Climate Change Impacts on Sustainable Bioenergy Generation in Pakistan

By

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Session 2020-22

Supervised by

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A Thesis Submitted to U.S.-Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirement for the degree of

MASTERS of SCIENCE in

ENERGY SYSTEMS ENGINEERING

U.S.-Pakistan Center for Advanced Studies in Energy (USPCAS-E)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

February 2023

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr. **Aqib Nawaz Khan** (Registration No. 00000326913), of U.S.-Pakistan Center for Advanced Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within similarity indices limit and accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Acknowledgements

First and foremost, all praise belong to Allah Almighty, the Most Benevolent, the Most Merciful, who has granted me the strength, persistence, courage, and willpower to pursue this work and bring it towards completion.

I would like to express my sincere gratitude to my supervisor, Dr. Rabia Liaquat for her brilliant supervision, a continued source of guidance, encouragements and support throughout my master’s research and thesis phase. I have been fortunate to find supervisors who cared deeply about my research progress and answered my every query in timely manner. It would not have been possible to conduct this research or finish my postgraduate studies without her invaluable mentorship. I would also like to thank my Guidance and Examination Committee (GEC) members, Dr. Kafait Ullah, Dr. Nadia Shahzad, and Dr. Syed Ali Abbas Kazmi for their advice and support through various stages of the project.

Finally, I would also like to thank Department of Energy Systems Engineering, USPCAS-E, NUST, my parents, brother, my colleagues, and peers for their continuous support during my MS journey.

I acknowledge the Pakistan Meteorological Department (PMD), especially their Research and Development group for their support for providing me with required data and helping me whenever needed. I would also like to thank the Pakistan Bureau of Statistics for producing and making available their model outputs of different parameters required in my research.

Dedication

I would like to dedicate this thesis to my loving parents, my inspirations in life, who taught me how to fight against the struggles of life. My father who supported me through every thick and thin of life, my mother who taught me to be patient and work hard until you achieve your goals, my brother who taught me how to face problems head on, my teachers whose guidance helped me to achieve this status in my life, my colleagues, peers and leaders who struggle to tackle climate change make this world a better place to live.

Abstract

Climate change endangers modern civilization by threatening essential infrastructure. Warming could affect many energy subsectors. This hurts growing economies. Climate projections are crucial for planning and controlling future bioenergy supplies, especially in agriculturally rich regions and countries. Climate change affects temperature, precipitation, and agricultural productivity. Using Pakistani cities as a study area, we examine the effects of climate change on sustainable bioenergy in a developing country. We estimate temperature and precipitation at a 25km resolution for the fifth phase of the CMIP5. Wheat, maize, rice, and sugarcane output is forecast based on optimal growing conditions and temperature and precipitation.. Muzaffarabad and Quetta would yield 3083.3 and 3319.28 Kgs/Hec. of wheat in 2081-99 and 2061-80, respectively. Based on temperature , Sibi and Peshawar would yield 6990.94 Kgs/Hec. and 6774.91 Kgs/Hec. of maize, respectively, whereas Peshawar would produce between 6717 Kgs/Hec. and 6801 Kgs/Hec . Bannu will produce between 2576.25 and 2616.84 Kgs/Hec. of rice between 2041 and 2060, whilst Muzaffarabad would produce between 2081 and 1999 between 2640 and 2681 Kgs/Hec. Islamabad will produce 69422 Kgs/Hec. in 2041-60 and 70101 Kgs/Hec. in 2081-99, depending on precipitation. Climate change will have an impact on planting seasons, according to our research. Several cities may respond positively and generate a large amount of crops. The ratio of crop residues to crop yields, as well as a variety of other biofuel-related characteristics, are discussed, and cities that are ideal for the future installation of bioenergy producing facilities are identified and recommended based on these criteria.

Keywords: *Climate Change Impacts, Bioenergy Generation, Temperature and Precipitation, RCP 4.5 & 8.5, Crops*

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Climate Change Impacts on Sustainable Bioenergy Production in Pakistan

Energy and Environment (IF = 3.154) (Under Review)

Abbreviations

CC	Climate Change
CMIP5	Coupled Model Intercomparison Project Fifth phase
GB	Gilgit Baltistan
GCM	General Circulation Model
GHG	Greenhouse Gas
IEA	International Energy Agency
Isl.	Islamabad
IPCC	Intergovernmental Panel on Climate Change
KPK	Khyber Pakhtunkhwa
Muzaf.	Muzaffarabad
PMD	Pakistan Meteorological Department
PBS	Pakistan Bureau of Statistics
QDM	Quantile Delta Mapping
RCP	Representative Concentration Pathway
RCR	Residue to Crop Ratio
SRES	Special Report on Emission Scenarios

Chapter 1

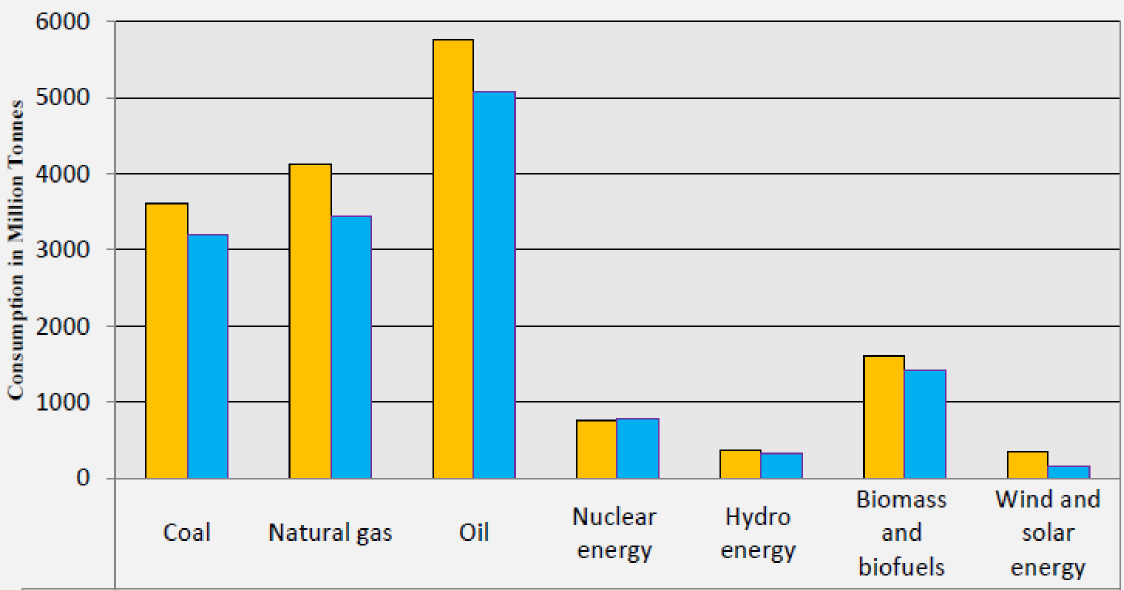
Introduction

1.1. Background

The state of the planet's climate is determined by a tangled network of interconnected subsystems, each of which has an effect on the way weather develops around the world. Mid-20th century, human activities have had a significant influence on the climatic conditions across the globe. Scientists from all over the world are currently working to gain a deeper understanding of this phenomenon and the repercussions it will have for the future of society. The IPCC reports that during the 20th century, the world experienced an average temperature increase of about 0.5 degrees Celsius, and McCarl [1] anticipated that it could climb by as much as 1.4 degrees Celsius at the 21st century's end. A rise in average global temperatures, a rise in sea levels, ocean acidification, shifts in the water cycle, and more frequent and intense extreme weather events are just some climate change (CC) affects can show its consequences. The most widely recognized of these repercussions is a rise in Earth's average atmospheric temperature, known as "anthropogenic warming". This increase in temperature has caused havoc on a great many ecosystems, habitats, and infrastructures all across the world. The evaluation reports produced by the IPCC have been helpful in providing an outline of the possible effects that CC would have on the energy business around the world [2–4]. Rising temperatures have been connected to an increase in desertification, the melting of glaciers, rising sea levels, and maybe more storms and other catastrophic events [1,5,6].

Both the demand for energy and the amount that it is consumed are continuing to go up due to the rise in population and improvement in social and economic situations. According to estimates provided by the International Energy Agency, the demand for energy on a global scale is expected to increase by thirty percent between now and the year 2040, even under the most optimistic scenario. A rise in demand of this magnitude is reflected in the projections for global energy consumption, which project that annual energy consumption would approach 16.5 billion tonnes by the year 2030, representing an increase of around 15%.

Multiple negative outcomes are connected to the burning of fossil fuels, including radiations of GHGs, water stress, and air contamination, all of which are detrimental to the atmosphere and contribute to the process of climate change [7,8]. Burning fossil fuels provides the majority of the world's energy. The beginning of the twenty-first century, there has not been a significant drop in the demand for traditional fossil fuels. As a consequence of this, natural gas, coal, and oil still account for the bulk of the energy used in the transportation of goods, the creation of electricity, the heating of buildings, and the energy used in power plants. Figure 1.1 presents a comparison between the energy consumption rate in 2020 (million tonnes) and the predicted energy consumption rate in 2030 [9] nuclear power, hydropower, biomass and biofuels, wind power, and solar power in addition to old-fashioned fossil fuels (coal, oil, and natural gas).



	Coal	Natural gas	Oil	Nuclear energy	Hydro energy	Biomass and biofuels	Wind and solar energy
2030	3601	4130	5766	764	365	1605	356
2020	3193	3451	5074	776	321	1428	162

Figure 1.1: Energy Consumption for 2020 and 2030 [9]

If traditional fossil fuels were used to generate energy at such a quick rate, eventually the majority of the naturally accessible energy supplies would be depleted, which would lead to an issue with energy security in the future. In addition, Greenhouse gases (GHGs) are produced when fossil fuels are burned; these gases are the principal drivers of variations in global climate and the greenhouse gases [10,11]. Transportation is a major contributor to the high use of oil, which is caused by the fact that oil is the most often used kind of energy on the planet. Since 1970, greenhouse gas emissions caused by transportation have increased by 84%, making this sector's contribution to overall energy consumption the most significant contributor to this trend. It is possible that by 2050, emissions from the transportation sector may reach around 12 gigatonnes of carbon dioxide per year if adequate environmental adaptation strategies are not implemented. According to the findings of a recent study, coal is the primary contributor of carbon dioxide emissions, producing 889 tonnes, followed by oil (735 tonnes) and natural gas (502 tonnes). Concerns have been expressed regarding energy security, the fast consumption of traditional fossil fuels, especially oil, leading to emissions, global warming, and climate change.

In light of what has been said above, it is imperative that research be conducted into low-carbon fuels for the survival of society in the long run. The most essential preventative step that should be taken as soon as possible is to lower rates of energy use and to invest in alternative, carbon-free, renewable energy supply.

At an unprecedented rate, renewable energy sources are increasing their share of the world's primary energy supply. At this time, renewable energy sources are responsible for providing 15% of the primary energy used throughout the world. The majority of this comes from bioenergy, which accounts for 10%, and hydropower, which accounts for 3%; the remaining 2% comes from various forms of renewable energy, such as sustainable sources of power like wind and solar panels. Scenarios and integrated assessment models (IAMs) for the World Energy Outlook According to one estimation, renewables might provide 20 to 30 percent of the fuel source for the entire planet by 2040, while studies show that a system that relies solely on renewable energy could be in place by 2050 [12].

1.2. Bioenergy Techniques

Bioenergy is a form of clean energy that can reduce the adverse effects that human activity has on the atmosphere while simultaneously bolstering rural economies [13]. Bioenergy is the term given to the sort of energy that is generated by living plants in their natural environments through the utilization of biomass as a carrier. This definition does not include materials that have been encased in the ground and transformed into fossil fuels [14]. Because of their abundance and widespread distribution, straw from the harvest, animal manure, and tree trimmings are all examples of agricultural waste [15], are the primary ingredients needed to make bioenergy. This is particularly true in many developing nations where agricultural sector is the country's main economic driver. If agricultural wastes are not managed in an intelligent manner, such as by burning waste straw and tossing cattle and poultry dung, this will result in the loss of a great deal of resources and will also cause damage to the environment (the soil, the water, and the air). Because of climate change and the need to preserve the environment, it is imperative that the most efficient use of agricultural waste be put toward the production of bioenergy over the long run [16].

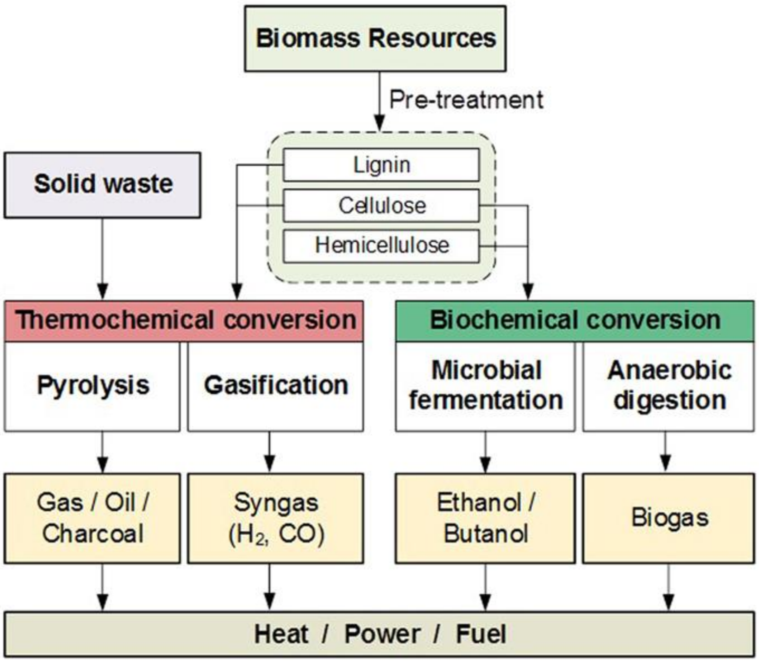


Figure 1.2: Flow chart for biomass conversion [17]

1.2.1. Thermochemical Processes

Pyrolysis and gasification are the two categories that make up the thermochemical processes that are used in the various bioenergy production systems. The formation of charcoal, liquids, and gases is the end consequence of pyrolysis, which is the process by which biomass is thermally decomposed in an oxygen-free environment (usually argon or nitrogen gas). Pyrolysis can be broken down into three distinct subcategories: standard, rapid, and flash. The initial step in the hemicellulose degradation process occurs at temperatures ranging from 470 to 530 Kelvin, followed by the breakdown of cellulose at temperatures ranging from 510 to 620 Kelvin, and then the breakdown of lignin at temperatures ranging from 550 to 770 Kelvin. In order to amplify the production of liquor products that result from the pyrolysis of biomass, one would need to use a process that possesses a high heating rate, a low temperature, and a short gas residence time. In order to produce a large amount of char, a method that involves low temperatures and a slow heating rate would be utilized. If you wanted to get the most out of your pyrolysis process and produce the most fuel gas, you should use a method that has a high temperature, a moderate heating rate, and a lengthy residence period [18].

$$Biomass \rightarrow Charcoal + Volatile\ Matter$$

Organic material is gasified by thermochemical reaction into syngas and char using gasifying carriers as air, oxygen, steam, or carbon dioxide. Syngas is the name given to the gaseous product, and char is the name given to the solid product. The creation of power and heat, as well as hydrogen and biofuels of the second generation, can be accomplished at a low cost through a process known as biomass gasification [19][20].

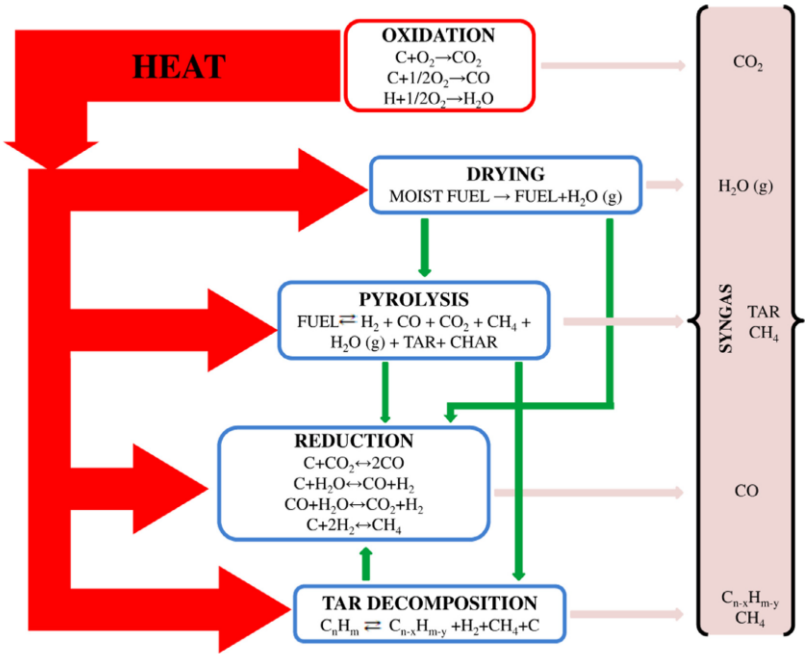


Figure 1.3: **Main stages of gasification process** [19]

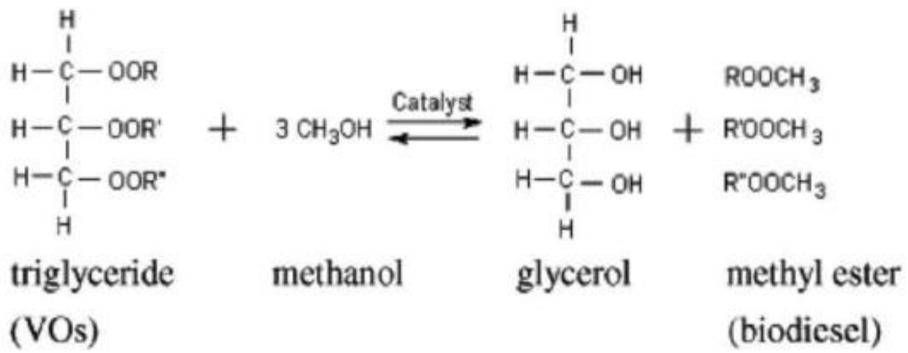
1.2.2. Biochemical Processes

Fermentation and anaerobic digestion are the two types of biochemical processes that are utilized in the production of bioenergy. The process of microbial organisms degrading and stabilizing organic materials under anaerobic conditions is referred to as anaerobic digestion [21]. This process results in the production of microbial biomass and biogas (a combination of carbon dioxide and methane that can be incinerated to generate energy). The anaerobic breakdown of garbage is a common form of waste treatment that can recover energy while also potentially lowering pollution levels. Since they often include large amounts of rapidly biodegradable components, many forms of agricultural and industrial waste are suitable for anaerobic digestion. Anaerobic digestion suffers from a variety of drawbacks, such as a low methane output and a process that is prone to instability, which precludes it from seeing widespread application [22].

