Optimizing Sustainable Energy Solutions: A Comprehensive Analysis of Environmental Impacts in Pakistan's Agricultural Sector Using the TIMES Model

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Session 2020-22

Supervised by

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THESIS ACCEPTANCE CERTIFICATE

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ABSTRACT

Energy security and environmental issues are the main concerns which are currently faced by Pakistan. The agriculture sector is highly dependent on fossil fuels and employs obsolete technologies for energy fulfilment, which produces GHG emissions. Generally, the agriculture sector’s energy demand is 50 PJ, major source of which is fossil fuels. Customized VEDA-TIMES, a linear programming optimization model is developed that focuses on existing technologies/machinery commissioned in agriculture sector to analyze direct energy demand, supplies and associated emissions for Pakistan by 2060. Through the integration of renewable energy sources, this study seeks to optimize the nation's agricultural energy system for reduced environmental impact and increased resilience. Starting in 2025, decentralized renewable alternatives are introduced through the solar inclusion and biodiesel inclusion scenarios, to meet global commitments. The model considers sustainable ways to reduce CO2 emissions while determining strategies to meet the sector's direct energy demands. The baseline for the study is business-as-usual scenario. The findings demonstrate how sustainability concerns are heightened by the emissions trajectory of business as usual. However, by giving solar PV adoption priority, the solar scenario reduces overall emissions by more than 16% until 2060. Additionally, biodiesel gradually lessens effects on environment while making use of agricultural waste, which otherwise be burnt and strongly contribute to overall GHG emissions. Evidence-based interventions such as renewable subsidies and conservation incentives are informed by optimized portfolios. Agriculture can move toward cleaner energy synergy, food security, rural livelihoods, energy fulfillment, and environmental stewardship with the right strategies. This multifaceted analysis serves as a comprehensive guide, offering actionable recommendations to propel Pakistan's agricultural sector towards a greener and more sustainable energy future.

Keywords: VEDA-TIMES, Emissions, Energy, Agriculture, Sustainability

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1. Muhammad Saad Awan, Kafait Ullah, Danish Hameed "Reducing Environmental Impact of Agriculture Sector in Pakistan Through Hybrid-Solar Powered Irrigation System" 5th International Conference on Emerging trends in Engineering Management & Sciences (ICETEMS-2023) (Published)

List of Abbreviations

Abbreviations: Description

AWP: Agriculture Water Pump

ATF: Agriculture Tractor Farm

ATH: Agriculture Tractor Haulage

AOE: Agriculture Other Energy

AQI: Air Quality Index

BAUS: Business as Usual Scenario

BIS: Biodiesel Inclusion Scenario

CO2: Carbon dioxide

EFOM: Energy Flow Optimization Model

ETSAP: Energy Technology System Analysis Program

ECC: Economic Coordination Committee

FAO: Food and Agriculture Organization

GHG: Green House Gas Emissions

GDP: Gross Domestic Product

Gt: Gigatons

GAMS: General Algebraic Modeling System

HSD: High Speed Diesel

IEA: International Energy Agency

IRENA: International Renewable Energy Agency

Kt: Kilotons

LEAP: Low Emission Analysis Platform

LDO: Light Diesel Oil

Markal: Market Allocation

Mt: Million Ton

NDCs: Nationally Determined Contributions

Pak-IEM: Pakistan Integrated Energy Model

PJ: Peta Joules

PV: Photovoltaic

RCTs: Resource Conservation Technologies

R&D: Research and Development

SIS: Solar Inclusion Scenario

TIMES: The integrated Markal EFOM System

UNFCC: United Nations Convention on Climate Change

USA: United States of America

VEDA-FE: Veda Front End

VEDA-BE: Veda Back End

Chapter 1

Introduction

1.1 Background

One of the recent global challenge humanities is facing is climate change. The agriculture sector is heavily dependent on human activity to contribute to greenhouse gas (GHG) emissions, which are mostly emitted by the burning of fossil fuel and irresponsible management of agricultural waste.[1] Around 81% of global energy needs are fulfilled by fossil fuels which includes gas, oil and coal supply. There is a need for long-term sustainable energy planning for the agriculture sector because of growing concern over energy shortage, accessibility issues and climate change. Many developed and developing countries have already started altering their long-term energy plans to decarbonize their energy consumption and move towards sustainable development.[2] Pakistan as a whole is currently facing energy crisis and agriculture sector is highly afflicted due to lack of planning, consideration, poor policy making, inefficient use of resources, population growth and unawareness with modern technologies.[3]

Pakistan's agriculture sector is facing severe energy supply and energy related issues owing to modernization, population, food security ultimately leading to more energy demand. Pakistan, with a population of about 220 million and a growth rate of 1.95%, is the sixth most populous country in the world.[4] Pakistan's economy is primarily based on the textile and agriculture sectors, with a GDP per capita of $1465.89 in 2020.[5] Every socioeconomic development linked with improving lives globally includes energy. However, the production and consumption of energy in every sector are largely to blame for the environmental damage caused by greenhouse gas emissions.[6]

In 2020, global emissions surged to an unprecedented 33.1 Gt of CO2. Experts have determined that severe consequences to human life and global stability may result from a failure to reduce global greenhouse gas emissions by at least 80%. The need to address global climate change stems from the fact that reducing greenhouse gas emissions is essential for sustainable development. It is challenging to put into practice policies for meaningful reductions that involve every nation, though. All United Nations Framework Convention on Climate Change (UNFCCC) members were requested to publish their intended NDCs as part of the 2013 international implementation of the NDCs, which took place in Poland. This unites all its members in the pursuit of enhancing the global response to the threat of global warming.[7]

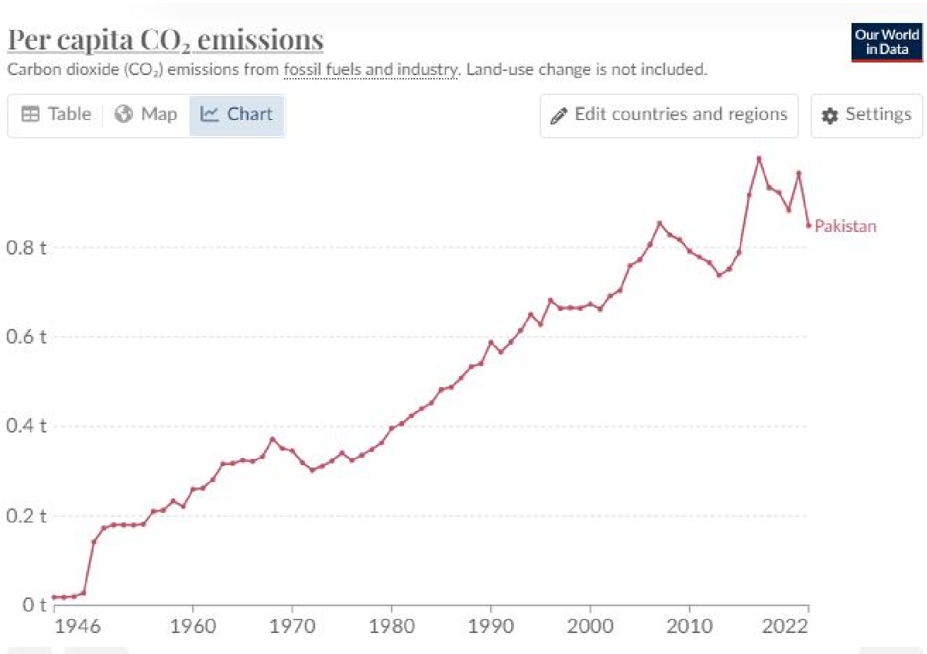

Figure 1.1 Annual CO2 Emissions by Pakistan [8]

The fossil fuels usage shows a prominent potential for GHG emissions mitigation. Pakistan is motivated to reduce greenhouse gas emissions to meet its NDC targets and become net carbon neutral. Figure 1.1 illustrates how overall emissions rose sharply in the latter half of the 1970s following the industrial revolution, with Pakistan's emissions peaking at 234.75 Mt CO2 in 2020. The National Climate Change Policy and its Framework for Implementation include important suggestions for mitigating climate change in a variety of industries, such as forestry, agriculture, and energy.[9] A study analyzed that how agricultural machinery contribute to environmental emissions, and how farmers are heavily reliant on energy resources like electricity and diesel.[10]

1.2 Energy Related Agriculture Sector Issues

Energy planning, energy policies, and traditional energy sources which aren't even included in national statistics are ignored by policymakers. Furthermore, there is no auditing done for both short- and long-term energy planning. This shows that nearly 50% of consumers, mostly rural households, are disregarded when it comes to energy planning and government investments in the provision of electricity.[11] Statistics from the World Energy Outlook (2020) show that 46 million or so people in Pakistan do not have access to electricity. [12].

Additionally, agriculture machinery like tractors used for farming, transport related machinery and tubewells for irrigation purposes relies heavily on imported fossil fuels, which includes high speed diesel and light diesel mainly. Also, the source for running electricity related power plants depends on imported coal. As per a report Pakistan import approx. 19 million tons of coal annually, half of which is consumed by power sector to provide electricity.[13] All this compile to play their part in producing huge energy related challenges, including energy disruption that not only disturbs agricultural operations, also damages the machinery. Then heavy prices on these fuels and their non consistent prices are another issue. This all leads to the sectors disturbance in meeting food challenges for the country.[14]

1.3 Regionally Available Solutions

The most practical and sustainable alternative to fossil fuel-based water pumps is a solar photovoltaic (PV) water pumping system, considering all of these variables as well as the industry's pressing need for energy. Solar-powered pumps offer several advantages for agricultural applications. One notable benefit is their low maintenance requirements, reducing the need for frequent and costly repairs. Additionally, these systems eliminate fuel costs entirely, making them a cost-effective and sustainable alternative. Their easy installation process further contributes to their appeal, providing farmers with a hassle-free solution for incorporating efficient water pumping technology.[15]

The reliability of solar-powered pumps makes them an attractive choice for agricultural operations. With unattended operation capabilities, these systems offer convenience and autonomy to farmers, allowing them to focus on other essential tasks. However, it's important to consider potential drawbacks, such as the initial high costs of implementation. While solar pumps may experience lower output during cloudy weather, their overall benefits, including independence from fuel and minimal maintenance, make them a promising technology for sustainable and efficient water management in agriculture.[16]

Also, biofuels are the best alternative to traditional fuels, for diesel engines for tractors and water pumps biodiesel is the alternate. With relatively low emissions, biodiesel offers an environmentally friendly alternative to traditional diesel. Its reliability is comparable to diesel, and the significant benefit is that no engine modification is required for its use. The biodiesel blending option B20 appears to be the most appropriate given our requirements. Since B20's viscosity and flash point are almost identical to those of diesel, no modifications to current engines are required.[17]

However, it's important to note some challenges associated with biodiesel. While it boasts lower emissions compared to pure diesel, its environmental impact is relatively higher than B100 (pure biodiesel). Additionally, the production of biodiesel poses challenges that need to be addressed, and further research is required to enhance its efficiency and overcome any limitations. Despite these considerations, the blend of 20% biodiesel and 80% diesel remains a viable option for us seeking a more sustainable and eco-friendly fuel alternative.[18]

1.4 Problem Statement

Pakistan is currently facing energy security and environmental issues owing to a continuous increase in urbanization, industrialization, and global warming. Moreover, the agriculture sector being the backbone of a country's economy is not given proper consideration for proper policy formulation, technological reforms and updating the sector in decade long of politics. The sector is currently using outdated technologies, facing fuel and electricity shortages, climate change affecting crops and land and burning of agricultural waste is still in vast quantities. There is a need to address these issues by using a futuristic approach models like VEDA-TIMES, that will help clearly analyze the issues and key areas of improvement and will help policymakers in drafting out a proper plan to counter these issues. It will also help in meeting the country's futuristic goals like net-zero emissions by 2060, energy fulfillment and increasing the economic capacity of country. All this will be possible only if proper consideration is given to the sector.

1.5 Research Objectives

The purpose of this research is to provide with a detailed model that will help analyze the whole structure of energy consumption in agriculture sector and emissions linked with them and propose approachable solutions to counter these issues to meet our committed goals for net-zero emissions by 2060. Following research objectives are chosen for this study:

- To develop a country specific agricultural sector TIMES model.
- To build energy transition scenarios that will help propose viable solutions for current energy conditions for the agriculture sector.

- Proposing suitable options for the agriculture sector to minimize its carbon emissions by 2060.

1.6 Research Motivation

Lack of research in this area as Pakistan’s agriculture sector is a major contributor to country’s GDP and employes a huge chunk of country’s labor, however proper consideration regarding energy accessibility and subsidies availability in areas of need is not given to the sector. Dependence of sectors performance on fossil fuels is another area to worry as Globally, fossil fuel supplies are steadily running out. It is anticipated that the world will run out of fossil fuels within the next 50 to 60 years if new oil resources are not discovered. Fossil fuels are essential for the operation of any nation's transportation, power, industry, agriculture, and other commercial endeavors.[19] The future of Pakistan is unsustainable due to the worldwide oil crisis and rising oil prices. Also, there is a need of time to work on climate action by optimizing the existing structure of energy usage in agriculture sector, as in 2021 Pakistan was the most vulnerable country that is affected by climate change and was ranked second in economic loss due to climate change. Agricultural waste management strategies are still not in force in rural areas, which is another issue that contributes to air pollution. Pakistan’s big cities Lahore, Karachi, Rawalpindi, and Peshawar have the worst AQI ranking as shown in figure.

