD_{t-i} + \Sigma_{i=1}^{n2} a_{2i} \Delta \ln URB_{t-i} + \Sigma_{i=1}^{n3} a_{3i} \Delta \ln OIL_{t-i} + \Sigma_{i=1}^{n4} a_{4i} \Delta \ln EGS_{t-i} + \beta_1 \ln HYD_{t-1} + \beta_2 \ln URB_{t-1} + \beta_3 \ln OIL_{t-1} + \beta_4 \ln EGS_{t-1} + \mu_t \ldots\ldots (2)$$

In equation 2, the drift component is α0, the long-run relationship is represented by β1 to β4, and the short-run relationship is represented by α1 to α4. While μt is the error term and ni is the optimal lag.

$$\Delta \ln CO2_t = \beta_0 + \Sigma_{i=1}^{n1} \beta_{1i} \Delta \ln HYD_{t-i} + \Sigma_{i=1}^{n2} \beta_{2i} \Delta \ln URB_{t-i} + \Sigma_{i=1}^{n3} \beta_{3i} \Delta \ln OIL_{t-i} + \Sigma_{i=1}^{n4} \beta_{4i} \Delta \ln EGS_{t-i} + \theta ECM_{t-1} + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The error correction model was established by testing the dependent as well as independent variables' co-integration, where θ is regarded as the rate of upsetting the long-term equilibrium.

$$R_n^2(s) = \frac{|S(s^{-1} W_n^{XY}(s))|^2}{S(s^{-1}|W_n^X(s)|^2).S(s^{-1}|W_n^Y(s)|^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

(Torrence and Webster, 1998) close wavelet coherence that facilitates the study of time series data in the time and frequency domain. It helps to gain information that was formerly undetected. It analysis causal and correlation between dependent and the independent variables from short to long-run Singh et al., (2023).

4.4 Results and Discussion

Table 4.2 reflect the result of the unit root test. The stationarity at the level and first difference was examined using the Augmented Dickey-Fuller (ADF) test. The findings demonstrated that the dependent variable CO2 and independent variable urbanization were stationary at a level I(0) whereas the independent variables hydroelectricity, oil and trade were stationary at the first difference I(1).

Table 4.2: ADF Unit Root test

Variables	Level t-statistics	Level Probability	1st diff t-statistics	1st diff Probability
CO2	-3.346437	0.0694*	-7.130325	0.0000***
HYD	-2.733856	0.2276	-6.881867	0.0000***
URB	-3.518516	0.0472**	-5.142552	0.0005***
OIL	-2.937822	0.1590	-5.326780	0.0003***
Trade	-1.031454	0.9308	-5.447846	0.0002***

Note: *significant at 10%, **significant at 5%, ***significant at 1%

Table 4.3 reflects the ARDL bound test for co-integration. The findings demonstrate a high co-integration between the dependent variable CO2 emissions and the explanatory variables hydropower, trade, oil and urbanization as the F statistic is greater than lower bound and upper bound. It rejects the null hypothesis at 1% significance as the F statistics is 5.964099 greater than 4.37. The results reveals that CO2 emissions are co-integrated with hydropower, trade, oil and urbanization.

Table 4.3: ARDL bound test for co-integration

Variables	F statistics	Co-integration	
F(CO2,HYD,TRADE,OIL,URB)	5.964099***		
Critical Value	1%	5%	10%
Lower bound	3.29	2.56	2.20
Upper bound	4.37	3.49	3.09

Note: *significant at 10%, **significant at 5%, ***significant at 1%

Table 4.4 expressed the outcomes of the ARDL model in the short term. The results reflects that oil consumption (OIL) and exports of goods and services (TRADE) are significant at 1% and have positive correlations with CO2 emissions (0.0011<0.01, 0.00<0.01). Whereas urban population (URB) and hydroelectricity consumption (HYD) has a negative relation with the emission of CO2 and is significant at 5% (0.025<0.05) and 1% 0.0045<0.01 hence it is certain that the urbanization and hydropower decreases CO2 emissions in Canada. The results reveals that a percent increase in urbanization leads to 0.20 percent decrease in CO2 emissions whereas, a percent rise in hydropower consumption decreases CO2 emissions by 0.08 percent in short run. While 1 percent increase in oil consumptions rises CO2 emissions by 0.66 percent and 1 percent increase in trade rises CO2 emission by 0.14 percent.

Table 4.4: Auto Regressive Distributed Lag short-run estimates

Variables	Probability	t-statistics	Coefficient
HYD	0.0045***	-2.986808	-0.087398
TRADE	0.0011***	3.464050	0.120463
OIL	0.0000***	8.523738	0.662078
URB	0.0248**	-2.319714	-0.202825

Note: *significant at 10%, **significant at 5%, ***significant at 1%

Table 4.5 reflects the estimate of long run ARDL. It is observed that the long-term relation between the independent variables and dependent variables. In which hydropower and urbanization has a negative affluence on CO2 emissions as 1 percent increase in hydropower consumption and urbanization leads to 0.11 % and 0.26 % decrease is CO2 emissions respectively. Whereas, oil and trade has a positive relationship with CO2 emissions, as a percent rise in oil consumption and trade increases CO2 emissions by 0.66 % and 0.12 % respectively.

Table 4.5: ARDL long-run estimates

Variables	Probability	t-statistics	Coefficient
HYD	0.0013***	-3.430445	-0.115060
TRADE	0.0000***	4.954776	0.158590
OIL	0.0000***	14.00984	0.656970

URB	0.0105**	-2.666218	-0.267021

Note: *significant at 10%, **significant at 5%, ***significant at 1%

Table 4.6 represents the outcomes of the diagnostic test. The Jarque Bera test was deployed and the outcomes show that the residuals are normally distributed. Ramsey RESET test result revealed that the model does not have any specification error. Breusch-Pagan Godfrey test has been used in conjunction with heteroscedasticity to determine whether the data used is homoscedastic or heteroskedastic and the result reveal that the dataset is homoscedastic. The Breusch Godfrey serial correlation LM test, which was the final step, demonstrates no serial correlation among the error components in the model.

Table 4.6: Diagnostic test

Diagnostic Test	Statistics	Decision
Jarque-Bera Normality Test, JB stat	x^2 : 2.308851 Prob : 0.315239	Normally distributed error terms
Ramsey RESET test	F-stat : 1.757725 Prob : 0.1915	Model is correctly specified
Breusch-Godfery serial Correlation, LM test	$Obs\ r^2$: 0.030713 Prob : 0.9848	No serial correlation
Heteroskedasticity Breusch-Pagan-Godfery test, Obs R-squared	$Obs\ r^2$: 6.113111 Prob : 0.5266	No heteroskedasticity

Table 4.7 shows the Granger causality test outcomes. Time series data are subjected to the test to determine if there's any pronounced impact of prediction from one variable to another. The

results shows that oil consumption Ganger causa CO_2 emissions while CO_2 emissions shows a causal linkage with hydropower. There is a bidirectional causal linkage between Trade and CO_2, urbanization and CO_2, oil and trade, and urbanization and oil.

Table 4.7: Ganger causality test

Direction of causality	F-statistics	Probability
HYD → CO2	0.03417	0.9664
CO2 → HYD	2.60420	0.0840*
TRADE → CO2	5.19955	0.0089***
CO2 → TRADE	3.15538	0.0512*
OIL → CO2	2.53983	0.0890*
CO2 → OIL	1.96582	0.1507
URB → CO2	3.69779	0.0318**
CO2 → URB	6.40674	0.0033***
HYD → TRADE	2.22194	0.1190
TRADE → HYD	0.13679	0.8725
OIL → TRADE	4.57397	0.0150**
TRADE → OIL	3.60743	0.0344**
URB → TRADE	0.65125	0.5258
TRADE → URB	1.02423	0.3665
OIL → HYD	1.25296	0.2945
HYD → OIL	0.21881	0.8042
URB → HYD	0.63775	0.5327
HYD → URB	0.46986	0.6278

URB → OIL		2.85044	0.0673*
OIL → URB		4.28623	0.0191**

Note: *significant at 10%, **significant at 5%, ***significant at 1%

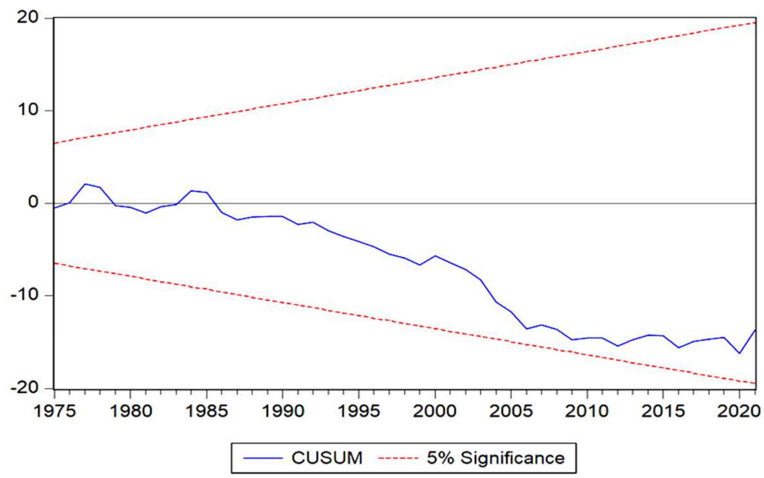


Figure 4.1: Cumulative sum of Square of recursive residuals

The cumulative sum of the square of recursive residuals stability test is helpful in determining the model's stability and estimated results of the test is shown in Figure 1. The result demonstrate that the consumption of oil (OIL) is positively related with CO_2 emissions, whereas hydroelectricity (HYD), Trade, and urban population is negatively correlated.

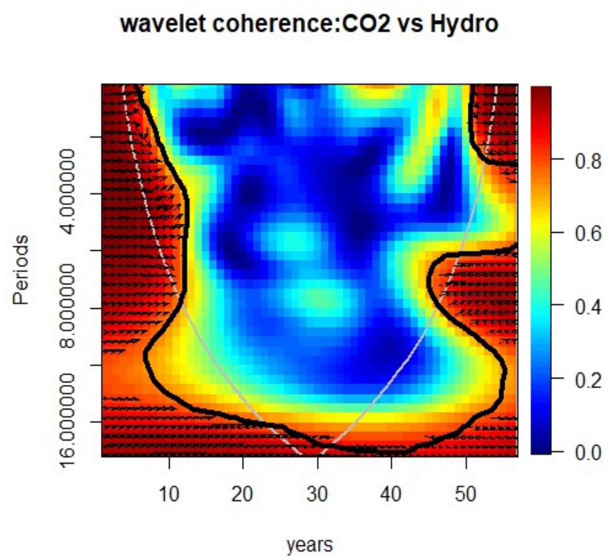


Figure 4.2 CO2 Vs Hydroelectricity

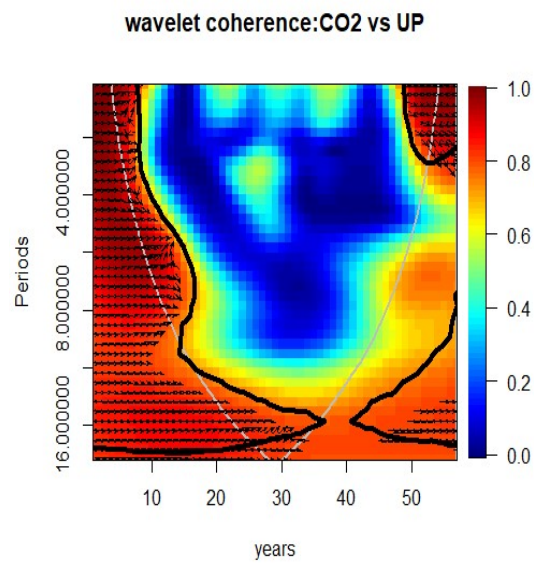


Figure 4.3 CO2 Vs Urban population

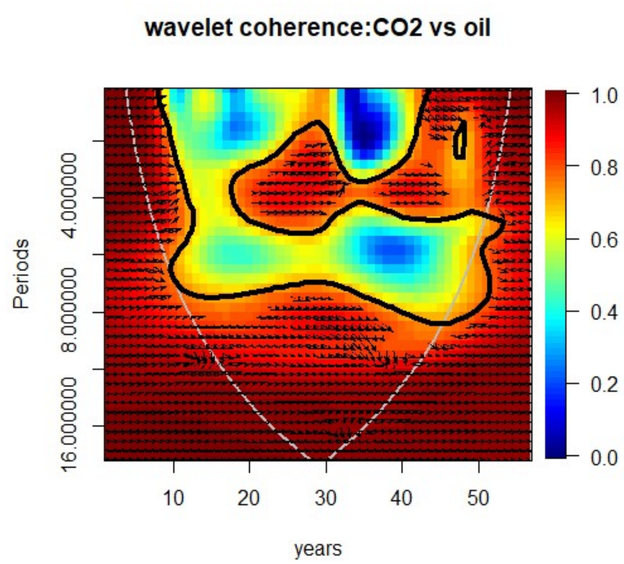


Figure 4.4 CO2 Vs Oil

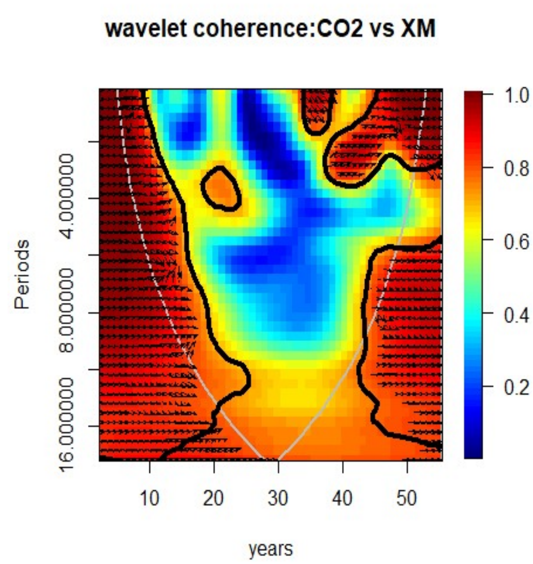


Figure 4.5 CO2 Vs Trade

In Figure 4.2 the results reflect cool blue and green colors in the center that means that the correlation between CO2 emissions and hydroelectricity ranges between 0.1 – 0.6 in short run as well as medium run whereas, it is seen that in long run there is dark red color which means the correlation gradually increases in the long run. The Figure 4.3 represents that in the beginning the urban population is highly correlated to CO2 emissions but as the year passes the correlation ranges decreases as the colors reflects the shades of blue, green and orange. Figure 4.4 displays dark red color that shows CO2 emissions and oil are highly correlated to each other and the upward and downward arrows represents the presence of causal linkage between the two variables. Figure 4.5 shows that CO2 emissions and trade are highly correlated in long run and the upward arrows represents causal linkage between CO2 emissions and trade whereas, the rightward arrow signifies phase in.

4.5 Conclusions

The relationship between CO_2 emissions, hydroelectricity, urban population, oil consumption, and trade in Canada from 1965 to 2021 was examined in this study. Wavelet Coherence was used to estimate the relation between the independent variables i.e. use of hydroelectricity, oil, urban population, and trade, and the dependent variable i.e. CO_2 emission. The test results shows a causal link between the all five variables both in the short and long run. The results indicated that oil consumption is highly significant with CO_2 emission both in short and long run, which is a not a good sign because they negatively influence environmental sustainability. Oil usage needs to be reduced in order to reduce CO_2 emissions. Hydroelectricity usage shows a negative correlation with CO_2 emissions and is also significant in the long run leading to decrease in CO_2 emissions. Whereas, trade is positively connected with CO_2 emission both in the short and long-run. The results of Wavelet Coherence reveals that in long run increasing hydroelectricity and urbanization reduces CO_2 emissions indicating that increase in urbanization and hydroelectricity can have considerable good impact on the environment. It also validates the EKC hypothesis, that with the increase in economic growth the pollution decreases.

As a result, our research suggests that promoting urbanization entails more than just boosting the number of people living in cities, as 1% growth in urbanization will reduce 0.26 % of CO_2 emission in the long run. The use of renewable energy should be promoted as 1% increase in hydroelectricity will decrease 0.11% of CO_2 emissions. Whereas, oil consumption has a highly positive impact, a percent rise in oil consumption leads to 0.66% increase in CO_2 emissions. Therefore the study suggests that biofuels should be encouraged as the blended fuel burn more cleanly minimizing the impact of conventional fuel. In the coming future, researchers should pay more attention to micro-stage data provided by the Canadian states in order to find out about the effects of renewable energy in long run and also estimates the future of renewable energy if it is promoted on the same pace.

CHAPTER 5

THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS

5.1 Overview

The aim of the study is to varify environmental Kuznets curve (EKC) hypothesis for affecting the CO_2 emissions by GDP and energy use for China, USA, India and UK. The 50 years data from the year 1971 to 2020 have been employing for this study. The study employed Fourier Agumented Dickey-Fuller (ADF) test and Fourier Kwiatkowski-Phillips-Schmidt-Shin (KPSS) to check the unit root and stationarity of data and experienced the co-integration by using Bootstrap Autoregressive Distributed Lag (ARDL) model. Further it explored the causal linkages between the variables by Fourier Toda-Yamamoto. Lastly the study used wavelet coherence to check the time and frequency dependency of the variables. The results indicates that there exist no co-integration between the variables of all the countries. Therefore the EKC hypothesis was rejected. The results reflected causal unidirectional linkage between CO_2 emissions and GDP of India and UK. Whereas, there is a oneway causal linkage between CO_2 and energy use of China. The CO2 mitigation according to the per people energy use is presented in figure 10. It is revealed that the net CO2 mitigation per people for the year 2020 was obtained by 0.507542, 5.418993 and 2.436347 Tonnes/people/year of India, USA and UK people respectively.The study suggests few stategise of technology and energy mix by which economic growth can be achieved without compromising the environmental quality.