The transformation of sugar into an alcohol or an acid is an example of the metabolic process known as fermentation, which takes place when an organism consumes sugar. One example of this would be the fermentation process, in which yeast converts sugar into alcohol in order to obtain energy for itself. The kinetic characteristics of the fermenting microorganisms, the type of feedstock, and the economics of the process all play a role in determining which approach is the most appropriate [23].

1.2.3. Other Processes

A catalyst-enhanced reaction, the consequence of triglycerides and alcohol that constitutes the process known as "transesterification" results in the production of alkyl esters. The production of biodiesel involves a process known as transesterification. Waste vegetable oils are considered to be a pollutant despite the fact that they might be used as a raw ingredient in the production of biodiesel, that they are affordable, and that they are readily available in large quantities. A catalyst is essential for the transesterification of vegetable oil into biodiesel. It is feasible to use nanoparticles, homogeneous and heterogeneous catalysts, as well as enzymatic catalysts. Homogeneous catalysts are regarded to be more effective than their heterogeneous equivalents. This is due to the fact that there are fewer limits placed on mass transfer and that conversion rates are higher. Researchers have turned to non-catalytic supercritical methanol/ethanol transesterification of vegetable oils because acid/base catalyzed transesterification makes biodiesel difficult to separate and purify.



1.3. Representative Concentration Pathway

The Earth system's response to CC will be shaped by human reactions in technology, economics, lifestyle, and government policy. This uncertainty necessitates the use of hypothetical future events to compare and contrast the outcomes of various courses of action. The IPCC has introduced a novel strategy for the creation of scenarios with the publication of its Fifth Assessment Report, also known as AR5. These hypothetical scenarios are what are identified as "representative concentration pathways", and the reason for this designation is that they encompass a wide range of potential scenarios involving radiative forcing [24].

The climate modelling community makes use of a predetermined set of concentrations for greenhouse gases and aerosols, as well as routes for changes in land usage, that are consistent with an aggregation of typical climatic results. The routes are determined by the radiative force that will have been produced at the 21st century's end. It is determined in Watts per square metre (W/m^2), and the term "radiative forcing" refers to the surplus heat that is retained due to enhanced levels of GHGs in the lower environment. The complexity of possible human emissions in the foreseeable future has been simplified down to just four sample scenarios.

Table 1.1: Four global radiative forcing pathways [25]

Radiative Forcing	*Atmospheric CO_2 equivalent (parts per million)	When
8.5	>1370	Until 2100, with an increase thereafter
6	850	Post-2100 stabilization
4.5	650	Post-2100 stabilization
2.6	490	Peak before 2100, followed by a drop

The marker scenarios from the SRES that were included in the IPCC 3rd and 4th Assessment models are narrower in scope than the RCPs, which encompass a wider range of potential outcomes. Rising levels of atmospheric greenhouse gases serve as the starting point for RCPs rather than socioeconomic activity. This is significant because every stage of the modelling process includes uncertainty, beginning with a socioeconomic scenario and continuing all the way to the implications of climate change. Starting with concentrations reduces effect estimation uncertainty because there are fewer phases. Because of this, the degree of ambiguity is more uniformly dispersed throughout the diverse factors. The Representative Concentration Pathways do not constitute a comprehensive set of estimates for socioeconomics, emissions, or climate change. Instead, they are internally consistent estimates of radiative forcing components utilized in later climate modelling. Unlike the SRES, some RCPs include climate change mitigation and adaptation programmes [26].

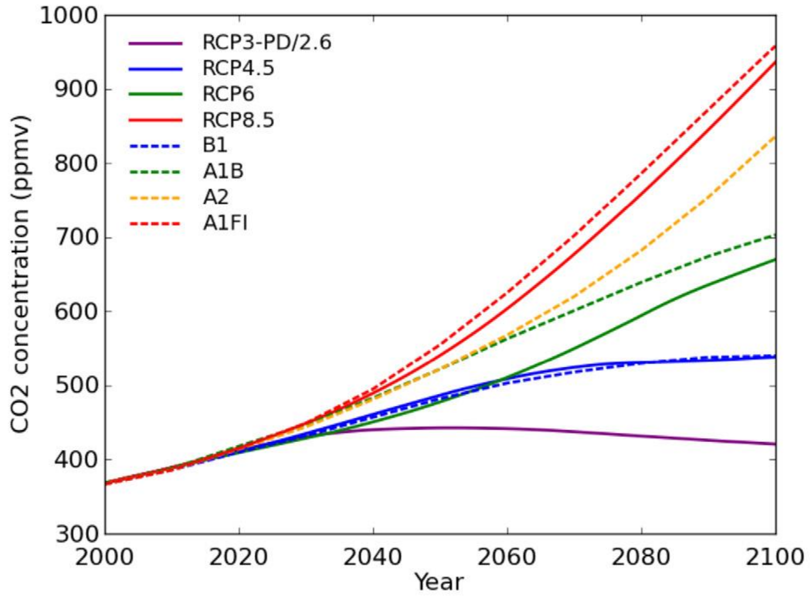


Figure 1.4: **Comparison of RCPs and SRES [27]**

Table 1.2: **Approximate carbon dioxide equivalent concentrations (ppm) [28]**

SRES	RCP	Approximate CO_2 equivalent concentrations by 2100 (parts/million)
(A1)(FI)		1.55×10^3
	85×10^{-1}	$>1.37 \times 10^3$
(A1)B		0.85×10^3
	60×10^{-1}	0.85×10^3
B2		0.80×10^3
	45×10^{-1}	0.65×10^3
B1		0.60×10^3
	26×10^{-1}	0.49×10^3

1.4. Nature of Issues

There are many different subsectors that make up the bioenergy industry of a country, and many of these subsectors are exclusive to a given area. Each of these subsectors has its own unique set of complexities and nuances, which should be considered when assessing how global warming may affect the bioenergy industry. The most important components of the bioenergy industry are agricultural crops, which are impacted by climate change, bio-wastes, and forest wastes, etc. produced by them; nevertheless, CC has a unique influence on each of these components individually. The effects on them need to be fully analyzed in order for the improvement of the future bioenergy industry to be carried out in the correct manner and with reliable information.

The utilization of fossil fuels underwent a sea change as a result of the Industrial Revolution (mostly fuel oil, coal, natural gas, or LPG). From 2005 through 2015, there was a general rising trend in the output of coal. In 2005, the volume was 6022 Mt (million tonnes), but by 2015, it had increased to 7713 Mt. This information comes from the IEA. The production of natural gas, much as the production of coal, continuously increased from 2005 to 2015, at its peak in 2005 it was 1104 Bcm, and in 2015 it was 1304 Bcm. When it comes to oil, the world demand was 3900 Mt in 2005, but by 2015, that number had increased to 4303 Mt. When all the numbers are taken into consideration, the scenario including fossil fuels continues to provoke discussion concerning its depletion. The search for alternative energy sources that are not based on fossil fuels is still ongoing, and it has been influenced by four global themes: a) the enervation of fossil fuels; b) the scarcity of reserves, which contributes to rising prices. c) the ecological problem associated to greenhouse gases, and d) increase in eco-unfriendly, sustainable, and organic buying [29,30].

Because of its dependence on temperature, dry bulb temperature, precipitation, relative humidity, solar insolation, flood patterns, soil fertilization, and other factors, bioenergy production is particularly susceptible to CC [12]. As a result of our emphasis on bioenergy generation, this is the case. As a consequence of this, we are obligated to give it the careful consideration it deserves before putting it into practice, considering the facts that we have gathered. There has been little investigation into how climate change would impact long-term bioenergy production; as a result, there is a significant knowledge vacuum in this area. As a consequence of this, we ought to conduct research on it and propose improved applications.

1.5. Research Objectives

Our goal in doing this research is to identify the magnitude of the effect that CC will have on the bioenergy industry in a developing nation. Because, as was said earlier, the many subsectors of the bioenergy production system are influenced in a variety of unique ways, this study was broken up into portions so that an accurate estimation of the effects could be made for each subsector. This project focuses on investigating the hypothesis of how a developing country's bioenergy production would be impacted by the changing climatic conditions that are being studied. For the purpose of this research, a few cities in Pakistan were selected as a case study since Pakistan was deemed to be an appropriate choice for a developing country in terms of this research. This study examines how changes in a developing nation's mean monthly temperature and precipitation levels alter the creation of bioenergy in the context of CC. The subsequent is a list of the goals that this research aims to achieve:

- To collect historical data for key ecological indicators across Pakistan.
- To predict future trends of key ecological parameters at different Representative Concentration Pathways.
- To evaluate the impacts of predicted key parameters on sustainable bioenergy generation systems.
- To provide recommendations for sustainable bioenergy production in future across Pakistan.

1.6. Scope and Limitation of Research

As part of this research, we are devoting a lot of attention to analyzing how climate change will have real-world consequences. We concluded that, to lessen the severity of the crisis, we needed to adjust our ways of living and transition to sources of energy that are renewable. In terms of the generation of bioenergy, Pakistan has a lot of untapped potential. Therefore, we will examine significant ecological indicators of bioenergy output and then forecast them across the horizon of 2100 utilizing sample concentration routes. This will provide us with a picture of the extent of sustainable bioenergy production in Pakistan's cities that have the most potential.

In this particular study, not all of Pakistan's cities were analyzed because there was not enough time or resources to do so. However, students who are interested in continuing this work and assessing other ecological features that were not covered in this study will have the opportunity to do so. This option will be available to students who participate in future iterations of this project.

1.7. Thesis Outline

Figure 1.4 presents an illustration of the organizational structure that the thesis possesses.

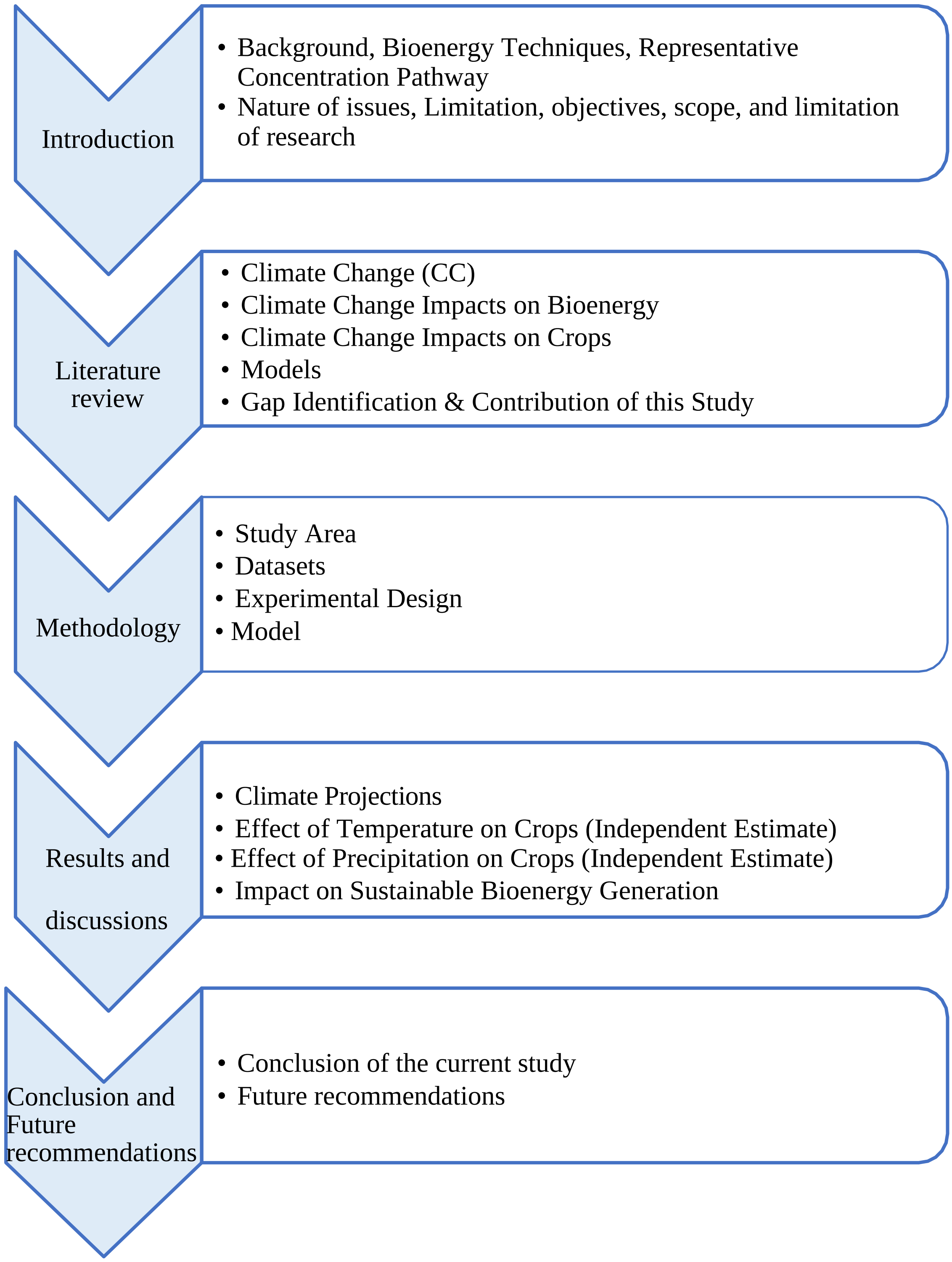


Figure 1.5: Thesis Flowchart

Summary

CC is one of the greatest dangers to modern civilization because it alters the normal weather patterns that modern infrastructure relies on. Producing bioenergy is one industry that will feel the effects of climate change in a variety of ways. This chapter introduced the suggested research and explained why bioenergy could be an excellent choice for the future. In this chapter, we'll take a close look at some of the more common approaches to generating bioenergy, weighing the pros and cons of each. Thermochemical procedures (like pyrolysis and gasification) and biochemical procedures (like anaerobic digestion and fermentation) are examples of these techniques. Also explained are representative concentration paths as a concept and how to implement them practically. Impacts of CC on bioenergy fabrication in growing nations have not been explored in depth. The intention of this research is to identify the ways in which global warming is impacting Pakistan's bioenergy sector and to provide potential responses. Finally, we reviewed the justifications for conducting this research, the aims of the investigation, and the suggested scale of the project.

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Chapter 2

Literature Review

2.1. Climate Change (CC)

An enhance in anthropogenic activity has led to a grow in the rate, magnitude, and duration of intense incidents during the past several decades, and this tendency is expected to persist into the immediate future. Some parts of the world are more vulnerable to the effects of shifting climatic extremes than others, therefore the frequency of extreme events does not vary equally across the globe. There have been several instances of devastating heat waves and floods in Pakistan during the previous five years [1–4].

Considering its wide range of effects, climate change mitigation should be a primary focus of efforts directed at achieving sustainability. Many phenomena, such as rising sea levels, desertification, a flurry of land use changes [5], and fluctuations in temperature and precipitation in various regions, have been driven by climate change, and it is anticipated that these phenomena will not be reversible (at least during the next hundred years) [6,7].

Therefore, information on anticipated catastrophic climatic changes in Pakistan is required as soon as possible in order to establish adaptation plans and policies that are effective and that can be implemented on time. The projections produced by climate models offer policymakers with vital knowledge that is relevant to their work. However, their effectiveness in projecting the present and future climatology has been called into question, mostly as a result of the significant amounts of uncertainty that arise throughout the processes of formal verification and validation. Through initiatives like the coupled models inter-comparison project, the scientific community is working to increase policymakers' trust in climate models by improving the performance of these tools and selecting the best models available [8].

2.2. Climate Change Impacts on Bioenergy

The sector of bioenergy that is highly susceptible to the effects of CC is also the one that offers the most opportunity for adaptation (both technologically and commercially). However, extensive use of bioenergy feedstocks that need a lot of land might have a detrimental impact on the climate, in addition to having a negative impact on ecosystems, nature's diversity and the economy [9]. As an outcome of the worldwide rise in bioenergy production, stakeholders involved in its use and regulation are making efforts to quantify the concept of sustainability. As a result of the fact that sustainability is more of a reflection of a variety of ever-evolving goals than of an actual or expected condition, assessments ought to investigate the relative advantages offered by a wide variety of potential routes leading to the achievement of these objectives. The concept of sustainability refers to a number of processes and affects that may be evaluated either directly or indirectly by utilizing a wide range of indicators [10,11]. These processes and impacts can be found in the realms of the environment, the economy, and society. Enhanced strategic management and planning of bioenergy resources, such as floods, droughts, and sustainable agriculture, depend critically on climate change projections [12]. This is especially true for regions that have the highest ability for the creation of bioenergy. Nevertheless, the climate projections that are obtained from general circulation models (GCMs) play a vital part in these studies of CC [13]. The unpredictability of future climatic conditions, along with the limited availability of data in high-altitude locations, makes it difficult to conduct reliable research, which in turn leads to less solid findings [14].

Bioenergy efficiency and the efficacy of bioenergy promotion policies in the face of CC call for a holistic examination of the connections between water use, agricultural methods, and the creation of innovative renewable energy sources. Agricultural operations will be impacted by variations in water availability as a consequence of CC's altered precipitation patterns, hence this action is essential [15]. Bioenergy's carbon impact is largely determined by how it is produced and used [16].

Bioenergy is a popular renewable energy source and fossil fuel alternative. For instance, switching up cropping patterns typically results in an increase in the amount of CO_2 emitted by land, and the ploughing, discing, planting, cultivating, and harvesting of energy crops all result in the production of a potent greenhouse gas known as N_2O [17]. Although Taiwan's bioenergy production is largely consistent, the nation's land usage and cropping patterns could be significantly altered as a outcome of the unpredictable impacts of CC [16]. CC exerts a significant influence on renewable energy. In the baseline warming scenario, the technology that has the greatest influence is bioenergy, which is dependent on the strength of CO_2 fertilization. Although fertilization is known to occur, its efficacy is not [18]. Although it is the most practical option to tackle climate change, widespread use of land-intensive bioenergy feedstocks has the potential to have negative climate consequences and to have an adverse impact on ecosystems, biodiversity, and people's ability to make a living (in terms of economics and technology). This is because climate change has the greatest impact on bioenergy, but bioenergy is also the most feasible way to combat climate change (in terms of economics and technology) [9].

In the European Union (EU), when it comes to alternative energy, bioenergy has surpassed wind and solar as the most popular option. Both the heating and the electricity industries are seeing an increase in their need for biomass. This can be seen in both the EU and the rest of the globe. While renewables accounted for 26% of EU electricity output in 2013, that number is expected to rise to 34% by 2020 and 45% by 2030. Two-sixths of the European Union's electricity came from renewables in 2013. During the period 2005–2012, the proportion of power generated from biomass climbed by 11% annually; in 2013, this proportion reached an all-time high of 18.7% of total renewable electricity consumption. It is anticipated that the amount of power generated by biomass would surpass 839 PJ by the year 2020 [19].