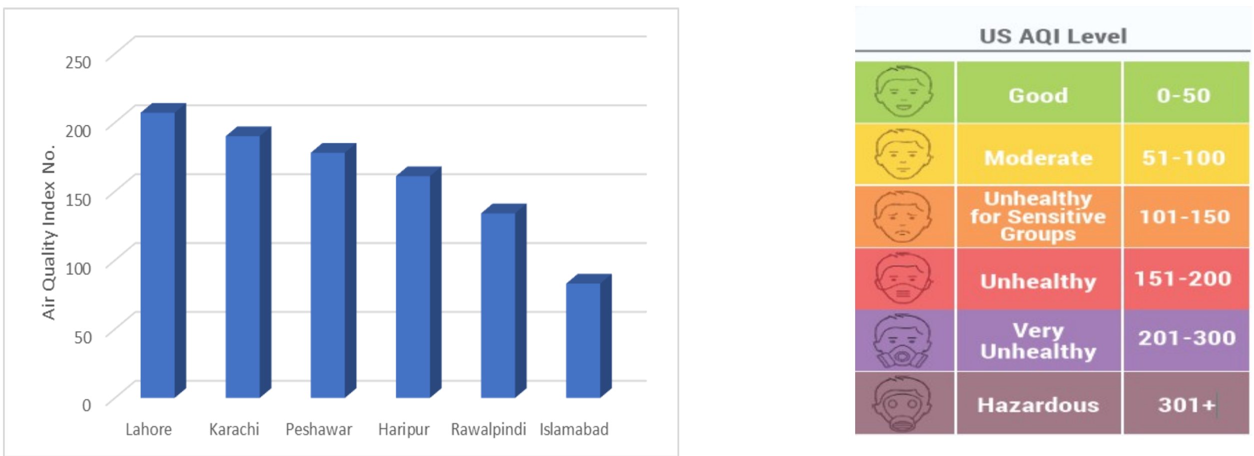

Figure 1.2 AQI Ranking [20]

1.7 Contributions

- The model made includes all the energy consuming machinery in the agriculture sector and can be updated for future work with available data.
- Identifies areas of improvement.
- Helps in identifying alternative technologies for multiple energy resources.
- Ability to bridge the gap between energy consumption and emissions.

1.8 Limitations of Research

- Emissions from burning of crops, land usage and carts usage are not discussed in the study.
- Solar water pumps specifications are not discussed and are beyond research area.
- Biodiesel making process, additives used are not discussed and are beyond research scope.

1.9 Thesis Structure

The thesis consists of six chapters. An overview of all the chapters is discussed here.

Chapter 1 briefly describes the overview of global carbon footprints, energy demand & supplies and energy related issues in the agriculture sector of Pakistan, the problem statement and the objectives of the research conducted.

Chapter 2 presents a literature survey which includes elementary thoughts on energy related issues of agriculture sector, VEDA-TIMES model usage and best practices adopted by researchers around the globe.

Chapter 3 incorporates the key assumptions of the developed model PAK-IEM for the agriculture sector. Moreover, data collection, model selection and scenario analysis are discussed in detail.

Chapter 4 describes the primary energy supplies and demand across various sectors of Pakistan. Furthermore, GHG emissions by major energy-consuming sectors are also highlighted.

Chapter 5 model development intends to describe the proposed approach for estimating long-term energy needs end-use and scenarios have been created to estimate Pakistan's agriculture sector's long-term demands and emissions from them.

1.10 Summary

This chapter discussed the problem formulation, scope of research, objectives and finding out research questions. Further technologies as alternative options are discussed with their merits and demerits. Additionally, limitations and scope of study are discussed to clearly understand the research area.

Chapter 2

Literature Review

In this chapter overall world situation regarding agricultural energy issues and emissions is observed also how to combat them to support Pakistan's net-zero emissions goals. Developed countries especially USA, France China and many others make climate action plans to minimize GHG emissions. Some countries converting their whole country system to renewable energy after 2030 but in Pakistan, the situation is totally different. Electricity production is based on imported coal, additionally country's fuel related machinery also relies mainly on imported oils, that all makes a huge burden to the economy and contributes to environmental emissions.

2.1 Pakistan's Status

The escalating energy demand in Pakistan, fueled by population growth, urbanization, and modernization, is intricately linked with the surging demand for energy in the agriculture sector. Pakistan's agriculture sector reveals the intricate dynamics of the country's energy landscape. Despite the sector relatively low energy intensity, it plays a pivotal role in driving national energy demand due to its vast scale. This crucial sector, however, grapples with challenges stemming from its substantial carbon footprint and susceptibility to climate variations. With approximately 38.5% of the labor force directly engaged in agriculture, contributing significantly to the country's GDP, the sector has witnessed a remarkable surge in energy requirements.[21] On a global scale, Pakistan holds the 8th position in wheat production, underscoring the pivotal role of agriculture in the global food supply chain.[22] According to data from the energy yearbook, the agriculture sector has already consumed 846 thousand tons of oil equivalent in the form of light fuels and electricity alone. Notably, a substantial portion of this energy, more than three times the figure, is consumed in the shape of high-speed diesel for activities such as operating tubewells, tractors, and associated transport vehicles.[23]

The escalating reliance on fossil fuel-based water pumps and tractors for irrigation and farming operations lies at the core of this substantial energy consumption. Pakistan already commissioned an estimated 12 million water pumps, with 90% dedicated to irrigation, and approximately 0.65 million tractors and agricultural machinery deployed in various agricultural processes.[5] This dependence on machinery fueled by fossil fuels is poised to intensify in the years to come, signifying a critical juncture where sustainable and efficient energy solutions are imperative to address both the energy needs of the agriculture sector and the broader implications for the country's energy landscape.

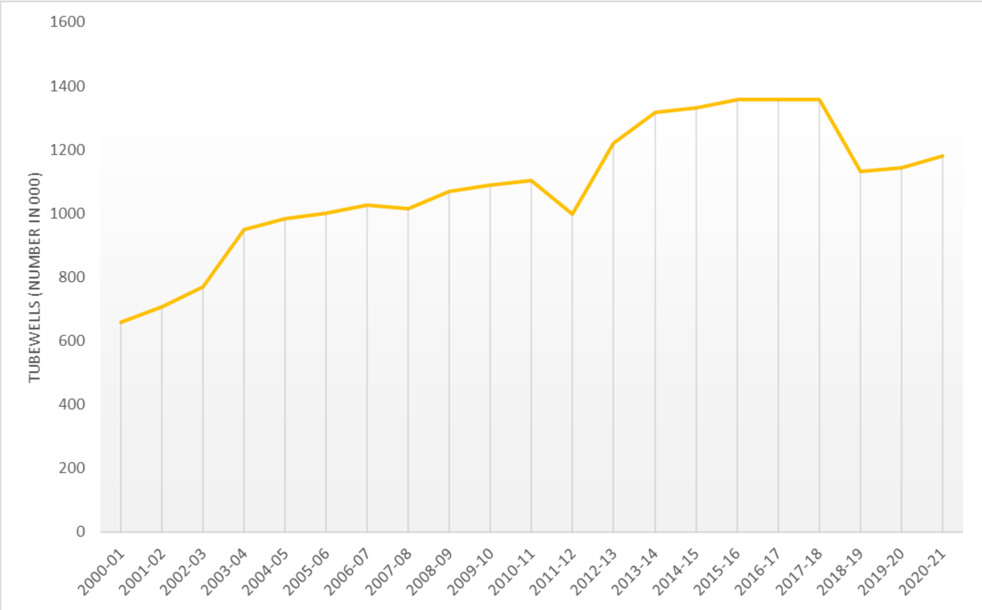

Figure 2.1 Yearly Data on Number of Tubewells in Pakistan [5]

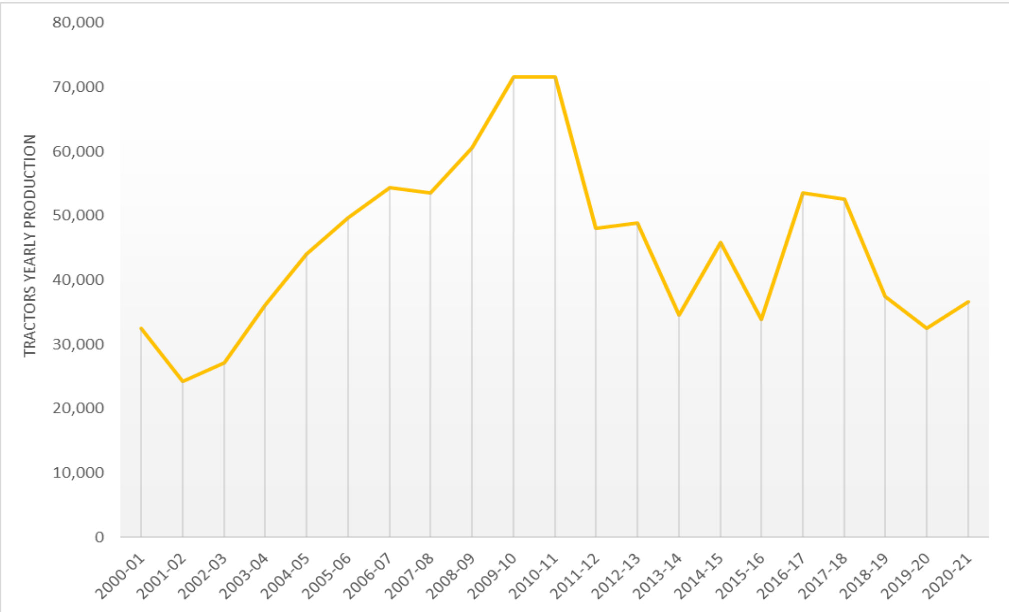

Figure 2.2 Data on Yearly Production of Tractors [5]

Recognizing the urgent need for addressing these challenges, there is a growing acknowledgment of the potential of renewable energy technologies (RETs) to mitigate the environmental impacts within the agriculture sector. Sustainable development in agriculture entails enhancing access to water, energy, and modern machinery to boost productivity while concurrently reducing CO2 emissions associated with key crops such as wheat, rice, cotton, maize, and sugarcane. This thorough approach aims to foster a balance between agricultural growth and environmental sustainability, crucial for ensuring a resilient and ecologically responsible future for Pakistan's agriculture sector.

2.2 World Status

Developed nations, such as China, USA Germany, and many more, are providing subsidies to encourage the use of renewable technologies in an effort to reduce greenhouse gas emissions.[24] Countries like USA are working on modeling tools, and projecting future energy forecast to help manage available resources in a better efficient way. They are introducing carbon tax policies to help reduce emissions from different sectors like transport, industry and agriculture.[25] Many other European countries like Sweden and France are working on building their energy models like TIMES to compare their regional energy related challenges and their projected future energy forecasts. To do so they are building a model to compare the space between both nations of accepting the inclusion of biomass and biofuels in their energy mix. The results show a great scope if properly plan policies are introduced in a manner that they increase the capacity with time. [26].

With 1.41 billion people living in China and 1.396 billion people living in India as of 2020, both countries are working toward becoming carbon neutral. All nations must immediately decarbonize their energy systems to keep global warming to 2°C, as stipulated by the Paris Agreement. Analysts and decision-makers have used energy system models to enhance comprehension and facilitate long-term energy planning decision-making, which has aided in the development of energy and climate policy in many nations.[27] As recently studies suggested that country like India is facing similar energy and environment related challenges. However, the country is actively working towards mitigating strategies that could potentially help in utilizing available resources and moving away from imported fuels, however there is a lot to be done yet it’s a great step towards achieving a sustainable future.[28].

2.3 Issues related to Direct Energy Consumption for Agriculture Sector in Countries like Pakistan

In this era economic globalization, marked by increased commerce and international interactions, has intensified the competition among countries. Technological innovations driving agricultural production have, in turn, elevated energy consumption in developing nations, contributing to a surge in emissions.[29] Agricultural production inherently involves extensive energy consumption, and as globalization propels production, the demand for energy escalates. Unfortunately, many developing nations heavily rely on non-renewable energy sources, exacerbating greenhouse gas emissions.[30]

Despite the significant environmental and economic implications associated with traditional fuel usage in agriculture, there remains a notable lack of awareness, particularly in disadvantaged regions such as small towns and villages. Bridging this awareness gap becomes pivotal in fostering a comprehensive understanding of the agricultural sector's impact on both the environment and the local economy.[31] Acknowledging and addressing these challenges are crucial steps towards achieving sustainable agricultural practices in the face of economic globalization. In countries such as India and Pakistan, comprehensive analyses focusing on the environmental impact of energy utilization in agriculture are scarce. A recent study aimed to address this gap by examining energy consumption trends over a decade in both nations. The findings underscored a concerning increase in the environmental impacts of energy utilization, attributed to the heavy reliance on coal for electricity generation in both India and Pakistan.[28] The study emphasized the critical need for sustainable agricultural practices, cautioning against energy intensification without due consideration of its environmental consequences.

Policymakers were urged to adopt strategies that promote innovation in farming techniques, increased greenhouse usage, and the adoption of cleaner electricity sources to effectively mitigate the environmental impacts associated with energy use in agriculture. On a global scale, the agriculture sector significantly contributes to greenhouse gas emissions, ranging from 14-30%. This substantial contribution is primarily attributed to various factors, including fossil fuel energy use, fuel-driven equipment, irrigation practices, livestock production, and the use of nitrogen-rich fertilizers. The study underscores the crucial role of fossil fuel energy in agriculture as a major contributor to CO2 emissions. These findings underscore the urgent need for sustainable practices and the adoption of cleaner energy sources to address the environmental challenges posed by energy utilization in the agriculture sector, both at the regional and global levels.[32]

Pakistan's electricity crisis is a multifaceted challenge rooted in insufficient investment in the power sector, diminishing gas reserves, and heavy reliance on imported oil. The high costs associated with electricity generation in Pakistan, exceeding global averages, present a significant hurdle for the agricultural sector, a major consumer of electricity for irrigation and other operations. This financial strain restricts the adoption of new technologies that could enhance efficiency and reduce environmental impacts.