5.2 Introduction and work progress of EKC

Several studies have been conducted to evaluate the environmental quality and the validity of the EKC hypothesis, mostly in terms of GHG emissions (Huang et al, 2008; Cho et al, 2014). Both the time series and panel data were used to uncover the EKC hypothesis. The research established the presence of the EKC hypothesis in 13 Asian, OECD, BRICS, Middle Eastern, and North American countries, respectively (Heidari et al, 2015 & Jebli et al, 2016; Shahbaz et al, 2019). Several studies have found that the EKC hypothesis is not embraced by Sub-Saharan African economies, five South East Asian nations, the top ten most inventive countries, and the 34 Annex-I countries (Kisswani et al, 2018; Gorus and Aydin, 2019).

Furthermore literature has been explored to know the relation between CO_2 emission, Energy use and GDP. There were countries like OECD, G7, Kuwait, Algeria, South Africa, Japan and MENA expressed a positive relation among the GDP and CO_2 emissions (Pablo-Romero, 2016; Odugbesan & Adebayo, 2020; Ahmad et al, 2021; and Al-Mulali, 2011) respectively. There also has been a causality test to check the relationship between the variables and it oberved that there is a one-way causal relation between GDP to CO_2 emissions (Jafari et al, 2015; Wang et al, 2019; Kirikkaleli & Adebayo, 2021). The various studied revealed unidirectional and bidirectional causal link from between CO_2 emissions to GDP (Adebayo, 2021). In a study of 31 developing countries showed a negative relation between GDP and CO_2 emissions (Aye and Edoja, 2017).

There are also some literature that explores the causal relationship between the GDP and energy. A study conducted on G7 nations showed a causal bidirectional relation link from GDP to energy use (Mutascu, 2016) also found a bidirectional relation between the variables in their studies. Whereas, Toda Yamamoto causality test on Russia's GDP and energy use reflected no causal link between them (Faisal et al, 2016). Further an author examined India's data from 1970 to

2008 of GDP and energy use to explore the causal link and found that there was a unidirectional link from energy use to GDP (Yang and Zhao, 2014).

The consequences of the ambiguous findings have been observed from the various prior studies, these are stated that the validity of the EKC hypothesis is not guaranteed for each and every case. Instead, it is significantly impacted by macroeconomic factors and particularly energy uses which are taken into consideration in the study. In the above studies smooth changes in causality and co-integration were also unnoticed. Therefore considering the structural breaks becomes important in time series data due to the presence of economic crisis, political changes and pandemic. The studies also have a gap to explain the time frequency dependency of the variables which is required for strategic policy formulation. Furthermore, the effects of economic growth in light of the CO_2 emission-induced EKC hypothesis for the top three largest economies and the UK will be investigated. As a result of above, the paper attempts to address a gap in the EKC and the work on it carried out for four major countries of the world.

On the other hand, Economic developments of the country and energy use have a significant impact on the environment. The first empirical investigation on the causation of economic development and energy usage verified the conservation hypothesis, demonstrating a causal and bidirectional linkage from economic growth to energy use (Kraft and Kraft, 1978). Some researcher suggested approaches to achieve a more sustainable condition in urban settings using tools including ecological footprint analysis, baseline setting and progress monitoring, direction analysis, sustainability targets, and strategic environmental assessment (Devuyst et al. 2001). The expansion of the economy has had a significant role in rising pollutants and GHGs (Ayobamiji & Kalmaz 2020). The effect of it has been observed in a variety of ailments in humans, including cancer and heart disease (Adedoyin et al, 2020; Oluwajana et al, 2021).

Grossmann and Krueger (1991) developed environment Kuznets curve (EKC) hypothesis that implied on existence of co-integration between economic development and environmental degradation. EKC revealed a non-linear link between economic development and a change in emission levels, depicted by an inverted U-shape curve (Rafiq et al, 2016). The ongoing economic expansion has become a threat to sustainability and environmental adversities but LPG consumption can be a transitional fuel in reducing GHG for the South Asian countries resulted by EKC hypothesis (Murshed 2018). EKC hypothesis was applied to the six hydropower countries that showed no relation between economic development and renewable energy usage on mitigating ecological footprints (Pata and Aydin, 2020). A study showed one unidirectional causal link from energy use to GDP. The result pointed out the need of energy mix to enable sustainable development (Adebayo et al, 2021).

The ARDL, EKC, Fourier Toda-Yamamoto and Wavelet Coherence independently used by various researchers for various countries, but these methods have not been used combined in a single research article. The various researchers have used some other methods. The review shown in table 5.1 is presenting the work by so many researchers in various countries those are used various methods and the affecting variables.

Table 5.1: Review of the work done by various researchers year-wise from 2013-2022

Study	Data	Countries	Variables	Methodology	Findings
Ziramba (2013)	1980–2009	Egypt, South Africa, and Algeria	HYD, GDP, CO_2	Toda-Yamamato Granger causality test , Engle and Granger cointegration,	HYD has a positive effect on GDP for Egypt , a two way relation was observed for Algeria, and for Egypt HYD $\neq$ GDP
Heidari et al. (2015)	1980-2008	Indonesia, Malaysia, Philippines,Singapore, and Thailand	GDP, Energy consumption, CO_2	PSTR, EKC	It support the EKC

Azad et al. (2016)	1976-2012	Australia	GDP, CO_2, Energy Consumption	VAR, VECM, ARDL	Effect of energy policy on socio-economic and environmental issues, CO_2
Marques and Fuinhas (2016)	2006 (M1)-2014 (M6)	Portugal	*LOFREG, LORH, LORT, SR, LSR, LSRPV, LSRW*	*ARDL*	*Observed a good relation relationship between EGR, ordinary & special, and economic movement*
Bekhet et al. (2017)	1980–2011	Gulf countries	*Y*, ENE, FD, CO_2	ARDL, Causality test	Increasing the CO_2 alongwith increasing the energy demand and which is fulfilled by conventional mode Saudi Arabia, UAE, and Qatar, Increasing the CO_2 for increasing GD in UAE, Oman, and Kuwait
Rudolf and Figge (2017)	1981-2009	146 Countries	*EF, Demographic and Economic variables*	ARDL	Gl has a +ve effect on EF of import and export
Alsaleh and Rahim (2018)	1990-2013	EU-28 region	GDP, CI, BIOCON, ENCON, TO, CO_2	ARDL, Panel Cointegration, FMOLS, DOLS, PMG	green and sustainable sources must be boosted significantly
Bello et al.(2018)	1971-2016	Malaysia	*EF, GDP, EE, Cons., Urb.*	Granger VECM	Urb. decreases the ecological footprint in the long-term
Imamoglu (2018)	1970-2014	Turkey	Forma economy, CO_2 and Env. Quality	Cointegration, DOLS, ARDL and FMOLS,	If the formal economy exerts positively higher than it affects the higher environmental quality as compared to the informal economy
Ummalla and Samal (2018)	1965–2016	China	HEC, CO_2, *Y*,	bound test , ARDL	EKC is untrue for China and CO_2 has a constructive effect on the HEC
Hasanov etal. (2019)	1992-2013	Kazakhstan	*CO_2, GDP, trend,*	EKC, ARDLBT, DOLS, FMOLS, CCR, ADF, KPSS	Needs to increase the Renewable energy to reduce the CO_2.
Abumunshar et al. (2020)	1985-2015	Turkey	*CO_2, GDP, OP, REC, NREC*	KEC, ARDL, DOLS, FMOLS, CCR, GC,	The Turkey government should be implement the policies which can help to reduce the costs of RE and increase the function of green energy. It will reduce its conventional energy consumption
Adebayo et al. (2020)	1980–2018	MINT nations	*Y*, TO, URB, EN, CO_2	PMG, panel Causality, CDS ,	GDP$\neq$ CO_2 TO$\rightarrow CO_2$ (−) TO$\rightarrow$ENE (+) URB $\rightarrow CO_2$ (+)
He at el. (2020)	1975-2018 different countries gives	BRICS Countries	*Trade, FDI, CO_2*	ARDL	Case-1:while China's trade and FDI on the lag of one-period of CO_2, emissions is the country of degeneration Case-2: When we examined short-term

	different data time period				causality, we found, that CO_2 emissions showed a causal relationship with trade, while FDI and CO_2 emissions wereless pronounced
Koc and Bulus (2020)	1971–2017	South Korea	ENE,CO_2, GDP, GDP^2,	ARDL,	*N*-shaped relationship CO_2 is increasing with increasing the GDP, ENE and decreasing with increasing the TO and REN
Langnel and Amegavi (2020)	1971-2016	Ghana	ECF, EC	ARDL	*Globalisation increases the EF in general*
Nathaniel (2020)	1971–2014	Niheria	GDP , trade, Energy use,	ARDL.	observed ecological footprint in the long term when Urbanization increases
Pata and Aydin (2020)	1965–2016	Brazil, China, Canada,India, Norway and the USA	HENE, CO_2, Y^2, *Y*, EN,	Fourier TYGC and Fourier bootstrap ARD,	EKC hypothesis is not valid HENE ↔ GDP in China HENE → GDP in Brazil
Rahman and Vu (2020)	1960–2015	Canada and Australia	URB, CO_2, *Y*, EN,	VECM causality , ARDL,	For Australia CO_2 is rising with escalating Y, In Canada CO_2 is rising with escalating Y, and URB
Sulaiman and Rahim (2020)	1980-2015	Egypt, Algeria, South Africa, Mauritius, Kenya, Morocco, Tunisia, and Zambia.	GDP,CO2, Technology, Biomass	EKC, ARDL, PMG, MG, DFE, FMOLS, DOLS	Increase the Renewable energy consumption to reduce CO_2
Tiwari et al. (2022)	1971(Quarter-1) to 2017 (Quarter-2),	Brazil and China	human capital , Hydro, urban, EF,	QARDL	Hydropower mitigates pollution
Murshed etal. (2021)	1995-2015	Bangladesh, India, Nepal, Srilanka, Pakistan	RGD, RGDP, FD, URB, OPEN, RELEC, CFP, EFP, CO2	ARDL, EKC, CIDF, CIPS DOLS,, FMOLS,	The EKC hypothesis for ecology and CO2 is compelling for all countries except Pakistan
Qayyum et al. (2021)	1991-2017	Southa Asian Countries	IF, urbanization	ARDL, PMG	The IE and urbanization increases the ecological footprint in the long-term and the short-term effect found different.
Yang and Usman (2021)	1995-2018	Top 10 countries with highest spending on UH	*EF, UP, UH, economic growth*	STIRPAT	Globalization decreases the EF
Bhowmik et al. (2022)	1985-2018	USA	*CO_2, MU, FU, TU, IPI, UNE, ENC*	EPC, ARDL, FU, TU,	validity of the EPC(Environmental Phillips Curve) in the US to investigate the impact of MU(monetary policy uncertainty), TU(trade policy uncertainty) and FU(fiscal policy uncertainty) on CO_2 emissions

Adebayo (2022)	1970 (Quarter-1)-1974 (Quarter-2)	Spain	ECI, REC, LCF, FF, FDI	Casualty test , Wavelet	Increase the Renewable energy consumption
Adebayo et al. (2022)	1992-2018	Russia	ECF, GDP, REC, NREC, TR	QQR, QUR	Relation between Economic growth and emission
Chu (2022)	1995-2015	OECD Countries	*IE, Tech, Env*	Quantile regression	The IE exerts a negative effect from the middle to the top quantile of the ecological footprint distribution
Hamid etal. (2022)	1980-2019	Oman	GDP, CI, FDI	EKC, ARDL, NARDL	Role of FDI, GDP, CI in CO2 reduction
Jahanger et al. (2022)	1990–2016	73 developing countries	TI, GDP., natural resources,	PMG-ARDL.	Globalization increases the ecological footprint in general.
Menegaki and Tiwari (2022)	1995-2015	10 top tourism destinations, USA, Italy, UK, Russia, Spain, France, China, Germany, Mexico, Turkey	*FDI, TDI, GDPC*	FTY, GCT, ADF	*FTY expressed that the tourism-led growth hypothesis is confirmed for the United States, Italy, the United Kingdom, and Russia, while economic growth Granger-causes tourism development in the United States only*
Ozturk et al. (2022)	1987-2019	Turkey	CO2, GINI, GDP, FD	ARDL, NARDL	Effect of positive or negative income inequality effect on CO2
Ozturk, Altinoz (2022)	1968-2017	Saudi Arabia	GDP, EN, HAJJ, OIL	DOLS, FMOLS, Casualty test	nexus between pilgrimage tourism, energy consumption, CO2 emissions, and economic growth
Zhou et al. (2022)	1971-2019	China	AP, GDP, EC, Trade, UrP	ARDL, NARDL	livestock production can help to reduce CO2 emissions

In this study top three CO_2 emitting countries China, USA, India and UK was chosen. UK has the history of starting industrial revolution but in last decade it has taken measures to curb its emissions. The China, USA and India are the largest economies in the world by PPP-GDP and also contributed as the major emitter of carbon dioxide. Therefore it is important to examine the EKC hypothesis of these countries. That was contributed to the existing EKC literature in following ways. Firstly, the analysis covered both emerging and advanced nations, where it provides a more accurate depiction of the co-integration and causative link between CO_2 emissions, GDP, and energy usage. Second, in dealing with time series data, this work considers the size and power problem as described in Monte Carlo simulation. Finally, the newly designed bootstrap ARDL co-integration process, wavelet coherence test, and Fourier Toda Yamamoto causality test were used in the study. The study also covers the following issues: (a) Does the carbon dioxide-induced EKC hypothesis prove true in the case of the world's top three economies and the United Kingdom?; (b) Is there a connection between economic development, energy consumption and CO_2 emissions?; (c) What is the frequency of dependence between CO_2 emissions, GDP, and energy consumption?; (d) Are the findings robust across the top three major economies and the UK?

5.3 Methodology and Data Assessment

The World Bank for the years 1971 to 2020 of the United States, China, India, and the United Kingdom (UK) have been used for analysis. The top three carbon emission countries whereas, UK was taken into study as it has the history of starting the industrial revolution and in recent decade the country has taken various measure to limit CO_2 so it makes the country important for testing the EKC hypothesis. The mathematical modelling is adopted from Singh et al. (2023), which is expressed as:

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 (\ln GDP)_t^2 + \alpha_3 \ln EU_t + e_t \quad \text{.......................................(1)}$$

CO_2 represents CO_2 emissions (kt), GDP in Per Capita (current US \$) and EU is Energy use (kg of oil equivalent per capita). All variables are in natural log form. To check the presence of unit root and stationarity Fourier ADF and Fourier KPSS was used respectively. Adding Fourier approximation has advantages over the previous ADF and KPSS test as it solves the problem of over fitting, it captures the gradual structural changes, sharp breaks and other type of non-linear trends (Enders et al, 2012).

$$\Delta y_t = \alpha_1 + \delta t + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \vartheta y_{t-1} + u_t ....(2)$$

The bootstrap ARDL bound test was used to examine the co-integration of variables in order to investigate the EKC hypothesis (McNown et al, 2018) and it can be written as.

$$\Delta CO_{2t} = c + \alpha_1 \ln CO_{2t-1} + \alpha_2 \ln GDP_{t-1} + \alpha_3 (\ln GDP)^2_{t-1} + \alpha_4 \ln EU_{t-1} + \sum_{i=1}^{p-1} \theta_1, i \Delta \ln CO_{2t-1} +$$
$$\sum_{i=1}^{p-1} \theta_2, i \Delta \ln GDP_{t-1} + \sum_{i=1}^{p-1} \theta_3, i \Delta (\ln GDP)^2_{t-1} + \sum_{i=1}^{p-1} \theta_4, i \Delta \ln EU_{t-i} + \sum_{j=1}^{k} \sigma_j D_{t,j} + \varepsilon_t ....(3)$$

CO_2, GDP and EU has unrestricted error correction model (ECM) whereas, $D_{t,j}$ is a Dummy variables included in equation to deal with structural breaks. The lags are selected based on Akaike information criteria (AIC). Bootstrap ARDL bound test measures the performance of ARDL bound test when the weakly exogenous regression assumption is violated. Furthermore, it solves the size problem of PSS critical values as indicated by the Monte Carlo simulations.

Moreover Fourier Toda-Yamamoto causality test was employed as it has an advantage of considering the gradual structural shifts that is important while analysing the causal link between the variables (Nazlioglu et al. 2016).

$$y_t = \alpha_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t=1} + ... + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t ....(4)$$

In order to bring things to a close, wavelet coherence can be employed to investigate the correlation and causes seen between dependent and independent variables in order to acquire previously unknown information. The application of wavelet coherence gives information of the short-run, medium-run and the long-run relationship between dependent and the independent variables (Torrence and Compo 1998; Torrence and Webster, 1998).

$$R_n^2(s) = \frac{|S(s^{-1}W_n^{XY}(s))|^2}{S(s^{-1}|W_n^X(s)|^2).S(s^{-1}|W_n^Y(s)|^2)} \quad \text{...(5)}$$

5.4 Results and Discussions

5.4.1 Unit root and stationarity test by Fourier ADF and Fourier KPSS

FADF and FKPSS tests results are shown in table 5.2 Fourier ADF and KPSS test has some advantages over the conventional model as adding Fourier to the test overcomes the problems of unknown multiple breaks. The maximum number of Fourier and lags were set to 3 and 4 respectively and the optimal Fourier and lag were chosen automatically by the AIC. The results shows that the variables CO_2 and EU of China rejected the null hypothesis presence of unit root at I(0) were as all other variables of all the four countries rejected the null hypothesis at I(1). The null hypothesis of stationarity for KPSS were failed to be rejected of all the variables for the four countries at I(1). The study employed bootstrap ARDL model, as the model can be applied to a time series data that is stationary at I(0), I(1) or the combination of both. Therefore the model was fit to be applied as the data were stationary in combination of I(0) and I(1).