2.3. Climate Change Impacts on Crops

The increased usage of fossil fuels causes in higher concentrations of carbon dioxide in the environment. This, in turn, turns as a heat trap and warms the surface of the earth, which causes temperatures to rise, snowpack and ice levels to decrease, and changes in the pattern of precipitation to occur [20–22]. Water budgets are being severely impacted by the ongoing climate change, which is increasing water needs for agricultural crops [23]. In particular, variations in the expected seasonal temperature and precipitation allocations will have profound implications on crop growth across all phases [16,22]. According to the findings of several studies, an rise in the quantity of CO_2 in the ambiance should encourage the growth of plants because CO_2 acts as a fertilizer[24]. But other studies have shown that when exposed to high levels of CO_2 in the air, plants will close their stomata, reducing their ability to take up oxygen and carbon dioxide through photosynthesis [25,26].

2.3.1. Crop Security

Both locally and worldwide, the impacts of CC present considerable dangers to the availability of food. As the world's population continues to grow, so does the pressure on already scarce resources like arable land, fresh water, and other agricultural inputs. This production is already struggling with the shortage of ground, water, and other agrarian inputs; anticipated climate change further adds to the difficulties. Several findings have found that rising temperatures and decreasing precipitation will lead to lower harvests of crucial essential crops like maize, rice, soybeans, and wheat. Many of these research' results provide the basis for this forecast [27]. Although fruits and vegetables are just as important to ensuring that people have access to food in the face of a changing climate, they have gotten less attention than the impact of CC on the production of staple crops [28].

2.3.2. Ideal Conditions for Crops

The highly probable factor to have a damaging impact on crop produces is an increase in temperature, and climate models can anticipate changes in regional temperature with better certainty than they can predict changes in precipitation. The average annual temperatures in regions that are suitable for growing wheat, rice, maize, and soybeans have increased by one degree Celsius over the course of the past century, and it is anticipated that these temperatures will persist to rise over the development of the next century. This trend is anticipated to be exacerbated if emissions of GHGs continue to increase. In order to assess the risk to the world's food supply, it is crucial to learn how a rise in temperature affects global crop yields, including any geographical heterogeneity. Subsequently, it is necessary to devise individualized adaptation strategies in order to provide food for a population that is continuously expanding across the globe [29].

Germination, growth, flowering, and the development of seeds are all processes that are strongly influenced by temperature in plants. Plants are sensitive to both low and high temperatures, and their ability to withstand these extremes varies greatly depending on the species and variety. Wheat has a higher tolerance for colder temperatures but a lesser tolerance for temperatures higher than 30 degrees Celsius. Cotton has a high tolerance for heat but a much lower tolerance for cold. Rice can withstand higher temperatures for somewhat longer than cotton can, but it needs a great deal more water to grow well [30].

2.3.3. Bioenergy Crops

The generation of ethanol from corn in the US has been an essential initial stage to achieving this objective [31,32]. Advanced bioenergy technology research has switched away from the alteration of edible crops like maize to biofuel creation due to concerns about the emergence of food-fuel competition in favor of the transformation of non-edible crops like regular grasses that produce fibre [32,33]. In addition, it is anticipated that the utilization of this more recent technology would result in the making of extra energy per unit of ground area while using less agricultural inputs (such as fertilizers and pesticides) than the manufacture of ethanol from grain does [31,32,34].

Second-generation, bioenergy-specific lignocellulosic crop use has been hailed as a more environmentally friendly substitute for edible crops in the manufacture of fluid transportation fuels, which in turn helps reduce GHGs emissions and boosts energy safety. Trees (Populus) and C4 grasses (miscanthus and switchgrass) are planted in temperate regions as part of short rotation coppice and intensive forestry. In order to make bioenergy crops economically competitive with traditional fossil fuel alternatives, it is essential to sustain high energy yields [35].

2.4. Models

There are plenty of models used previously for forecasting among which few of those are explained here. Variations in temperature and precipitation caused by CC are likely to have an influence on harvest production in a number of different countries. The latitude of the nation, the topography, and several other geographical aspects all have a role in determining the severity of the damage. Changes in the circumstances necessary for crop development, such as the pH of the ground, the humidity matter of the soil, and the temperature, can have an impact on how production is affected by CC [36]. Both direct and indirect influences of CC on agricultural production are possible. Variations in temperature and precipitation go under the category of direct impacts, whereas alterations in soil quality, insect infestations, diseases, and weeds fall under the category of indirect effects [37].

McBride and colleagues used a total of 19 criteria, which they then organized into six distinct categories, in order to estimate the ecological viability of bioenergy systems (ground quality, water condition and quantity, GHG, biodiversity, air condition, and productivity). The suite is anticipated to be a helpful instrument for collecting the key ecological consequences of bioenergy [38], and this includes capturing such consequences in relation to a wide variety of bioenergy systems, including a variety of paths, sites, and administration strategies. The creation of a mixed optimization-assessment approach for the production of sustainable bioenergy that takes into account the interdependencies of the system's energy, food, water, and land components, generates cost-effective and environmentally friendly strategies and policies by modifying livestock and crop patterns, allocates water and energy resources, and accounts for the complexity of the system's uncertainties [39].

There is a unified stochastic programming and recourse model created by Kung et al. in order to investigate the possible impacts of water contest across sectors on agronomic systems and eventual bioenergy improvement. This model examines the most effective patterns for the growth of bioenergy while taking into consideration the possibility for shifts in equilibria involving the usage of water [15]. Quantile Mapping, Quantile Delta Mapping, and Detrended Quantile Mapping are all statistical downscaling and bias-correction approaches that can be used to gain insight into past, present, and future severe events in Pakistan (1996–2095). The quantitative difference method (QDM) is the only method that has been shown to be capable of explicitly maintaining the indicator of long-term CC from the years 1976 to 2095 [8].

2.5. Gap Identification & Contribution of this Study

The influences of climate on bioenergy are dependent on the geographical location as well as the regionally distinctive characteristics, none of which are easily transferable to other regions. In addition, the majority of the earlier studies that were conducted to forecast how CC will influence the energy industry mostly focused on developed nations and regions with well-established energy infrastructures. The water impacts in Taiwan that were analyzed are appropriate for a nation of Taiwan's size, and farmland distribution is constant there; however, this may not be the case in other countries, and the model that was employed has some ambiguity and calls for more debate [15]. Due to climate change, cropping patterns will vary greatly from country to country, which will have an impact on the development of bioenergy [16]. (Taylor et al., 2008) says that even in an ideal situation in which elevated pointedly progresses productivity and drought lenience through improved plant–water relations and soil water management, better rooting depth and density caused by elevated, and a lengthier budding season due to later agedness, these crops could still be harmful to the ecosystem in hydrologically sensitive areas. In light of the fact that this assessment does not provide a comprehensive response to these concerns, it is clear that there is still more work to be done in this regard [35]. There is no way to quantify the potency of CO_2 [18]. Forecasts on deployment levels and climatic implications are extremely challenging due to the fact that technical advancement is fraught with unknowns and political decision-making is fraught with uncertainty [9].

The studies that were described above, along with the vast majority of those that came before them, focused on bioenergy, and included specific information on a variety of countries or locations that were likely to be susceptible to CC over the course of the century. As far as we know, no research has been done in Pakistan to find out how different climate change scenarios will affect the country's temperature and rainfall. This work will not look into how well CMIP5, bias-correcting methods, and other similar methods work. The specific objectives of this study are to figure out the climate factors (like temperature and rainfall), forecast the production of Pakistan's most vital crops, and find the city that is most likely to be able to produce crops and bioenergy despite the influences of CC over the next century.

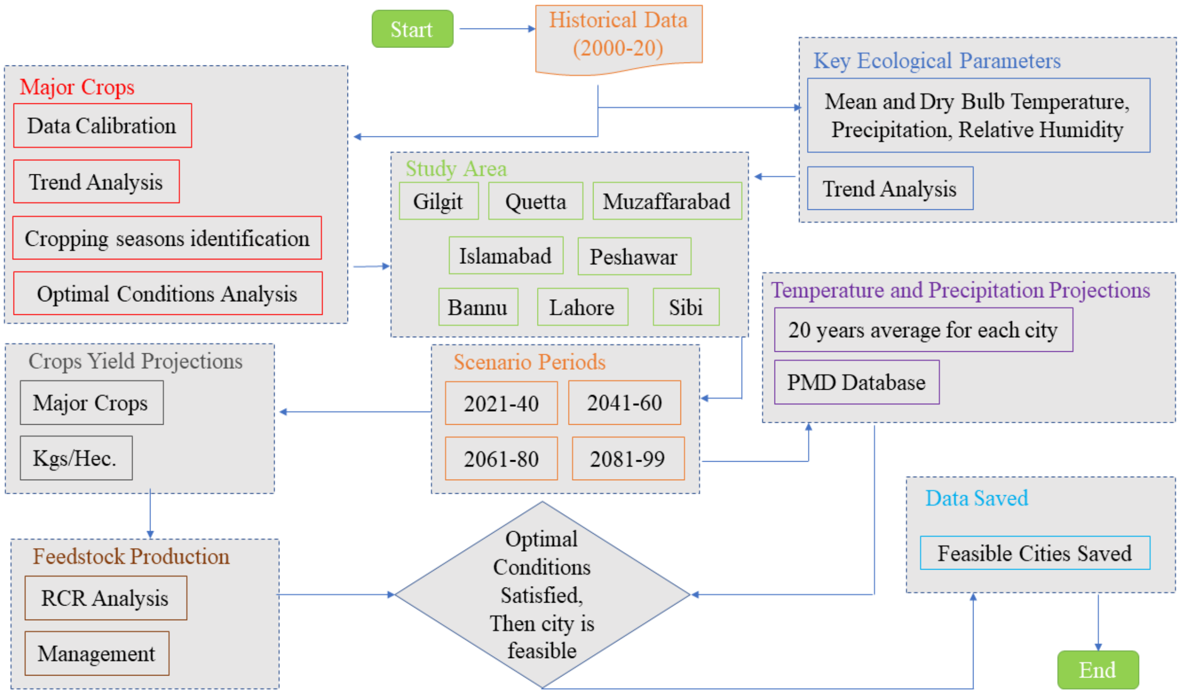

Figure 2.1: Proposed Methodology Flowchart

Summary

This chapter delivers a concise review of the prior research paper that investigated the possible effects of CC, specifically how it would affect bioenergy and agriculture. The vulnerability of the problem that is crop security and bioenergy crops to shifts in the circumstances of the surrounding environment is brought to light here. The impacts of human-caused global warming are examined, along with the ways in which bioenergy shifts and adapts in response to rising temperatures. The purpose of this literature evaluation is to assist define the contributions that this research provides by identifying the gaps in the existing body of knowledge (literature).

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Chapter 3

Methodology

3.1. Study Area

Several studies have found that South Asia is an area where climate change is happening quickly. Because snow and glaciers are such important parts of the water supply system, these variations in temperature could have a big influence on it [1,2]. South Asia is home to the country of Pakistan, also recognized as the Islamic Republic of Pakistan. Its coordinates are 30.3753 degrees north latitude and 69.3451 degrees east longitude. India, Afghanistan, Iran, and China border it. The Arabian Sea and Gulf of Oman border its southern coastline for 1,046 kilometers (650 miles). Afghanistan's Wakhan Corridor separates it from Tajikistan to the north, and it shares a coastline with Oman. The Wakhan Corridor is located in Afghanistan.

Both the landscape and the climate of Pakistan are extremely varied. In terms of geography, the provinces of Sindh and Punjab in Pakistan are positioned on top of the Indian tectonic plate, whereas Balochistan and the majority of Khyber Pakhtunkhwa are part of the Eurasian plate and are predominantly on the Iranian plateau. In the Indus-Tsangpo Suture Zone can be found the country of Pakistan. Gilgit-Baltistan (GB) and Azad Kashmir are located on the periphery of the Indian plate. The climate ranges from tropical to mild, and the southern coastal areas are characterized by arid circumstances. There is a monsoon season, also known as flood season, during which significant amounts of rain fall, and a dry season, during which there is little to no rain at all. Pakistan experiences four different seasons: a warm and dry winter (December–February), a hot and dry spring (March–May), a southwest monsoon season (also known as the summer rainy season; June–September), and a waning monsoon season (October–November). There is a large range in the annual rainfall, and there are many instances of drought and flooding alternating with one another.

The problem statement for this research project was to investigate the effects that CC has had on different types of bioenergy in Pakistani cities. For the purpose of this investigation, we are concentrating on independent estimates. This means that we have held all of the other variables, such as soil fertility, CO_2 levels, dry bulb temperature, and urban sprawl, etc., constant and have only considered two variables, namely, temperature and precipitation.

We gathered the data from the major cities in Pakistan and conducted an analysis of the effect that temperature and precipitation have on crop yield. This, in turn, will have an effect on the patterns of bioenergy generation in the time period (2021-40, 2041-60, 2061-80, and 2081-99), and it will provide us with information regarding the impact trend on crop yield measured in kilograms per hectare. Since biomass is a feedstock for the technology, any decrease or increase in the generation of biomass has an immediate and direct impact on the generation of bioenergy.

The cities that are going to be looked at in this article are spread throughout several different provinces in Pakistan, and each of them has its own distinct set of climatic qualities and geographical features, as can be seen in Figure 3.1. The regions of Gilgit Baltistan (GB), Punjab, Azad Kashmir, and the Islamabad Capital Territory each only have one city, while Balochistan and Khyber Pakhtunkhwa (KPK) each have two cities. Balochistan and Khyber Pakhtunkhwa each have two cities. All of these cities have been chosen for examination based on three key factors: climate vulnerability, arable and non-arable land, and its impact on the stability of Pakistan. Numerous cities in Pakistan would be severely impacted by climate change, but the selected cities were picked due to the availability of data, its impact on Pakistan's stability, and they are climate-vulnerable regions. All of the selected cities contain have either arable or non-arable land, which was one of the selection criteria because we wish to determine in the future whether arable lands will change their behavior and become more advantageous for crop yield or vice versa.

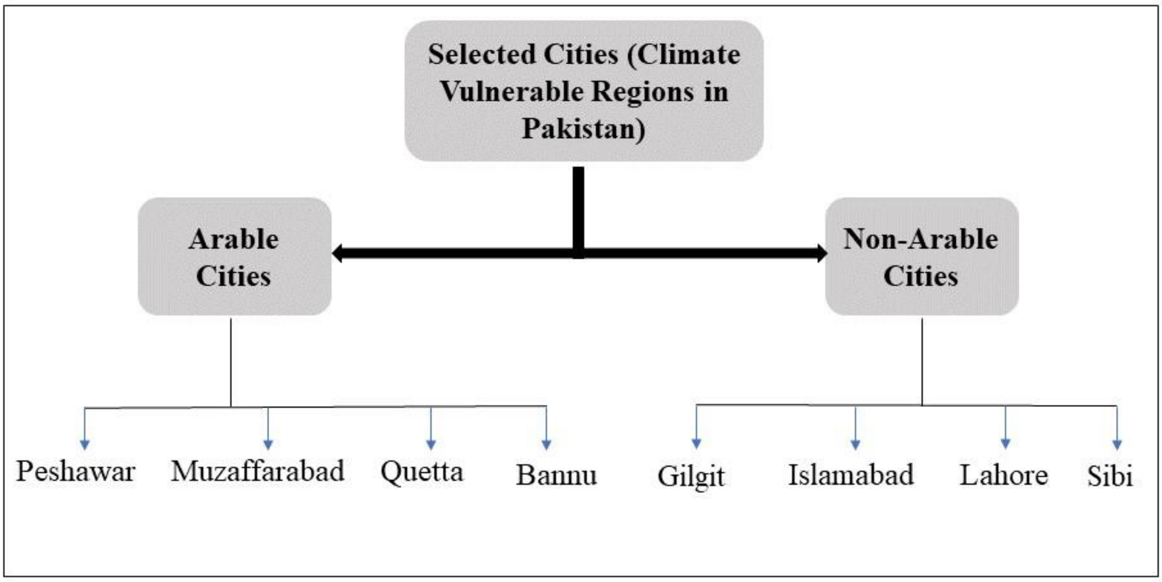

Figure 3.1: Study area based on selection parameters

Gilgit is the capital city of Gilgit Baltistan, which has complete land area of 38,000 km^2 and is situated at 35.8819 degrees North and 74.4643 degrees East. According to Wikipedia, it has an elevation of 1,500 metres and a climatic rating of 7 (extremely cold). Muzaffarabad is a city in the Azad Kashmir province that spans a total area of 6,177 km^2 and can be found at 35.8819 degrees North and 74.4643 degrees East. According to Wikipedia, the elevation is 737 meters, and the climate is a 7 (extremely cold). Within the Islamabad Capital Territory, the city of Islamabad spans a total area of 906.5 km^2 and can be found at 33.6844 degrees North and 73.0479 degrees East. Its lowest elevation is 490 meters, while its maximum elevation is 1,584 meters, and it has a environment that is classified as 2A: hot and humid. Peshawar, which encompasses a total area of 215 km^2 and is located in the Khyber Pakhtunkhwa province, can be found at coordinates 34.0151° N and 71.5249° E. It has an elevation of 331 meters with a climate that is classified as 2B (hot and dry). Bannu is a metropolitan area that spans an area of 1,227 km^2 and is located in the Khyber Pakhtunkhwa province. Its coordinates are 32.9910 degrees North and 70.6455 degrees East. According to Wikipedia, the climate is a 1B, which translates to "Very Hot and Dry". Lahore is a city in the province of Punjab that spans an area of 1,772 km^2 and can be found at 31.5204 degrees North and 74.3587 degrees East. The elevation is 217 meters above sea level, and the climate is categorized as 1B: Very Hot and Dry. In the province of Balochistan, the sprawling metropolis of Quetta occupies an area of 3,501 km^2 and can be found at 30.1798 degrees North and 66.9750 degrees East. It has a climate classified as 3B (warm and dry) and is located 1,680 meters higher than sea level. Last but not least, the city of Sibi in Balochistan has an area of 346 km2 and can be found at 29.5532 degrees

North and 67.8808 degrees East. It has a climate of type 0B (very hot and dry) and is located 130 meters above sea level. The RETScreen Expert software serves as the basis for all of the climate conditions that were discussed previously for the selected cities, and it has been utilized to validate these circumstances. The geographic positions of all of the cities are depicted in Figure 3.2.