The persistent issue of power outages and load shedding in Pakistan further compounds the challenges faced by agriculture. These disruptions lead to crop losses, damage to agricultural equipment, and impaired irrigation systems, resulting in an estimated annual cost of $1 billion.[3] Recognizing the need for improvement, the World Bank in 2017 emphasized investments in improved seeds, technology, and water infrastructure to enhance productivity in Pakistan.[33] Amidst rapid population growth, achieving sustainable agricultural intensification becomes imperative to meet the escalating demand for food. Technical solutions addressing CO2 emissions reduction and increasing the share of renewable energy in the electricity system are critical components of a comprehensive strategy. The adoption of such measures can not only alleviate the electricity crisis but also contribute to a more resilient and sustainable agricultural sector in Pakistan.[34]

In the Pakistani context, the agriculture sector combined with environmental challenges and carbon emissions, primarily coming from the dominance of oil and electricity in its energy consumption, underscoring the urgency of climate change mitigation measures, especially given agriculture's substantial contribution of 41% to total emissions.[19] This highlights the critical need for interventions in both the energy and agriculture sectors. Empirical findings emphasize the influential role of energy as a substitute for labor and capital in Pakistan's agriculture. It becomes evident that investing in modern technologies is essential to not only reduce energy consumption but also enhance overall economic growth.[35] The transition from non-renewable to renewable energy sources within the agricultural landscape is deemed imperative. The escalating demand for fossil fuels in agriculture has a direct correlation with increased carbon emissions, necessitating policy interventions that promote sustainable practices.[14]

Gas and electricity consumption emerge as key drivers of agricultural economic growth in Pakistan. In this context, policy recommendations gain prominence, focusing on controlling the surge in oil prices and strategically diversifying energy supply sources. These measures are crucial for fostering sustainable practices and ensuring the long-term economic viability of Pakistan's agriculture sector.[36]

2.4 Linear Modeling Approaches and their Pros in Visualization of Complex Energy Dynamics

Advanced models such as MARKAL, LEAP, and TIMES have found widespread application globally in establishing frameworks for sustainable energy. However, their implementation in underdeveloped countries like Pakistan, particularly in rural agricultural regions, remains limited. These models offer a systematic approach to achieving sustainable goals, yet the challenge lies in bridging the gap between theoretical frameworks and practical implementation.[37] The TIMES model, known for its versatility, can assess the environmental impact across various sectors, including transportation, agriculture, and energy. It serves as a valuable tool for identifying strategies to reduce carbon emissions. In the agriculture sector, the TIMES model proves instrumental in optimizing energy-intensive processes, such as fuel consumption and irrigation, to minimize carbon emissions while ensuring food security.[34]

Table 2.1 LEAP and TIMES Comparison

TYPES OF MODELS	TIMES	LEAP
Simulation tool		✓
Scenario tool	✓	✓
Equilibrium tool	✓	
Top-down tool	✓	
Bottom-up tool	✓	✓
Operation optimization tool	✓	✓

Table 2.2 Purpose of Using

PURPOSE OF THE MODEL	TIMES	LEAP
Scenario analysis	✓	✓
Increase understanding	✓	✓
Tool development	✓	
Investigate responses		✓
Inform policy	✓	✓

Expanding its application to the domestic sphere, the model can analyze energy consumption patterns and propose improvements for energy efficiency, integrating renewable sources into residential buildings. Additionally, in the transportation sector, the TIMES model proves beneficial for assessing the impact of different fuels and technologies on carbon emissions. Policymakers and researchers can leverage this model to devise comprehensive strategies for promoting low-carbon alternatives like electric cars and biodiesel, fostering sustainable development across diverse economic sectors. The TIMES model, therefore, emerges as a versatile and indispensable tool for informed decision-making and environmental impact assessment.[38]

In a recent study, the TIMES model was employed to assess the potential of various renewable energy sources in France and Sweden. This model proved to be a valuable tool for optimizing and analyzing energy systems over a long-term planning horizon. Its unique capability to incorporate detailed site-specific characteristics enabled a comprehensive consideration of sustainability-related issues.[26] Globally recognized for its effectiveness, the TIMES model has been widely utilized to evaluate renewable energy sources and optimize energy systems. Its significance extends to providing detailed insights into the transport sector across various countries. The model allows for the analysis of diverse scenarios and the competition between different energy sources, contributing to a nuanced understanding of decarbonization characteristics and options for the transport sector. Notably, its application in examining and comparing such aspects in countries like China and the USA highlights the model's versatility and utility in shaping informed energy policies.[25] Similarly, TIMES methodology is used by countries like Ireland and United Kingdom to develop their long-term energy plans, that could lead to a clean and sustainable energy future for the countries.[39]

The Pakistan Integrated Energy Model (Pak-IEM) built on TIMES methodology stands out as a comprehensive tool designed on the foundation of the TIMES framework. Going beyond the conventional approach, this model seamlessly integrates a series of crucial factors, including financial considerations, economic implications, energy supply dynamics, national resources, energy consumption patterns, environmental impact assessments, technological advancements, energy efficiency parameters, and conservation measures.[40]

2.5 Research Gap

- From the studies above it is observed that there exists a huge gap in planning, management, and proper policy formulation framework in developing and developed countries.
- As for Pakistan very limited literature is available focusing on energy consumption in agriculture sector and emissions from them.
- Also, for Pakistan there is a lack of proper methodology in formulation of policies for the agriculture sector.
- Usage of proper models like TIMES is not yet considered properly for policy formulation or studying the intensity of sector.
- Most studies for Pakistan are for emissions from overall energy consumption, whole of agriculture sector neglecting some machinery like tractors, or without the use of optimization models.

Key findings from the literature suggest the need for a model that could help visualize the complexity of agriculture sector and propose solutions to counter the inefficiencies, energy accessibility issues and technological challenges.

2.6 Summary

The chapter commences with the Pakistan status in energy consumption and dependency on energy sources, steps taken to counter the dependency on imported resources. Then moving towards global energy consumption and emissions and how the different nations are working towards enhancing their energy efficiency. Then literature focuses on the issues of agriculture sector of Pakistan in terms of energy consumption, energy shortage and emissions from the sector. Additionally discusses the models used worldwide and how they are helping countries meet their sustainability goals all this followed by a research gap.

Chapter 3

Research Methodology

In our study, we tested the power of VEDA-TIMES to unravel the complex areas of the agriculture sector, providing a detailed understanding of its complexity. The primary objective was to obtain a precise visualization of emissions stemming from energy consumption and to pinpoint areas for improvement. Given our focus on optimizing environmental emissions, we opted for a bottom-up approach, aligning with the robust capabilities of the TIMES model. This approach allowed us to meticulously source data tailored to our emission optimization goals.

The TIMES model, a main theme in our analytical framework, not only facilitated the exploration of diverse scenarios but also empowered us to scrutinize the competition dynamics among biomass sources, solar energy, and fossil fuels. To seamlessly integrate the agriculture sector into the VEDA-TIMES framework, we edited the Pak-IEM energy consumption data tailored specifically for agriculture sector. This incorporation involved integrating critical indicators such as population and GDP growth rates for Pakistan, enabling us to project environmental and air pollution impacts.

For the comprehensive data required for machinery, energy consumption, yearly usage, and available technologies, we adopted a multifaceted approach. While some data was readily available from sources like the energy yearbook, economic survey, and various reports, we complemented these with insights gleaned from papers, articles, and additional sources. This meticulous data curation process ensures the accuracy and reliability of our study. In the below sections of this chapter, we will be discussing the tools, model and scenarios taken for getting effective results that will help us in analyzing the dynamics of agriculture sector.

3.1 VEDA TIMES

VEDA-TIMES stands as a sophisticated and powerful bottom-up linear programming model designed to optimize complex energy systems. Its designed goals are to pinpoint the most cost-effective blend of technologies and fuels essential for meeting the diverse spectrum of energy service demands. This model offers an all-encompassing view of the entire energy sector, seamlessly covering everything from resource extraction and conversion to the intricate domains of transmission, distribution, and eventual end-use.[38] A noticeable feature of VEDA-TIMES lies in its flexibility, allowing for intricate modeling of specific sectors, with a particular emphasis on sectors like agriculture. This flexibility facilitates detailed exploration of the environmental footprints of each sector, paving the way for the identification of sustainable technological solutions. Notably, the model's adaptability extends to the incorporation of various user-defined constraints, enhancing its applicability to diverse scenarios and ensuring a robust analytical framework for our study.

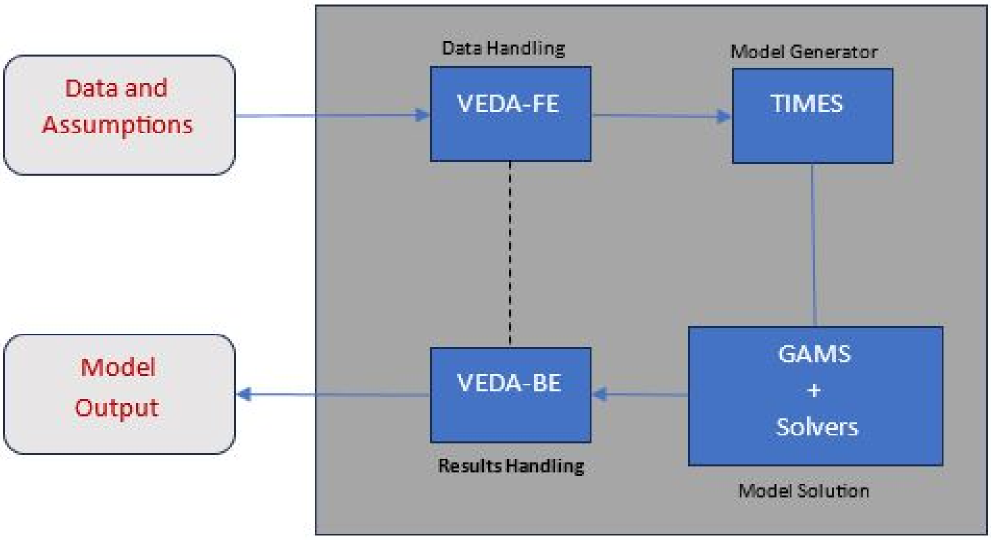

Figure 3.1 Overview of Veda-TIMES

Moreover, the TIMES model describes a comprehensive long-term perspective, offering the capability to model both energy and environmental scenarios. This temporal dimension proves crucial in evaluating the lasting impacts of diverse strategies and policies. The model's versatility extends to the assessment of potential impacts related to alternative technologies, energy efficiency improvements, and the seamless integration of renewable energy sources. This unique functionality provides policymakers and researchers with invaluable insights, aiding in the formulation of effective decarbonization pathways. The model's distinctive feature lies in its ability to consider multiple sectors and their intricate interdependencies, fostering a holistic approach to environmental impact assessment. This holistic perspective proves instrumental in identifying integrated strategies geared towards achieving sustainable development.[39]

Acknowledged widely as a pivotal tool in the realm of energy system analysis, the TIMES model stands out as a valuable benchmarking instrument. Its widespread recognition and usage empower stakeholders to compare diverse scenarios and policies across regions and countries, further solidifying its status as a cornerstone in the field.

Within the agricultural sector, the TIMES model emerges as an indispensable tool, optimizing energy-intensive processes such as irrigation and fertilizer production. The primary goal is to minimize carbon emissions while ensuring food security, exemplifying its commitment to sustainable practices. In the domestic sphere, the model delves into intricate energy consumption patterns, deftly identifying opportunities for efficiency improvements and the seamless integration of renewable sources into residential buildings. Similarly, in the transport sector, the TIMES model systematically evaluates the impact of diverse transportation technologies and fuels on carbon emissions. Through this analysis, it provides strategic insights to promote the adoption of low-carbon alternatives, such as electric vehicles and Biodiesel, aligning with the global shift towards sustainable mobility solutions.

3.2 Pakistan Integrated Energy Model (PAK-IEM)

The construction of the Pak-IEM model involves the utilization of the TIMES framework, a successor to the MARKAL framework, with support from the Energy Technology Systems Analysis Program (ETSAP) and the International Energy Agency (IEA). Functioning within the TIMES framework, Pak-IEM operates as a complete system that goes beyond mere energy modeling. It delves into the intricate web of policy assessments, meticulously weighing the costs and benefits associated with various energy strategies. As a guiding force for the nation, Pak-IEM plays a pivotal role in shaping sustainable energy policies for Pakistan. Its multifaceted approach ensures a comprehensive evaluation of diverse elements, making it an indispensable tool for steering the country toward a sustainable energy future.[41] The VEDA model management system serves as organizing input data and processing outcomes. This process involves arranging model input data into Excel workbooks, managed efficiently by the VEDA (FE), to develop a comprehensive model for calibration and reference scenario development.

The flexibility of the Pak-IEM model extends to accommodating various alternative scenarios for calibration and reference, allowing for a robust exploration of future possibilities and policy evaluations. The results generated by the model undergo thorough analysis using the VEDA (BE), providing a detailed and insightful summary of the VEDA/TIMES system. This integrated approach ensures a sophisticated and comprehensive modeling system, aligning with international standards and leveraging advanced frameworks to address the complexities of Pakistan's energy landscape.