Table.5.2 Unit root and stationarity test by Fourier ADF and Fourier KPSS

Countries Variables	FADF I(0)	FADF I(1)	Frequency (lags)	FKPSS I(0)	FKPSS I(1)	Frequency
India						
CO_2	-1.713	7.482***	1(0)	0.274***	0.059	2
GDP	-4.007	-6.145***	1(0)	0.276***	0.052	1
EU	-2.711	-7.171***	1(0)	0.277***	0.065	3
USA						
CO_2	-2.506	-8.099***	1(0)	0.124***	0.033	3
GDP	-4.240	-5.822***	1(0)	0.085***	0.034	1
EU	-3.226	-7.564***	1(0)	0.352***	0.024	2
China						
CO_2	3.967**	-5.501***	1(0)	0.466***	0.057	2
GDP	-2.780	-4.567***	1(0)	0.162***	0.085	2
EU	-4.177**	-5.405***	1(0)	0.217***	0.086	1
UK						
CO_2	-3.358	-8.099***	1(0)	0.074***	0.033	3
GDP	-3.364	-5.822***	1(0)	0.086***	0.034	1
EU	-2.419	-7.564***	1(0)	0.160***	0.024	2

*Optimal lag automatically by AIC *** & ** denotes 1% & 5%significance level*

5.4.2 Bootstrap ARDL for Co-integration

The ARDL bootstrap procedure is allows to renormalizing the ARDL equation so that every series are considered as dependent variable. Bootstrap ADRL is a better test for co-integration than the conventional model as it solves the problems associated with size and power. It also eliminates the possibility of inconclusive inference. The null hypothesis is rejected only if the overall F-stats & t-stats of dependent lagged variables are greater and the t-stats of independent variable needs to be more negative than its critical values respectively. There are two types of degenerate case as described by (McNown et al, 2018). Degenerate the case #1 in which the overall F-stats and t-stats of dependent variable are significant. And in case #2, the overall F-stats and t-stats of independent variable are significant.

Table.5.3 Bootstrap ARDL (BARDL)

Countries Model	AIC	F-stat	t-stats dep	t-stats indep	Lags	Dummy
India						
BARDL	-4.5338	1.049862	-0.807735	1.089122	(2 0 2 2 0 0 2	(78 79 84
1%		27.26664	-2.512890	25.16526	2 0 2 2 0 2 0	85 91 93 94
5%		21.01311	-1.630251	19.24065	1 2)	07 08 15
						18)
USA						
BARDL	-4.815454	1.674139	2.519893***	2.097972	(2 2 0 1 2 1 1	(96 07 08
1%		67.60787	-0.788188	6.599140	0 1 2 2 0 1 1	09 10 11)
5%		52.60908	-0.129860	4.501646	1 2)	
China						
BARDL	-3.702702	2.403083	-1.624726	0.452895	(1 0 1 0 1 1 1	(76 81 91
1%		7.546009	-4.355833	9.029647	0 1 1 1 0 1 1	01 02 03 04
5%		5.383963	-3.549187	6.453293	1 0)	05 09 11
						15)
UK						
BARDL	-3.717644	5.949951	-4.454051***	6.86407***	(1 1 1 2 1 1 1	(82 06 07
1%		20.96659	-0.685813	5.768166	2 1 1 1 2 1 1	09 13 18
5%		14.85043	-0.137343	3.603875	1 2)	19)

*Bootstrap = 5000 Optimal lag automatically by AIC ***& **denotes 1% & 5% significance level*

In table 5.3 the dummy variables are the multiple break points. The structural break points were identified using the Zivot & Andrew unit root test and were also crossed checked by breakpoint unit root ADF test of all the variables separately for all the four countries. The null hypothesis of no co-integration cannot be rejected as the overall F-stats, t-stats of independent variable are not greater than their critical values neither the t-stats of dependent variable is less than its critical value. As seen in table 5.3 only in UK the t-stats of independent variable is more than its critical value whereas, t-stats of dependent variable for USA and UK are more negative than its critical value. Therefore null hypothesis cannot be rejected and the results shows that EKC hypothesis does not holds for these four countries.

5.4.3 Toda-Yamamoto causality test for Evaluating the Linkage between the Variables

Table 5.4 is representing the results of Fourier Toda-Yamamoto causality test for checking the linkage between the variables. According to the Monte Carlo simulation ignoring structural breaks can results in misspecification error. Hence the Fourier function was added to the previous Toda-Yamamoto to overcome the misleading causality results. The null hypothesis of causality is based on zero restrictions parameters. The Single frequency Fourier Toda-Yamamoto causality test is more powerful while dealing with observations between 50 -100 to define the direction and magnitude of relationship. Therefore it is the accurate methodology as we have 50 observations. The results shows the unidirectional link between CO_2 and GDP for UK and India whereas, one way causal link between CO_2 and energy use for China. Rest all the other variable has no causal link.

Table.5.4 Fourier Toda-Yamamoto

Countries Variables	t-Stats	p-value	Fourier
India			
CO_2→GDP	10.45073	0.005378***	3
GDP→ CO_2	0.265631	0.875627	3
CO_2 →EU	1.695807	0.428312	2
EU→ CO_2	1.454075	0.483339	2
GDP→ EU	0.632464	0.728891	1
EU→ GDP	1.608010	0.447533	1
USA			
CO_2 →GDP	2.058036	0.357358	3
GDP→ CO_2	0.434872	0.804599	3
CO_2 →EU	3.236870	0.198209	1
EU→ CO_2	1.391171	0.498782	1
GDP→ EU	1.938069	0.379449	3
EU→ GDP	0.436228	0.804034	3
China			
CO_2 →GDP	0.161275	0.922528	2
GDP→ CO_2	0.717671	0.698489	2
CO_2 →EU	7.342904	0.025440***	3
EU→ CO_2	2.420826	0.298074	3
GDP→ EU	2.587839	0.274194	1
EU→ GDP	1.097855	0.577569	1
UK			
CO_2 →GDP	10.92921	0.0042324***	3
GDP→ CO_2	0.050034	0.975293	3

$CO_2 \rightarrow$EU	1.811878	0.404162	3
EU$\rightarrow CO_2$	0.798068	0.670968	3
GDP$\rightarrow$ EU	0.299453	0.860944	1
EU$\rightarrow$ GDP	2.050256	0.358751	1

*Optimal lag automatically by AIC *** denotes 1% significance level*

5.4.4 Wavelet Coherence

Wavelet coherence expressed the co-movement of two time series data and it measures the variance at each time and frequency. The abscissa of the wavelet represents the years while the ordinate refers to periods. The colour bands on the right side shows the level of correlation where the red colour shows absolute correlation and vice-versa. The grey line is the cone of influence, below which the interpretation becomes difficult due to discontinuity. Whereas, 5% significance level denoted by the black contour. The period from 0-4 refer to short-run, 4-8 medium-run and 8-16 long-run. The right ward and left ward arrows have been refers to the phase in and phase out respectively. Whereas the upward and downward arrow reflecting the causal link.

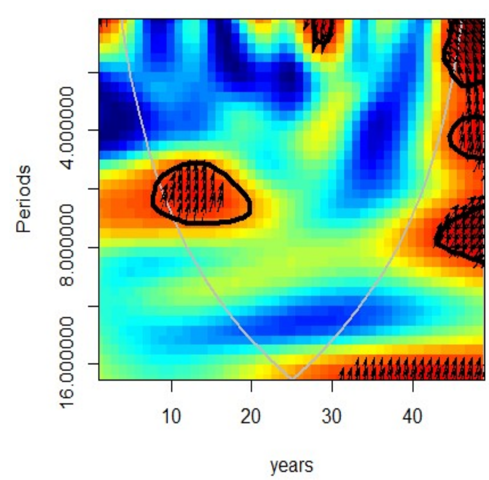


Figure 5.1 Wavelet coherence India CO_2 Vs GDP

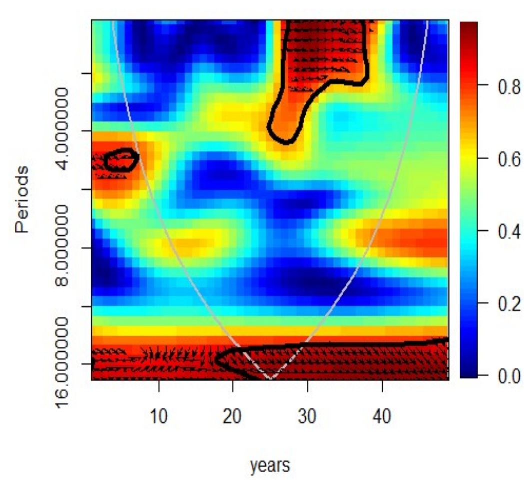
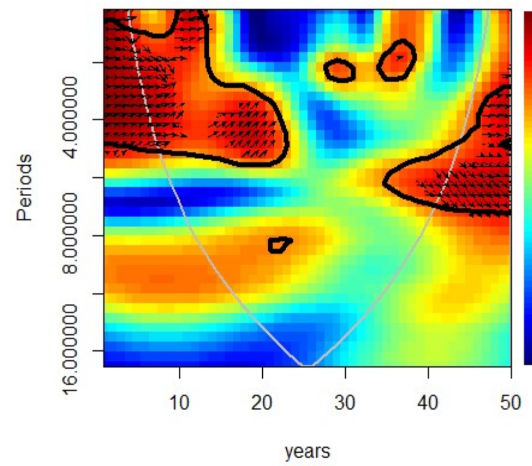


Figure 5.2 Wavelet coherence India CO_2 Vs EU

In figure 5.1 the upward arrow in medium-run indicates that GDP leads to CO_2 emissions. Figure 5.2 shows the downward arrow in short-run reflecting energy use lead to CO_2 emissions.



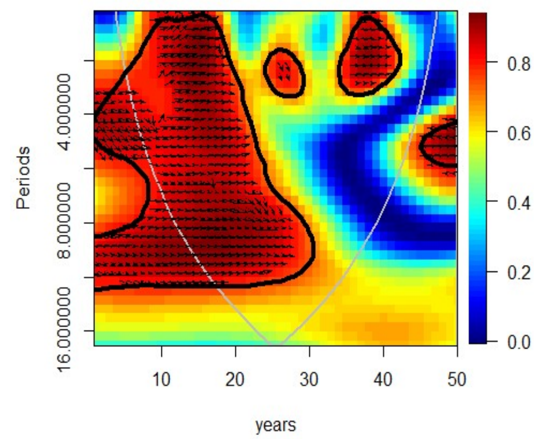
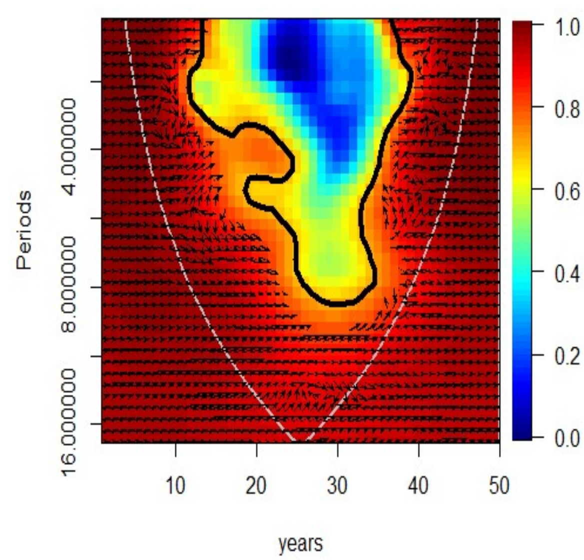


Figure 5.3 Wavelet coherence USA CO_2 Vs GDP **Figure 5.4** Wavelet coherence USA CO_2 Vs EU

In figure 5.3 the arrows are towards the right in short-run indicating correlation between CO_2 emissions and GDP whereas, the arrows on medium-run are downwards reflecting that GDP leads to CO_2 emissions. In figure 5.4 the arrows are pointing rightward and downwards stretched across short-run, medium-run and long-run. The rightward arrow shows correlation between CO_2 emissions and energy use whereas; the downward arrow reflects that energy use leads to CO_2 emissions.



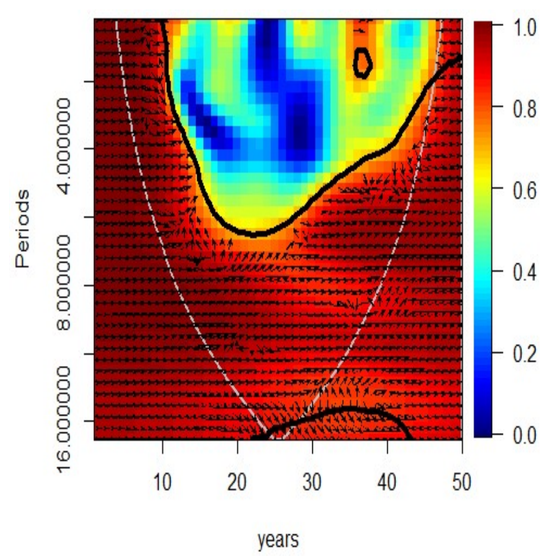
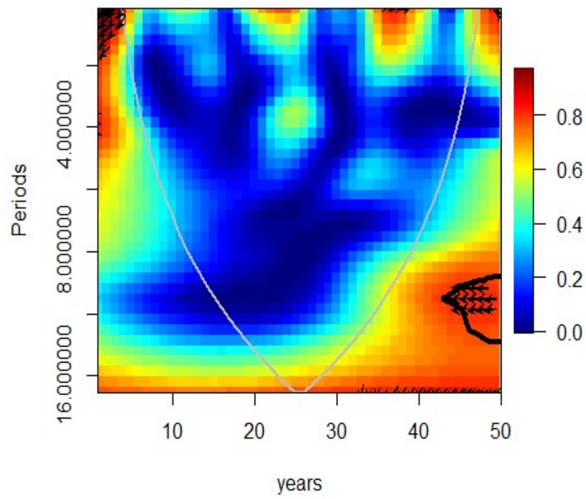


Figure 5.5 Wavelet Coherence China CO_2 Vs GDP **Figure 5.6** Wavelet Coherence China CO_2 Vs EU



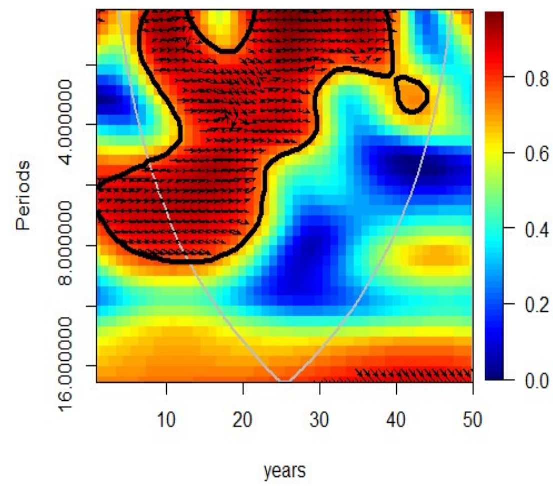


Figure5.7 Wavelet Coherence UK CO_2 Vs GDP **Figure 5.8** Wavelet Coherence USA CO_2 Vs EU

In Figure 5.5 the results shows absolute correlation between CO_2 emissions and GDP. The presence of upward and downward arrows stretched across the three term reveals that CO_2 emissions leads to GDP as well as GDP leads to CO_2 emissions. Figure 5.6 shows rightward arrow indicating correlation between CO_2 emissions and energy use whereas, downward arrows indicates energy use leads to CO_2 emissions.

In Figure 5.7 there are leftward arrows showing phase-out relationship between CO_2 emissions and GDP. Figure 5.8 shows downward and rightward arrows spread between the short-run and long-run reflecting correlation as well as energy use leads to CO_2 emissions respectively.

5.4.5 Energy Use and CO2 Mitigation

The energy use per people per year is given in figure 5.9 for India, USA and UK peoples. The highest energy used by the USA people in a year of 2020 was 7181.28kWh and by the UK people 3228.66KWH and by Indian People was 672.60kWh. It is observed that the lowest energy is used by the Indian people as compared to two developed countries like USA and UK.