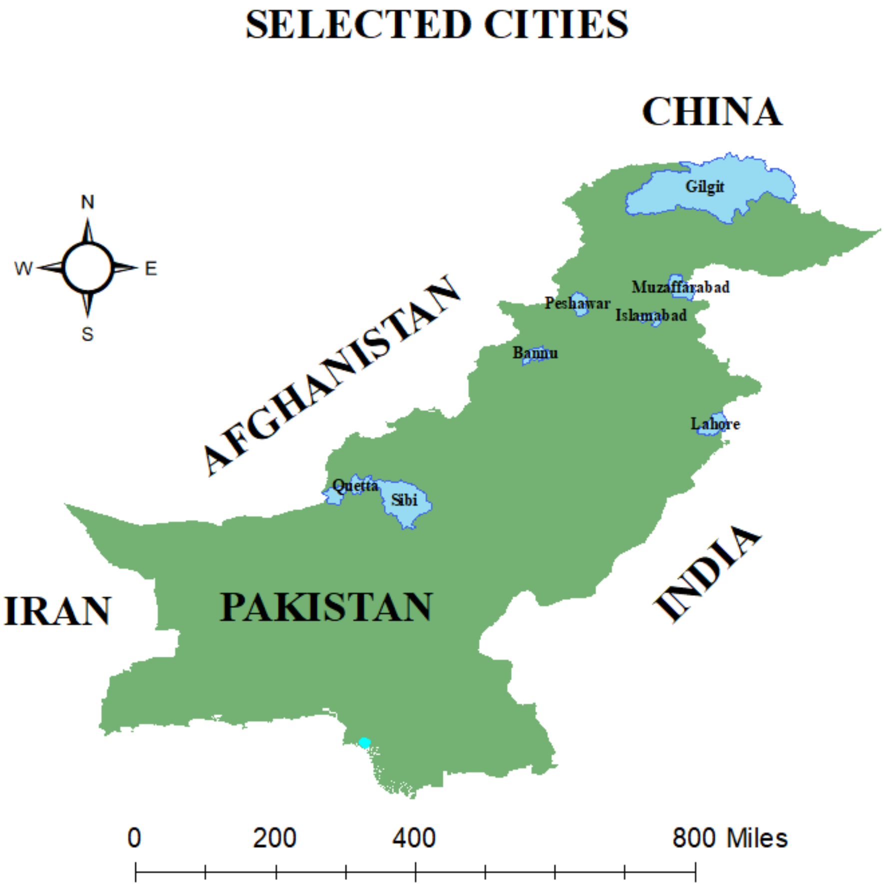

Figure 3.2: Geographical location of the study area

3.2. Datasets

The recorded monthly data of key ecological indicators of agricultural waste or bioenergy that are mean temperature, mean dry bulb temperature at 0300 UTC, precipitation, and mean relative humidity at 0300 UTC at eight various sites for the time period of 2000-20 from Pakistan Meteorological Department (PMD), Research and Development wing are shown in Table 3.1. These sites include Gilgit, Quetta, Muzaffarabad, Islamabad, Peshawar, Bannu, Lahore, and Sibi.

Table 3.1: Average Temperature (°C), Dry Bulb Temperature (°C), Precipitation (mm) and Relative Humidity (%)

CITIES	2000-04	2005-08	2009-12	2013-16	2017-20
TEMPERATURE (°C)					
Gilgit	16	16.2	16.025	16.225	16.05
Quetta	17.62	17.25	17.2	17.675	17.425
Muzaffarabad	21.36	20.725	20.9	20.075	19.25
Islamabad	21.86	21.45	21.8	21.425	21.075
Peshawar	23.48	23.175	23.25	23.1	22.975
Bannu	24.04	23.925	23.575	22.55	22.6
Lahore	25.24	25.05	25.05	24.325	24.85
Sibi	27.8	27.325	26.525	26.6	27
DRY BULB TEMPERATURE (°C)					
Gilgit	12.46	11.625	11.4	11.975	12.175
Quetta	12.56	12.625	12.825	13.425	13.525
Muzaffarabad	15.76	15.175	15.3	15.2	14.375
Islamabad	17.38	17.2	17.475	17.35	17.4
Peshawar	19.26	19.05	19.05	19.5	19.3
Bannu	22.18	20.95	20.35	20.125	19.825
Lahore	21.98	21.9	21.95	21.85	21.525
Sibi	23.38	23.075	23.075	24.36667	24.15
PRECIPITATION (mm)					
Gilgit	134.06	134.35	178.675	146.725	132.7
Quetta	161.72	237.125	298.5	209.375	267.475

Muzaffarabad	1299.7	1598.5	1376.875	1365.425	1449.425
Islamabad	1189.56	1418	962.5	1476.075	1374.2
Peshawar	453.68	646.625	622.875	535.6	480.25
Bannu	207.26	398.35	382	435.125	360.825
Lahore	509.88	669.325	588.175	838.1	754.3
Sibi	113.5	255.625	252.175	181.4	232.05
	RELATIVE HUMIDITY (%)				
Gilgit	65.6	71.625	72.425	71.5	69.625
Quetta	54.1	63.425	60.775	51.7	46.45
Muzaffarabad	75.08	79.1	77.725	80.275	77.875
Islamabad	77.42	80.8	77.075	81.15	79.5
Peshawar	69.52	71.275	69.725	67.275	66.5
Bannu	54.96	60.1	58.95	65.45	64.1
Lahore	68.04	70.025	68.075	71.8	71.475
Sibi	54.82	65.475	66.45	55.1	57.8

After then, the fluctuation of each city's mean temperature during the course of the study was used to rank the cities in ascending order. The independent estimations that were taken into consideration for this study can be seen as the mean temperature and precipitation that are displayed in Figure 3.3 that was created by ArcGIS. However, it has not been validated over the past ten years by comparison to data obtained from the meteorological station at the National University of Sciences and Technology (NUST). Although experts from the Research and Development wing of the Pakistan Meteorological Department have previously reviewed the accuracy and usefulness of this dataset, it has not yet been validated.

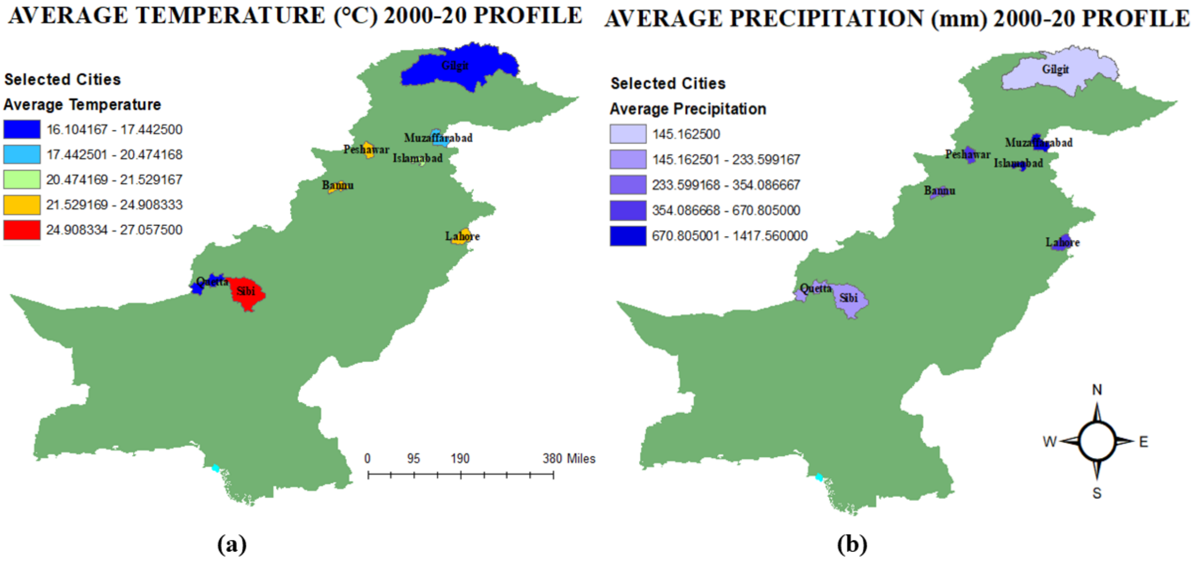

Figure 3.3: Profiles of study area between time period 2000-20 (a) Temperature (°C) (b) Precipitation (mm)

The representative concentration pathways (RCPs), which were made available under the CMIP5 repository and made public in March 2013, were used to construct climate forecasts in this body of work. The simulated data were then checked against PMD predicted mean temperature and precipitation data with a 25km resolution, as well as the outputs of the Climate Explorer KNMI software (https://climexp.knmi.nl/start.cgi), in order to validate and verify the results. The database (website) of the Pakistan Bureau of Statistics was combed for information pertaining to the year 2020, and then that information was used in this investigation to extrapolate the production of a variety of crops all the way out to the year 2100. The data from the database (website) of the Pakistan Bureau of Statistics (PBS) for the time period extending from 2016–17 to 2020–21 (P) were analyzed in sort to achieve a better comprehension of the trend fluctuations of the crops that are displayed in Table 3.2.

Table 3.2: **Wheat, Maize, Rice, and Sugarcane yield**

YEARS	WHEAT YIELD		MAIZE YIELD		RICE YIELD		SUGARCANE YIELD	
	(Kgs /Hec.)	**% Change**	**(Kgs /Hec.)**	**% Change**	**(Kgs /Hec.)**	**% Change**	**(Kgs /Hec.)**	**% Change**
2016-17	2,974	-	4,550	-	2,514	-	61,972	-
2017-18	2,851	-4.1	4,718	3.7	2,568	2.1	62,096	0.2
2018-19	2,806	-1.6	4,968	5.3	2,563	-0	60,956	-1.8
2019-20	2,867	2.2	5,615	13	2,444	-5	63,827	4.7
2020-21 (P)	2,974	3.7	5,970	6.3	2,524	3.3	69,536	8.9

In this particular study, research was conducted on wheat, maize, rice, and sugarcane; all of these cereals and sugarcane are considered to be important crops in Pakistan. The report compiled by the PBS serves as the foundation for the estimation of the complete yield of each crop produced in Pakistan. Wheat is Pakistan's primary staple crop, so maintaining a healthy supply of it is essential to the country's overall food security. According to the data presented in Table 3.2, it contributes 1.8% to the overall GDP and 9.2% to the value added in the agricultural sector. The wheat crop produced a record-breaking 27.293 million tonnes during the 2020–21 academic year, which is a increase of 8.1% over the 25.248 million tonnes generated the prior year. Additionally, the wheat crop produced a yield of 2,974 kgs/hectare, which is an increase of 3.7%. Both of these figures represent increases over the previous year's production levels. Maize is Pakistan's third-largest cereal crop, following rice and wheat in importance. It adds 3.4% to the quantity attached to farming and 0.6% to the overall GDP. The output raised by 7.4% to 8.465 million tonnes in the year 2020–21, compared to the previous year's total of 7.883 million tonnes, which was produced. Rice is an important crop for both food and cash. After wheat, it is the second valuable crop grown specifically for staple foods, and after cotton, it is the second most significant crop farmed specifically for exportable goods. It contributes 0.7% to GDP while also contributing 3.5% to the value added in the agricultural sector. A record-breaking increase in production of 13.6%, from 7.414 million tonnes in the previous year to 8.419 million tonnes during the 2020–21 fiscal year. Sugar-related firms make up Pakistan's second-biggest agro-industrial sector after textiles and are highly dependent on sugarcane, a high-value cash crop. Textiles are Pakistan's largest agro-industrial sector. Its production accounts for 0.7% of the entire fiscal output and 3.4% of the value added to agricultural products. In the fiscal year 2020–21, production increased by 22.0%, going from 66.380 million tonnes in the preceding year to 81.009 million tonnes in this year.

3.3. Experimental Design

We chose eight different cities, collected the data from those cities, and then used two different RCPs (4.5 and 8.5) to project the climate for the time period 2100. This allowed us to generate independent estimates of the temperature and the amount of precipitation that occurred during the years 2000–20. We determined their accuracy by comparing their findings to those obtained from the PMD database as well as the Climate Explorer KNMI software. We looked at how production has been trending for the target crops. The future scenario was broken down into four time periods of twenty years each (2021–40, 2041–60, 2061–80, and 2081–99), and then it was extrapolated through a model over the duration of a century. This was done in order to reduce the predicted uncertainties. The crops of Pakistan served as the primary inspiration for this action.

3.4. Model

The PMD database and the Climate Explorer KNMI programme were utilized in order for us to calibrate the evaluation of the climate models. The approaches that they took are analyzed in this section. Because climate models are not foolproof, the climatology that is simulated and the climatology that is seen will differ from one another slightly. The model state will move closer to the model climate as the prediction develops; however, this movement will be confounded by the anticipated change in the climate. Short-term climate estimates generally benefit from the application of bias correction.

As previously discussed in section 2.2, wheat, maize, rice, and sugarcane are all acknowledged as important crops in Pakistan. Sugarcane is also an important crop. We began by considering the cropping season of the various plants we were interested in cultivating in Pakistan so that we could identify which environment would be ideal for the best possible growth of those plants. Pakistan has two distinct growing seasons throughout the year. The beginning of the first planting season, also known as "Kharif," occurs in April and continues through June. The harvest takes place in December. The best part of this time of year agricultural cycle consists of the cultivation of rice, sugarcane, cotton, maize, moong, mash, bajra, and jowar. Planting takes place from October to December during the "Rabi" season, which is the second season, while harvesting takes place from April to May of the subsequent year. The majority of its components include wheat, gramme, lentil (masoor), tobacco, rapeseed, barley, and mustard. The performance of the agriculture industry in 2020–21 is generally beneficial, expanding by 2.77% rather than the projected 2.8% throughout the course of the next fiscal year. Major crops, such as wheat, rice, sugarcane, maize, and cotton, all have an yearly growth rate of 4.65 percent. The Pakistani harvest schedule is detailed in Table 3.3, which you may view here.

Table 3.3: Approved crop calendar for Pakistan

	DATES OF RELEASE OF CROP ESTIMATES		
CROPS	**First**	**Second**	**Final**
Wheat (Rabbi)	1st Feb.	1st April	1st August
Maize (Kharif and Rabbi)	-	-	-
Rice (Kharif)	1st Sept.	1st Dec.	1st Feb.
Sugarcane (Kharif)	1st July	1st Nov.	1st April

After that comes an analysis of the data from section 2.2 regarding the yield of the crops that are being targeted. We investigate the trends they have displayed as well as the percentage shift that has occurred over the past few years. After then, an analysis of the optimal conditions will take place. The research indicates that the optimal temperatures for the development of significant crops are as follows: 19–22 degrees Celsius for wheat [3], 28–34 degrees Celsius for maize [4], 25–35 degrees Celsius for rice, and 27–38 degrees Celsius for sugarcane [5]. Each type of plant suffers a unique and gradual decrease in yield for every degree Celsius as the temperature rises. If the temperature rises by 1 degree Celsius, the yield of wheat will fall by 6% [3,6–8], the yield of maize will decrease by 7.4% [4,7], the yield of rice will decrease by 3.2% [7], and the yield of sugarcane will decrease by 10% [5,9–11]. It is advised that wheat receive between 500 and 750 millimeters of precipitation [12], that maize receive between 500 and 1000 mm [7,13,14], that rice receive between 1000 and 2520 mm [7,14], and that sugarcane receive between 1000 and 1500 mm [5,9–11,14].

Following that, for the subsequent and final stage, we applied the extrapolation method. To begin, we compared how the yield of each crop changed for every degree Celsius or millimeter that the temperature dropped. After that, we examined the forecasted temperature or amount of precipitation for each of the selected cities and compared it to the degree to which it deviates from the ideal for that temperature or amount of precipitation. The final step in the process consisted of forecasting the yield based on whether the temperature or the amount of precipitation fell within or outside of the ideal range. Independent estimations were used for the study since the yield of crops is reliant on a broad range of critical factors, such as temperature, precipitation, humidity, the availability of water, the available land, and many others.

After that, the residue to crop ratio is one of the most significant factors that will influence bioenergy output. Throughout the biofuel supply chain, it is probable that different environmental indicators may be required at various stages and activities. Manufacturing of feedstock is a part of the supply chain, its administration, and the logistics underlying its conversion and eventual use. The majority of these categories belong to the early phases of the production chain (i.e., the generation and reaping of feedstock), whereas only some kinds are applicable to the latter phases. In the early phases, when there are more categories to pick from and they are more diversified, it is more challenging to establish which indicators should be emphasized and how to measure them. When using biodiversity indicators, it is essential that both the indicators chosen, and their interpretation be tailored to the situation at hand. For instance, scales may be used to indicate site-certain recovery schemes and territory needs for regionally threatened genus. The entire study project's technique is broken down into its component parts and presented in Figure 3.4.

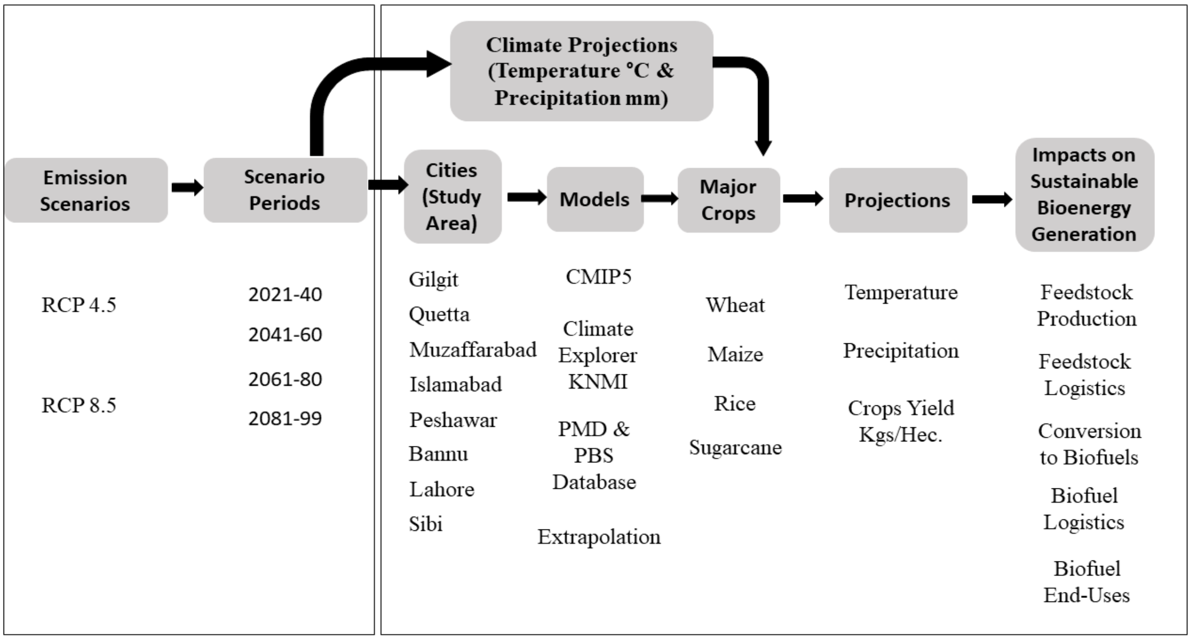

Figure 3.4: Methodology flowchart adopted in this study

Summary

This chapter includes information on a variety of processes that need to be carried out in order to anticipate climate variables and predict agricultural production for the entire century. After selecting eight different cities from all over Pakistan and collecting data related to it from the PMD database and data related to major crops from the PBS database, it is evaluated using the Climate Explorer KNMI software and from the meteorological station at the National University of Sciences and Technology (NUST) for validation purposes.