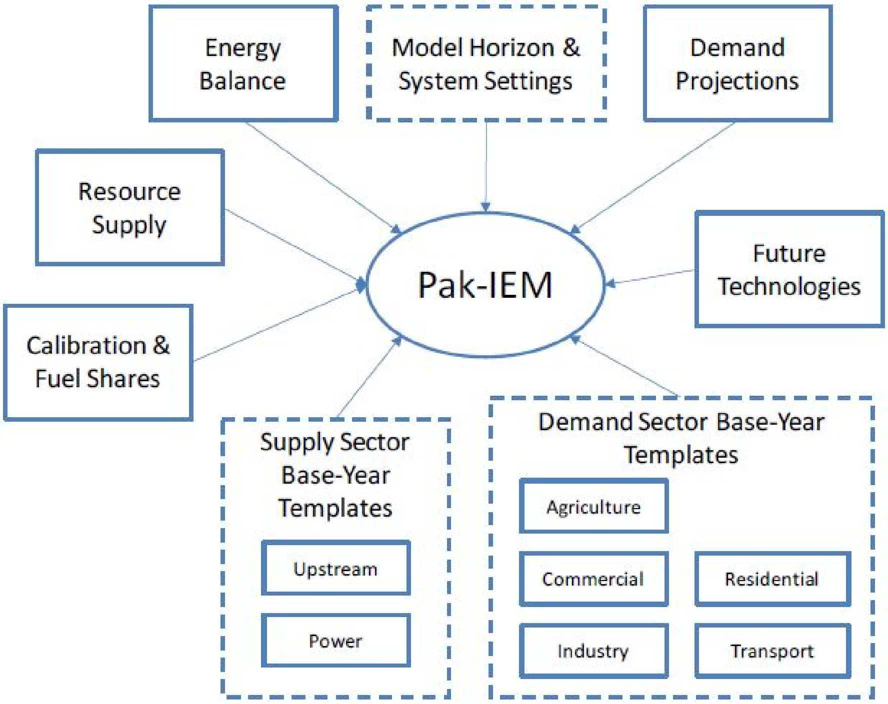

Figure 3.2 Structure of Pak-IEM

3.3 Data Collection

This study focuses on the TIMES model within the framework of the Pak-IEM model, concentrating yearly timeframes. While Pak-IEM encompasses all economic sectors, this analysis specifically delves into the agricultural domain, aiming to evaluate forecasted direct energy-related environmental impacts starting from 2020. Pakistan's extensive land area, totaling approximately 79.6 million hectares, with nearly half of it dedicated to cultivation, underscores the sector's significance. The direct energy consumption in agriculture encompasses the usage of electricity and fuels to operate agricultural machinery and tube wells, encompassing both government and privately-owned installations.

The agriculture sector model in Pak-IEM is used as a base model, and further data of energy balance and all other details are updated according to available data and assumptions.

												Unit:	TOE
						Petroleum Products		Liquefied					
		Natural Gas @					Non	Petroleum					Total
		Raw Gas	Processed Gas	Total Gas	Crude Oil	Energy	Energy	Gas	Coal	Hydro	Nuclear	Electricity	
		*	**							***	***	***	
	ENERGY SUPPLIES												
a	Indigenous Pro	25,517,553		25,517,553	3,698,479			607,940	4,129,323	8,007,673	2,230,835		44,191,803
b	Imports		9,920,947	9,920,947	9,083,344	10,679,138		508,897	12,401,205			118,957	42,712,488
c	Exports & Bunkers			0	(305,364)	-409,342	-41,548						(756,254)
d	Stock Changes #			(16,985)	39,587	-187,678	20,430	-239					(144,885)
e	Net Primary	25,517,553	9,920,947	35,421,515	12,516,046	10,082,118	(21,118)	1,116,598	16,530,528	8,007,673	2,230,835	118,957	86,003,152
	TRANSFORMATIONS												
f	Gas Processing	-19,188,113	18,646,952	-524,176									(524,176)
g	Petroleum Refineries				-12,127,042	11,226,466	400,535	215,436					(284,605)
h	Electric Power	-2,219,652	6,428,472	-8,648,124		-2,310,032	2,013		-4,123,008	-8,007,673	-2,230,835	11,728,833	(13,588,826)
i	Energy Transformed (f+g+h)			-9,172,300	-12,127,042	8,916,434	402,548	215,436	-4,123,008	-8,007,673	-2,230,835	11,728,833	(14,397,607)
	DIVERSIONS												
k	Transport & Distribution Losses			-3,444,909								-2,409,857	(5,854,766)
l	Auxiliary Consumption of Energy Sector			-195,315		-280,080	0	-44,540				-393,851	(913,786)
m	Consumption f	-2,607,491	-1,654,598	(4,262,089)			-353,943		(1,200)				(4,617,232)
n	Spare By-product Electricity from PASMIC											469,420	469,420
o	Statistical Differences				-389,004	-149,372	-23,461	83,678					(478,159)
p	Final Energy Use (e+j+k+l+m+n+o)			18,346,902	0	18,569,100	4,026	1,371,172	12,406,320	0	0	9,513,502	60,211,022

Figure 3.3 Updated Energy Balance for Pak-IEM

The model includes data of each machinery, available stocks, and all existing technologies, most of which is taken from energy yearbook 2020, Pakistan economic survey, state of industry reports, IEA, IRENA, FAO, and many other relevant data bases. Which is then further worked for most suitable data according to current situation.

3.4 Technology Selection

Sustainable technologies for our study are selected as per the requirement of agriculture sector and earlier studies based on South Asia. The following two technologies are discussed which are considered for the study.

3.4.1 Solar Water Pumping Technology

In Pakistan, the agricultural sector grapples with a significant challenge the absence of reliable electricity access, compelling farmers to heavily rely on diesel. This predicament is further emphasized by the harsh reality that more than 12 million people in Pakistan still lack access to electricity, as highlighted in a Statista report. Amidst these challenges and the sector's acute energy demands, the Solar Photovoltaic (PV) water pumping system emerges not only as a fitting solution but also as a sustainable alternative to the prevalent use of fossil fuel-based water pumps. Embracing solar technology in agriculture can not only address energy woes but also pave the way for environmentally friendly and resilient practices, marking a crucial step towards a more sustainable and inclusive agricultural landscape in Pakistan.

Table 3.1 Comparison of Water pumping options[16]

Sr. No	Water Pumping Technology	Advantages	Disadvantages
1	Solar Photovoltaic Water Pumping	✓ Minimum Maintenance Cost ✓ Zero Emissions ✓ No fuel is required	✓ Work only when solar radiation is available. ✓ High initial cost
2	Diesel Pump	✓ Moderate initial cost ✓ Can be operated any time of day and night. ✓ Easy availability of sales and service	✓ High maintenance cost ✓ High operating cost ✓ Create noise pollution and air pollution. ✓ Continuous supervision is necessary
3	Electric Water Pump	✓ Easy to install. ✓ Can be portable. ✓ Moderate initial cost	✓ Availability of grid is required. ✓ Interrupted or poor supply will increase down time
4	Windmill Water pumping	✓ No emissions ✓ No fuel is required	✓ High initial cost ✓ High Maintenance cost
5	Hydraulic Ram	✓ Long lasting ✓ Minimum installation cost ✓ Minimum maintenance cost	✓ Feasible where surface water is available

3.4.2 B20 Blend

Biodiesels represent a compelling renewable energy source with global potential to meet diverse energy needs. Within our study context, certain biofuels emerge as robust alternatives to the cost-intensive high-speed diesel. Not only do biofuels exhibit lower emissions compared to diesel, but they also present a cost-effective solution by utilizing agricultural waste, contributing to the reduction of greenhouse gas (GHG) emissions. Biodiesel, among various biofuels, stands out as superior to fossil fuel-based diesel on multiple fronts. It can be derived from both edible and non-edible oils, sharing many characteristics with petroleum diesel. Opting for biofuels as a viable energy source offers sustainability advantages, as the carbon dioxide produced during combustion becomes part of the natural feedstock cycle, creating a closed and environmentally beneficial process. In Pakistan, several regulations by the Economic Coordination Committee (ECC) further support the integration of biodiesel blends into the national energy consumption landscape.[42] For instance, providing duty exemptions on plants and machinery used in biodiesel production serves as a proactive measure to encourage the adoption of this eco-friendly energy alternative.

Table 3.2 Comparison of Biofuel blends[17]

Sr. No	Water Pumping Technology	Advantages	Disadvantages
1	B20	✓ 20% biodiesel, 80% diesel ✓ Less Emissions ✓ No engine modification required for use. ✓ Equally reliable as diesel	✓ Greater emissions compared to other blends. ✓ Greater research is required
2	B100	✓ 100% biodiesel ✓ Made only from agriculture residue. ✓ Greater emission reduction	✓ Engine modification required. ✓ Not suitable for diesel engine ✓ Create noise pollution and air pollution. ✓ Continuous supervision is necessary
3	Diesel	✓ Easily accessible ✓ 100% diesel ✓ Best for engines	✓ High emissions ✓ High cost

3.5 Scenario Building

Three Scenarios are built for the study, where reference scenario is business as usual scenario (BAUS), involves the current condition of agricultural energy system. Further solar integration scenario and Biodiesel inclusion scenario is introduced to include renewable energy technologies. Scenarios are shown in table below.

Table 3.3 Scenario Description

Scenarios	Description
BAUS	Business as Usual Scenario
SIS	Solar Integration Scenario
BIS	Biodiesel Integration Scenario

3.6.1 Business as Usual Scenario

To visualize in depth the complete dynamics of Pakistan's agriculture sector's energy consumption and carbon emissions this business-as-usual scenario is built. It serves as a reference point, reflecting the continuation of current practices and trends in the energy system. In this scenario, no significant changes are assumed in terms of technology adoption, fuel sources, or policies. Essentially, it represents the true state of Pakistan's agriculture energy system at present. The BAU scenario includes technologies and energy sources that are currently prevalent in Pakistan's agricultural system. The sector relies on conventional non-renewable sources such as diesel and traditional grids, aligning with historical consumption patterns. This setup allows for the assessment of greenhouse gas emissions trajectories without the influence of sustainability measures, indicating the likely continuation of past trends in conventional energy use.

Moreover, the scenario implies limited technological progress within the agricultural sector, depicting a state of inertia where innovation and adoption of new technologies remain restricted. This serves as a benchmark for comparative assessments against alternative scenarios, such as the Solar Inclusion Scenario (SIS) and Biofuel Inclusion Scenario (BIS). By establishing a baseline, the BAU scenario facilitates the evaluation of the impacts of diversifying fuel sources and adopting cleaner solutions, particularly in terms of efficiencies, emissions, and overall sustainability performance.

The reference case shown below shows energy input from various sources and their end use in BAUS case.

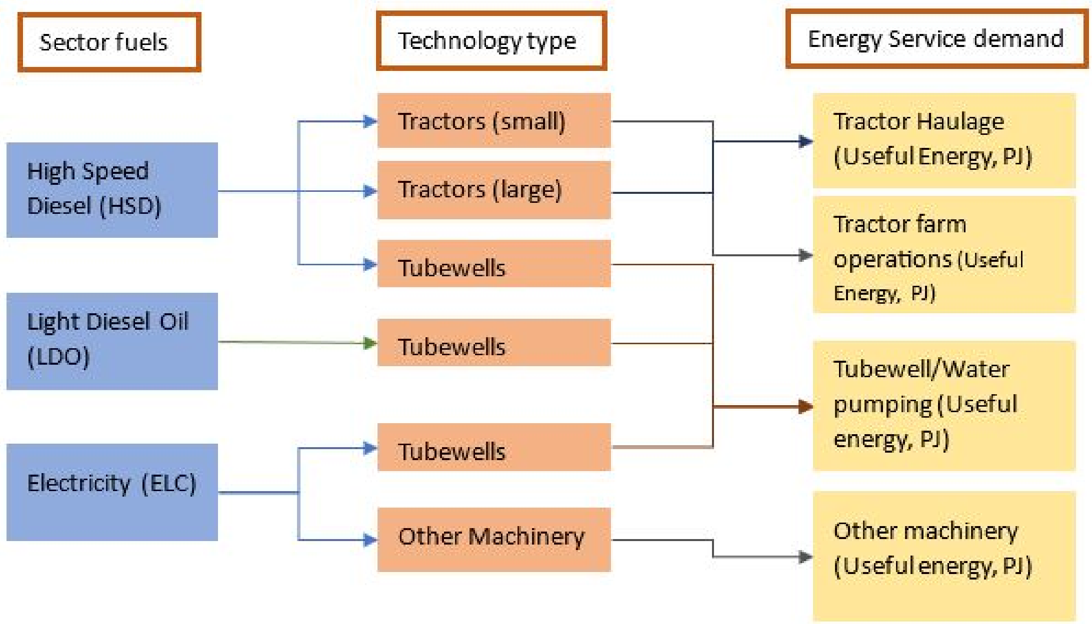

Figure 3.4 Reference Energy System for BAUS

3.6.2 Solar Inclusion Scenario

The Solar Inclusion Scenario (SIS) involves the integration of solar energy technologies into Pakistan's agricultural sector, with a focus on assessing the environmental impact and potential benefits of incorporating solar solutions to meet the energy needs of agriculture. Developed on the same TIMES model as the Business-as-Usual Scenario (BAU), SIS specifically emphasizes the widespread adoption of solar photovoltaic (PV) technology, converting sunlight into electricity for various agricultural operations.

The scenario incorporates multiple strategies. The first strategy involves increasing solar capacity over time, starting with a 20% inclusion in 2025 and gradually scaling up to 50% by 2060, reflecting anticipated growth and advancements in solar technology. The second strategy maintains a constant 20% inclusion throughout the period. In the third strategy, the inclusion begins at 20% and, through more intensive measures, reaches a 70% inclusion by 2060. However, these implementations primarily target irrigation systems involving tubewells and water pumps. As tubewells constitute 24.88% of high-speed diesel consumption in our study, this share is subject to the inclusion of solar technology. The purpose of employing these strategies is to visualize in depth on the changing dynamics for solar inclusion. Like what emission reduction are seen if different proportion of solar water pumping is introduced. As major source of diesel consumption in agriculture are tractors, however increasing the transformation of tubewells to solar technology will effectively help reduce these emissions and can counter issues like accessibility to electricity and energy shortage.