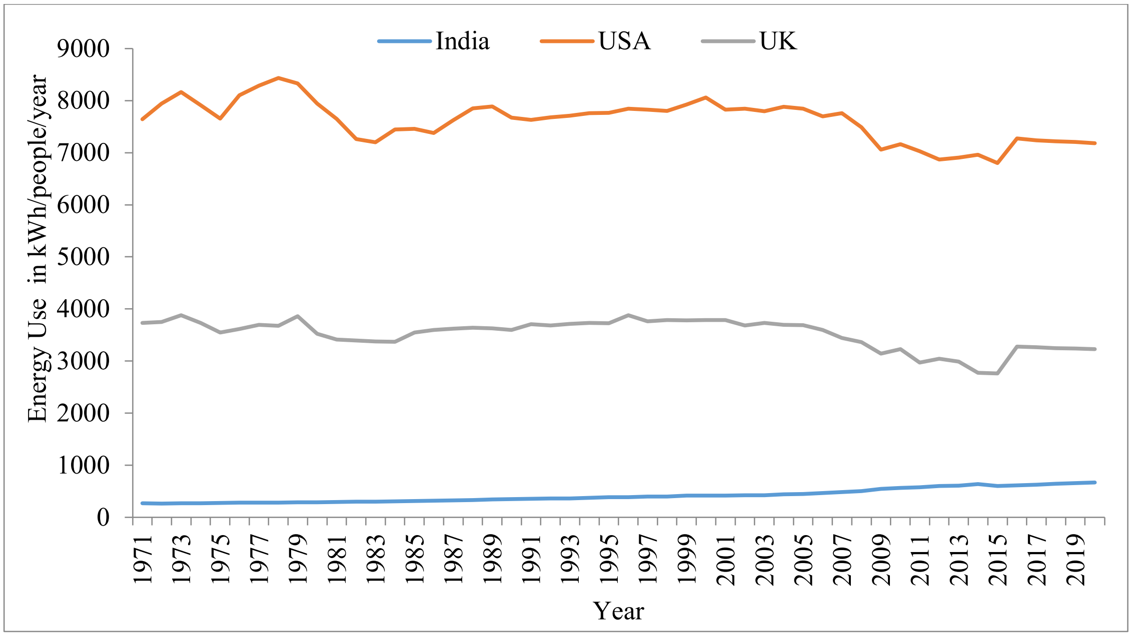


Figure 5.9: Energy use in kWh/people/year

India is a developing country and the Industrial revolution in all fields is required in 360 degree manner. This energy use is being meeting out through commercial energy generated in power plants. Approximately 60% of electrical energy is produced by thermal power. The CO_2 is the main content in the flues gases exhausted from the thermal power plant. And the Carbon dioxide is the major pollutants and cause of global warming. The other pollutants also exhausted from the power plants like SO_2 and NOx. If the power has to be generated by renewable energy or net zero energy production method like solar, wind, geothermal and OTEC etc, than the CO2 can be mitigated according to the application of energy use. Mittal et al. (2012), Kaushik et al. (2014), Lal et al (2014) and Singh et al. (2023) studied and presented the CO2 mitigation evaluation method and the same is applied in this communication. The CO2 mitigation according to the per people energy use is presented in figure 5.10. It is revealed that the net CO2 mitigation per people for the year 2020 was obtained by 0.507542, 5.418993 and 2.436347 Tonnes/people/year of India, USA and UK peoples respectively.

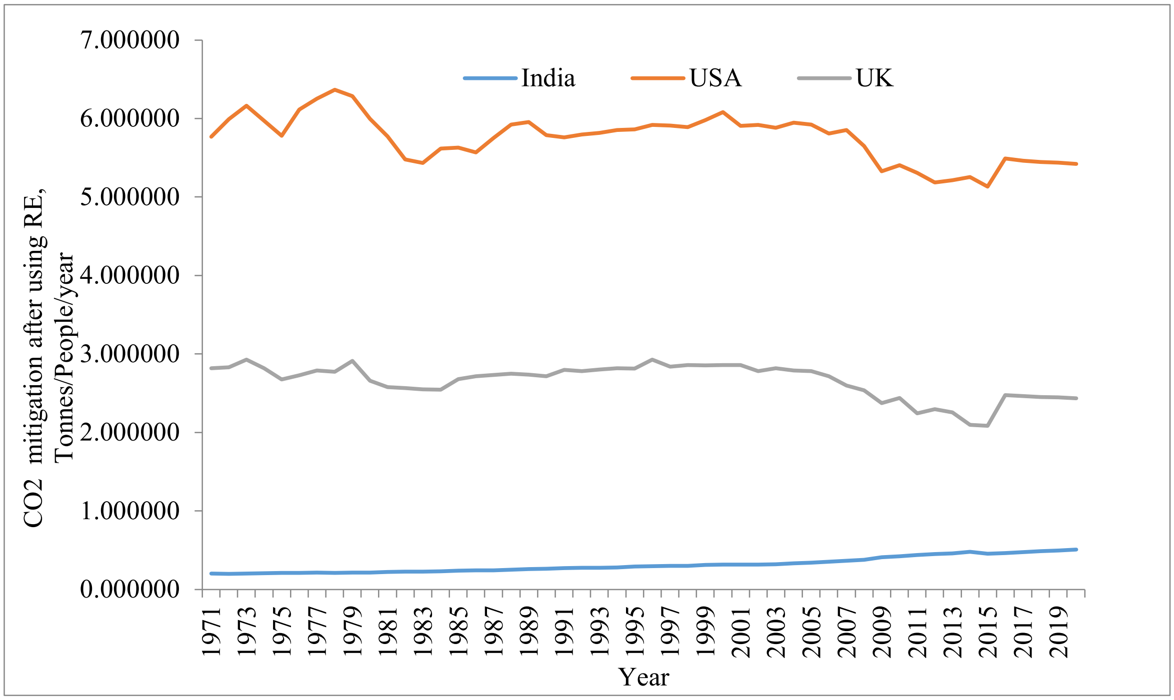


Figure 5.10: CO2 mitigation after using RE for commercial power generation

5.5. Conclusion and Policy implications

Economic progress achieved at the expense of environmental well-being is unlikely to be sustainable in the long run. As a result, modern development plans are commonly linked with environmental welfare objectives, with economic and environmental benefits expected to occur concurrently. The study showed that EKC hypothesis was rejected which indicates with higher economic growth the environment quality doesn't improve. Although the study was done on a combination of both developed and the developing countries but still neither showed any signs of holding the EKC hypothesis. Therefore economic growth can be the cause of environmental degradation but it can be a solution only when the countries have the intension to use its economic profit for developing better technology which will help in reducing environmental problems. The major concerns for any countries should be how to achieve growth with minimum environmental degradation by using cost-benefit analysis approach. So that growth strategies can be observed in alignment with the environmental policy. The wavelet result shows that there is a casual linkage between energy use and CO_2 emissions. The CO2 mitigation according to the per people energy use is presented in figure 10. It is revealed that the net CO2 mitigation per people for the year 2020 was obtained by 0.507542, 5.418993 and 2.436347 tonnes/people/year of India, USA and UK peoples respectively.

Therefore strategies countering the emission problems while using conventional energy should be made and implemented. In order to achieve net zero carbon emissions the countries have to tackle the CO_2 emissions using strategies. Firstly, conventional sources of energy should be replaced with green energy, while considering the geographical advantages of their respective regions like solar energy can be a major source of green energy for the regions lying between the latitude lines of tropic of cancer and the tropic of Capricorn. Secondly, CO_2 should be captured from the point of emission and stored or utilized to produce by-products like ink and sodium bicarbonate $NaHCO_3$.

The conventional energy producing power plants exhaust degraded the environment and it is recommended to use the non-renewable energy sources to reduce the degrading of environment quality. In drawing things to close the study has certain limitations due to the availability of data. Future research can be done on other countries with the same variables and including the other greenhouse gases as it has been the main reason for global warming and is the major concern for all the nations that it yet to be tackled.

CHAPTER 6

THE SUSTAINABILITY OF RENEWABLE ENERGY

6.1 Overview

In the study fifty seven years of time series data (1965 – 2021) was analysed to check the sustainability of renewable energy both in short run and long run using ARDL model as the data was stationary at the combination of I(0) and I(1). The results showed that CO_2 emission negative relation with renewable energy. As CO_2 emissions reduces with the increasing use of renewable energy. Renewable energy also has a very significant impact on agricultural as the electricity used for agricultural activity is more sustainable. The usage of renewable energy promotes green economy whereas, economic growth encourages environmental sustainability. However the waste and E-waste management needs to be promoted as nuclear energy has a highly radioactive waste materials which needs to be disposed properly as if it is leaked it will not only effect the country but also the neighbouring countries.

6.2 Introduction

In Scandinavian nations, increasing emissions is directly proportional to population and income while persisting at high levels. Due to the direct relationship between total energy consumed and CO_2 emissions, the amount of energy used per person has a high correlation with per capita income. Due to their immediate negative health effects and the relatively small areas they pollute, governments appear eager to reduce SO_2 and NO_x emissions; nevertheless, they gradually reduce CO_2 emissions, mainly during phases of high economic growth. Until recently, developed countries accounted for the majority of human-caused GHGs emissions. But now the percentage of emissions from the emerging economy has also grown dramatically and is estimated to increase more in future. Several researchers believe that one of the primary factors contributing to the expansion of greenhouse gases, which are responsible for climatic instability and global warming is the increase in CO2 emissions. A group of affluent nations devised the Kyoto Protocol in response to the danger that climate change posed to the environment worldwide. The largest international undertaking in terms of politics and geography is the Climate Change Framework Convention and Kyoto Protocol, which support national policies and actions to mitigate climate change. Under the rules of the Protocol, which came into force in February 2005, the industrialised countries (as a group) vowed to reduce their national emissions over the first commitment period of 2008–2012 by around 5% compared to the year 1990.

Even though France, Canada, Italy, Japan, Germany, the United Kingdom, the Russian Federation, and the United States have taken steps to tackle climate change, the G8 Gleneagles Action Plan was presented in July 2005 to promote sustainable development. Since the signing of the Kyoto Protocol and the debates that followed, the topic of how carbon dioxide emissions relate to economic development has been a contentious one. The research tries to analyse the short run and long run relation of Renewable energy Vs CO2 emission and Renewable energy and Agricultural activity. The study also check the causal linkage between the variables.

The vast majority of research indicates that while economic growth does increase energy use, it does not result in a long-term reduction in carbon emissions. In order to provide guidance for the sustainable development of a region or a country, some academics employ econometric models to investigate the short- and long-term dynamic interactions between elements including carbon release, financial growth, suburbanization, and international trade. The environmental Kuznets curve (EKC) hypothesis demonstrates the relationship between environmental pollutants like CO_2 and GDP as an inverted U-shaped curve (Jebli et al. 2016, Leal & Marques. 2020, Rafiq et al. 2016, Dong et al. 2017, Shahbaz et al 2019). Numerous studies have examined the causative relationship and unidirectional linkage between energy, GDP, and CO_2 emissions utilising the most recent econometric techniques including ARDL, Wavelet coherence, and Fourier Toda-Yamamoto (Yang & Zhao. 2014, Adebayo et al. 2020, Adebayo et al. 2021, Khobai and Roux. 2017, Faisa et al. 2016, Jafari et al. 2015, Wang et al. 2019, Aydoğan & Vardar. 2020, Kirikkaleli et al.2020, Kirikkaleli, & Adebayo. 2021, Al-Mulali, U. 2011, Wu et al. 2022, Adebayo TS. 2020, Gao & Zhang. 2021. A study that used life cycle analysis (LCA) to examine the effects of ethanol and biodiesel in Latin America found a 70% reduction in greenhouse gas emissions when biofuels are used instead of fossil fuels and recommended turning 5% of pastureland into energy crops to increase biofuel production for low carbon emissions and significant economic benefit Canabarro et al. 2023. Based on bibliometric research, the economic potential of biofuels was examined from 2001 to 2022. The findings showed that the US, China, India, and Europe are the largest biofuel markets, but many sustainable biofuel markets still lag behind those of underdeveloped and emerging nations Hasan et al. 2023. A study recommended creating microbial cell factories to increase the production of biofuel Maurya et al. 2023. Researchers looked at 31 developing nations with poor clean energy production and discovered a negative correlation between GDP and CO_2 emissions Aye et al. 2017, while only a few research revealed a positive correlation between GDP and CO_2 emissions (Teng et al.2021, Ahmed et al.2019, Ahmed et at. 2020, Odugbesan and Adebayo. 2020, Pablo et al. 2016, Wasti et al 2020. Using the Fourier ARDL, Fourier bootstrap Toda-Yamamoto, and wavelet coherence techniques, the EKC hypothesis on time series data for the three major countries of the USA, France, and Japan was examined from 1965 to 2020. This analysis revealed that France reached the breakeven point in 1978, which showed CO2 decreases with increasing use of nuclear energy, while the South Asian EKC hypothesis was also validated, reflecting a positive impact of using LPG on the environment Singh et al. 2023 and Murshed M. 2021.

6.3 Methodology and Data Assessment

To conduct the study, we used secondary data from the World Bank Development Indicators (WDI) to test our assumptions and accomplish our objective. Equation 1 was created to analyse the relationship between CO2 emissions, GDP, renewable energy usage (RE), Agricultural production (AP) of the France from 1965 to 2021.

ln *CO2 = f (*lnGDP*,* lnAP*,* lnRE)…………………………………………(1)

Here, ln is the natural log in the equation above, and Table 1 defines the variable description has definitions of the variables.

$$\Delta \ln CO2_t = a_0 + \sum_{i=1}^{n_1} a_{1i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{n2} a_{2i} \Delta AP_{t-i} + \sum_{i=1}^{n3} a_{3i} \Delta \ln RE_{t-i} + \beta_1 \ln GDP_{t-1} + \beta_2 \ln AP_{t-1} + \beta_3 \ln RE_{t-1} + \mu_t ......(2)$$

The letters a1 to a3 in the equation above reflect the short-run relationship, b1 to b3 represent the long-run relationship, and a0 the drift component.

$$\Delta \ln CO2_t = \beta_0 + \sum_{i=1}^{n_1} \beta_{1i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{n2} \beta_{2i} \Delta \ln AP_{t-i} + \sum_{i=1}^{n3} \beta_{3i} \Delta \ln RE_{t-i} + \theta ECM_{t-1} + \mu_t ....(3)$$

In the equation above, the letters a1 to a 4 stand for the short-run relationship, b1 to b4 for the long-run connection, and a0 for the drift element. While t is the error term and ni is the ideal lag.

6.4 Results and Discussions

The stationarity at level and first difference was investigated using the Augmented Dickey Fuller (ADF) test. It is applied to time series in order to assess the order of the variables' integration. Table 6.1 (ADF) summarises the augmented Dickey-Fuller's results. The outcomes demonstrated that the dependent variable and the independent variables were all stationary at level and first difference.

Table 6.1: ADF unit root test

Variables	I(0) t-stats	I(0) p-value	I(1) t-stats	I(1) p-value
CO_2	-2.229	0.4664	-6.011	0.003***
GDP	-3.266	0.08*	-5.77	0.0001***
RE	-2.47	0.338	-5.5	0.01***
AP	-2.228	0.456	-4.56	0.02***

****, ** &*denotes 1%, 5% & 10% significance level.*

The long-term relationship between the dependent and independent variables is assessed using the Auto Regressive Distributed Lag bond (ARDL) bound test. The upper bound and lower bound are two critical variables that the test displays. The lower bound assumes that all the variables are equal, while the upper limit assumes that there is a first difference for all of them in this situation. The null hypothesis is rejected and co-integration is shown to exist if the upper limit value is less than the F statistic. Table 6.2 indicates the results of ARDL bound test, the value of F statistics (11.47903) is much greater than the upper bound statistic indicating the existence of significant co-integration between the dependent and the independent variable

Table 6.2: ARDL bound test

Variables	F-Statistics		
F (CO_2,GDP,RE,AP)	11.47903**		
Critical Value	1%	5%	10%
Lower Bound	3.65	2.79	2.37
Upper Bound	4.66	3.67	3.2

****, ** &*denotes 1%, 5% & 10% significance level.*

Table 6.3: ARDL short run

Variables	P-value	t-Statistics	Coefficients
RE	0.0001***	-4.457	-0.43
AP	0.0597**	-2.41	-0.23
GDP	0.0004***	-3.8	-0.296

****, ** &*denotes 1%, 5% & 10% significance level.*

Table 6.3 illustrates the results of short run ARDL test whereby RE and GDP are significant at 1% and are negatively related whereas AP is significant at 5% and also has a negative relationship with the CO2 emission which is favourable for environmental sustainability.

To ascertain whether or not the residuals are regularly distributed, the Jarque-Bera test was used. Given that the Jarque Bera probability is 0.66 (0.05), it is likely that the residuals have a distribution that is normally distributed. To check the model for specification issues, the Ramsey RESET test was used. According to the Ramsey RESET test probability of 0.318 (>0.05), the model is free of specification mistakes. The Breusch-Godfrey serial correlation test was performed to determine whether or not there is serial correlation among the error components in our model. The Breusch-Godfrey serial Correlation test probability of 0.122 (>0.05) shows that there is no serial correlation among the error components in our model. The diagnostic test have been carried and presented in table 6.4

Table 6.4. Diagnostic tests

JB Normality Test	2.02	0.66
Ramsey RESET test	10.25	0.318
Breusch-Godfery serial Correlation	16.68	0.122
Heteroskedasticity B.P.G. test, Observed R-squared	5.46	0.325

The Granger causality test results are shown in Table 6.5. To determine whether there is any predictability between one variable and another, the test is run on a time series of data. The outcome suggests that RE-CO2, GDP-CO2, CO2-GDP, and CO2-RE have an unusual unidirectional causal relationship whereas, CO2-AP has a unidirectional causal linkage.