Pakistan grows wheat, maize, rice, and sugarcane. Also significant is sugarcane. We considered the cropping season of the plants we wanted to grow in Pakistan to determine the best environment for their growth. Pakistan has two growing seasons. First planting season, "Kharif," begins in April and lasts till June. Picking up in December. The most important crops for this season are rice, sugarcane, cotton, maize, moong, mash, bajra, and jowar. The "Rabi" season follows, with planting occurring in the fall (October–December) and harvesting occurring in the spring (April–May). Essential ingredients include wheat, grame, lentil (masoor), tobacco, rapeseed, barley, and mustard. The agriculture business will grow by 2.77 percent in 2020–21, above the expected 2.8%. Wheat, rice, sugarcane, maize, and cotton all grow 4.65% annually. Then, crop yield data is analyzed. We look at their recent patterns and percentage shifts.

Then, optimal conditions are analyzed. The best temperatures for crop growth are wheat needs 19–22°C, maize 28–34°C, rice 25–35°C, and sugarcane 27–38°C. Each plant type's yield decreases gradually with each degree Celsius of warming. If the temperature climbs 1 degree Celsius, wheat yield falls 6%, maize yield falls 7.4%, rice yield falls 3.2%, and sugarcane yield falls 10%. Wheat, maize, rice, and sugarcane need receive between 500 and 750 millimeters of precipitation. Finally, we used extrapolation. We compared crop yields per degree Celsius or millimeter of temperature decline. Then, we compared each city's expected temperature or precipitation to the optimum for that temperature or precipitation. The final phase was to forecast the yield based on whether the temperature or precipitation was ideal. The study employed independent estimates since crop output depends on several factors, including temperature, precipitation, humidity, water availability, and land.

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Chapter 4

Results and Discussion

4.1. Climate Projections

Since the impact of CC on the power generation industry is the primary focus of this study, we focus primarily on analyzing how fluctuations in temperature and precipitation have an effect on bioenergy. Despite the fact that bioenergy is dependent on a number of different variables, we do so because that is the primary concern of the study. We used a variety of methodologies, such as CMIP5, PMD database, and Climate Explorer KNMI software for RCPs, to investigate changes in temperature and precipitation in eight different cities across the country, each of which has a climate that is distinct from the others. This was necessary because their analysis has never been done in the framework of CC impacts on sustainable bioenergy generation. The PMD was responsible for giving the data that was used for the projections of each city. The IPCC's Fifth Evaluation Article served as the foundation for the downscaling of CC scenarios to a spatial resolution of 25 km. Different behaviors are observed there depending on the kind of climate that exists there. The results of the investigation are presented below, analyzed from the perspective of two typical concentration paths.

4.1.1. Temperature Projections

The RCP 4.5 and RCP 8.5 models are utilized to make temperature forecasts. At least two cities are selected from each of Pakistan's provinces, with the minimum number being two. The following cities are being taken into consideration for this project: Gilgit, Quetta, Muzaffarabad, Islamabad, Peshawar, Bannu, and Lahore. They are arranged from the coldest to the hottest of the bunch. The entire century is broken up into its component parts by using these four unique time periods: 2021–40, 2041–60, 2061–80, and 2081–99. Figures 4.1 and 4.3 depict the increases in average temperature that have occurred in the parts of the country that are under consideration. The RCP 4.5 scenario is depicted in Figure 4.1, whereas the RCP 8.5 scenario is shown in Figure 4.3.

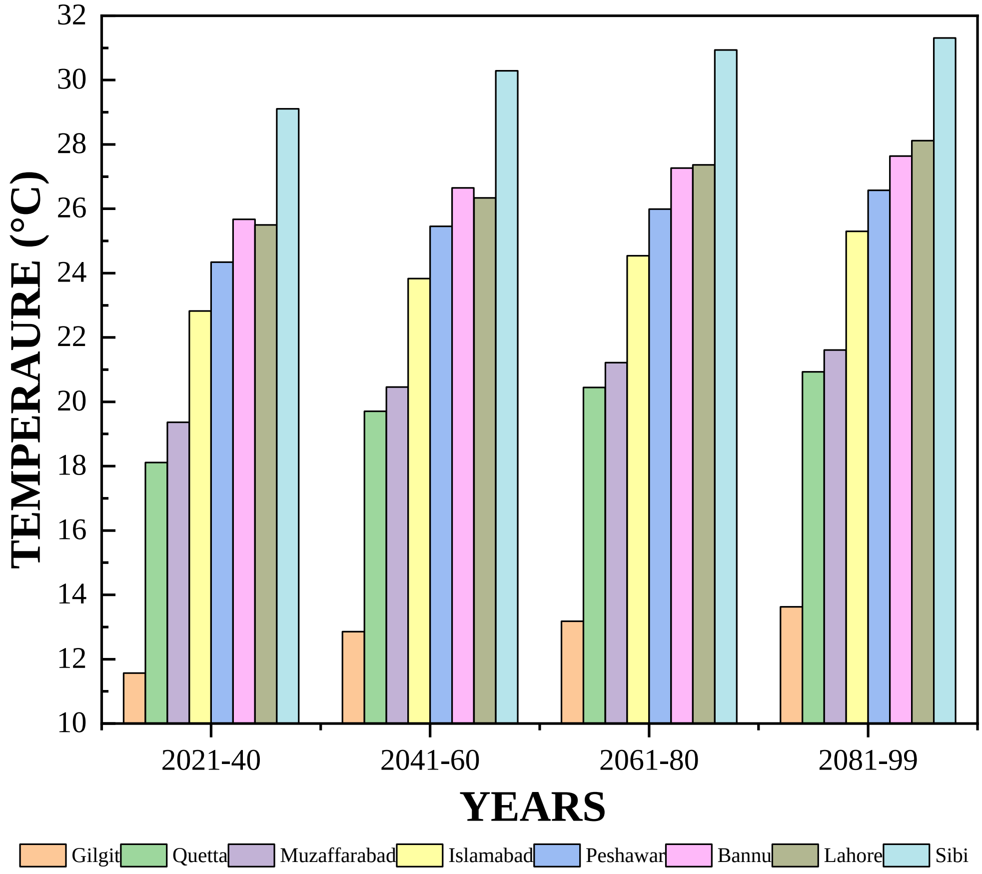

Figure 4.1: Average temperatures(°C) for each city across the century under RCP 4.5

According to the intermediate RCP 4.5 scenario, the rise in temperature due to climate change displays a pattern that is, for the most part, constant across all of the time periods that are anticipated for the entire century (as shown in Figure 4.1). Our findings reveal that the selected locations would see an increase in temperature of around one degree Celsius to one and a half degrees Celsius between the years 2021-40 and 2041-60 as a direct result of the CO_2 that is sequestered in the earth's atmosphere. The trend, however, begins to move in the opposite direction between the decades 2061–80 and 2081–99. This prediction is consistent with the RCP 4.5 emissions scenario, which predicts that emissions will begin to decline after 2045–55 and that the rate of temperature increase would level out at the century's end as the radiative forcing level steadies at 4.5 W/m^2 before next century under the RCP 4.5 scenario, which is a steadying scenario that uses a variety of technologies and techniques to reduce greenhouse gas emissions. This prediction indicates that emissions will begin to decline after 2045–55 and that the rate in light of the causes of CC, the production of crops and the creation of bioenergy in this scenario is perhaps more hopeful than it should be.

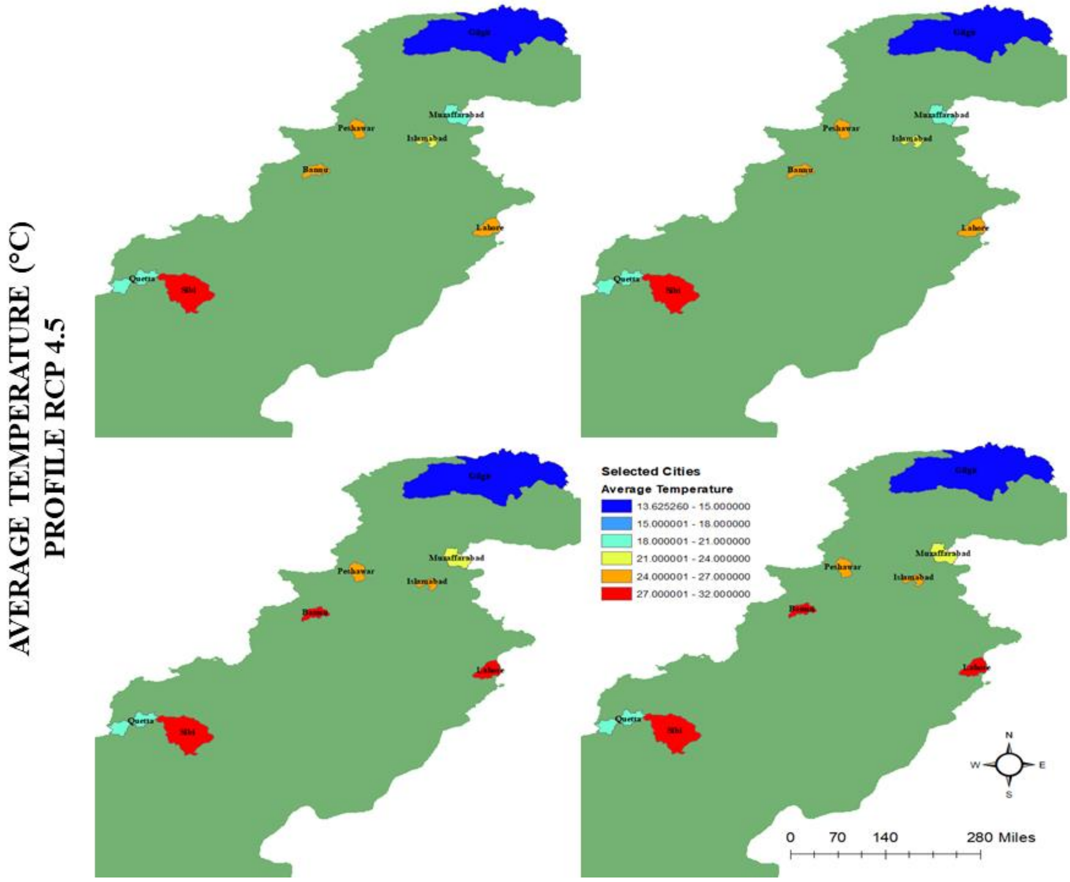

Figure 4.2: **Average temperature (°C) profile RCP 4.5 (a) 2021-40 (b) 2041-60 (c) 2061-80 (d) 2081-99**

The government-initiated measures and the switch to solar energy generation at the domestic level because of load shedding are responsible for Bannu having the lowest temperature rise (1.96327 °C) throughout the course of the century [1]. The greatest increase (3.8%) occurs between 2021-40 and 2041-60, and then it gradually decreases after that. Gilgit has the second-lowest temperature rise, which is 2.05926 degrees Celsius, although it has a different pattern than Bannu because of where it is geographically located and the climate zone in which it resides [2].

Because Quetta is situated on the Baluchistan plateau, the city has extremely hot summers and extremely cold winters. Temperatures in the city have risen by 2.8536 degrees Celsius due to the effects of CC, making it the location that has been most severely affected by the phenomenon. The daily sun radiation-horizontal population growth, the rapid expansion of industry, automobiles that contribute to pollution, and refrigerators that generate chlorofluorocarbon (CFC) are the key contributors to this [3]. Industrialization, a high number of automobiles, and urbanization are all interrelated factors that have led to an increase in temperature, and the two cities of Lahore and Islamabad have had the second and third biggest increases in temperature out of all the regions [4].

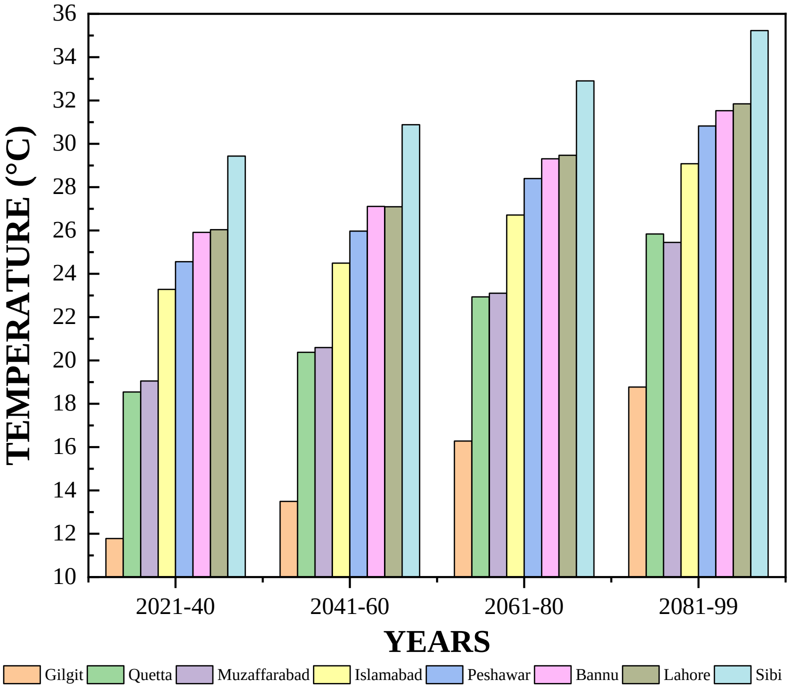

Figure 4.3: Average temperatures(°C) for each city across the century under RCP 8.5

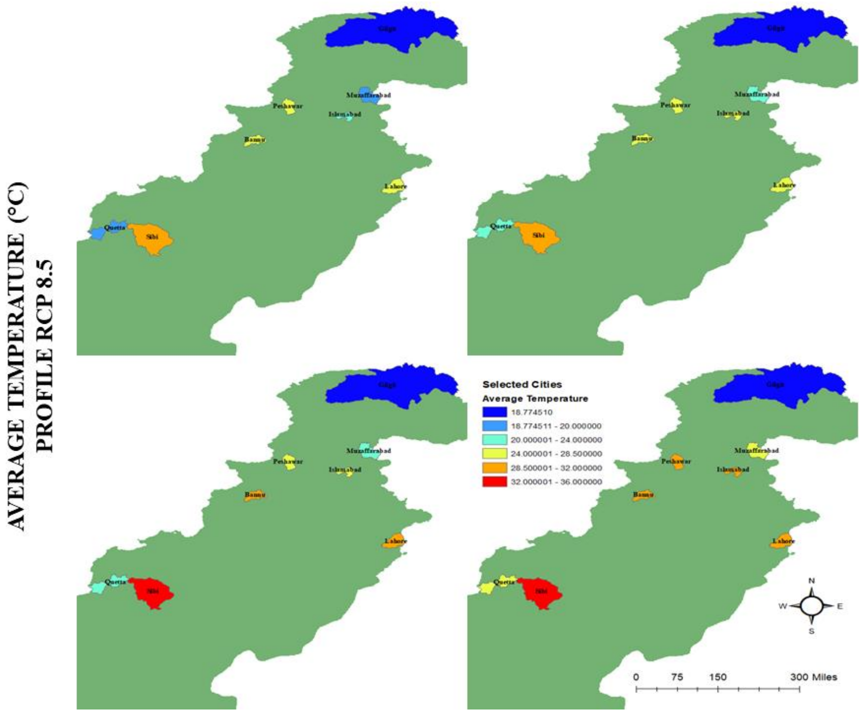

Figure 4.4: Average temperature (°C) profile RCP 8.5 (a) 2021-40 (b) 2041-60 (c) 2061-80 (d) 2081-99

According to Figure 4.3 for RCP 8.5, the temperature would rise at a faster rate than RCP 4.5 throughout the course of the century, ultimately reaching a maximum of 7.2897 °C (Quetta) or 39.34% (during the period of 2021–2099). This would be the case despite the fact that the temperature would rise at a slower rate than RCP 4.5. Other locations also show a significant increase in temperature toward the century's end under RCP 8.5, with Bannu exhibiting the lowest relative rise in temperature, at 21.68% (5.61661 °C), throughout the period of 2021–2099 [1]. This is the case even though Bannu shows the highest absolute rise in temperature. Because to CC, the average temperature in the country's selected areas is projected to rise by 27.98% by the century's end. Figure 4.5 gives an overall summary of the projections made using the two RCPs for the selected region over the course of the whole century.

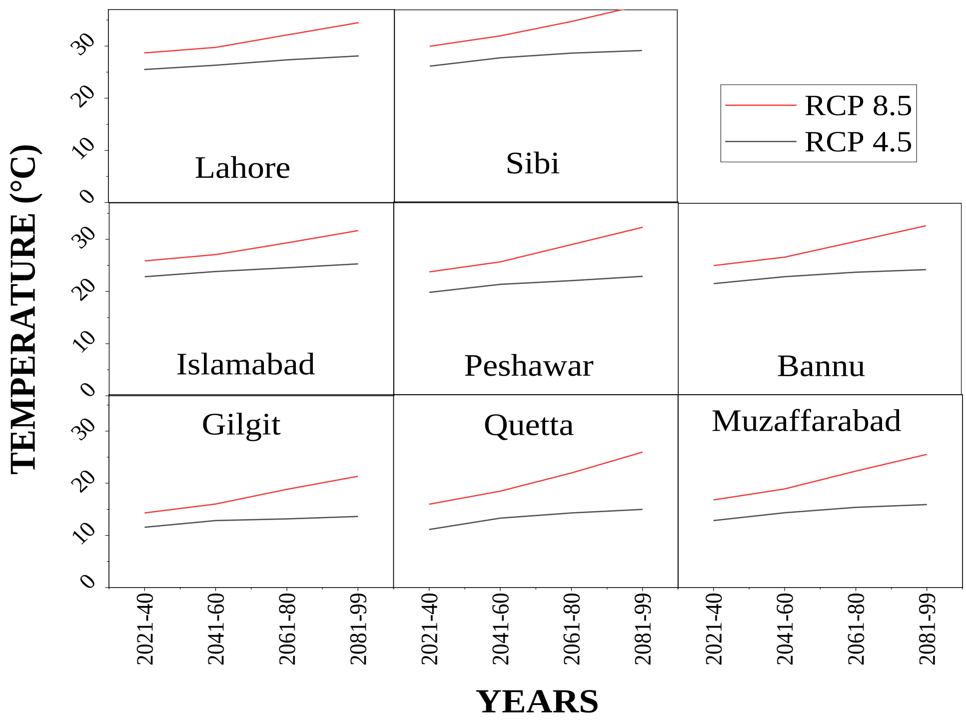

Figure 4.5: Average temperatures(°C) for each city across the century under RCP 4.5 and RCP 8.5

4.1.2. Precipitation Projections

The RCP 4.5 and RCP 8.5 models have been used to make the precipitation forecast. At least two cities from each of Pakistan's provinces were chosen as candidates for this survey. Gilgit, Quetta, Muzaffarabad, Islamabad, Peshawar, Bannu, and Lahore are among the cities being considered for the position. Sibi is also on the list. They are arranged at random with regard to the amount of precipitation. There are four distinct time periods that are utilized in order to partition the entire century: 2021–40, 2041–60, 2061–80, and 2081–1999. Figures 4.6 and 4.8 show the increases in average precipitation that have occurred across the country in the regions that are under attention. Figure 4.6 illustrates the RCP 4.5, whereas Figure 4.8 demonstrates the RCP 8.5.