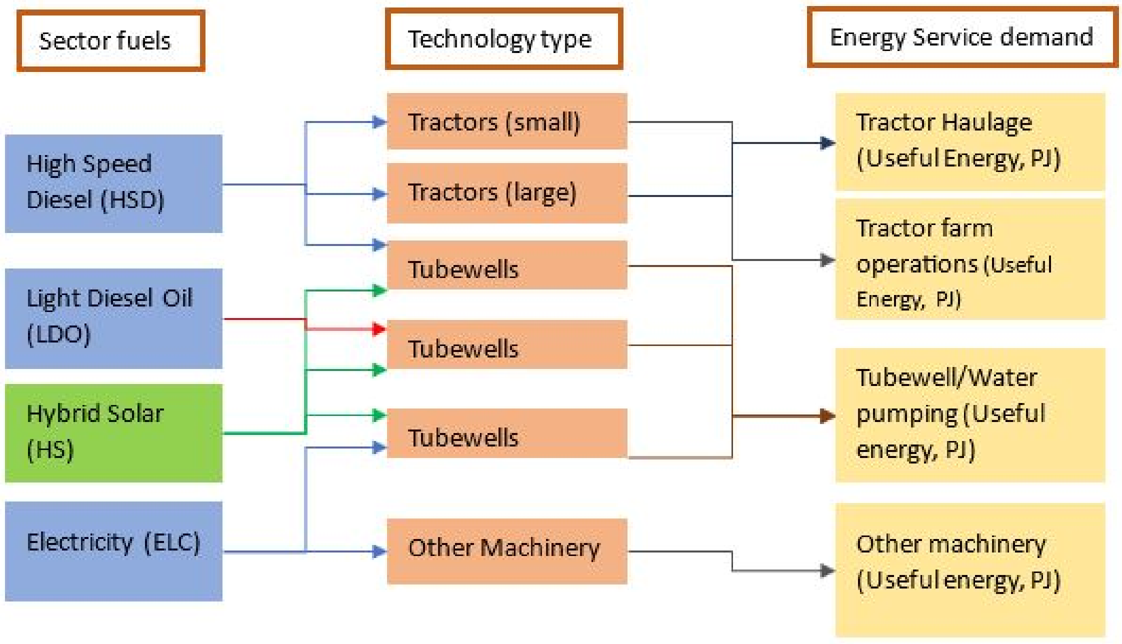

Figure 3.5 Reference Energy System for SIS

3.6.3 Biodiesel Inclusion Scenario

The Biodiesel Inclusion Scenario (BIS) involves integrating biodiesel into Pakistan's agricultural sector to assess its environmental impact and potential benefits as a sustainable solution. Here base model is Business-as-Usual Scenario (BAUS), the BIS focuses on widespread biodiesel adoption within agriculture, utilizing organic materials such as crops, agricultural residues, or waste to provide a renewable energy source. Within this scenario, consideration is given to B20, a blend comprising 20% biodiesel and 80% petroleum diesel, deemed particularly suitable for heavy-duty vehicles like trucks and tractors. Blends having higher share of biodiesel are avoided to prevent potential issues such as impacts on engine warranties and gel-like consistency in cold temperatures. Following a phased approach like the Solar Inclusion Scenario (SIS), BIS introduces B20 into the reference system from 2025, progressively increasing its share from 50% by 2040 and achieving full integration by 2060. While the primary goal of B20 utilization is not focused on emissions reduction compared to SIS, the scenario aims to transition towards sustainable energy production and utilization. The central objective is to use agricultural waste within the agriculture sector itself, making biodiesel a more sustainable alternative to traditional imported fossil fuels due to its local accessibility and utilization of agricultural waste.

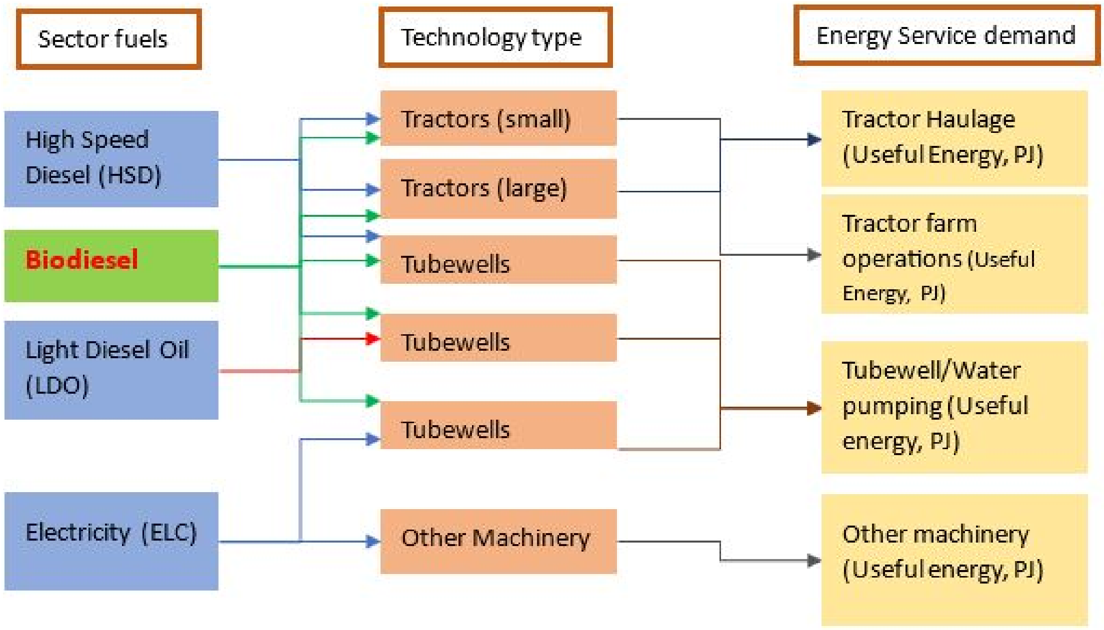

Figure 3.6 Reference Energy System for BIS

3.6 Analytical Procedure

All the above discussed data is incorporated into the model to evaluate it for the desired areas. The model is based on excel and incorporates multiple data which is then used to evaluate multiple results. The modeler can give data, build scenarios, introduce new technologies, define and interpret the existing technologies and can define the format of results in the VEDA-FE. It's a used interface and can work on multiple sheets, which are properly formatted and provided with TIMES code, that are used to tell the model about commodities, processes, and transformations etc. This whole series of process can be done on Veda-FE. Below given is interface of VEDA-FE.

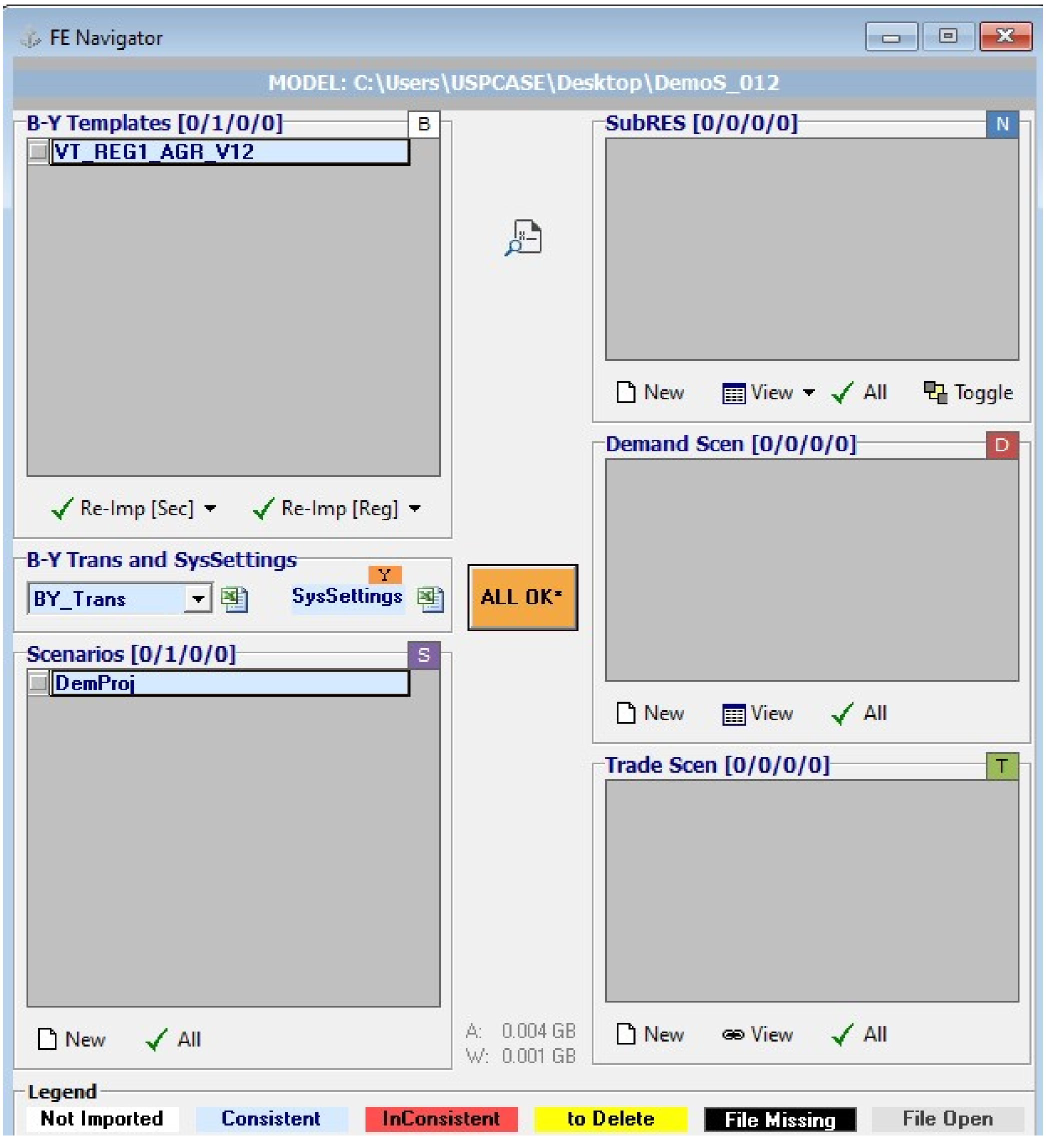

Figure 3.7 VEDA-FE Interface

Further this interface is mainly the Navigator which accumulates the data and gets it ready for further actions and tells if there are broken links, errors, or issues during the synchronization procedure. Then a case manager exists which after successful synchronization can load the data into GAMS which is further run for proposed results. Case Manager mainly allows you to run the desired scenarios and opt between different technologies you have included.

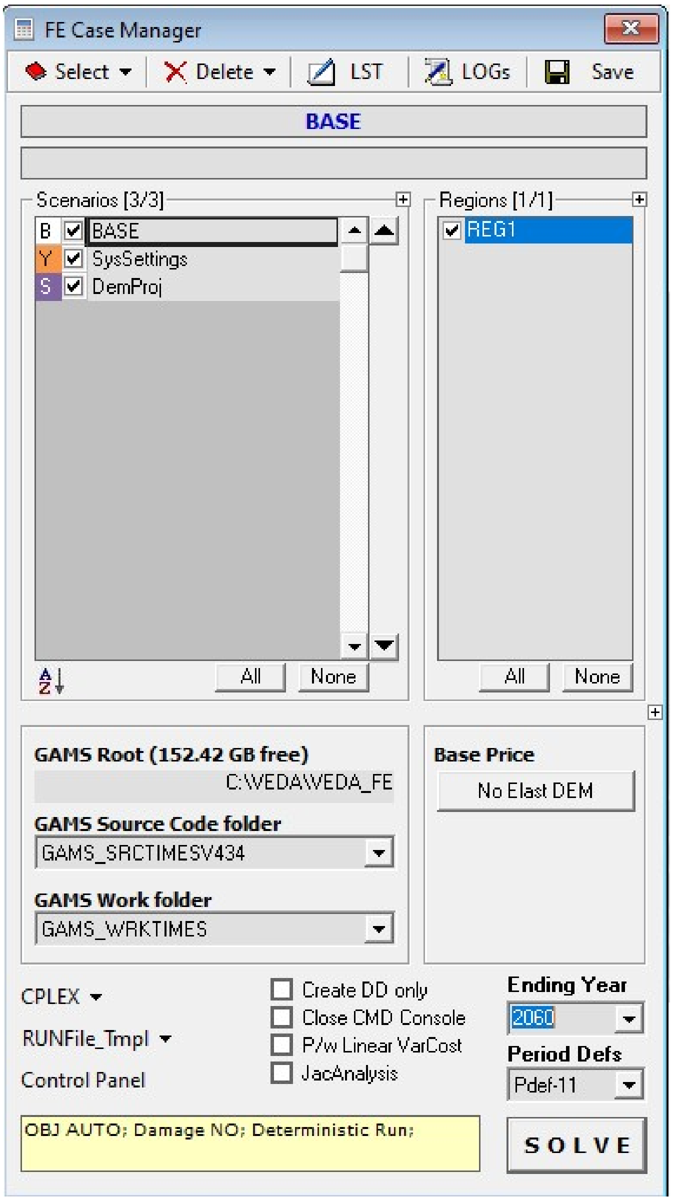

Figure 3.8 Case Manager for VEDA-FE

Then GAMS modeler is used to run the model, read the TIMES code, and evaluate the scenarios for multiple results. This whole procedure takes a shift to VEDA-BE as the results are stored there for user review. GAMS stands for general algebraic modeling system and is mainly as a programming language that read and evaluates the data provided to VEDA. A picture showing the running of model and result creation in GAMS is shown below.