Table 6.5: Granger causality test

Direction of Causality	**F-stats**	**Pvalue**
RE-CO2	5.1	0.096*
AP-CO2	9.13	0.0004***
CO2-AP	3.78	0.0596**
GDP-CO2	7.9	0.0011***
CO_2-GDP	9.7	0.0003***
CO2-RE	4.8	0.0123***

****, ** &*denotes 1%, 5% & 10% significance level.*

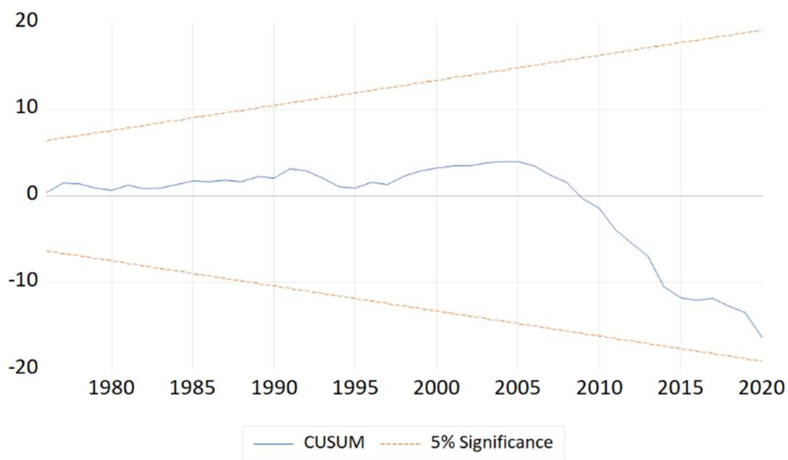


Figure 6.1: CUSUM test

Cumulative sum of the recursive residuals stability test was employed to check the stability of the model and as the statistics are between the critical bounds as shown in the Figure 6.1 ensures the stability of the parameter.

6.5 Conclusion

There is a significant relationship between CO2 emissions, energy consumption and economic growth of France. It has a wide range of options for defining its specific energy strategy concerning to sustainable and renewable energy sources that environmentally sustainable and is also for long-term. That would enable them to change their energy methods reducing environmental harm while steadily and consistently increasing the energy supply over time. By encouraging the development and wide-spread use of alternative and renewable energy technology it may also significantly contribute to ensuring that the environment that is left to future generations in a more habitable and clean state. However the waste and E-waste management needs to be promoted as nuclear energy has a highly radioactive waste materials which needs to be disposed properly as if it is leaked it will not only effect the country but also the neighbouring countries.

CHAPTER 7

THE FUTURE OF THE SHIFT IN ENERGY SYSTEM AND THE UNITED NATIONS NET ZERO CARBON EMISSION

7.1 Overview

In this communication, the time series data of three major countries USA, France and Japan from 1965 to 2020 for CO_2 emission, GDP and nuclear energy (NE) are evaluated. It is also analysed and validated the EKC hypothesis while using nuclear energy for electricity generation. Fourier ARDL is used to investigate the hypothesis criteria and the Fourier Bootstrap Toda-Yamamoto (FBTY) causality test is used for causal linkage between the variables as well as the wavelet coherence, it is also presented the time and frequency dependency of the variables. The CO_2 mitigation by using the NE is also assessed for all three countries and assessed that the France, Japan and U.S. mitigated the CO_2 per year is 0.0463 Million Metric Ton (MMT), 0.0239 and 0.0728 MMT per year respectively. Similar to that the SO_2 is reduced by using the NE is 24.322, 43.527 and 132.592 MMT/year and NOx is reduced approximately 0.2847, 0.147, 0.4478 MMT/year by France, Japan and U.S. respectively by applied the NE for power generation. The evidence of the EKC, Fourier Bootstrap and Toda-Yamamoto clarify the important role of nuclear energy in terms of carbon mitigation to achieve UN net zero carbon emission by 2050. Hence in order to meet the UN target of net zero carbon emission by 2050 US and Japan should increase the production of nuclear energy as France meets its 74.1% energy demand through NE validating the EKC hypothesis on the other hand all the three countries should increase the production of tidal energy due to their geographical location as tides are much more predictable than wind and sun keeping in consideration the expenses incurred and a full proof plan for disposing NE residuals in a safe place as NE residuals are highly radioactive and contains traces of thorium and uranium.

7.2 Introduction

The Industrial development is the main backbone of any country for their economic development and it requires the electrical energy, so the energy is the wheel of any economy. Presently conventional sources of energy like coal and petroleum fuels are the main sources of energy for a century and due to its negative impact on the environment, world's researcher are working on to find out the better alternatives. The whole community of researchers and scientist are also want to develop a technology for achieving net zero carbon emission. The Nuclear energy, solar energy and wind energy may have important role to achieve the target of net zero carbon emission. It is observed that France meet its 70% of electricity generating through nuclear energy, in China 19.7% is the total share of nuclear energy and in Japan 30% of is the total share of nuclear energy in electricity generation. Obviously, the nuclear energy may be one source of present as well as future energy (Worldbank.org). The annual CO_2 emission of four major power Counties like USA, France, China and Japan is presented in figure 7.1.

It is observed that CO_2 emission of China is not reducing even though using the nuclear energy for power generation it means its power consumption is more than its generation and demands have been fulfil via commercial fuels like coal, gas and petroleum etc. The addition of nuclear power generation in the china is not so longer that's why its long-term study is not viable to continue at present. The annual CO_2 emission of France, Japan and U.S. has been reduced after using the nuclear power for this region the authors using only these three countries for the study.

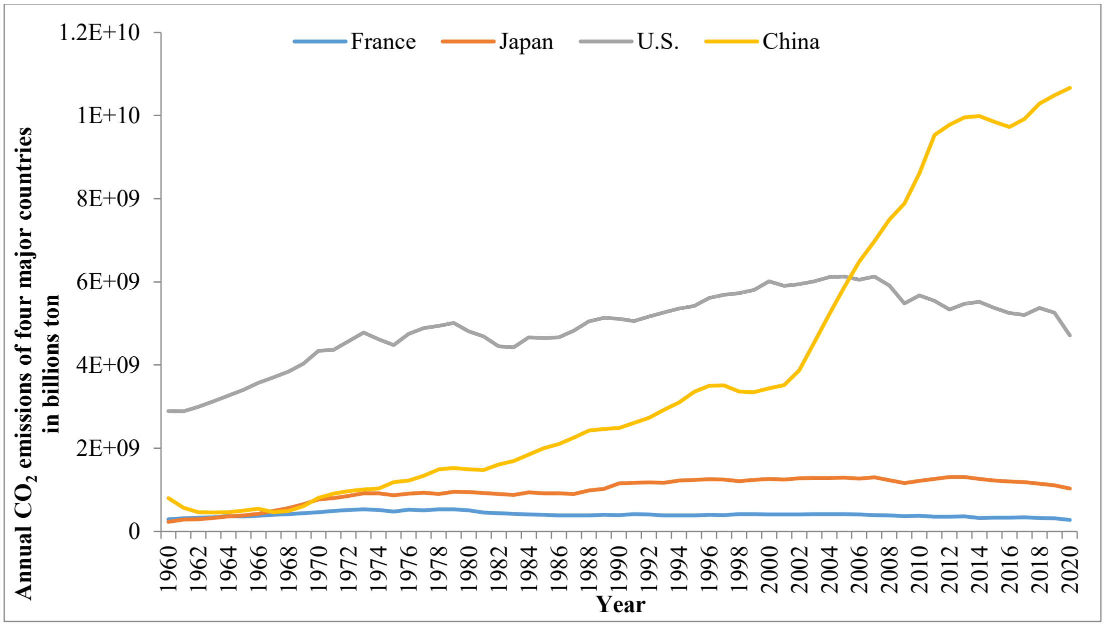


Figure 7.1: Annual CO2 emissions of France, Japan, U.S. and China in billions ton (worldbank.org)

Some of the researchers were presented their views in the global meets to recognise pollution prevention measures like Stockholm conference 1972, and in the Rio conference 1992. The Kyoto Protocol encouraged and promoted the consumption of renewable energy for limiting GHGs (Bildirici and Gökmenoğlu 2017). The Environmental Kuznets Curve (EKC) hypothesis is a theory by which the relation between per capita pollutant like CO_2 and per capita Gross development product (GDP) can be assessed and it has an inverted U-shape. Grossmann and Krueger (1991) developed the EKC Hypothesis and checked the strength of the analysis. The EKC depicted an inverted U-shape curve relation between economic growth and transition in the emission levels (Heidari et al. 2015, Jebli et al. 2016, Leal and Marques 2020, Rafiq et al. 2016, Dong et al. 2017, Salim et al. 2019, Shahbaz et al. 2019, Koc and Bulus 2020, Murshed 2020 a).

The EKC showed no observable effect between economic growth and renewable energy consumption for the top six hydropower countries, the five South East Asian countries, the Sub-Saharan African countries, top 10 innovative countries, and other 34 listed countries where the power generation by the conventional fuel doesn't influence the environment (Kisswani et al. 2018, Gorus and Aydin 2019, Pata and Aydin 2020. Jin and Kim 2020).

Furthermore, the causal relationship between energy, Gross domestic products (GDP) and Carbon dioxide (CO_2) emissions have an important role for econometric analysis. Some studies also presented the causal unidirectional link between energy use and GDP (Yang and Zhao 2014, Adebayo 2020 a, Adebayo et al. 2021). Few studies also presented the bidirectional link between GDP and energy (Mutascu 2016, Khobai et al. 2017). Faisal et al. (2016) reflected no causal link between the variables used in the EKC hypothesis. Many studies conducted by the researchers to check the causal relationship between GDP and CO_2 emissions (Jafari et al. 2015, Wang et al. 2019, Aydoğan and Vardar 2020, Jihuan 2021. Kirikkaleli et al. 2021, Kirikkaleli and Adebayo 2021). In other side some studies have been carried out and evaluated the unidirectional and bidirectional link between CO_2 emissions and GDP (Al-Mulali 2011, Wu et al. 2018, Adebayo et al. 2020 b, Gao and Zhang 2021). And some studies also presented their views towards the positive relation between GDP and CO_2 emissions (Pablo et al. 2016, Ahmed et al. 2019 & 20, Odugbesan et al. 2020, Wasti et al. 2020, Ahmed et al. 2020, Odugbesan and Adebayo 2021, Teng et al. 2021). Aye and Edoja (2017) studied on 31 developing countries and shows a negative relationship between GDP and CO_2 emissions but those countries having very less clean energy production. Whereas the Iwata et al. (2010) and Ozcan et al.(2020) studied the validity of EKC hypothesis while using nuclear energy.

Developing the better alternatives of conventional energy sources are on its peak level and the validation of clean energy or renewable energy in being tested by the EKC hypothesis. The EKC hypothesis states that a co-integration relation exists between economic growth and environmental pollution. The validation of EKC hypothesis have been carried out while using clean sources of energy, in this regards liquefied petroleum gas (LPG) can also approved as a transitional fuel to reducing the GHGs in the South Asian countries (Albela et al. 2012, Raslavicius et al. 2014, Ekbordin and Tami 2016, Murshed 2018, Murshed 2020 b). Hydropower is also advantageous over solar energy and can be adopted as a good source for clean energy and it provides a steady power supply is it's another benefit (Solarin and Ozturk 2015). The review progress of various researchers is shown in table 7.1 with the data taken for the period, studied countries, variables used in methodology and the findings.

Table 7.1: Summary of various studies for EKC, ARDL etc. methodologies used by researchers

S.No.	Study	Data	Countries	Variables	Methodology	Findings
1.	Apergis and Payne (2010)	1992–2004	11 CIS countries including Kazakhstan	QLF	FMOLS	IUS means valid EKC hypothesis
2.	Shahbaz et al. (2013)	1965–2008	South Africa	CC, EN, FD, TO, CO_2	ARDL, ECM,	CO2 increasing with increasing CC and EN and decreasing with increasing FD
3.	Li and Lin (2015)	1971–2010	Low, middle, and high-income countries	*Y*, URB, EN, CO_2	Dynamic panel threshold regression models	In low and middle income countries, when Y,EM and URB increases means increases CO2 and CO2 increases with increasing Y and EN and decreasing with increasing URB in high income

						countries
4.	Abbasi and Riaz (2016)	1971–2011	Pakistan	*Y*, FD, CO_2	VECM, Granger	CO2 increasing with increasing Y and not found a good relation with FD
5.	Al-Mulali et al. (2016)	1980(1990)-2010	107 countries including Kazakhstan	QLF	DOLS	IUS for the group with Kazakhstan
6.	Shahbaz et al. (2016)	1970Q1–2011Q4	Malaysia	*Y*, EN, TO, URB, CO_2	Bayer–Hanck, ARDL bounds testing approach, VECM Granger causality	The CO2 increasing with increasing Y, EN and TO but decreasing with increasing URB
7.	Lau et al. (2016)	1965–2010	Malaysia	HEC, *Y*, and CO_2	Granger causality	Y and HEC granger cause CO_2 in the long run, however, HEC granger causes CO_2 in the short run
8.	Ozatac et al. (2017)	1960–2013	Turkey	*Y*, EN, TO, URB, FD,CO_2	ARDL, causality	EKC hold GDP → CO_2 (+) EN → CO_2 (+) URB → CO_2 (+)
9.	Bekhet et al. (2017)	1980–2011	Gulf countries	*Y*, ENE, FD, CO_2	ARDL, causality	CO_2 → ENE in Saudi Arabia, UAE, and Qatar FD → CO_2 in UAE, Oman, and Kuwait

10.	Saidi and Mbarek (2017)	1990–2013	19 emerging economies	*Y*, Y^2, TO, URB, FD, CO_2	Panel regression	EKC is hold in these countries because CO2 is decreasing with increasing in FD and URB
11.	Bildirici and Gökmenoğlu (2017)	1961–2013	G7 countries	HEC, *Y*, and CO_2	MSVAGC approach	HEC causes Y in overall, and two-way causation in some G7 economies
12.	Salahuddin et al. (2018)	1980–2013	Kuwait	*Y*, EC, FDI, CO_2	ARDL, VECM	CO2 is increasing with increasing the Y,EC.FDI
13.	Shittu et al. (2018)	1981–2014	Malaysia	URB, DEF, CO_2	Quantile regression and ARDL	CO2 increasing with increasing the DEF and decreasing with increasing URB
14.	Akbota and Baek (2018)	1991–2014	Kazakhstan		ARDL	IUS
15.	Ummalla and Samal (2018)	1965–2016	China	CO_2, *Y*, and HEC	ARDL bound test,	EKC is invalid. CO_2 has a positive influence on HEC
16.	Pata (2018)	1974–2014	Turkey	CO2, Y, FDI, REN, URB, and HYDEC	ARDL and FMOLS	HYDEC and REN do not affect CO_2, EKC is valid
17.	Sinaga (2019)	1978–2016	Malaysia	HEC and *Y*	ARDL	HEC reduces environmental degradation

18.	Charfeddine and Kahia (2019)	1980–2012	MENA region	*Y*, RENE, FD, CO_2	Panel vector	CO2 is increasing with increasing Y,REN and FD
19.	Dong et al. (2019)	1960–2012	Developed economies	*Y*, URB, EN, CO_2	threshold regression model	CO_2 is increasing with increasing REN and URB
20.	Jian et al. (2019)	1982–2017	China	*Y*, FD, EN, CO_2	VECM, impulse response	Increasing the EN means increasing CO_2 as well and FD but when increasing Y decreasing the CO_2
21.	Koc and Bulus (2020)	1971–2017	South Korea	GDP, GDP^2, ENE, CO_2	ARDL,	*N*-shaped relationship CO2 is increasing with increasing the GDP, ENE and decreasing with increasing the TO and REN
22.	Wang et al. (2020)	1990–2014	APEC nations	*Y*, IND, EN, CO_2	Dynamic-unrelated seemingly regression	CO2 is increasing with increasing Y,IND and URB
23.	Bekun et al. (2020)	1971–2015	Nigeria	*Y*, Y^2, FDI, EC, CO_2	ARDL	EKC is hold CO2 is increasing with increasing Y, GDP,EC and decreasing with increasing the FDI

24.	Nondo and Kahsai (2020)	1970–2016	South Africa	*Y*, URB, ENE, IND	ARDL, VECM	CO2 is increasing with increasing ENE, IND and URB
25.	Rahman and Vu (2020)	1960–2015	Australia and Canada	*Y*, EN, URB, CO_2	ARDL, VECM causality	In Australia CO2 is increasing with increasing *Y* In Canada CO2 is increasing with increasing Y, and URB
26.	Dogan and Inglesi-Lotz (2020)	1980–2014	European countries	Y, Y^2, EN, CO_2	Panel OLS, FMOLS	EKC does not hold CO2 is decreasing with increasing GDP
27.	Pata and Aydin (2020)	1965–2016	Brazil, China, Canada, India, Norway and the USA	Y, Y^2, EN, HENE, CO_2	Fourier bootstrap ARDL, Fourier TYGC	EKC hypothesis is not valid HENE → GDP in Brazil HENE ↔ GDP in China
28.	Leal and Marques (2020)	1990–2014	OECD countries	Y, Y^2, TO, CO_2	FMOLS, DOLS, AMG, CSD	EKC hypothesis is not valid CO2 is increasing with increasing OPand REN
29.	Adebayo et al. (2020 b)	1980–2018	Mint nations	*Y*, TO, URB, EN, CO_2	Pedroni, Westerlund Coint., PMG, CSD, panel causality	GDP$\neq$ CO_2 TO→CO_2 (−) TO→ENE (+) URB → CO_2 (+)

30.	Anser et al. (2020)	1995–2015	G-7 countries	CO_2, ITR, FDI, GEE, HEXP, INEQ, EG	Random effect, panel causality	CO2 is increasing with increasing ITR , GDP, FDI and GEE
31.	Nathaniel (2020)	1971–2014	Indonesia	Energy use, trade, GDP.	ARDL.	Urbanization increases the ecological footprint in the long term
32.	Khattak et al. (2020)	1980–2016	BRICS	CO_2, GDP, RE, YPC, YPC^2	CCEMG technique	EKC hold CO2 is increasing with increasing YPC and IN and decreasing the increasing RE
33.	Rehman et al. (2020)	2000–2018	Pakistan	CO_2, EC, GDP, PG	GRA Model Hurwicz method	CO2 is increasing with increasing GDP, EC and PG
34.	Zmami and Ben-Salha (2020)	1980–2017	GCC countries	CO_2, GDP, EC, URB, TRA, FDI	STIRPAT model, PMG	EKC valid CO2 is increasing with increasing EC and FDI
35.	Pata and Kumar (2021)	1980–2016	China and India	FDI, HEC, coal, CO_2, and EFP	ARDL	HEC upsurges CO_2 and EFP for China but no influence on India.
36.	Bilgili et al. (2021)	1980–2019	USA	HYDEC and CO_2	CWT approach Continuous Wavelet transformation	In the short run, HYDEC intensifies environmental degradation,

						however, in long run, it reduces
37.	Tiwari et al. (2022)	1971Q1 to 2017Q4 1971Q1 to 2017Q4	Brazil and China	Hydro, EF, urban, and human capital	QARDL	Hydropower mitigates pollution
38.	Jahanger et al. (2022)	1990–2016	73 developing countries	Technological innovation, natural resources, economic growth, development of human capital and financial development.	PMG-ARDL.	Globalization increases the ecological footprint in general.