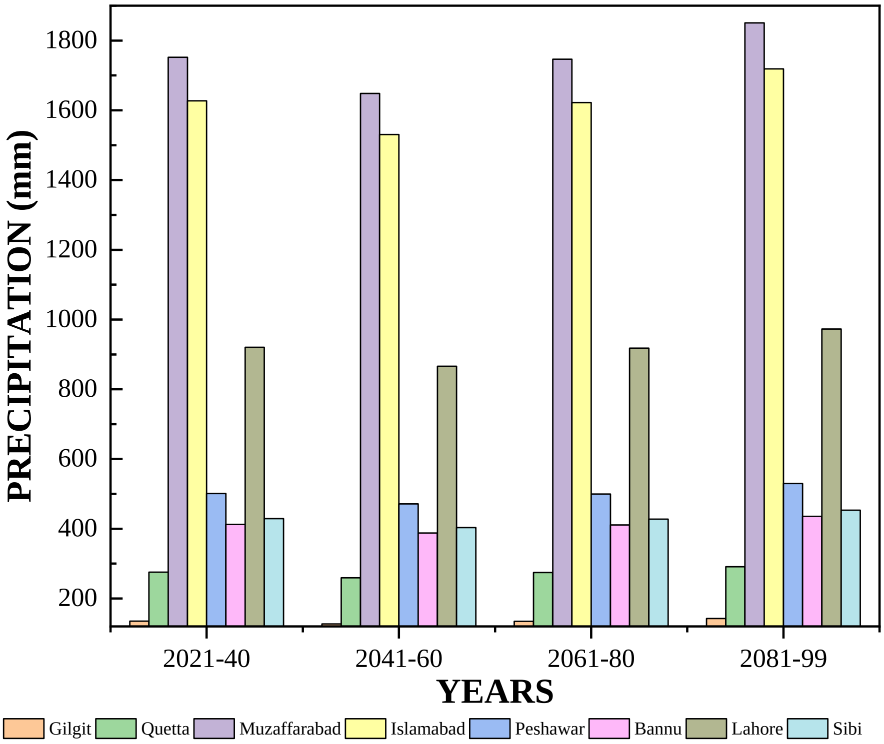

Figure 4.6: Average precipitations(mm) for each city across the century under RCP 4.5

Figure 4.6 depicts how the climate-related change in precipitation under the intermediate RCP 4.5 scenario follows a trend that is, for the most part, consistent across the time periods that are anticipated for the whole century. As was expected [5,6], our findings show that there will be a decrease of approximately 7-8% for the selected locations between the years 2021–40 and 2041–60 due to the CO_2 that is trapped in the earth's atmosphere and the rise in temperature that takes place over the same time period. This decline will take place between the years 2021–40 and 2041–60. However, the trend shifts again to one of growing throughout the decades 2061–80 and 2081–99 respectively. According to the RCP 4.5 emissions scenario, emissions will begin to decrease after 2045–2055, and the rate of precipitation decrease will level off by the century's end as the radiative pressing level steadies at 4.5 W/m^2 before 2100. Additionally, the RCP 4.5 emissions scenario predicts that the rate of temperature growth will level off by the century’s end. The RCP 4.5 scenario is a steadying scenario that uses a variety of technologies and approaches to reduce greenhouse gas emissions [6]. This scenario is part of the Representative Concentration Pathway (RCP) series. Concerning the growth of agricultural output and the generation of bioenergy in light of climate change, this scenario may be considered a touch overly optimistic.

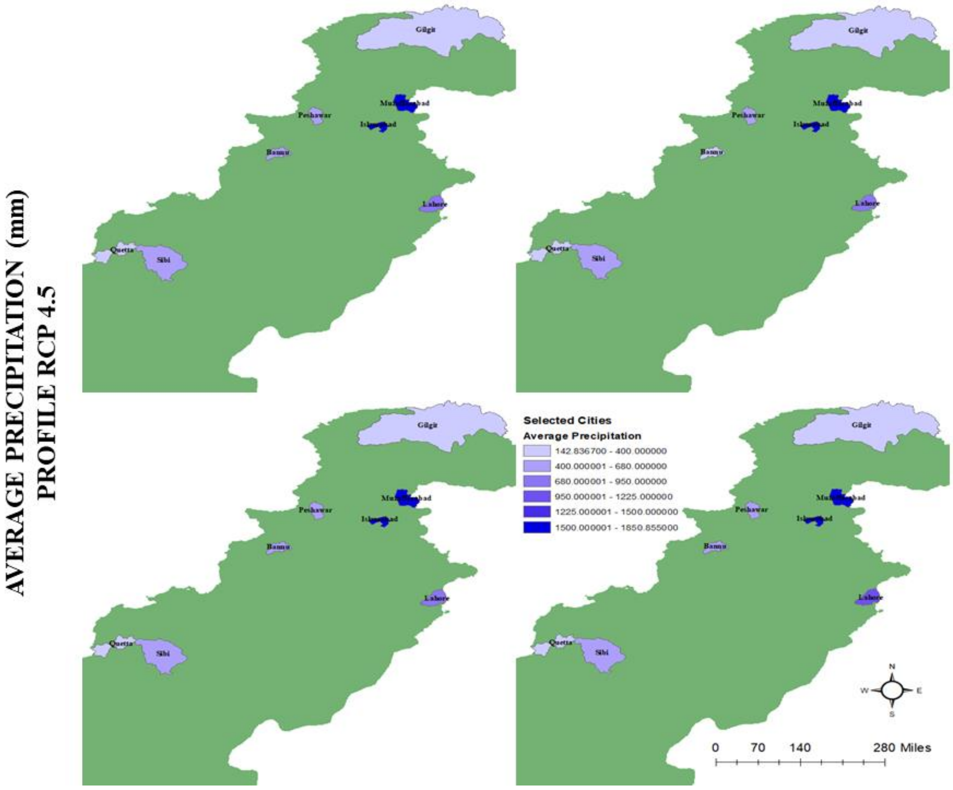

Figure 4.7: Average precipitation (mm) profile RCP 4.5 (a) 2021-40 (b) 2041-60 (c) 2061-80 (d) 2081-99

Because of its geographical location and climate zone, Gilgit has seen the greatest rise in precipitation throughout the course of the century analyzed [2]. This increase was 6.7%, which is equivalent to 7.6367 millimeters. Following a decrease of 8.0038 mm between the years 2021–40 and 2041–60, there was subsequently an increase in the years that followed [6]. The largest increase, which was 21.1 mm, happened between the years 2020 and 2021–40. Both Quetta and Gilgit share the exact same pattern and the second-highest rise in precipitation (6.43%, or 15.5672 millimeters), both of which are caused by the comparable weather conditions in both locations.

Islamabad is the city that has seen the least amount of a rise in precipitation, at only 5.82%. This is primarily because of the moisture-laden breezes that, in the hills' woodlands, cause rain to fall, which in turn causes the temperature to drop throughout the summer. Lahore has had the second lowest increases in precipitation of any area during the previous century [4], and this is mostly because to the growing presence of industry, a significant number of automobiles, and urbanization, all of which are interconnected with one another.

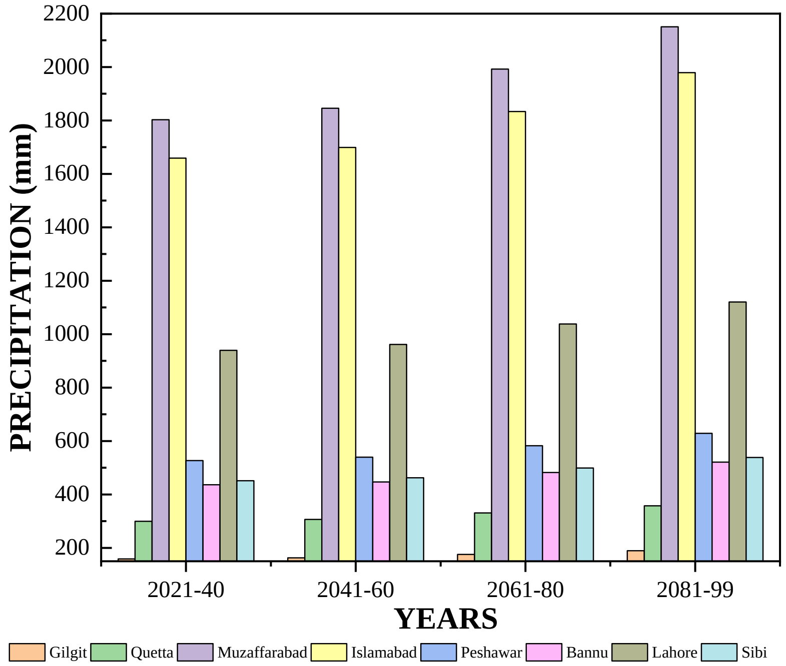

Figure 4.8: Average precipitations(mm) for each city across the century under RCP 8.5

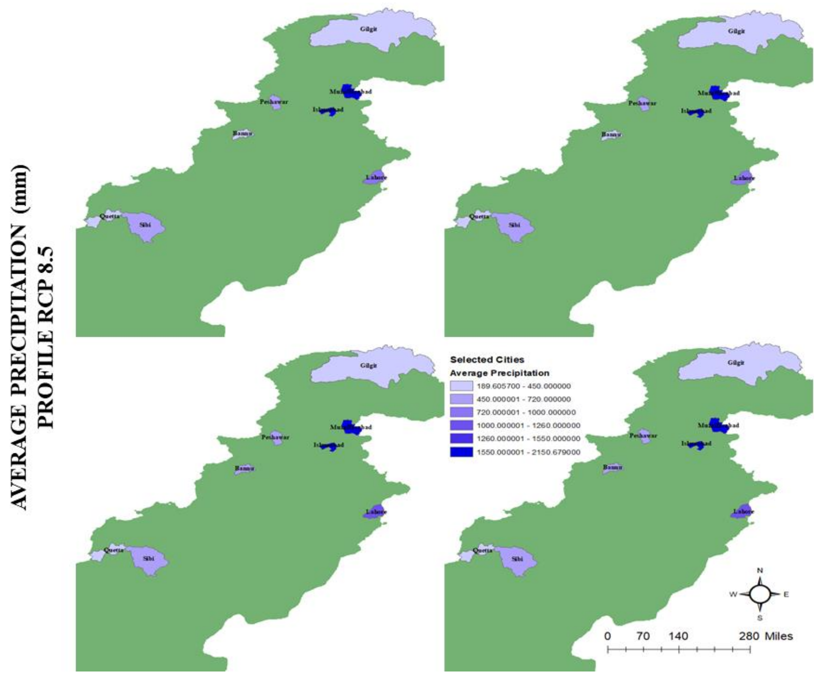

Figure 4.9: Average precipitation (mm) profile RCP 8.5 (a) 2021-40 (b) 2041-60 (c) 2061-80 (d) 2081-99

According to Figure 4.8 for RCP 8.5, the precipitation would grow at a rate that was quicker than RCP 4.5 during the course of the century, reaching a maximum of 26.87% at Gilgit (over the period of 2021–1999) [2]. Other places indicate a large rise in precipitation under RCP 8.5 over the course of the century, with Islamabad exhibiting the lowest relative increase at 20.243% (319.973 mm) from 2021 to 2099 [4]. By the end of this century, certain sections of the country will see an increase in annual precipitation of 22.15 percent on average as a direct effect of CC. Figure 4.10 provides a high-level summary of the projections that have been made using two different RCPs for the particular location over the course of the entire century.

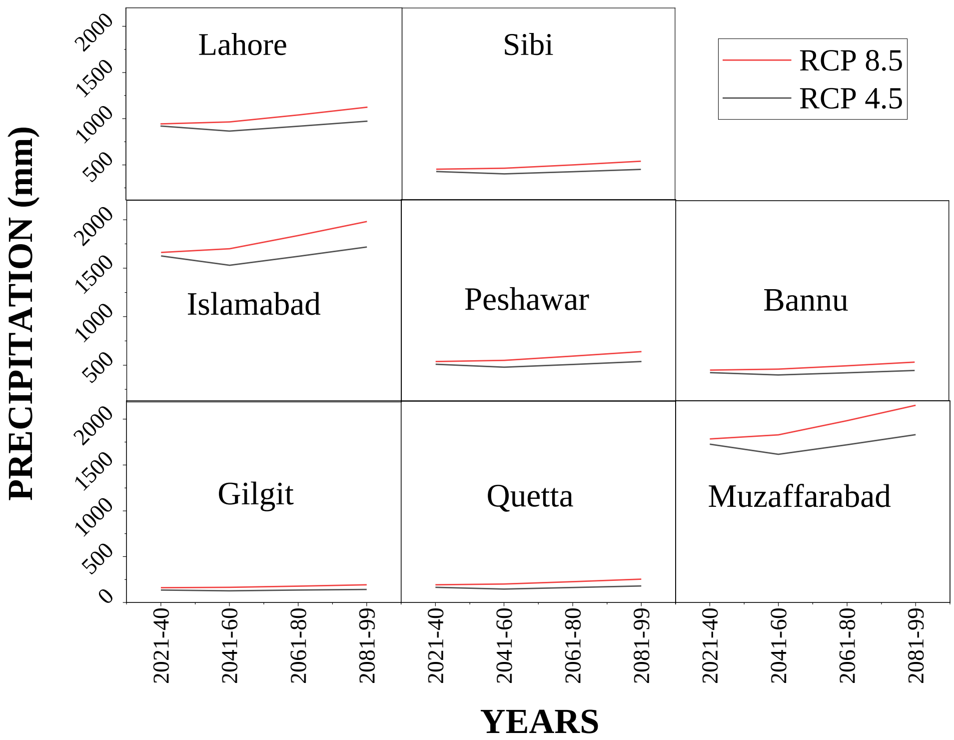

Figure 4.10: Average precipitation(mm) for each city across the century under RCP 4.5 and RCP 8.5

4.2. Effect of Temperature on Crops (Independent Estimates)

The key crops of Pakistan are subject to both high heat stress and mild heat stress, both of which alter their optimal temperature. Crops are altered by a wide range of critical elements, some of which contain temperature, precipitation, humidity, the accessibility of water, the convenience of land, and so on. The temperature is the only variable included in the essential indicators for this section because the aim of include it is to establish how the climate affects the crops that have been selected. Independent estimations are also taken into consideration. In the selected regions, an analysis of wheat, maize, rice, and sugarcane is carried out using RCP 4.5 and RCP 8.5 for the time periods 2021-40, 2041-60, and 2061-80, and for the time period 2081-99 respectively. Wheat needs temperatures between 19 and 22 degrees Celsius [7], maize needs temperatures between 28 and 34 degrees Celsius [8], rice needs temperatures between 25 and 35 degrees Celsius, and sugarcane needs temperatures between 27 and 38 degrees Celsius [9]. Every type of plant has a unique rate of yield reduction for every degree Celsius as the temperature rises. For every 1 degree Celsius that the temperature rises, there will be a 6% decrease in the yield of wheat [7,10–12], 7.4% decrease in the yield of maize [8,11], 3.2% decrease in the yield of rice, and a 10% increase in the yield of sugarcane [13–15].

4.2.1. RCP 4.5

Starting with the base year, 2020, and continuing to the time intervals that have been selected to divide the whole century, the change in temperatures under RCP 4.5 is displayed throughout several time periods. The temperature variations that have taken place are displayed in Table 4.1.

Table 4.1: Change in temperatures(°C) under RCP 4.5

CHANGE IN TEMPERATURE (°C)

YEARS	Gilgit	Quetta	Muzaf.	Isl.	Peshawar	Bannu	Lahore	Sibi
2021-40	1.196	-3.7554	0.603	0.5213	0.18271	0.3827	1.156	0.6683
2041-60	1.2895	1.59093	1.0971	1.012	1.11443	0.9742	0.8397	1.1777
2061-80	0.3223	0.73919	0.7574	0.7048	0.53451	0.6211	1.0318	0.6472
2081-99	0.4475	0.48524	0.3954	0.7604	0.58538	0.3679	0.7504	0.3778

Since RCP 4.5 is a steadiness scenario, all the temperatures by the century's end are optimistic and all fall under the 2°C tolerance set by the Paris Agreement. As previously stated, Quetta is the only city that would see a drop in temperature of 3.75541 °C showed in Table 4.1 from 2021 to 2040 because of daily horizontal radiation and other factors [3].

Wheat output during the century is shown in Table 4.2, with temperature variations by RCP 4.5. The wheat production is 2974 Kgs/Hec at the moment. Production rises when city temperatures approach the ideal range for wheat, which is 19-22 °C [7,10–12]. Only twice, in the time periods 2061–80 and 2081–99, is the production of wheat in Muzaffarabad is greater than the production at the time. The most desirable areas are Peshawar, Quetta, Islamabad, and Muzaffarabad according to the results.

Table 4.2: Wheat Production (Kgs/Hec) w.r.t temperature 4.5

WHEAT PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	1328.66	1520.7	1578.2	1658.1
Quetta	2536.25	2743.01	2874.91	2961.5
Muzaffarabad	2626.37	2877.64	3012.8	3083.3
Islamabad	2745.78	2646.87	2521.1	2385.4
Peshawar	2518.04	2357.11	2261.73	2157.3
Bannu	2276.28	2144.81	2033.98	1968.3
Lahore	2253.36	2200.34	2016.23	1882.3
Sibi	1648.15	1495.45	1379.97	1312.6

The production of maize during the century with temperature change is shown in Table 4.3 by RCP 4.5. The yield of maize is 5970 Kgs/Hec currently. The findings show that only Sibi will produce more maize than is now being done in all the chosen time frames, which are 2021–40, 2041–60, 2061–80, and 2081–99. To produce maize, Gilgit is the worst city. Bannu and Lahore show intermediate production of Maize.

Table 4.3: **Maize Production (Kgs/Hec) w.r.t temperature 4.5**

MAIZE PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	0	0	0	0
Quetta	1351.98	1863.88	2190.44	2404.81
Muzaffarabad	1575.1	2197.2	2531.83	2706.49
Islamabad	3442.58	3687.45	3998.82	4334.76
Peshawar	4006.41	4404.84	4640.97	4899.58
Bannu	4604.96	4930.44	5204.84	5367.39
Lahore	4661.69	4792.95	5248.78	5580.3
Sibi	6160.06	6538.11	6824.01	6990.94

The production of rice during the century with temperature change by RCP 4.5 is shown in Table 4.4. 2524 Kgs/Hec of rice are currently produced per year. Production rises when city temperatures approach the ideal range for rice, which is 25-35 °C [11]. The findings show that Lahore would produce more maize than the current production of Pakistan in 2021-40 and 2041-60, Bannu in 2041-60, and Peshawar in 2081-99. For the cultivation of rice, Lahore, Bannu, Peshawar, and Islamabad are the most desired cities.