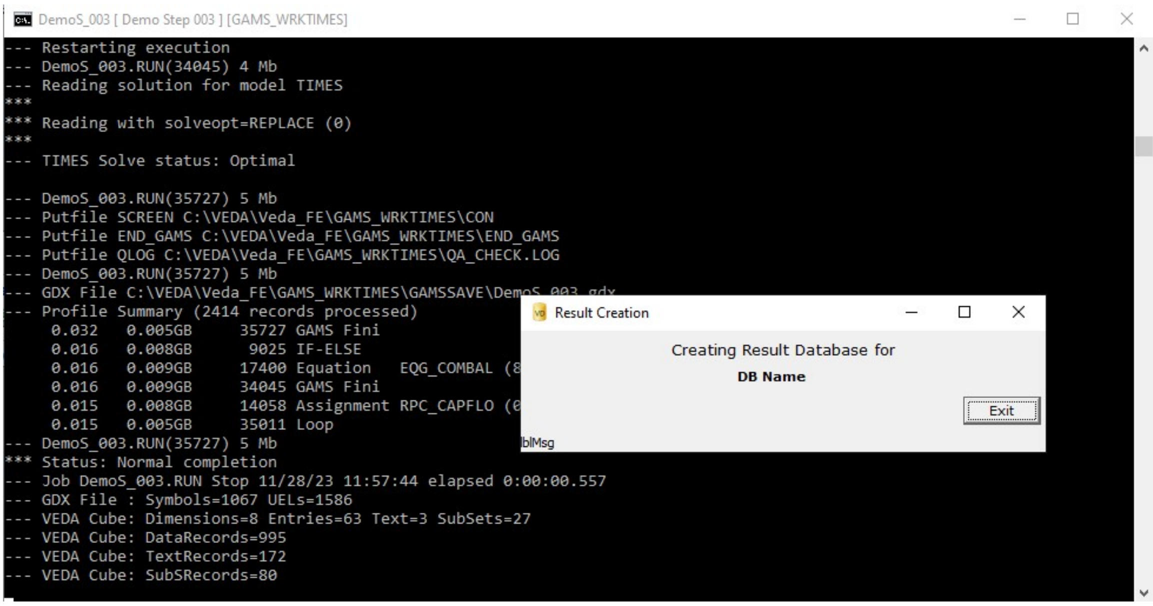

Figure 3.9 GAMS interface

As discussed, results are then stored into VEDA-BE, where we have the option to build tables according to our required results. Here for this study, we have considered results for demands and emissions from the agricultural sector. Veda Back END is linked with GAMS and gives the modeling results. It also gives you the freedom to add or remove years, commodities, processes from the results according to your results requirements. Also, you can compare results from multiple sectors, scenarios, and complete models in VEDA-BE. Interface of VEDA-BE is shown below.

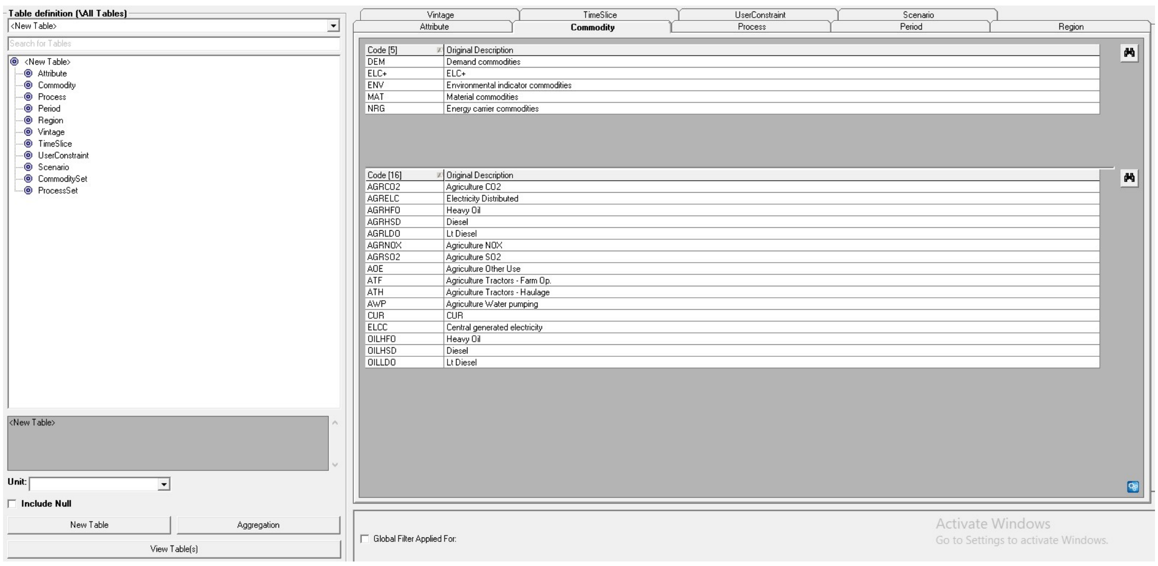

Figure 3.10 VEDA-BE Interface

There is multiple excel sheets involved in the formulation of data used for this whole model. Technologies, commodities, processes, life of different machineries, emissions, energy input and output are included in those data sheets. They are all then linked by TIMES code, that help VEDA read the data, and give forecasting results in the form of different outputs, like demand, supply, cost, and emissions. This all process is quite a complex one to do and has many limitations, however it's one of the best existing methodologies to evaluate results based on demand. As the model uses a bottom-up approach, by just providing about demand side data for base year it helps to forecast demand and emissions linked with those demand in coming years.

Csets	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
\I: Set Membership	Commodity Name	Commodity Description	Unit	Balance Equ Type Override	Timeslice Tracking Level	Peak Monitoring	Electricity Indicator
NRG	AGRHSD	Diesel	PJ				
	AGRLDO	Lt Diesel	PJ				
	AGRHFO	Heavy Oil	PJ				
	AGRELC	Electricity Distributed	PJ		ANNUAL		ELC
DEM	AWP	Agriculture Water pumping	PJ				
	ATH	Agriculture Tractors - Haulage	PJ				
	ATF	Agriculture Tractors - Farm Op.	PJ				
	AOE	Agriculture Other Use	PJ				
ENV	AGRCO2	Agriculture CO2	Kt				
	AGRSO2	Agriculture SO2	Kt				
	AGRNOX	Agriculture NOX	Kt				

Figure 3.11 Pictorial of building Commodities for reference case.

3.7 Limitations

Due to the vast area of study, that includes the whole agriculture sector, the study has multiple data limitations. This first includes data limitations, as the data on agriculture tractors and machinery linked with agriculture other than tubewells is not separately available. Also, the sources include tractors diesel energy consumption in transport, whereas there is no proper data on what percentage tractors acquire in the energy consumption in transport. By referring to various surveys, books and reports we have helped ourselves with the study.

3.8 Summary

This chapter gives details of methodology used, base mode and scenarios for study. Followed by the details on scenarios, why they are chosen for agriculture sector. The study then discusses the complete procedure of building the model, data used and limitations.

Chapter 4

Results and Discussion

Using the data gathered data, scenarios with different approaches for a 40-year horizon were derived from the developed energy mode. The results from the PAK-TIMES model's BAUS and other scenarios will be discussed further in upcoming sections. Following that, a comparison of energy consumption, machinery responsible and linked emissions was given.

4.1 Agriculture Machinery and their Energy Demand

The insights derived from the results of TIMES model offer a comprehensive understanding of the vast dynamics within Pakistan's agriculture sector energy requirements. Unlike prior studies that primarily concentrated on evaluating emissions stemming from agricultural activities, our novel approach delves deeper into the machinery's energy consumption, growth trajectories, and the anticipated emissions landscape. It serves as an illustrative depiction of the sector's energy consumption, focusing on four pivotal types of direct energy-consuming equipment. These encompass Agricultural Water Pumps (AWP), an inclusive category featuring tubewells, water pumps, and lift pumps; Agricultural Tractors Farm (ATF), a category encapsulating all tractors exclusively utilized for farming purposes; Agricultural Tractors Haulage (ATH), intricately linked with transportation and operations extending beyond traditional farming functions; and Agricultural Other Energy (AOE), encompassing medium to small-sized machinery.

The TIMES model's outputs furnish results pertaining to both energy demand and emissions, measured in Peta-joules (PJ) and Kilotons (Kt), respectively. In the reference energy system, the energy supply is a composite of electricity (19.02%), high-speed diesel (76.8%), and light diesel oil (4.18%). This nuanced analysis not only sheds light on the current energy landscape within the agriculture sector but also provides invaluable insights for shaping sustainable planning and decision-making processes. Figure below shows a descriptive of different machinery and their energy demand.

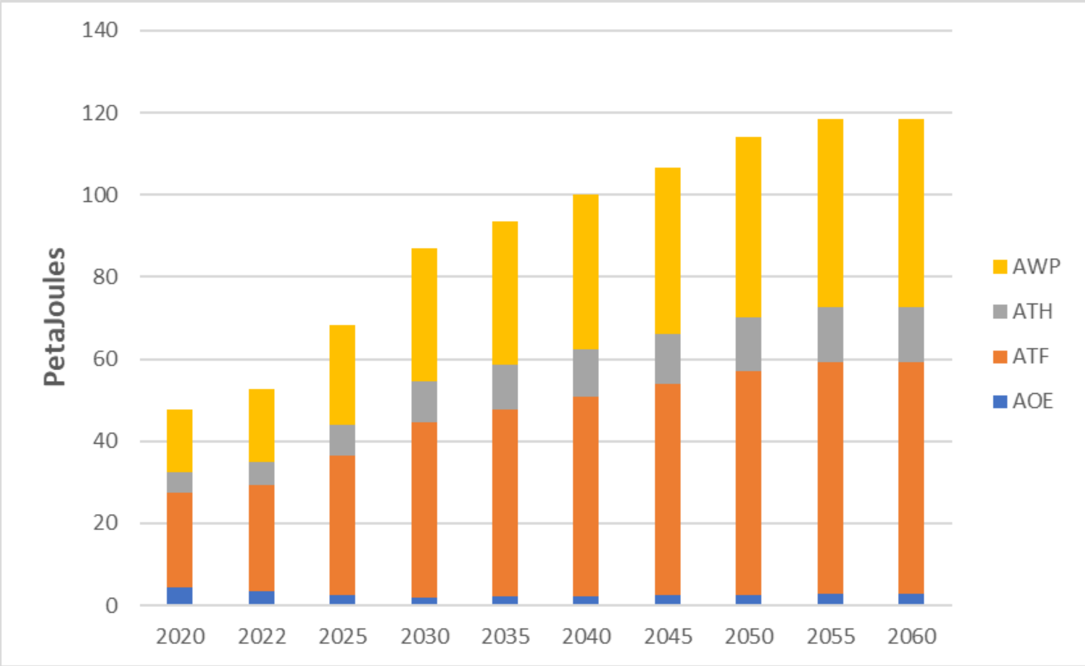

Figure 4.1 Country's growing Agricultural Energy Demand

The above figure shows details about energy consumption of different machinery, and their futuristic demands. Here it is evident, Agricultural Tractors for Farm Operations (ATF) emerging as the predominant energy consumer. Projections indicate a doubling of its demand by 2060, primarily fueled by combustion of fossil fuels. Following closely is the Agriculture Water Pumps (AWP), placed as the second-largest contributor to energy demand. This whole process relies on a combination of fossil fuels and grid electricity, with an anticipated threefold increase in demand by 2060. It's noteworthy that an excessive reliance on fossil fuels in this category could pose a significant concern for the entire sector. Agriculture Tractor Haulage (ATH) and Other Agricultural Operations (AOE) also surface as noteworthy contributors to the overall energy demand over the years.

For the base year in reference case, the demand for High-Speed Diesel (HSD) stands at approximately 157 PJ for running agricultural machinery, including tractors, tubewells, and other interconnected usages. Under current scenarios, this demand for high-speed diesel is projected to surge to 234 PJ by 2060, with tractors being the primary end-users driving this upward trajectory in the agricultural sector. This analysis underscores the critical importance of understanding and addressing the evolving energy needs of key agricultural machinery to ensure sustainability and efficiency in the sector.

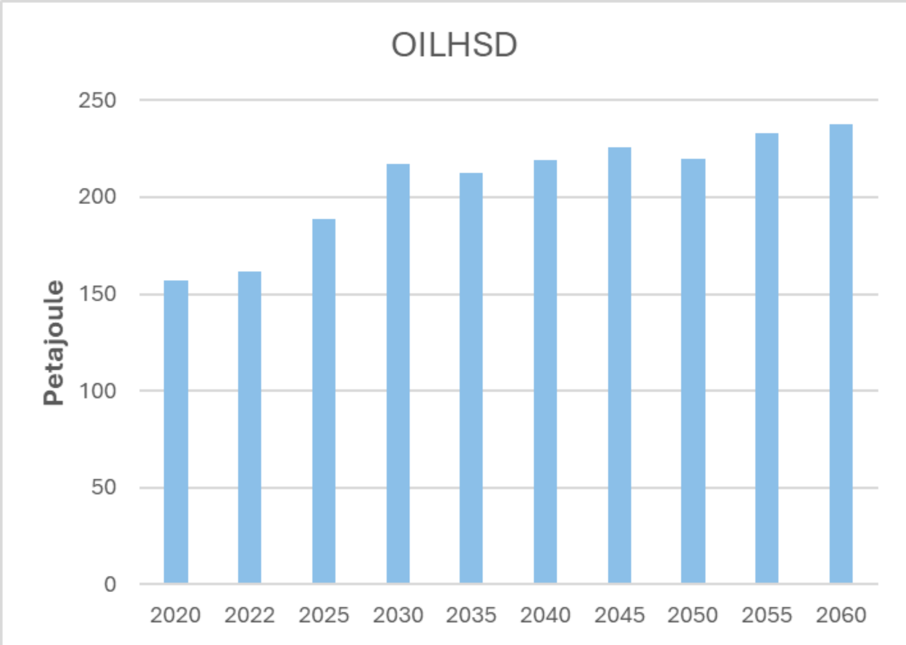

Figure 4.2 Growing High Speed Diesel Supply

The figure shows expected increasing energy demand of agriculture sector. In about 40 years the demand is expected to grow by 70% of existing demand. However no proper planning or capacity building is in stage to meet these energy demands. The agriculture sector is the main sector that is affected hardly by the country's energy shortage. As agricultural population is linked mainly with rural areas and in Pakistan even if the whole country is provided with electricity there are some rural areas that are not benefited from this reserve, which motivates the areas linked with sector ultimately to opt for costly fossil fuels. With the increase in growth in population and urbanization the food security challenges will increase which ultimately evolves more productivity from the agriculture sector. Agricultural productivity depends upon energy demand for the facilitation of agricultural processes, which needs to be updated with the latest technologies to efficiently use the available resources and transition towards sustainable ones.