Abedayo (2022 a) assessed the environmental sustainability and ecological footprint of Turkey linked with oil and hydro energy consumption. Abedayo (2022 b)It was also studied the environmental consequences of fossil fuel in Spain by using the wavelet-based granger casualty approach and also find the effect of renewable energy consumption. Alam et al. (2022) presented the pathways for securing the environmentally sustainable economic growth via efficient use of energy with the application of bootstrapped ARDL approach. Alam and Sabir (2022) studied the economic growth and energy consumption for Bahrain with the application of VECM and ARDL approach. Singh et al. (2022) analyzed India's Logistic performance index using ARDL it reveals that the India is far behind in reaching the environmental sustainability of LPI. Alvarado et al. (2022) studied the impact of the informal economy on the environmental and ecological footprint via the globalization and urban concentration. Farook et al. (2022) presented the effect of globalization on CO_2 emission via EKC. Hamid et al. (2022) added their contribution in the field of decarburization pathways included the role of foreign direct investment, democracy, governance, renewable energy and economic growth in Oman.

The role of energy efficiency, renewable energy production and finance inclusion in the field of environment sustainability are very important for sustainable development of the earth. The similar study for 11 countries is presented by the Khan et al. (2022). Muhammd et al. (2022) have been exploring the aggregate domestic consumption and CO_2 emission for environmental sustainability in Pakistan. Murshed et al. (2022 a) studied the CO_2 restraining agenda for 11 countries with the implication of sustainable development and Argentina with the role of renewable energy transition and trade globalization (Murshed 2021, Murshed et al. 2022 b).

The Kuznet curve hypothesis applied by Murshed for studied the carbon and ecological trails. It was also assessed the effect of LPG on environment with the same hypothesis with the ARDL analysis in South Asia (Murshed 2022 c). The similar studies have been carried out by the various researchers which are presented the role of economic growth, globalization, energy consumption and renewable energy applications, globalization, carbon emission, nuclear energy utilization, hydro energy, biomass energy and agricultural productivity on the environmental sustainability in various countries (Nathaniel 2021, Ozturk et al. 2022, Pan and Adebayo 2022, Ramzan 2022, Rehman et al. 2022 a, Rehman et al. 2022 b, Shi et al. 2022, Wang et al. 2023, Wu et al. 2022, Zhang et al. 2022, Zhou et al. 2022).

The very few literatures available on validity of EKC hypothesis while using nuclear energy. The above studies don't take structural breaks into considerations. The smooth changes in causality and co-integrations are important and should be recognised. The time and frequency dependency of the variables are essential for strategic policy formulation that went unnoticed in the above literature.

In this study, the world's three biggest energy producing countries have been studied for the use of nuclear energy and reducing the atmospheric pollution parameter like CO_2, SO_2 and NO_x. The China is the third highest power producing country but it has recently started power generation through nuclear energy therefore long-term analysis is not possible. That's why the USA, France and Japan have been taken for this study.

7.3 Methodology and data Assessment

The study has been conducted on a time series data from the period 1965 to 2020 for the top three energy producing countries (USA, France, and Japan) by Nuclear capacity were analysed to check the validity of EKC hypothesis.

7.3.1 Using EKC Hypothesis

The environmental Kuznets curve (EKC) general model (supported the long term logarithmic form) is adopted for this study which is suggested by Emrah and Salih (2021) is given by the equation 1 such as follows-

$$lnCO_{2t} = \beta_0 + \beta_1 lnGDP_t + \beta_2 \, (lnGDP)_t^2 + \beta_3 (lnGDP * lnNE)_t + \beta_4 lnNE_t + \varepsilon_t \qquad (1)$$

Where, β_0, β_1, β_2, β_3 and β_4 are estimated parameters and t is time index, ε is error terms and is NE an explanatory variable which can be Nuclear Energy production. The per capita carbon dioxide (per capita CO_2) is environmental degradation factor and per capita GDP is the economic activity factor.

The estimated parameters defined the five ddifferent forms of hypothesis based on the test or value limit between environmental degradation factor (per capita CO_2) and economic activity factor (per capita GDP) which are given as below (Yasin et al. 2018).

i. $\beta_1 = \beta_2 = \beta_3 = 0$ conclude a flat pattern no relationship between environmental degradation factor (per capita CO_2) and economic activity factor (per capita GDP).

ii. $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 = 0$ conclude in a U-shaped relationship between environmental degradation factor (per capita CO_2) and economic activity factor (per capita *GDP*).

iii. $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$ and $\beta_4 > 0$ conclude an inverted U-shaped relationship i.e. EKC relationship between environmental degradation factor (per capita CO_2) and economic activity factor (per capita *GDP*).

iv. $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$ conclude in an N-shaped relationship between environmental degradation factor (per capita CO_2) and economic activity factor (per capita *GDP*).

v. $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$ conclude in an inverse N-shaped relationship (or EKC postulates) between environmental degradation factor (per capita CO_2) and economic activity factor (per capita *GDP*).

The data of GDP per capita (current US $) were collected from World Bank 2020 (world bank 2020), and data for carbon dioxide (CO_2) emission in million tonnes and nuclear energy generation in terawatt hours have been taken from BP stats 2021 (BP stats 2021).

7.3.2 Fourier ADF unit test

To capture the non-linear trends, gradual and sharp structural breaks the Fourier ADF, Fourier GLS, Fourier LM and Fourier KPSS are used to check the presence of unit root and stationarity. It may also solve the problem of over-fitting. The using of Fourier form are suggested by Gallant and other researchers (Gallant 1981, Becker et al. 2006, Enders and Lee 2012a) in which trigonometric functions have been used to capture large variations from the mean of the dependent variable. It has such advantages over the traditional model as it taken into account a large number of soft transient structural breaks.

For this modelling using the Fourier function of Gallant (1981) and added the structural changes to KPSS test by Becker etal (2006), so that time, number and form were not predetermined after that Ender and Lee (2012) added these time, number and form nonlinear functions to the Dickey-Fuller (DF) type test (unit root test).

$$\Delta y_t = \alpha(t) + \delta t + \vartheta y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + u_t \quad (2)$$

In above Equation 2, $\alpha(t)$ is a deterministic term as a function of time, p is the optimal lag length determined by Akaike (AIC) and Schwarz (SIC), u_t is a stationary error term with variance and β_i and ϑ are coefficient. To prevent the autocorrelation problem, delayed values of Δy are included in the model. For null hypothesis $\vartheta = 0$ is the problematic ad per the Ender and Lee (2012) and this problem can be eliminated by using Fourier function to the deterministic term and expressed as:

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{n} \gamma_{1k} sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2k} cos\left(\frac{2\pi kt}{T}\right) \quad (3)$$

Where n is the number of Fourier frequency, the higher or excess frequency components may causes the overfitting problem due reducing the degree of freedom. Thatswhy taking the Fourier component for a single frequency and found:

$$\alpha(t) = \alpha_0 + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) \quad (4)$$

After a simple modification it is to allow the deterministic term to the time dependent function and the FADF unit root test with single frequency equation is found by putting the equation (5) in to equation (2) and get the new equation for optimal leg length as follows:

$$\Delta y_t = \alpha_1 + \delta t + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi}{T}\right) + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \vartheta y_{t-i} + u_t \quad (5)$$

If the value of ϑ is zero states the series have unit root. Where k is Fourier frequency and T is number of observations or data processed. By the boot strap simulation, it is observed that the t statistic is greater than the table value which leads to the variables can be determined as a stationary process.

7.3.3 The Fourier Toda Yamamoto causality test

The Toda and Yamamoto (TY) developed a method in 1995 depend on vector auto regression (VAR), applied for the level values of the series and removes the long-term information loss. The TY casualty test with environmental degradation factor and GDP and NE can be written as follows:

$$y_t = \alpha_0 + \alpha_1 t + \alpha_2 sin\left(\frac{2\pi kt}{T}\right) + \alpha_3 cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad (6)$$

$$y_t = \alpha_0 + \gamma_1 sin\left(\frac{2\pi k}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) + v_t \quad (7)$$

Where as ε_t is a stationary disturbance with variance, k represents the single frequency selected for the approximation,

The Fourier bootstrap Toda-Yamamoto causality test is employed as Fourier takes into consideration the abrupt and gradual structural shifts, while bootstrap increases the power of test statistics therefore both Fourier and bootstrap is used while analysing the causal link between the variables (Nazlioglu et al. 2016) is shown in equation (8).

$$y_t = \alpha_0 + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \cdots + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (8)$$

7.3.4 Co-integration regression and Dynamic ordinary least square (DOLS) or F- Test

Tsong et al, (2020) developed Fourier approximation to test co-integration without estimating the specific break dates as the structural breaks of unknown form can be approximated with low-frequency Fourier components. While testing for co-integration between the variables the assumption of strictly exogeneity is violated as it is rather restrictive in practice. Therefore asymptotic distribution of Cl_f^m test will depend on unknown nuisance parameter and the estimation of co-integration vector is not efficient. There are several methods to deal with such problem like Dynamic ordinary least square (DOLS). The DOLS regression, test statistics and F test can be summarizes as follows.

$$y_t = \sum_{i=0}^{m} \delta_i l^i + \alpha_k sin\left(\frac{2\pi kt}{T}\right) + \beta_k cos\left(\frac{2\pi kt}{T}\right) + x_t'\beta + \sum_{i=-1}^{l} \Delta x_{t-i}' \emptyset_i + \varepsilon_t^* \qquad (9)$$

$$CI_f^m = T^{-2}\omega_\varepsilon^{*-2} \sum_{i-1}^{T} S_t^{*2} \qquad (10)$$

where as CI_f^m is the KPSS type Cointegration statistic to test the null of Cointegration with structural break, S_t is the partial sum of OLS residuals, and ω_ε is the represents the estimator for long run variance of ε_t. The test is verified with the null of absence of the Fourier component ($\alpha_k = \beta_k = 0$) against the alternative of nonlinear trend or structural changes. The F test for the hypothesis testing is evaluated by the equation (11) given as follows:

$$F^m(k^*) = max_{k\epsilon\{1,2,3\}} F^m(k) \qquad (11)$$

Where $F^m$is FMOLS (Fully modified ordinary least squares), $F^m(k)$ is the Dynamic ordinary least squares (DOLS) is estimated by.

$$F^m(k) = \frac{(SSE_0^m - SSE_1^m(k))/2}{SS\ _1^m(k)/(T-q)} \qquad (12)$$

The 0 and 1 subscript in the SSE are denoted by the null and alternate hypotheses, q is the number of parameters and k is unidentified under the null hypothesis.

7.3.5 Wavelet Coherence

In drawing things to close wavelet coherence facilitates the study of time series data in the time and frequency domain. It helps to gain information that was formerly undetected. It analyses causal and correlation between dependent and the independent variables from short to long-run (Torrence et al. 1998).

$$R_n^2(s) = \frac{|S(s^{-1}W_n^{XY}(s))|^2}{S(s^{-1}|W_n^X(s)|^2).S(s^{-1}|W_n^Y(s)|^2)} \quad \text{...(10)}$$

From the above equation it is observed that the time and location are two main parameters of wavelet. W^{xy} is the cross wavelet and it depends on individual wavelet W^x and W^y which are the wavelets for each time series. The S is smoothing operator and s is scale and n is time index, $s^{-1}$is used to convert energy density, the values of R^2 shows the different features in the wavelet these are:

i. $0 \leq R^2(k, s) \leq 1$ Indicates the smoothing process overtime.
ii. $R^2 \approx 1$ indicates black line with red colour picture
iii. $R^2 \approx 0$ indicates weakly correlated with blue colour picture
iv. $R^2 \approx squared\ value$ it provides only the strength of correlation but does not provide any information about the direction

Torrence and Compo (1998), Pal and Mitra (2017) developed the procedure to detect the wavelet coherence differences through above mentioned indications of deferrals in the wavering of two time series

7.4 Results and Discussion

The results of Fourier ADF, Fourier GLS, Fourier LM and Fourier KPSS (eq.2-4) test are presented in Table 7.2 and Table 7.3. It is observed that the Fourier approximation has an extra edge over the conventional model as it solves the problems of unknown multiple breaks. The lags and Fourier have been automatically chosen by AIC and SCC criteria. Whereas, the maximum lags found 4 and maximum Fourier found 3.

Table 7.2: Unit root test by Fourier ADF and Fourier GLS

Countries & Variables	FADF I(0)	FADF I(1)	Fourier component	FGLS I(0)	FGLS I(1)	Fourier component
USA						
CO_2	-3.943	-3.873**	1	-2.975	-2.639*	1
GDP	-4.189*	-2.859*	1	-4.055*	-4.144*	1
NE	-5.532***	-4.843**	1	-2.962	-4.945***	1
FRANCE						
CO_2	-2.956	-7.360***	1	-3.144*	-5.737***	2
GDP	-1.246	-4.855**	1	-1.592	-3.262*	1
NE	-2.805	-4.052*	2	-0.879	-4.224**	1
JAPAN						
CO_2	-6.707***	-6.983***	1	-3.161	-7.252***	1
GDP	-7.359***	-5.353***	2	-2.532	-5.532***	1
NE	-4.714***	-8.635***	2	-2.834	-3.546*	2

*Optimal lag automatically by AIC ***, ** &*denotes 1%, 5% & 10% significance level*

The unit root test by Fourier ADF, Fourier GLS and Fourier LM rejected the null hypothesis of unit root in a combination of I(0) and I(1) for all variables and all the three selected countries. Whereas, the null hypothesis of stationarity for the Fourier KPSS is rejected at I(0) but accepted at I(1) of the variables for all the three countries.

Table 7.3: Unit root and Stationarity test by Fourier LM and Fourier KPSS

Countries & Variables	FLM I(0)	FLM I(1)	Fourier component	FKPSS I(0)	FKPSS I(1)	Fourier component
USA						
CO_2	-1.261	-2.696*	1	0.232***	0.034	1

GDP	-3.916*	-4.128**	1	0.099***	0.051	1
NE	-2.016	-5.545***	2	0.291***	0.068	3
FRANCE						
CO_2	-2.642	-7.494***	1	0.394***	0.280	2
GDP	-1.741	-4.414**	1	0.266***	0.029	1
NE	-2.330	-2.578*	3	0.170***	0.166	3
JAPAN						
CO_2	-1.298	-7.043***	1	0.213***	0.070	1
GDP	-1.833	-4.401**	1	0,120***	0.138	2
NE	-2.256	-2.659*	1	0.168***	0.081	3

*Optimal lag automatically by AIC ***, ** &*denotes 1%, 5% & 10% significance level*

Fourier ARDL model developed by Tsong etal 2016 is adopted for the study. The model enabled to approximate the breaks of unknown form. Therefore estimating specific break dates has not been necessary as it automatically included while adding Fourier components. The model is restricted upto four independent variables only and the maximum number of Fourier found 3. The optimal lag and lead are automatically chosen by AIC. The asymptotic critical values are being tabulated by simulation techniques.

Table 7.4: Fourier ARDL (FARDL)

Countries & Variables	F-Stats	CIF	Fourier component
USA			
FARDL	69.632	0.091	2
1%		0.198	
5%		0.124	
FRANCE			

FARDL	52.106	0.083	1
1%		0.163	
5%		0.099	
JAPAN			
FARDL	27.362	0.059	2
1%		0.163	
5%		0.099	

*Optimal lag automatically by AIC ***& **denotes 1% & 5% significance level*

The table 7.4 presented the results of Fourier ARDL. It is expressed the Fourier components for approximating unknown structural breaks that provides strong evidence in favour of the validation of the EKC hypothesis while using nuclear energy in long-run for all three countries. Hence, the study proved that with economic growth and increasing the utilization of clean energy will also be decreasing the environmental pollution in long-run. It is also provides strong evidence of the existence of inverted U-shaped curve relation between income and environmental pollution as the null hypothesis of co-integration is accepted for all three countries.

The Toda-Yamamoto approach is used to evaluate the problem of conventional model by estimating VAR (p+d) where d is maximum integration order of variables. Whereas, Fourier Toda-Yamamoto takes into account for both the abrupt and gradual breaks. Further the Wald statistic may not follow an asymptotic chi-square distribution as it is dependent on the number of frequencies. Therefore to overcome the problem, bootstrapping is applied.