Table 4.4: **Rice Production (Kgs/Hec) w.r.t temperature 4.5**

RICE PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	1375.42	1462.35	1488.37	1524.52
Quetta	1922.02	2015.61	2075.31	2114.5
Muzaffarabad	1962.81	2076.55	2137.72	2169.66
Islamabad	2304.23	2349	2405.93	2467.34
Peshawar	2407.31	2480.15	2523.33	2570.61
Bannu	2516.74	2576.25	2502.36	2472.64
Lahore	2527.11	2551.11	2494.32	2433.71
Sibi	2327.72	2258.6	2206.33	2175.81

Table 4.5 display the sugarcane production throughout the course of the century with temperature change as predicted by RCP 4.5. Currently, 69536 Kgs/Hec of sugarcane is produced annually. When city temperatures reach the 27–34 °C [9,13–15] optimal range for sugarcane, production increases. The results indicate that in 2061–80 and 2081–99, Lahore and Bannu will produce more sugarcane than Pakistan now does. Lahore, Bannu, Peshawar, and Sibi would be cities of importance for sugarcane farming.

Table 4.5: **Sugarcane Production (Kgs/Hec) w.r.t temperature 4.5**

SUGARCANE PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	0	0
Quetta	10755.7	18813.1	23953.1	27327.3
Muzaffarabad	14267.6	24059.5	29326.5	32075.6
Islamabad	43661.7	47516	52416.9	57704.7
Peshawar	52536.3	58807.6	62524.3	66594.8
Bannu	61957.5	67080.6	71399.6	73958.1
Lahore	62850.5	64916.5	72091.2	77309.4
Sibi	66544.5	60593.9	56093.9	53466.5

Error! Reference source not found. displays radar graphs of wheat, maize, rice, and s ugarcane production for RCP 4.5 with relation to temperature for the given time periods throughout the selected locations.

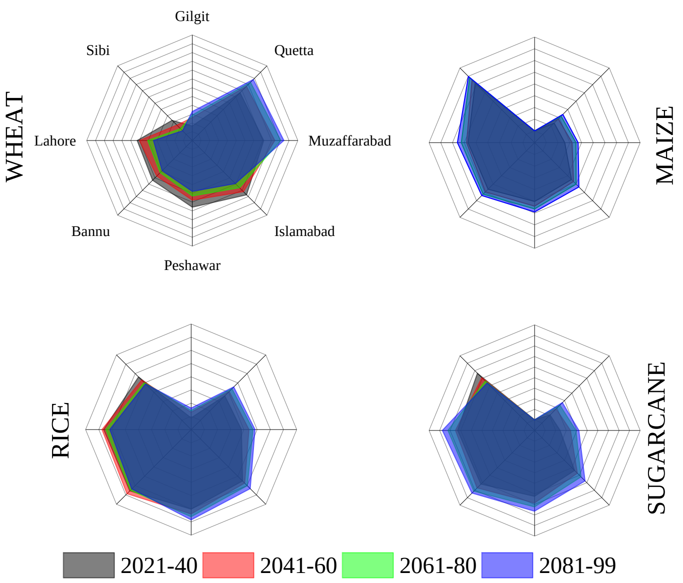

Figure 4.11: **Wheat, Maize, Rice and Sugarcane Production (Kgs/Hec) w.r.t temperature 4.5**

4.2.2 RCP 8.5

The variation in temperature that is predicted to occur as a result of RCP 8.5 is depicted using a number of different time periods, beginning with the base year of 2020, and continuing on through the time intervals that have been chosen to divide the entire century. Table 4.6 illustrates the temperature shifts that have taken place over the course of the study.

Table 4.6: Change in temperatures under RCP 8.5

	CHANGE IN TEMPERATURE (°C)							
YEARS	**Gilgit**	**Quetta**	**Muzaf.**	**Isl.**	**Peshawar**	**Bannu**	**Lahore**	**Sibi**
2021-40	1.4093	-3.323	0.2918	0.979	0.3952	0.6201	1.6985	0.9902
2041-60	1.7117	1.8317	1.5423	1.211	1.41781	1.2022	1.0584	1.4112
2061-80	2.7878	2.5564	2.5103	2.225	2.42405	2.1936	2.3752	2.0209
2081-99	2.4956	2.9014	2.345	2.367	2.424	2.2207	2.3701	2.3263

Since RCP 8.5 is a worst-case scenario, all the temperature increases by the end of the century will be 5-7 °C according to RCP 8.5 [16]. As previously stated, Quetta is the only city that would see a drop in temperature of 3.32322 °C showed in Table 4.6 from 2021 to 2040 because of daily horizontal radiation and other factors [3].

Wheat output throughout the course of the century is shown in Table 4.7 along with temperature change as anticipated by RCP 8.5. The current yearly production of wheat is 2974 Kgs/Hec. Production rises when city temperatures approach the 19–22 °C [7,10–12] range that is ideal for growing wheat. The findings show that, except for Quetta in 2061–80, no city's output of wheat will exceed that of the present century over the time periods chosen. Quetta, Muzaffarabad, and Islamabad would be significant cities for sugarcane production.

Table 4.7: **Wheat Production (Kgs/Hec) w.r.t temperature 8.5**

WHEAT PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	1328.66	1634.1	2131.56	2576.88
Quetta	2536.25	2863.11	3319.28	2289.42
Muzaffarabad	2626.37	2901.59	2776.91	2358.41
Islamabad	2745.78	2529.61	2132.46	1710.07
Peshawar	2518.04	2265.04	1832.5	1399.81
Bannu	2276.28	2061.04	1670.32	1274.05
Lahore	2253.36	2064.49	1640.65	1217.72
Sibi	1648.15	1389.2	1028.58	613.465

Table 4.8 display maize production throughout the course of the century together with temperature change predicted by RCP 8.5. 5970 Kgs/Hec of maize are produced annually as of now. When city temperatures reach the 28–34 °C [8,11] range, which is suitable for growing maize, production increases. The results indicate that several cities, including Islamabad and Peshawar in the years 2081–1999, Bannu and Lahore in the years 2061–80, and Sibi in the years 2021–40, will produce more maize than the nation at the time. The output of maize would be substantial in the abovementioned cities.

Table 4.8: **Maize Production (Kgs/Hec) w.r.t temperature 8.5**

MAIZE PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	350.064	1452.58
Quetta	1351.98	2161.22	3290.61	4572.42
Muzaffarabad	1575.1	2256.48	3365.5	4401.61
Islamabad	3442.58	3977.75	4961.01	6006.76
Peshawar	4006.41	4632.77	5703.66	6774.91
Bannu	4604.96	5136.07	6105.19	5295.2
Lahore	4661.69	5129.31	6178.64	5156.07
Sibi	6160.06	5580.61	4687.78	3660.05

The output of rice throughout the course of the century is shown in Table 4.9 together with the change in temperature projected by RCP 8.5. Currently, 2524 Kgs/Hec of rice is produced yearly. Production rises when city temperatures approach the 25–35 °C [11] range, which is ideal for rice cultivation. The findings suggest that cities like Islamabad would produce more rice than the entire country at the time in 2061–2080, Bannu in 2041–60, and Lahore in 2021–40 and 2041–60. The abovementioned cities, as well as Sibi and Peshawar, would all produce a significant amount of rice.

Table 4.9: **Rice Production (Kgs/Hec) w.r.t temperature 8.5**

RICE PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	1375.42	1513.68	1738.84	1940.41
Quetta	1922.02	2069.97	2276.45	2510.79
Muzaffarabad	1962.81	2087.38	2290.14	2479.56
Islamabad	2304.23	2404.07	2581.84	2436.51
Peshawar	2407.31	2521.83	2491.92	2296.08
Bannu	2516.74	2616.84	2418.52	2239.15
Lahore	2527.11	2612.6	2405.09	2213.66
Sibi	2408.48	2291.27	2128.04	1940.15

Table 4.10 display the sugarcane production throughout the course of the century together with the change in temperature predicted by RCP 8.5. The current annual production of sugarcane is 69536 Kgs/Hec. When city temperatures reach the 27–34 °C [9,13–15] range, which is suitable for sugarcane farming, production increases. The results indicate that cities like Peshawar, Bannu, and Lahore will produce more sugarcane than the entire nation at the time in 2061–2080, 2041–60, and 2021–40, respectively. The abovementioned cities would all generate a considerable quantity of sugarcane, as well as Sibi and Islamabad.

Table 4.10: **Sugarcane Production (Kgs/Hec) w.r.t temperature 8.5**

SUGARCANE PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	0	12339.2
Quetta	10755.7	23493.2	41269.8	61445.3
Muzaffarabad	14267.6	24992.5	42448.5	58576.8
Islamabad	43661.7	52085.2	67561.7	68957.3
Peshawar	52536.3	62395.2	73728.1	56866.7
Bannu	61957.5	70317.1	67408.1	51966.1
Lahore	62850.5	70210.7	66252	49771.2
Sibi	66544.5	56453.4	42400.3	26223.9

Figure 4.12 shows radar graphs of the production of rice, wheat, maize, and sugarcane for RCP 8.5 in relation to temperature for the specified time periods throughout the chosen sites.

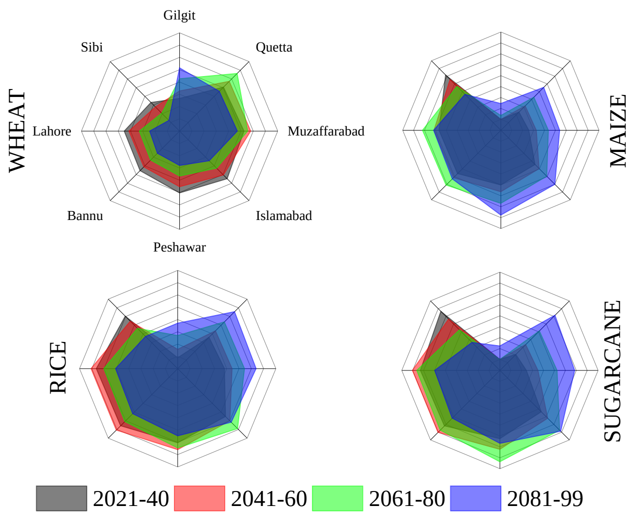

Figure 4.12: **Wheat, Maize, Rice and Sugarcane Production (Kgs/Hec) w.r.t temperature 8.5**

4.3. Effect of Precipitation on Crops (Independent Estimate)

Important crops in Pakistan are impacted by high and low rainfall amounts relative to the appropriate quantity of precipitation for such crops. Crops are impacted by an amount of significant aspects, such as temperature, precipitation, humidity, water availability, land availability, etc. Precipitation, which is present to observe how it impacts the crops that have been chosen, is the only variable in this section's crucial indicators when independent estimates are considered. The analysis of wheat, maize, rice, and sugarcane is conducted for the time periods of 2021–40, 2041–60, 2061–80, and 2081–99 for the selected regions using RCP 4.5 and RCP 8.5. For the best growth of important crops, the amount of precipitation is 500-750 mm for wheat [17,18], 500-1000mm for maize [11,19,20], 1000-2520 mm for rice [11,20], and 1000-1500 mm for sugarcane [9,13–15,20]. Each crop has a distinct rate of yield loss.

4.3.1. RCP 4.5

Table 4.11 shows the change in precipitation under RCP 4.5 throughout multiple time periods, starting with the base year 2020 and continuing to the time intervals chosen to split the whole century.

Table 4.11: Change in precipitation(mm) under RCP 4.5

CHANGE IN TEMPERATURE (°C)								
YEARS	**Gilgit**	**Quetta**	**Muzaf.**	**Isl.**	**Peshawar**	**Bannu**	**Lahore**	**Sibi**
2021-40	21.1	33.6	112.6	46.4	24.22	28	40	19
2041-60	-8.004	-16.315	-103.71	-96.32	-29.6722	-24.414	-54.5	-25.397
2061-80	7.9536	15.4793	98.396	91.381	28.1514	23.1629	51.706	24.0951
2081-99	8.0469	16.4034	104.271	96.837	29.832	24.5456	54.793	25.5336

All of the precipitation by the end of the century is optimistic and is within the 7-8% tolerance given since RCP 4.5 is a stabilization scenario [5,6].

Table 4.12 display the century's wheat production together with fluctuations in precipitation calculated using RCP 4.5. Presently, 2974 Kgs/Hec of wheat are produced. When city precipitation reaches the 500-750 mm level that is favorable for wheat, production increases [17,18]. The amount of wheat produced in Peshawar exceeds the amount produced at the moment just twice, in the decades 2021–40 and 2081–99.

Table 4.12: Wheat Production (Kgs/Hec) w.r.t precipitation 4.5

WHEAT PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	0	0	0	0
Islamabad	0	0	0	0
Peshawar	3191.7	2403.01	2973	3432
Bannu	2081	1703.18	2077	2111.56
Lahore	2153.36	2104	2149.65	2129
Sibi	2103.4	2039.54	2100.005	2210

The production of maize throughout the course of the century with fluctuation in precipitation is depicted by RCP 4.5 in Table 4.13. Currently, maize is yielding 5970 Kgs/Hec. When city precipitation gets close to the 500-1000 mm range that's good for maize, production increases [11,19,20]. According to the results, only Peshawar will generate more maize than is now being done in all four of the selected time periods (2021–40, 2041–60, 2061–80, and 2081–99). Lahore is also a good place to cultivate maize. Bannu and Sibi demonstrate intermediate maize production.

Table 4.13: Maize Production (Kgs/Hec) w.r.t precipitation 4.5

MAIZE PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	0	0	0	0
Islamabad	0	0	0	0
Peshawar	6530	6121	6412	6717
Bannu	4980	4210	4968	5367.39
Lahore	5848	5713	5839.12	5901
Sibi	5130	4871	5121.56	5641

Table 4.14 display the output of rice throughout the course of the century together with changes in precipitation predicted by RCP 4.5. Currently, 2524 Kgs/Hec of rice is produced annually. The results indicate that Muzaffarabad and Islamabad would produce more maize than Pakistan does at the moment. Muzaffarabad, Islamabad, and Lahore are the most sought-after cities for rice farming.

Table 4.14: **Rice Production (Kgs/Hec) w.r.t precipitation 4.5**

RICE PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	2627	2612	2621	2640
Islamabad	2610	2599	2601	2629
Peshawar	0	0	0	0
Bannu	0	0	0	0
Lahore	2103	2003	2099	2356
Sibi	0	0	0	0

The output of sugarcane throughout the course of the century is shown in Table 4.15 with respect to the change in precipitation projected by RCP 4.5. The yearly production of sugarcane is now 69536 Kgs/Hec. Production rises when city precipitation reaches the 1000–1500 mm [9,13–15,20] optimum range for sugarcane. According to the findings, no city will generate more sugarcane than is already being done. Cities like Muzaffarabad, Islamabad, and Lahore will be crucial for sugarcane growing.

Table 4.15: **Sugarcane Production (Kgs/Hec) w.r.t precipitation 4.5**

SUGARCANE PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	64530	64555	64511	63415
Islamabad	65231	69422	65220	64330
Peshawar	0	0	0	0
Bannu	0	0	0	0
Lahore	68631	67115	68610	68789
Sibi	0	0	0	0

Radar graphs showing the production of rice, wheat, maize, and sugarcane for RCP 4.5 in connection to precipitation over the designated time periods are displayed in Figure 4.13 for the selected sites.

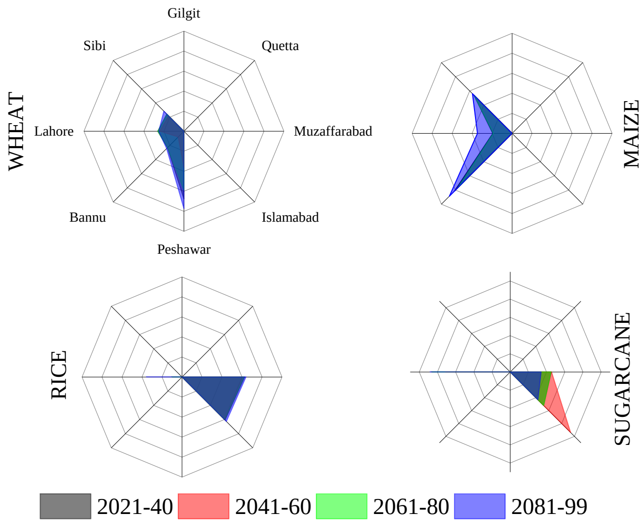

Figure 4.13: **Wheat, Maize, Rice and Sugarcane Production (Kgs/Hec) w.r.t precipitation 4.5**

4.3.2 RCP 8.5

Table 4.16 shows the change in precipitation under RCP 8.5 throughout many time periods, starting with the base year 2020 and continuing to the time intervals chosen to split the whole century.

Table 4.16: Change in precipitation(mm) under RCP 4.5

CHANGE IN TEMPERATURE (°C)

YEARS	Gilgit	Quetta	Muzaf.	Isl.	Peshawar	Bannu	Lahore	Sibi
2021-40	44.584	57.58	163.7	78.721	50	52.187	58.94	41.456
2041-60	3.7831	7.13	42.911	39.492	12.5426	10.3908	22.3611	10.7447
2061-80	12.9213	24.3528	146.566	134.886	42.8397	35.49	76.3749	36.6987
2081-99	13.9473	26.2864	158.202	145.595	46.2411	38.3079	82.439	39.6126

Since RCP 8.5 represents the worst-case scenario, it predicts that all increases in precipitation by the end of the century would occur in certain locations while decreasing in others [2].

Table 4.17 depict wheat output throughout the course of the century in relation to predicted precipitation change from RCP 8.5. Currently, 2974 Kgs/Hec of wheat are produced annually. When city precipitation reaches the 500–750 mm [17,18] range, which is suitable for growing wheat, production increases. The results indicate that no city's wheat output would surpass that of the 20th century across the selected time periods, with the exception of Peshawar for the whole century and Sibi in 2081–2099.

Table 4.17: **Wheat Production (Kgs/Hec) w.r.t precipitation 8.5**

WHEAT PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	0	0	0	0
Islamabad	0	0	0	0
Peshawar	3440	3480	3603.1	3815.6
Bannu	2118	2201	2440	2700
Lahore	2135	1615.4	1411.4	1210
Sibi	2215	2310	2478	3478

Currently, 5970 Kgs/Hec of maize is produced yearly, and Table 4.18 show maize production during the course of the century in accordance with the precipitation change anticipated by RCP 8.5. Production rises when precipitation in cities reaches the 500–1000 mm [11,19,20] range, which is ideal for maize cultivation. The findings show that certain cities would produce more maize than the country at the time, notably Peshawar throughout the century, Lahore in the years 2061–80, and Bannu and Sibi in the years 2081–99. The aforementioned cities would produce a sizable amount of maize.