4.2 Emissions

Meeting the escalating energy demands of Pakistan's agriculture sector results in a substantial and concerning amount of greenhouse gas (GHG) emissions, primarily stemming from fossil fuel usage, as illustrated in **Figure 4.3**. Diesel-powered engines, a key contributor, emit approximately 73.4 Kt of carbon dioxide per petajoule of energy produced. The visual representation of scenario outcomes over the projection period highlights the significant environmental impacts. The reference case scenario which here wo take BAUS indicates an upward trajectory in emissions, reaching an estimated 17,318 Kt by 2060. This projection underscores the imperative need to reform existing energy consumption patterns to mitigate adverse climatic impacts. Transitioning towards sustainable and renewable energy sources becomes paramount for curbing the sector's carbon footprint and fostering environmental sustainability.

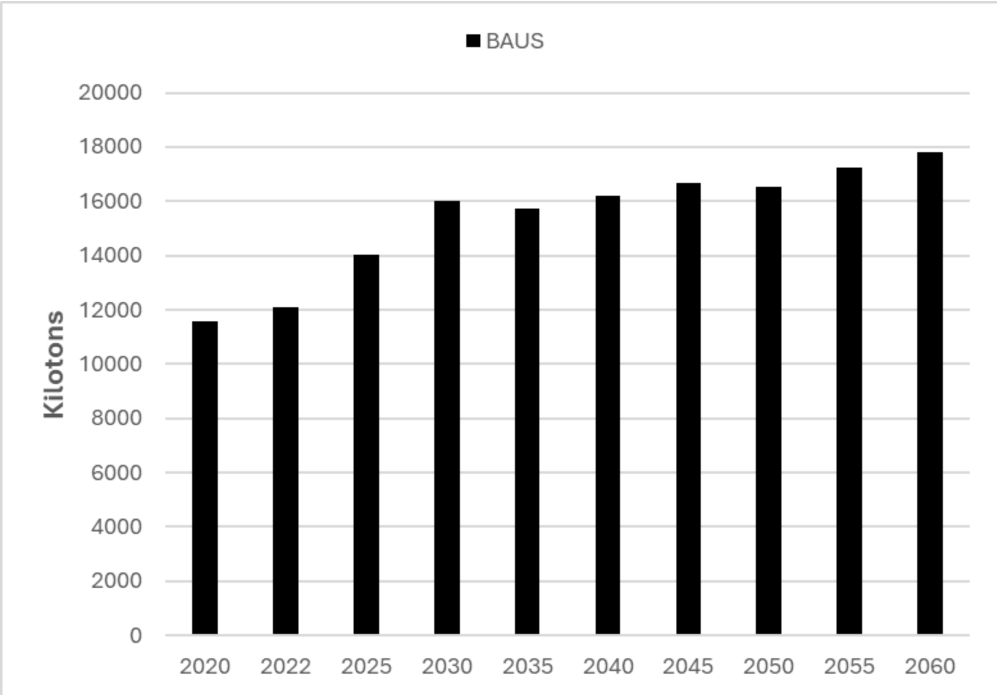

Figure 4.3 Futuristic Emissions from the Agriculture Sector

The continuous and substantial rise from the sector's emissions needs emphasizes the critical need for a reevaluation of heavy reliance on fossil fuels. Urgency is evident in transitioning towards sustainable alternatives to counter the impact of escalating consumption. A focused effort is required to adopt renewable energy sources and implement efficiency measures. This strategic shift is essential to ensure the long-term viability and resilience of the agricultural sector in the face of increasing energy demands and environmental challenges. By visualizing Figure 4.3 it is evident that timely counter measures are necessary to put stop to these increasing emissions. Currently Pakistan has less than 1% of solar PV system installed for agricultural operations, which if not increased will obviously show the emissions increase like above. This increase in emissions seen in BAUS is due to neglecting renewable sources and efficient technologies. This graph trajectory will change only if proper consideration is given to new technologies, which are discussed in the paper and there are many others, world is working on.

4.3 Scenario Outcomes

In the Renewable technologies, specifically solar and biodiesel, are introduced in two distinct scenarios starting from 2025.

4.3.1 Emission Reduction from SIS

The transformative impact of the Solar Inclusion Scenario (SIS) becomes even more apparent upon closer examination. This scenario, designed to integrate solar energy solutions into Pakistan's agricultural sector, showcases remarkable results in terms of emission reduction. The standout achievement is a substantial decrease of up to 2,200 Kt in overall agricultural sector emissions by the year 2060. This significant outcome can be attributed to the strategic introduction and adoption of solar water pumping technologies, with a particular focus on including a 50% inclusion rate.

The SIS's success is most evident in its targeted approach towards tubewells. While the current feasibility of applying solar technology to tractors may pose challenges, the reduction in fossil fuel dependency for tubewells is a noteworthy step forward. This shift aligns seamlessly with sustainable practices, representing tangible progress towards meeting environmental objectives. The reliance on solar power for tubewells addresses a critical aspect of the agriculture sector's energy consumption, contributing substantially to the overall emission reduction goal.

To offer a more detailed perspective, the SIS is dissected into specific inclusion levels: 20%, 50%, and 70%. Each of these sub-scenarios provides a nuanced understanding of how different degrees of solar technology adoption can influence the agricultural sector. The tiered approach allows for a comprehensive analysis of the potential impact of solar technology at varying levels of integration. The 20% inclusion level serves as an introductory phase, laying the foundation for solar technology adoption. This initial step allows for a modest yet meaningful reduction in emissions, setting the stage for further advancements. As the scenario progresses to the 50% inclusion level, the impact becomes more pronounced, with a significant decrease in overall emissions. This signifies the growing effectiveness of solar solutions, particularly in energy-intensive processes like water pumping.

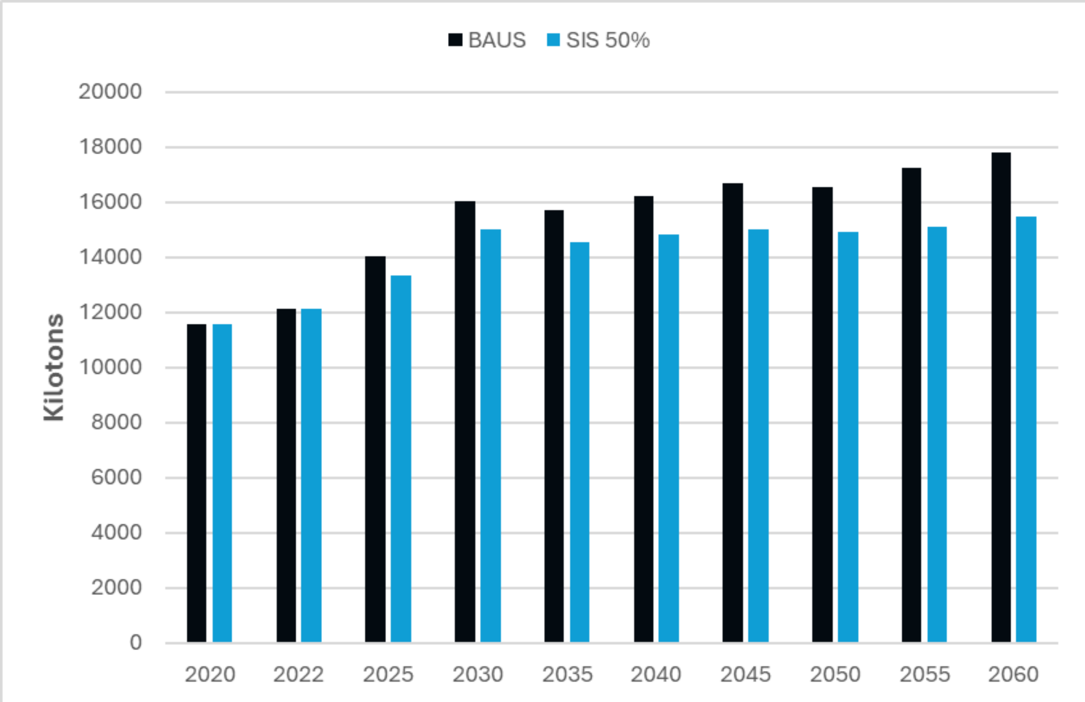

Figure 4.4 Emission Reduction by Inclusion of Solar Water Pumping up to 50%

In Figure 4.4 it is clearly seen that increasing capacity of solar water pumping technology overtime from 20% to 50% will reduce quite emissions compare to the size and intensity of sector. Additionally, to delve deeper into the nuances of the Solar Inclusion Scenario (SIS), we further broke down this transformative approach into two distinct sub-scenarios. In the second sub-scenario, we focused on the continuous inclusion of 20% solar water pumping technology throughout the subsequent years. This approach aimed to gauge the impact of a constant increase in the deployment of solar pumps within the agricultural sector, with the inclusion rate reaching up to 20% only.

The graph depicted in Figure 4.5 illustrates a consistent and parallel trend, showcasing the intricate relationship between emission reduction and the gradual increase in solar technology with emissions increase in the adoption of solar water pumping technology. As more pumps are integrated into the sector over time, the emission reduction aligns proportionally with the increment in the inclusion rate. This dynamic relationship highlights the potential for emission reduction as a direct outcome of the strategic and consistent incorporation of solar technology.

By the year 2060, this second sub-scenario contributes to a substantial reduction in sector emissions, amounting to approximately 862 kt when compared to the Business-as-Usual Scenario (BAUS). This noteworthy reduction signifies the positive impact of sustained adoption of solar water pumping technology within the agricultural sector. It reinforces the idea that continuous efforts to increase the deployment of solar solutions can lead to tangible and sustained benefits in terms of emission reduction, contributing significantly to the overall environmental goals of the agricultural sector.

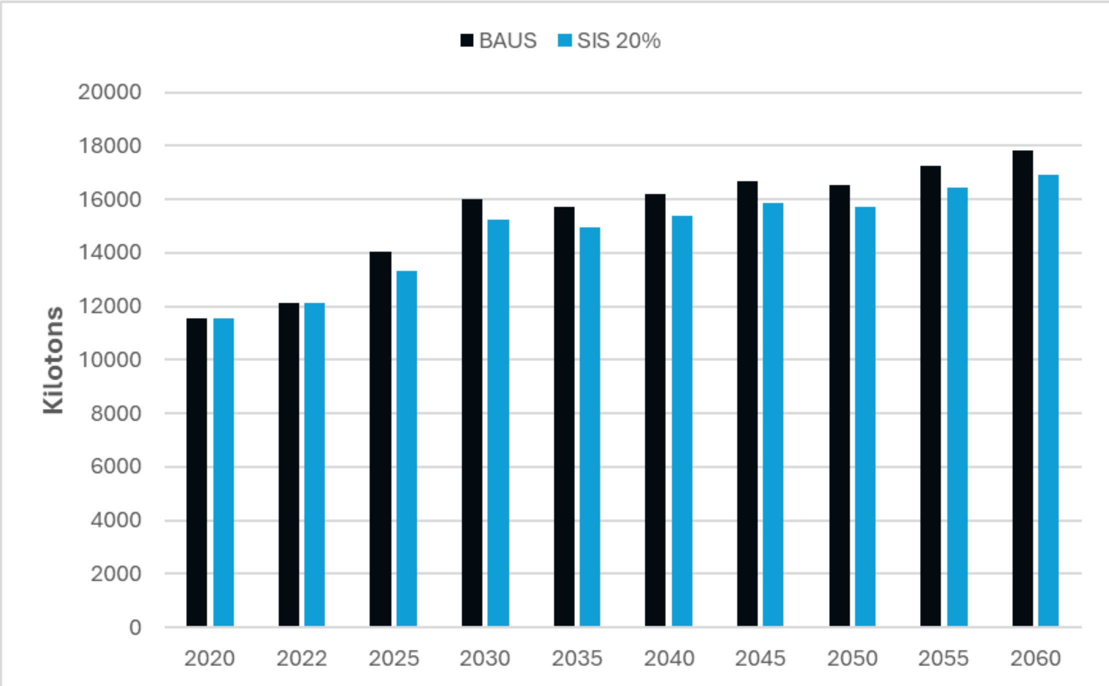

Figure 4.5 Emission Reduction by Inclusion of Solar Water Pumping up to 20%

Moreover, in the third sub-scenario, we pursued an even more ambitious trajectory, aiming to achieve a significant 70% reduction in emissions by the year 2060. Commencing with a modest 20% inclusion in 2025, this scenario demonstrated a remarkable impact on emissions, resulting in a substantial reduction of 2,973 Kt compared to the Business-as-Usual Scenario (BAUS), as illustrated in Figure 4.6.

These outcomes underscore the extraordinary potential of solar water pumping technology in revolutionizing the agricultural sector's energy landscape. The consistent and substantial reduction in emissions across all three sub-scenarios emphasizes the dependability and efficacy of these technologies. Previous studies have consistently advocated for the alignment of such sustainable technologies with global sustainability goals. The evolving pattern of gradually increasing the share of solar water pumping technology from 20% to an ambitious 70% exemplifies a strategic approach that policymakers can consider. By expanding the use of these technologies, there is a tangible pathway toward achieving the grueling goal of net-zero emissions. These scenarios not only showcase the immediate benefits of emission reduction but also provide a roadmap for long-term sustainability in the agricultural sector.

The careful consideration and implementation of such strategies can propel the agricultural industry toward a more environmentally conscious and sustainable future.