Table 7.5: Fourier Bootstrap Toda-Yamamoto

Countries & Variables	Wald	p-value	Bootstrap p-value	Fourier component

USA				
CO_2→GDP	0.029	0.866	0.851	1
GDP→CO_2	0.275	0.600	0.598	1
CO_2→NE	4.269	0.038**	0.040**	1
NE→CO_2	3.657	0.056**	0.060*	1
GDP→NE	5.459	0.019**	0.029**	1
NE→GDP	2.924	0.087*	0.090*	1
FRANCE				
CO_2→GDP	1.758	0.185	0.213	2
GDP→CO_2	0.041	0.839	0.831	2
CO_2→NE	0.716	0.397	0.413	2
NE→CO_2	1.106	0.293	0.314	2
GDP→NE	3.483	0.062*	0.079*	2
NE→GDP	5.081	0.024**	0.036**	2
JAPAN				
CO_2→GDP	0.355	0.552	0.544	1
GDP→CO_2	7.264	0.007***	0.009***	1
CO_2→NE	0.000	1.000	0.999	1
NE→CO_2	0.312	0.577	0.578	1
GDP→NE	0.058	0.809	0.832	1
NE→GDP	0.051	0.822	0.795	1

*Optimal lag automatically by AIC ***,**&* denotes 1%,5%&10% significance level, Bootstrap=1000*

Table 7.5 presented the results of Fourier bootstrap Toda-Yamamoto (eq.5-9). These results are reflecting the bidirectional causal link from CO_2 emissions to nuclear energy and also a two way link from GDP to nuclear energy for USA. Further in case of France, the consequence replicates the bidirectional linkage between GDP and nuclear energy, and in the case of Japan the results expressed the unidirectional link between GDP and CO_2 emissions.

The Wavelet coherence shows the co-movement of the two time series data from short-run to long-run. The vertical axis and horizontal axis of Wavelet coherence are represents by periods and years respectively. The short-run, medium-run and long-run periods are refers to 0-4, 4-8 and 8-16 respectively. The colour band on the right side reflects the level of correlation between the variables where red hot refers to highly correlated and darkest blue represents the lowest correlation. The black contour represents the 5% significance level. The grey line is the cone of influence below it interpretation is difficult due to discontinuity. The upward and downward arrow represents the causal linkage, whereas the rightward and leftward arrows refer to the phase in and phase out respectively.

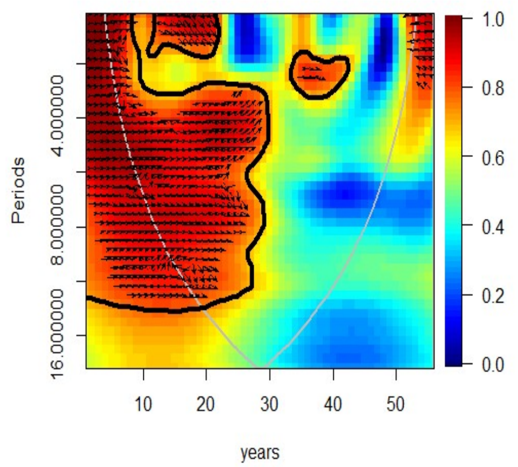


Figure 7.2 Wavelet Coherence USA CO_2 Vs GDP

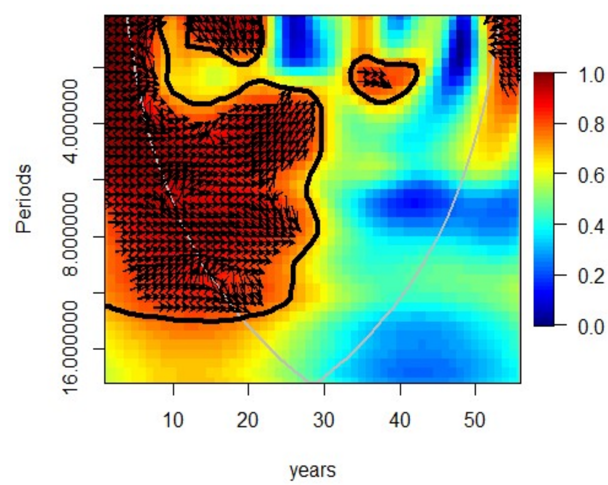
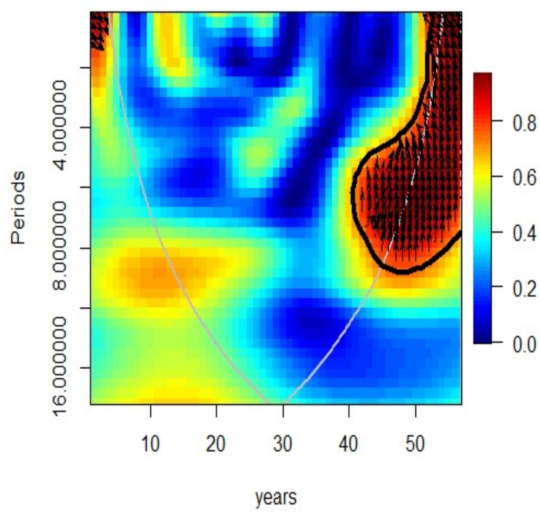


Figure 7.3 Wavelet Coherence USA CO_2 Vs NE

In figure 7.2 (eq.10) wavelet coherence of United State of America (USA) for CO_2 Vs GDP shows that for the first 25 years the red hot colour expressed high correlation between CO_2 emission and GDP for medium term. The rightward arrow in the middle represents the phase in; whereas the upward and downward arrows represents causal link between CO_2 emission and

GDP. Figure 7.3 shows the Wavelet coherence between CO_2 emission and nuclear energy (NE), and it is observed a healthy correlation between the two by bright red colour from short-run to medium-run. The upward and downward arrows refer the causal link from CO_2 emission to NE.



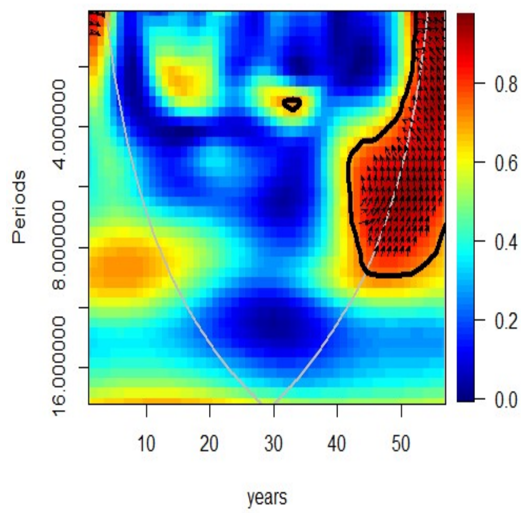
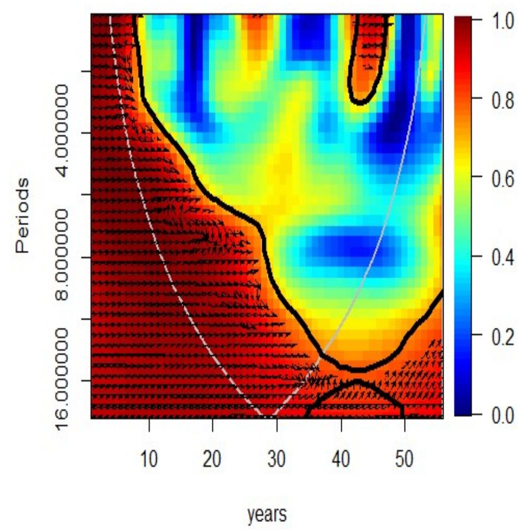


Figure 7.4 Wavelet Coherence France CO_2 Vs GDP **Figure 7.5** Wavelet Coherence France CO_2 Vs NE

Figure 8.4 shows the Wavelet coherence between CO_2 emission and GDP for France. In which the last 20 years shows red hot colour and upward arrows, it means the variables are highly correlated and also has a causal linkage relation. Figure 7.5 represents the Wavelet Coherence between CO_2 and NE for the period of the years from 2000 to 2020 of France, and it is observed the bright red colour which indicates CO_2 emission and NE are well correlated. The upward arrow shows causal link between CO_2 emission and NE.

Figure 7.6 shows the Wavelet coherence of CO_2 emission and GDP for Japan. The red hot colour, upward and downward arrows are spread from short-run to long-run from the year 1965 to 2020. It expressed the high correlation and causal linkage between CO_2 emission and GDP of Japan. Figure 7.7 also represents the correlation between variables from short-run to medium-run for the first 20 years only. The rightward arrows refers to phase-in, and for the later 40 years it reflects the dark blue colour which means there is no correlation between the variables.



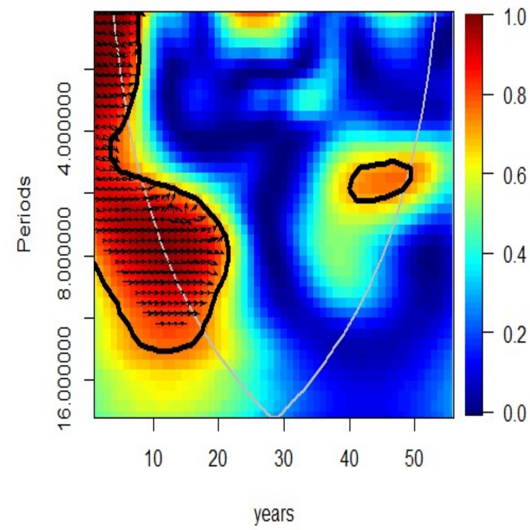


Figure 7.6 Wavelet Coherence Japan CO_2 Vs GDP

Figure 7.7 Wavelet Coherence Japan CO_2 Vs NE

7.5 BAU estimation for energy demand meet out through NE and carbon mitigation

The fifty six years analysis of France showed that power generation through nuclear energy took twenty nine years i.e. 1993 to reach the breakeven point were CO_2 emission was 362.0301million tonnes and electricity production via nuclear energy was 368.188 TWh as shown in figure 7.8. Further it took almost eight years to cross the breakeven point after which the CO_2 emission started declining. According to thirty years (2021-2050) of business as usual (BAU) estimates if France continues to meet its increasing demand of electricity through nuclear energy, CO_2 emission will be mitigate by 15% declining to 212 million tonnes by 2050 generating 734.9321 TWh of electricity.

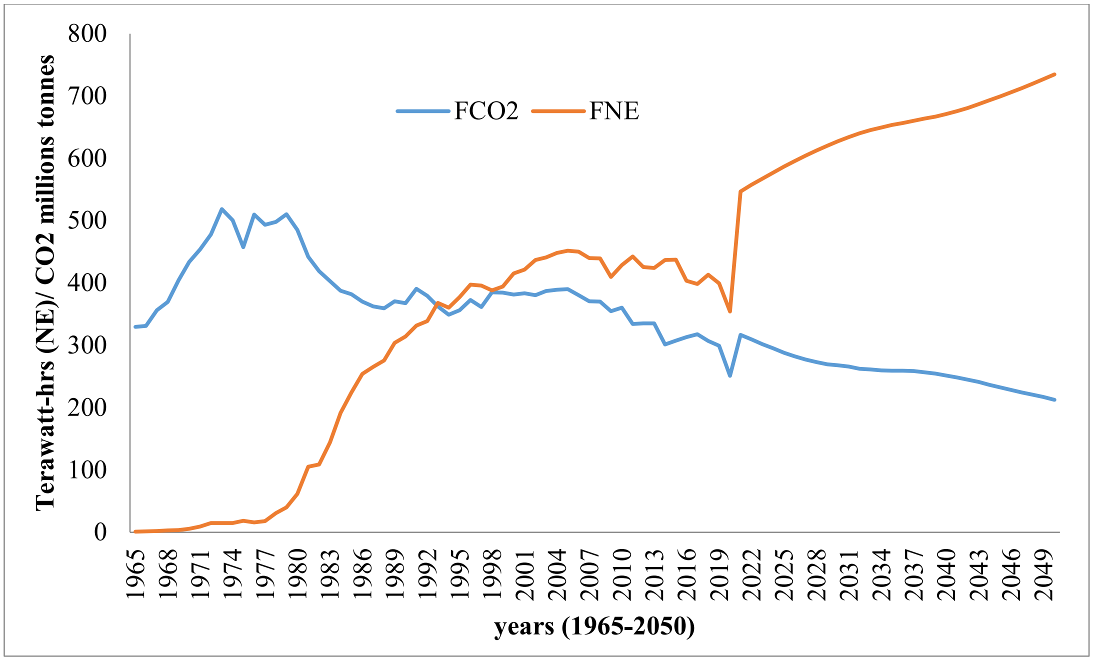


Figure 7.8 BAU Estimation of France for Energy Demand Meet out via NE and CO_2 emission

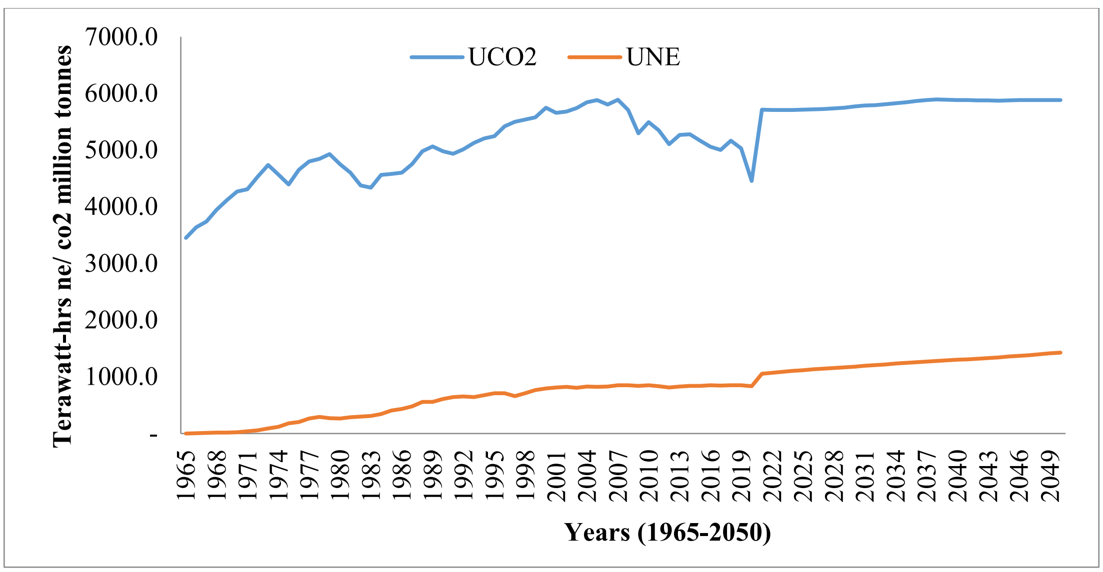


Figure 7.9 BAU estimation of USA for Energy Demand Meet out via NE and CO_2 emission

As we know the USA produce's highest units of electricity through nuclear energy worldwide yet it is far away from reaching the breakeven point i.e. where CO_2 emission is equal to electricity generation through nuclear energy. From figure 7.9 presented the BAU estimation of USA for Energy Demand Meet out via NE and CO_2 emission. In which, during the year 1974-1976 the NE production increased by 36.518% which had a positive impact and mitigated CO_2

emissions by 7.627%, after which the NE declined thus leading to an increase in CO_2 emission. The BAU estimate indicates that the USA needs to increase its electricity production through nuclear energy in order to meet its high electricity demand for offsetting the CO_2 emission by 2050. If USA continues to produce electricity via nuclear energy at the same pace then it will require more than 2500 years to reaches the breakeven point.

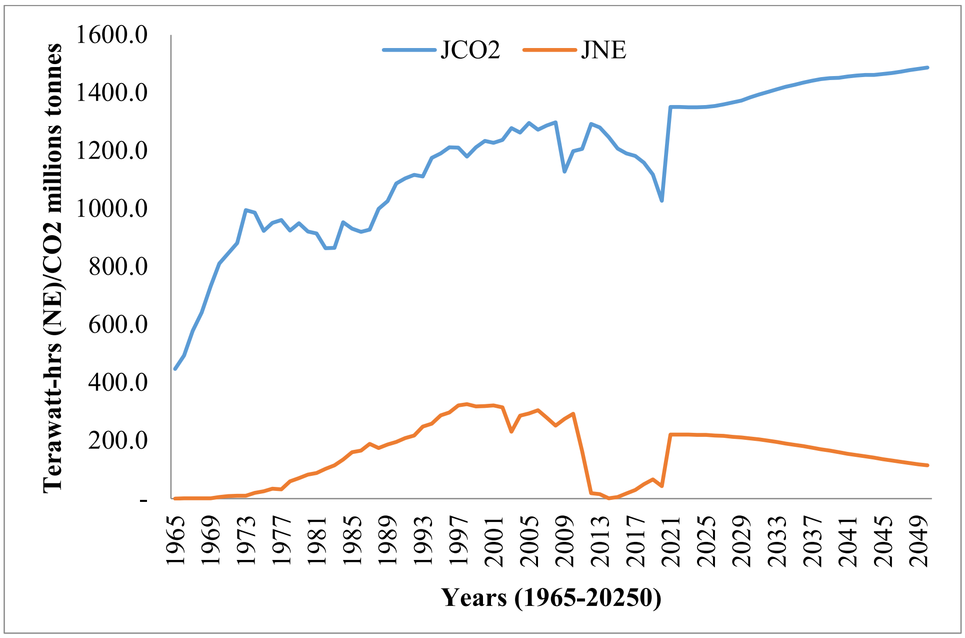


Figure 7.10 BAU estimation of Japan for Energy Demand Meet out via NE and CO_2 emission

Japan first commercial nuclear power reactor began operating in mid-1966 and nuclear energy has been a national strategic priority since 1973 after which power generation via NE took an increasing trend but the scenario totally changed after 2011 Fukushima nuclear accident after which the use NE declined from 162.9 TWh to 18 TWh in 2012. It further declined to 0.5 TWh in 2014 touching the horizontal axis. It has been noted that almost after a decade Japan took an initiative to increase the production of electricity via nuclear energy. From figure 7.10, the BAU estimates that NE will be in a declining tread till the year 2050. Hence, to mitigate the CO_2

emission to reach the net zero carbon emission Japan needs to increase the pace of electricity generation via NE.