Table 4.18: **Maize Production (Kgs/Hec) w.r.t precipitation 8.5**

MAIZE PRODUCTION (Kgs/Hec)

CITIES	2021-40	2041-60	2061-80	2081-99
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	0	0	0	0
Islamabad	0	0	0	0
Peshawar	6721	6748	6779	6801
Bannu	5410	5541	5912	5979
Lahore	5874	5901	5972	5899
Sibi	5655	5699	5899	5974

Table 4.19 combined depict the output of rice during the course of the century in accordance with the change in precipitation predicted by RCP 8.5. The current annual production of rice is 2524 Kgs/Hec. According to the research, Lahore in the years 2061–80 and 2081–99 will produce more rice than the entire nation, followed by places like Muzaffarabad and Islamabad which exceeds through all time periods.

Table 4.19: **Rice Production (Kgs/Hec) w.r.t precipitation 8.5**

RICE PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	2655	2668	2674	2681
Islamabad	2619	2628	2662	2670
Peshawar	0	0	0	0
Bannu	0	0	0	0
Lahore	2348	2352	2529	2560
Sibi	0	0	0	0

Table 4.20 display the sugarcane production throughout the course of the century together with the change in precipitation predicted by RCP 8.5. 69536 Kgs/Hec is the current annual sugarcane output rate. Production rises when city precipitation reaches the 1000–1500 mm [9,13–15,20] range, which is ideal for sugarcane planting. According to the findings, only Lahore would produce more sugarcane than the entire country at that time in 2081–99.

Table 4.20: **Sugarcane Production (Kgs/Hec) w.r.t precipitation 8.5**

SUGARCANE PRODUCTION (Kgs/Hec)				
CITIES	**2021-40**	**2041-60**	**2061-80**	**2081-99**
Gilgit	0	0	0	0
Quetta	0	0	0	0
Muzaffarabad	63445	62001	60032	54030
Islamabad	64666	64364	61951	56213
Peshawar	0	0	0	0
Bannu	0	0	0	0
Lahore	68401	69501	69450	70101
Sibi	0	0	0	0

Figure 4.14 for the chosen sites displays radar graphs for the production of rice, wheat, maize, and sugarcane under RCP 8.5 in relation to precipitation across the defined time periods.

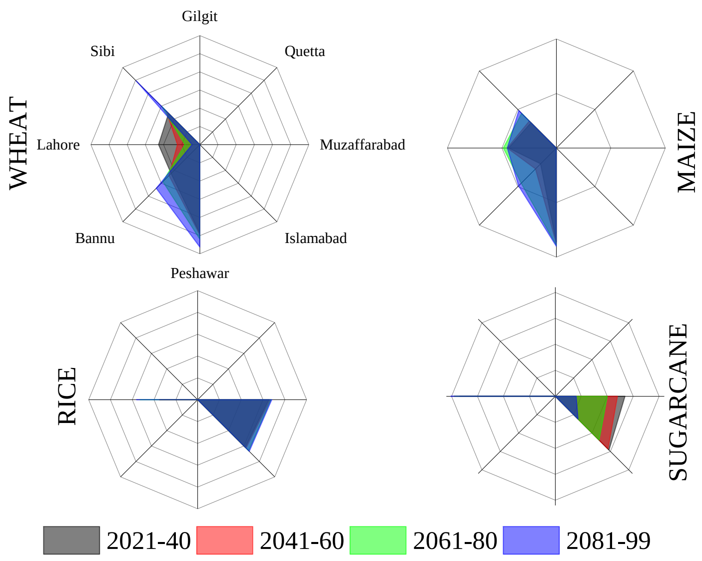

Figure 4.14: **Wheat, Maize, Rice and Sugarcane Production (Kgs/Hec) w.r.t precipitation 8.5**

Table 4.21 and Table 4.22 contain a comprehensive summary of the portion devoted to the outcomes. The table that covers the temperature is Table 4.21, while the table that covers the precipitation is Table 4.22. Both tables show the minimum and maximum tolerance limits of temperature and precipitation for the crops, which include wheat, maize, rice, and sugarcane, respectively, so that they can develop to their full potential. The production is shown in connection to RCP 4.5 and 8.5, along with the cities and time periods that will be ideal and will have the highest output possible.

Table 4.21: Crops Temperature tolerances', Yield drop and Production w.r.t RCP 4.5 and 8.5 [7–15]

CROPS	Min. Optimum T °C	Max. Optimum T °C	Yield Drop/°C rise %	Max Production Kgs/Hec	RCP 4.5	Max Production Kgs/Hec	RCP 8.5
Wheat	19	22	6	3083.3	Muzaf. (2081-99)	3319.28	Quetta (2061-80)
Maize	28	34	7.4	6990.94	Sibi (2081-99)	6774.91	Peshawar (2081-99)
Rice	25	35	3.2	2576.25	Bannu (2041-60)	2616.84	Bannu (2041-60)
Sugarcane	27	38	10	77309.4	Lahore (2081-99)	73728.1	Peshawar (2061-80)

Table 4.22: **Crops Precipitation tolerances' and Production w.r.t RCP 4.5 and 8.5 [11,13–15,17,18,20]**

CROPS	Min. Optimum Precipitation mm	Max. Optimum Precipitation mm	Max Production Kgs/Hec	RCP 4.5	Max Production Kgs/Hec	RCP 8.5
Wheat	500	750	3432	Peshawar (2081-99)	3815.654	Peshawar (2081-99)
Maize	500	1000	6717	Peshawar (2081-99)	6801	Peshawar (2081-99)
Rice	1000	2520	2640	Muzaf. (2081-99)	2681	Muzaf. (2081-99)
Sugarcane	1000	1500	69422	Islamabad (2041-60)	70101	Lahore (2081-99)

All of the facts mentioned in the preceding sections are summed in the form of Figure 4.15, which depicts the behavior of Pakistani cities in response to changing climate conditions and the conversion of arable land to non-arable land and vice versa or remaining the same and showing same behavior.

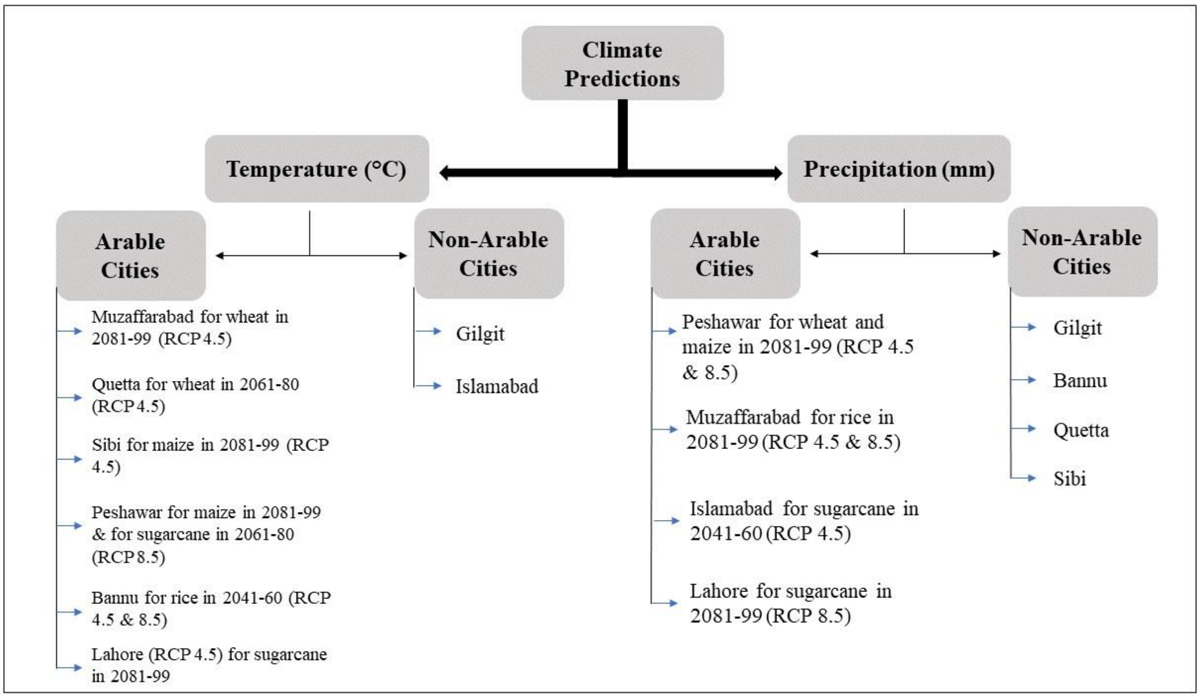

Figure 4.15: Selected cities behavior to climate change

4.4. Impact on Sustainable Bioenergy Generation

In order to determine the bioenergy capacity, it was essential to first compute the crop production based on the fluctuation that is likely to occur in the next era according to RCP 4.5 and 8.5. The method entailed doing an analysis on each of the chosen cities and picking the best suited site based on the resulting data primarily because agricultural biomass is one of the principal feedstocks for the development of bioenergy. This investigation seeks to quantify the amount of crop-related residue that will ultimately be created [21]. The residue-to-crop ratios can be found in Table 4.23.

Table 4.23: **Residue to crop ratios (RCR)**

Crops	Residue	Residue Type	RCR, average	RCR, min	RCR, max
Wheat	Straw	Field	1,00	0,50	1,30
Rice	Straw	Field	1,00	0,42	1,30
Rice	Husks	Process	0,20	0,15	0,36
Maize	Stalks	Field	1,25	1,00	2,25
Maize	Cobs	Process	0,33	0,20	0,86
Maize	Shells (husk)	Process	0,22	0,20	0,30
Sugarcane	Trash	Field	0,12	0,10	0,20
Sugarcane	Bagasse	Process	0,30	0,26	0,32

The RCR, as was discussed previously, is one of the most important elements that will impact the production of bioenergy. The Figure 4.16 summarizes all of the other key factors that will impact the bioenergy generation's sustainability. It's possible that different environmental indicators may be required at various stages and activities during the course of the biofuel supply chain. The making of feedstock, its administration, and the logistics behind its conversion and final usage are all included in the supply chain. Figure 4.16 has a number of different types of indicators. The majority of these categories pertain to the early stages of the supply chain (i.e., the manufacture and collecting of feedstock), whereas less classifications apply to the latter phases. Because there are more categories to choose from and they are more diverse in the early stages, it is more difficult to determine which indicators should be prioritized and how to quantify them. It is important to choose and understand biodiversity indicators in a way that makes sense for the place where they are used. For example, indicators can be chosen to show site-specific improvement plans and territory needs for regionally threatened species. Smeets and Faaij (2010) state that expert judgement and global ecosystem analysis can estimate the three-dimensional areas needed to safeguard biodiversity, but site-specific conditions and biodiversity goals yield the best protected areas. Thus, biodiversity goals create effective protected areas. Common ecological measures, such as total vegetative cover, species richness, and the presence, density, or cover of indicator species, have geographical distribution and magnitude definitions and should represent the evaluation aim

[22]. The biofuel supply chain presented in Figure 4.16 can use greenhouse gas indicators throughout all steps.

After considering all that has been said, we may reach the following conclusion: RCR and the other factors have an immediate effect on the growth of sustainable bioenergy. Now that we have gathered statistics, we will evaluate it to determine which cities have the potential according to our results to produce the largest production using the biofuel system that is shown in Figure 4.16.

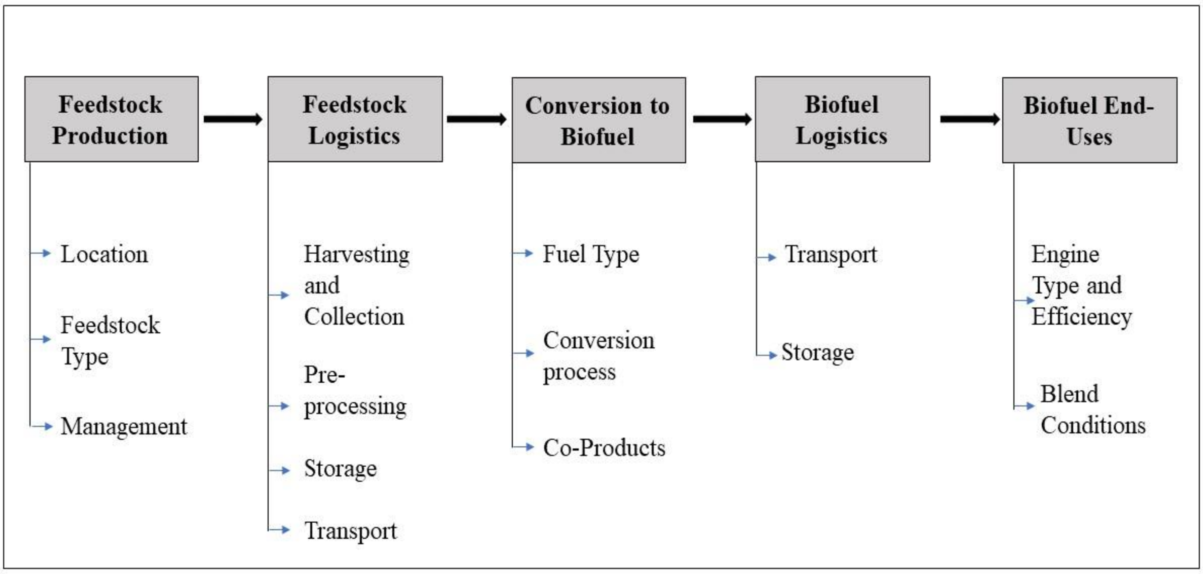

Figure 4.16: Biofuel System

Muzaffarabad, Quetta, and Peshawar are the cities that have showed the most improvement for wheat, while Peshawar is the city that has shown the most progress overall. Both Sibi and Peshawar have achieved impressive results with maize, which has a significant untapped potential for the development of bioenergy. Because of the changing environment, Bannu and Muzaffarabad are the two cities that are most suited for growing rice and will have the maximum output. The tiled numbers for sugarcane in Lahore, Peshawar, and Islamabad have showed some encouraging trends. The findings of all of these tests are discussed in the section that you just read. As a result, the feedstock logistics unit ought to be established in these regions in order to improve the environment's overall resilience. And the power plants that are constructed in these regions will also contribute to the improvement of the biodiversity. This is because they will be of assistance to the entire community in the previously mentioned cities, as they will generate employment opportunities and reduce the costs of transporting biomass, thereby making a greater contribution to the achievement of sustainability goals [23].

Summary

The wheat projection predicts that Muzaffarabad (2081-99) and Quetta (2061-80) would have the highest production in terms of temperature, while Peshawar (2081-99) will have the highest production in terms of precipitation (RCP 4.5 & 8.5). (RCP 4.5 & 8.5). Both Sibi (2081-99) and Peshawar (2081-99) will generate the most maize in terms of temperature (RCP 4.5 and 8.5), but Peshawar (2081-99) will produce the most maize in terms of precipitation (RCP 4.5 & 8.5). Based on temperature (RCP 4.5 & 8.5), Bannu (2041–60) will produce the most rice, whereas Muzaffarabad (2081–99) would produce the most rice based on precipitation (RCP 4.5 & 8.5). Lahore (2081-99) and Peshawar (2061-80) would produce the most sugarcane based on temperature (RCP 4.5 and 8.5), whereas Islamabad (2041-60) and Lahore (2081-99) will do so based on precipitation (RCP 4.5 & 8.5).

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Chapter 5

Conclusions and Recommendations

5.1. Conclusions

CC is one of the extremely serious dangers to our current way of life, and it will undoubtedly have an impact on many elements of our existence, including bioenergy systems. Our findings suggest that, in the worst-case situation of CC, the bioenergy system in Pakistan's selected cities would suffer significant consequences. This research investigated the effects of CC on the production of sustainable bioenergy in the cities of Gilgit, Quetta, Muzaffarabad, Islamabad, Peshawar, Bannu, Lahore, and Sibi, which are all located in different Pakistani provinces, using GCMs, bias correction techniques, and other models. The shifts in temperature and precipitation, as well as their impacts on the output of wheat, maize, rice, and sugarcane in the aforementioned cities, were computed using datasets and other models to predict RCP 4.5 and 8.5 under various future scenario-periods. The lack of favorable conditions would have a severe influence on crop production. Both of these factors will work in tandem; for example, a decline in agricultural output would make it more difficult to meet the rising demand from bioenergy users. This positive feedback effect would be disastrous for Pakistan, a developing country with a frail economy. According to the RCP 4.5 scenario, if emissions begin to drop by the 2050s, agricultural production might have optimal circumstances in some of the selected cities in terms of the independent variables (temperature and precipitation). Only Quetta would experience a temperature drop for RCPs 4.5 and 8.5, followed by a climb until the century's end. According to temperature RCP 4.5, Muzaffarabad, Sibi, Bannu, and Lahore will produce the most wheat, maize, rice, and sugarcane in the latter half of the century. Quetta and Peshawar would produce the most wheat and rice, respectively, with Peshawar producing the most maize and sugarcane (RCP 8.5). Peshawar will be feasible for producing wheat and maize under RCP 4.5 and 8.5 precipitation, but Muzaffarabad will be viable for growing rice under RCP 4.5 and 8.5 precipitation, and sugarcane under RCP 4.5 and 8.5 precipitation in Islamabad and Lahore. The disadvantages could be mitigated further by implementing functional canal systems, deploying more energy- and temperature-resistant technologies, and making better use of available water. The fact that crop production in places like Lahore, which has a high population density and experiences significant seasonal temperature variations, is not as severely impacted by temperature as it is in some smaller districts across the country, indicating that this region is more dependent on other, far more important factors.

5.2. Future Recommendations

On the basis of these results of this research project, some suggestions for the future include putting more of an emphasis on renewable energy sources and the requirement for sufficient crop protection measures. After disastrous floods hit much of Sindh province and the southern part of Punjab province, it took 60 days for the water to drain out and 30 days for the land to be ready for agricultural production. Climate change and rising temperatures near colder places melted glaciers and spilled water into the surrounding areas, causing the flood. The first and most significant recommendation is that we ought to build additional dams for the purpose of storing water and channeling it in challenging conditions using an appropriate canal system to sustain it. As a result of the fact that Pakistan has been hit by devastating flooding not once, but twice in the past ten years, this is an essential necessity. Another option is to focus on regions that have adapted effectively to CC and plant crops bearing the conclusions of this study in mind. This would be an effective use of resources. Finally, national and domestic incentives for renewable energy use should highlight the importance of renewable technology.

Appendix-A

Climate Change Impacts on Sustainable Bioenergy Production in Pakistan

Energy and Environment (IF = 3.154)

Authors: Aqib Nawaz Khan, Rabia Liaquat, Umair Safdar