7.6 CO_2 Mitigation for using the Nuclear energy

The power generation from nuclear energy is shown in table 7.5 for France Japan and U.S. for the year 2020. The data for nuclear energy power generation is taken from the source (IES 2022). The Mittal et al. (2012) estimated the specific coal consumption per kW has 0.77 kg/kWh and we have selected the same value for the calculation of specific coal consumption. Kaushik et al. (2014) and Lal et al.(2014) studied the CO_2 equivalent, whereas the average CO_2 equivalent for electricity have been taken as 0.98 kg/kWh CO_2. The total coal required to produce the electrical power (equivalent to nuclear power generation) in France, Japan and U.S. for the year 2020 are 47254.9, 24392.8 and 74305.46 MT respectively. The CO_2 emission is to be reduced by using the nuclear fuel (clean energy fuel) is France, Japan and U.S. during the year 2020 is 46309.8, 23904.97 and 72819.35 MT/year. The CO2 reduction from the year 1980 to 2020 by using the nuclear energy to produce electrical energy is shown in figure 7.11. The other pollutants can also be saved like SO_2 and NOx by all three countries is given in the table 7.6. It is noted that the huge sum of carbon dioxide production can be avoided by using the NE for power generation which is beneficial to reduce the global warming also.

Table 7.6: Electrical energy generation by Nuclear energy during the year 2020

Country	**Nuclear electricity generation capacity (million kilowatts)**	**Nuclear electricity generation (billion kilowatt hours)**	**CO2 Mitigation MMT/year**	**SO2 emission saved MMT/Year**	**NOx emission saved per year MMT/year**
France	61.37	379.50	0.046309802	84.32238	0.284757

Japan	31.68	43.00	0.023904973	43.52695	0.146991
U.S.	96.50	789.88	0.072819353	132.5918	0.447763

*MMT-Million Metric Ton, MT -Metric Ton

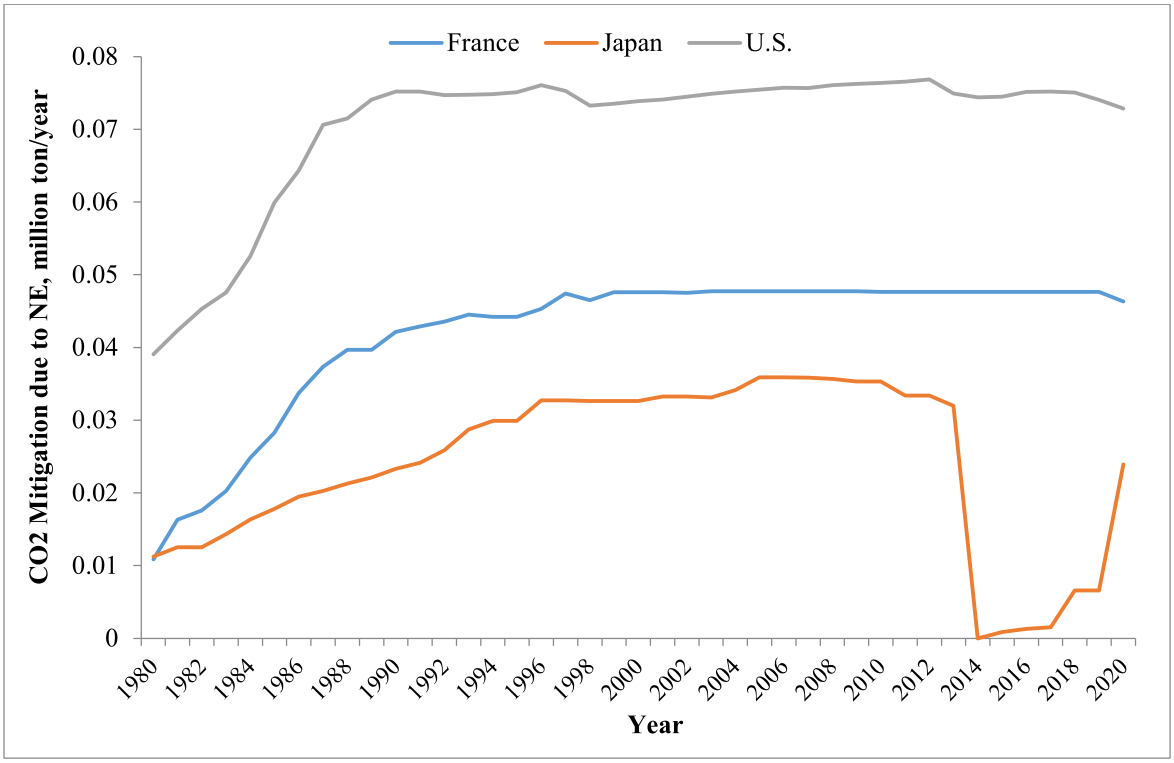


Figure 7.11: Carbon dioxide mitigation year-wise during 1980 to 2020

7.7 Conclusion and Policy suggestion

Among all the three countries only France has been able to reach the breakeven point way back in 1993. France has also showed a positive impact of the use Bof NE for electricity generation as with the increase in NE CO_2 emission has declined over the period of time. Although the USA is the highest producer of electricity through NE in the world still its major demands are meet by 36% petroleum, 32% natural gas, 11% coal and only 8% from NE. Japan's national strategy priority was production of electricity through nuclear energy in 1973 but the scenario totally changed after the Fukushima nuclear accident in 2011 the percentage of NE use dropped to

99.95%. Almost after a decade Japan government took an initiative to increase the production of electricity via NE.

The USA and Japan meets their energy requirements 36% and 40% respectively via petroleum. Whereas the coal and petroleum are the major emitter of carbon dioxide (CO_2), Sulphur dioxide (SO_2), and nitrous oxide (NO_x) which not only harm the environment and increase global warming but also has negative impact on human health. Therefore the USA and Japan needs to develop carbon capture utilization and storage technology (CCUS) which captures carbon before it enters the atmosphere and it can be further utilized to produce by-products like Sodium bicarbonate, ink, carbon fibres, methanol and bio plastics, at present CCUS technology captures 40mt CO_2 all around the world. According to the geographical location of all the three countries the study suggests to promote tidal energy for electricity generation as tides are more predictable than wind and sun.

The study has been conducted to check the validity of EKC hypothesis while using nuclear energy for USA, France and Japan. The results showed strong evidence in favour of EKC hypothesis while using nuclear energy and it is observed that the utilization of clean energy (Nuclear Energy) for electrical power generation will reduce the environmental pollution in long-run. It will also help the nations in achieving the sustainable developmental goals of net zero carbon emission by 2050. The CO2 mitigation by using the NE is also assessed for all three countries and it is assessed that the France, Japan and U.S. mitigated the CO2 per year is 0.0463 Million Metric Ton (MMT), 0.0239 and 0.0728 MMT per year respectively. Similar to that the SO2 is reduced by using the NE is 24.322, 43.527 and 132.592 MMT/year and NOx is reduced approximately 0.2847, 0.147, 0.4478 MMT/year by France, Japan and U.S. respectively by applied the NE for power generation.

Although nuclear energy is a clean energy but its residuals are highly radioactive as it has the traces of thorium and uranium. Therefore it is needed to develop a full proof plan for disposing NE residuals in a safe place. The cost of disposing the radioactive waste should also be added in the total cost of electricity generation via nuclear energy. So that, there is no fund problem occurred in future for disposing the waste in a safe place. Future research can be done on minimizing the cost of disposing the leftovers.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

8.1 Conclusions

The study was conducted on various nations to analyse the sustainability of renewable energy sources and also to check the validity of the Environmental Kuznets curve hypothesis mainly for the developed countries. As the study was conducted on time series data for a time period of more than five decades hence it was important to consider structural breaks so the Fourier function was used.

Study for Biofuel, Biomass and Hydroelectric:

- The study for oil, Biofuel and hydroelectric energy consumption for Canada have been carried out for relationship between CO_2 emissions, hydroelectricity, urban population, oil consumption, and trade in Canada from 1965 to 2021.
- Wavelet Coherence was used to estimate the relation between the independent variables i.e. use of hydroelectricity, oil, urban population, and trade, and the dependent variable i.e. CO_2 emission. The test result shows a causal link between the all five variables both in the short and long run.
- The results also indicated that oil consumption is highly significant with CO_2 emission both in short and long run, which is a not a good sign because they negatively influence

environmental sustainability. Oil usage needs to be reduced in order to reduce CO2 emissions.

- The use of renewable energy should be promoted as 1% increase in hydroelectricity will decrease 0.11% of CO2 emissions. Whereas, oil consumption has a highly negative impact on environment, a percent rise in oil consumption leads to 0.66% increase in CO2 emissions. Therefore the study concluded that the biofuels should be encouraged as the blended fuel burn more cleanly minimizing the impact of conventional fuel. In the coming future, researchers should pay more attention to micro-stage data provided by the Canadian states in order to find out about the effects of renewable energy in long run and also estimates the future of renewable energy if it is promoted on the same pace.
- Hydroelectricity usage shows a negative correlation with CO2 emissions and is also significant in the long run leading to decrease in CO2 emissions. The trade is positively connected to the CO2 emissions for both the short and long-run. The results of Wavelet Coherence reveals that in long run increasing hydroelectricity and urbanization leads to reduces CO2 emissions indicating that increase in urbanization and hydroelectricity can have considerable good impact on the environment. It also validates the EKC hypothesis, that with the increase in economic growth the pollution decreases.
- As a result, our research suggests that promoting urbanization entails more than just boosting the number of people living in cities, as 1% growth in urbanization will reduce 0.26 % of CO2 emission in the long run.

Study for Renewable energy

- To verify environmental Kuznets curve (EKC) hypothesis for affecting the CO2 emissions by GDP and energy use for China, USA, India and UK. The 50 years data of renewable energy from the year 1971 to 2020 have been employing and found the economic progress achieved at the expense of environmental well-being is unlikely to be sustainable in the long run. As a result, modern development plans are commonly linked with environmental welfare objectives, with economic and environmental benefits expected to occur concurrently. The study showed that EKC hypothesis was rejected which indicates with higher economic growth the environment quality doesn't improve. Although the study was done on a combination of both developed and the developing countries but still neither showed any signs of holding the EKC hypothesis.
- Therefore economic growth can be the cause of environmental degradation but it can be a solution only when the countries have the intension to use its economic profit for developing better technology which will help in reducing environmental problems. The major concerns for any countries should be how to achieve growth with minimum environmental degradation by using cost-benefit analysis approach. So that growth strategies can be observed in alignment with the environmental policy. The wavelet result shows that there is a casual linkage between energy use and CO2 emissions. The CO2 mitigation according to the per people energy use is presented in figure 10. It is revealed that the net CO2 mitigation per people for the year 2020 was obtained by 0.507542, 5.418993 and 2.436347 tonnes/people/year of India, USA and UK peoples respectively.
- Therefore strategies countering the emission problems while using conventional energy should be made and implemented. In order to achieve net zero carbon emissions the

countries have to tackle the CO_2 emissions using strategies. Firstly, conventional sources of energy should be replaced with green energy, while considering the geographical advantages of their respective regions like solar energy can be a major source of green energy for the regions lying between the latitude lines of tropic of cancer and the tropic of Capricorn. Secondly, CO_2 should be captured from the point of emission and stored or utilized to produce by-products like ink and sodium bicarbonate $NaHCO_3$.

- The conventional energy producing power plants exhaust degraded the environment and it is recommended to use the non-renewable energy sources to reduce the degrading of environment quality. In drawing things to close the study has certain limitations due to the availability of data. Future research can be done on other countries with the same variables and including the other greenhouse gases as it has been the main reason for global warming and is the major concern for all the nations that it yet to be tackled.

Study for Nuclear Energy

- The study carried out for nuclear energy for three major countries USA France and Japan and also tested for China. The China doesn't used nuclear energy for long time that's why the china doesn't use for the study. The time series data of three major countries USA, France and Japan from 1965 to 2020 for CO_2 emission, GDP and nuclear energy (NE) are evaluated. It is also analysed and validated the EKC hypothesis while using nuclear energy for electricity generation.
- Among all the three countries only France has been able to reach the breakeven point way back in 1993. France has also showed a positive impact of the use of NE for electricity generation as with the increase in NE CO_2 emission has declined over the period of time. Although the USA is the highest producer of electricity through NE in the world still its

major demands are meet by 36% petroleum, 32% natural gas, 11% coal and only 8% from NE. Japan's national strategy priority was production of electricity through nuclear energy in 1973 but the scenario totally changed after the Fukushima nuclear accident in 2011 the percentage of NE use dropped to 99.95%. Almost after a decade Japan government took an initiative to increase the production of electricity via NE.

- The USA and Japan meets their energy requirements 36% and 40% respectively via petroleum. Whereas the coal and petroleum are the major emitter of carbon dioxide (CO2), Sulphur dioxide (SO2), and nitrous oxide (NOx) which not only harm the environment and increase global warming but also has negative impact on human health. Therefore the USA and Japan needs to develop carbon capture utilization and storage technology (CCUS) which captures carbon before it enters the atmosphere and it can be further utilized to produce by-products like Sodium bicarbonate, ink, carbon fibres, methanol and bio plastics, at present CCUS technology captures 40mt CO2 all around the world. According to the geographical location of all the three countries the study suggests to promote tidal energy for electricity generation as tides are more predictable than wind and sun.
- The study has been conducted to check the validity of EKC hypothesis while using nuclear energy for USA, France and Japan. The results showed strong evidence in favour of EKC hypothesis while using nuclear energy and it is observed that the utilization of clean energy (Nuclear Energy) for electrical power generation will reduce the environmental pollution in long-run. It will also help the nations in achieving the sustainable developmental goals of net zero carbon emission by 2050.
- The CO2 mitigation by using the NE is also assessed for all three countries and it is assessed that the France, Japan and U.S. mitigated the CO2 per year is 0.0463 Million

Metric Ton (MMT), 0.0239 and 0.0728 MMT per year respectively. Similar to that the SO2 is reduced by using the NE is 24.322, 43.527 and 132.592 MMT/year and NOx is reduced approximately 0.2847, 0.147, 0.4478 MMT/year by France, Japan and U.S. respectively by applied the NE for power generation.

Suggestions:

- Concerning to sustainable and renewable energy sources that environmentally sustainable and is also for long-term. That would enable them to change their energy methods reducing environmental harm while steadily and consistently increasing the energy supply over time.
- By encouraging the development and wide-spread use of alternative and renewable energy technology it may also significantly contribute to ensuring that the environment that is left to future generations in a more habitable and clean state. However the waste and E-waste management needs to be promoted as nuclear energy has a highly radioactive waste materials which needs to be disposed properly as if it is leaked it will not only effect the country but also the neighbouring countries.

It is concluded that the use of renewable energy lower CO_2 emissions in case of France. Whereas, Canada, USA, Japan and India has a long way to reduce CO_2 emission and the BUA estimates shows that if the transition in the same pace it won't be able to achieve the goal of becoming carbon neutral by 2050. The results also revealed that the use of nuclear energy for electricity generation resulted is nuclear accident in Fukushima Japan which had a huge impact on its GDP and energy stability.

8.2 Limitations

- The study was conducted to check the sustainability of renewable energy sources. But the waste and E-waste generated while producing electricity by renewable sources needs to be analysed.
- The results of long run estimates can variate with the actual results, if the nation improve the technology and policy as it can accelerate the pace at which the renewable energy is being implemented.

8.3 Future work

- The study focused on the yearly time series data: however it can be applied to quarterly and monthly data. Hence it will be interesting to evaluate the present frequency of implementation are efficient or not.
- The methods and models used in the study can be further explored to check the sustainability of renewable energy for other nations. This can help the stakeholders in making better informed decisions.

8.4 Applications

- The long-run estimates can be effectively analysed to make decisions concerning to improving the technology and innovating new ideas for becoming carbon neutral.
- Based on the models estimates the stakeholders can take decisions to optimize their efficiency.

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List of Publication

Table 2.2: Publications

RO	Publication	Status	Publisher/ Index
RO1	Kumari, S. & Kumar, N. "Analysis of Hydroelectric energy, Urbanization and Trade on CO2 emissions in Canada: Wavelet coherence model" IIMBG Journal of Sustainable Business and Innovation (2023), ISSN: 2753-4022, eISSN: 2753-4022	Accepted	Emerald
RO2	Kumari, S. & Kumar, N. "Investigating the EKC Hypothesis for major Carbon Emitting Economies: Evidence from ARDL, Fourier Toda-Yamamoto and Wavelet Coherence Approach" Submitted in International Journal of Environmental Science and Technology (JEST) (Springer), on 30/04/2023-IF.3.519, Q1	Communicated	SCI, Scopus, UGC Care
RO3	Kumari, S. & Kumar, N. "Analysing the sustainability of renewable energy in France" Ecology, Environment and Conservation, ISSN - 0971-765X	Accepted	UGC CARE, Web of Science
RO4	Singh et al., Role of nuclear energy in carbon mitigation to achieve United Nations net zero carbon emission: Evidence from Fourier bootstrap Toda-Yamamoto, Environment Science Pollution Research Int. (ESPR-Springer), 30(16):46185-46203, 2023, https://doi.org/10.1007/s11356-023-25572-x, Q1	Published	SCIE