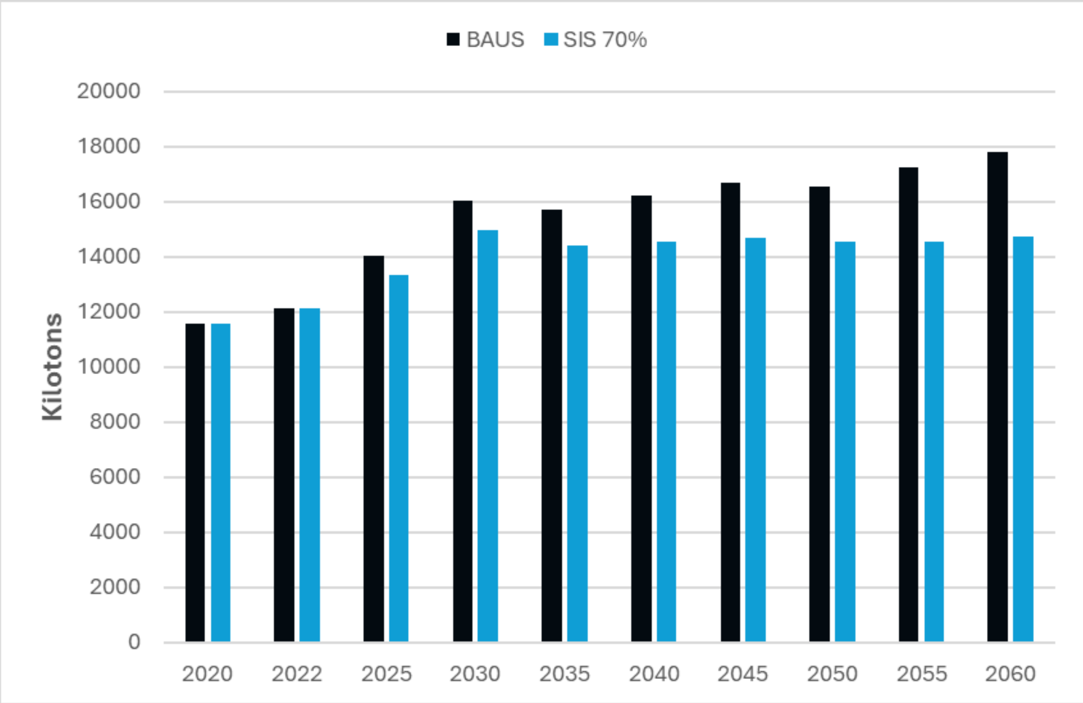

Figure 4.6 Emission Reduction by Inclusion of Solar Water Pumping up to 70%

The 70% inclusion level represents an ambitious but achievable milestone. At this stage, the agricultural sector experiences a substantial shift towards solar energy reliance, resulting in a noteworthy reduction in carbon emissions. The 70% inclusion level serves as a testament to the transformative potential of solar technology when embraced on a larger scale. It also highlights the adaptability and scalability of such solutions to meet the increasing energy demands of the agricultural sector.

In essence, the Solar Inclusion Scenario not only proves to be a catalyst for emission reduction but also a pathway towards a more sustainable and environmentally conscious agricultural sector. The tiered inclusion levels offer a strategic roadmap, allowing for a phased and realistic transition to solar technology adoption. As the agricultural sector considers these innovations, it moves closer to achieving not only environmental goals but also enhancing energy efficiency and resilience. The success of the SIS lies not just in its quantitative achievements but in its qualitative contribution to fostering a greener and more sustainable future for Pakistan's agriculture.

4.3.2 Emission Reduction by BIS

The Biodiesel Inclusion Scenario (BIS) unfolds as a transformative narrative in Pakistan's ambitious future to reshape its agricultural energy landscape. As shown in Figure 4.7, this scenario doesn't merely represent a shift in fuel preferences, also it embodies a comprehensive strategy aimed at achieving multiple objectives, ranging from emission reduction to efficient waste management within the agricultural sector. Commencing in 2025, the BIS introduces Biodiesel in the form of B20, a fine blend comprising 20% biodiesel and 80% traditional diesel. This phased introduction isn't just a regular replacement, but a thorough plan aligned with Sustainable Development Goals (SDG-7 and SDG-13). The importance of including this blend lies in leveraging waste, reducing emissions, and unlocking economic benefits through sustainable practices.

The phased integration of B20 into the agricultural sector is a deeply studied and adaptive process. Starting with the substitution of 50% of diesel with biodiesel until 2040, the scenario visions a comprehensive transition, envisioning the utilization of 100% biodiesel by 2060. This approach ensures a smooth transition, acknowledging the intricacies of the agricultural landscape and allowing for a gradual shift.

Beyond its role as a renewable energy source, Biodiesel becomes a pinpoint for addressing the formidable challenge of agricultural waste management. The phased introduction of the B20, with its compatibility with existing engines and seamless integration into current practices, underscores its productive and immediate nature. Although B20 is still in the research and development phase, it serves as an accessible solution for tractors and various agricultural machinery, providing a sustainable alternative to traditional diesel.

The significance of the BIS transcends emission reduction. It signifies Pakistan's futuristic commitments to innovation and sustainability in its agricultural practices. In the face of complex energy landscapes, the BIS emerges as a powerful source, addressing environmental challenges, supporting economic sustainability, and ensuring the long-term resilience of the agricultural sector. Incorporating Biodiesel scenarios into the broader energy landscape marks a stable shift. It's not merely a change in fuel choices; it's a visionary move toward a circular, environmentally friendly, and economically viable future for Pakistan's agriculture. The BIS, through its contribution to emission reduction and promotion of sustainable practices, stands as a stepstone for a resilient and environmentally conscious agricultural sector.

The phased transition allows for the adaptation of existing infrastructure, machinery, and practices, ensuring a smooth integration that aligns with the realities of Pakistan's agricultural sector. Furthermore, it opens avenues for research and development, creating a breeding ground for innovation and technology adoption within the agricultural community. Additionally, the flexibility embedded in the BIS enables farmers to gradually transition without facing immediate and drastic changes. This phased approach acknowledges the existing challenges, such as the compatibility of machinery and the need for a reliable and steady supply of biodiesel. It also provides room for continuous improvement, allowing for adjustments based on real-world feedback and evolving technologies.

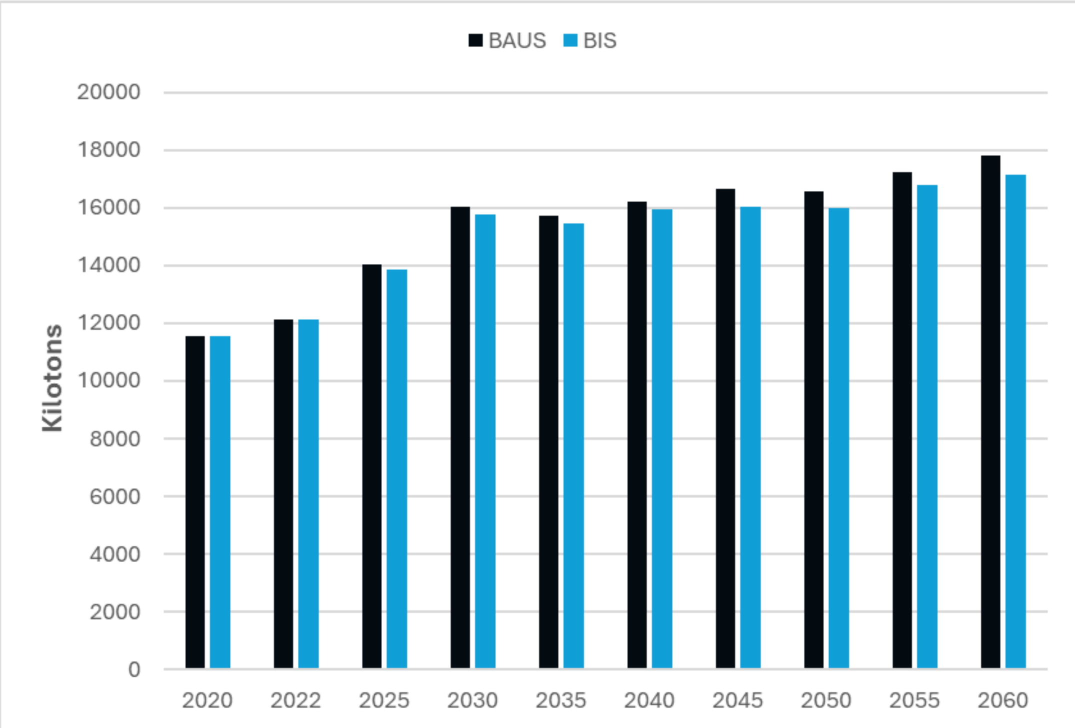

Figure 4.7 Emission Reduction by Inclusion of B20

In the broader context, the BIS aligns seamlessly with the national and global objectives for sustainable development. By strategically introducing biodiesel in a phased manner, the scenario accounts for the intricate set of factors influencing the agricultural sector. This includes considerations such as machinery compatibility, the availability of biodiesel, and the need for supportive policies to facilitate a smooth transition. Furthermore, the BIS contributes to the overarching goal of reducing the carbon footprint of the agricultural sector. The inclusion of Biodiesel, derived from organic materials, not only provides a renewable energy source but also addresses the challenge of agricultural waste disposal. This circular approach ensures that waste generated in agricultural processes is transformed into a valuable resource, mitigating environmental impact.

The economic benefits of the BIS extend beyond emission reduction. By harnessing biodiesel derived from local sources, the agricultural sector can reduce its dependence on imported fossil fuels. This, in turn, contributes to energy security and economic resilience, aligning with national priorities for self-sufficiency. In conclusion, the BIS emerges as a transformative strategy that goes beyond the conventional ways of emission reduction. It represents a unique approach to sustainable agriculture, encompassing environmental, economic, and social dimensions. By strategically introducing biodiesel into the agricultural energy landscape, Pakistan can pave the way for a resilient, circular, and environmentally conscious future for its agricultural sector. The phased integration, supported by innovation and collaboration, positions the BIS as a beacon of sustainability in the complex dynamics of Pakistan's energy and agriculture intersection.

4.4 Validation

The assessment of carbon dioxide emissions from the agriculture sector is a critical aspect of our study, particularly when compared to the results generated by the Pakistan Integrated Energy Model (Pak-IEM). This comparative analysis serves as a robust validation mechanism, ensuring the accuracy and reliability of our model predictions. By examining the trend from 2020, our base year, to 2040, the final year for Pak-IEM data, reveals intriguing insights. The observed similarity in trends is noteworthy, affirming the coherence and consistency between the two models. However, some differences merit consideration for a comprehensive understanding.

Our model exhibits slightly higher emissions compared to Pak-IEM. This variance can be attributed to several factors intricately woven into the view of Pakistan's evolving agricultural landscape. A primary contributor is the contemporary agricultural sector's reduced reliance on light diesel oil, historically a main source for tube wells. While light diesel oil may not boast optimal energy efficiency, it emits lower levels of carbon dioxide. This historical shift in fuel preferences, influenced by technological advancements and changing practices, plays a pivotal role in shaping emission outcomes. Moreover, the differences can be traced back to the technologies employed and the degree of dependency on fossil fuels. The intricacies of agricultural practices, evolving machinery, and energy source preferences create a dynamic landscape with varied emission profiles.

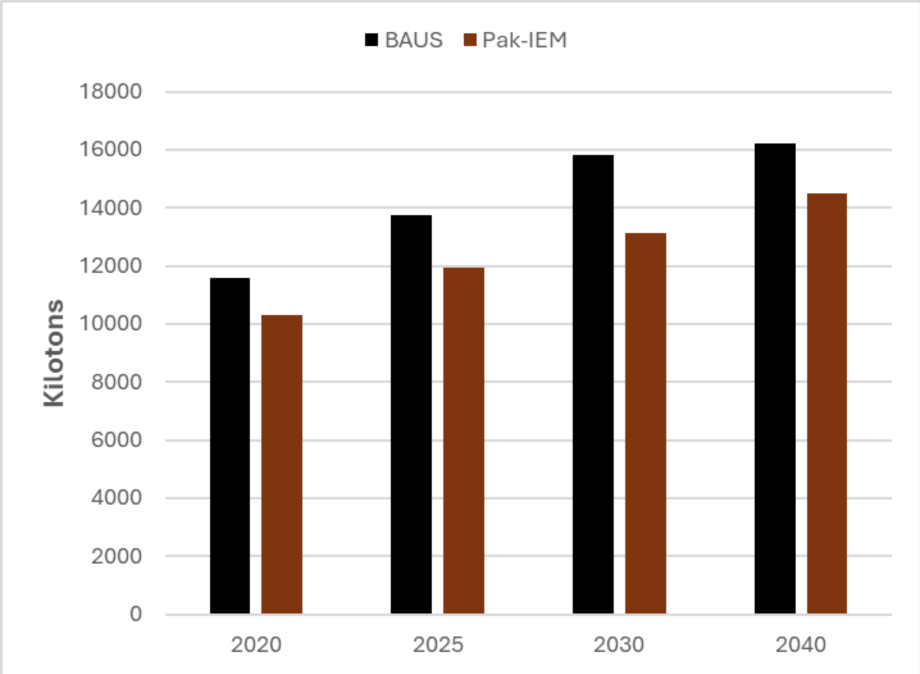

Figure 4.8 CO2 Emissions

This validation process underscores the importance of a thorough understanding of the agricultural sector's complexities. It reaffirms the need for continuous refinement and enhancement of models to align with the evolving dynamics of the agricultural domain. Policymakers can leverage these validated insights to craft targeted interventions that effectively address the specific challenges and opportunities within Pakistan's agricultural sector. As we strive for sustainability, this validation exercise not only enhances the credibility of our study but also contributes to the broader discourse on sustainable agricultural practices in the context of evolving energy landscapes.

4.5 Summary

This chapter mainly discusses results from different scenarios. Starting with emissions from the sector and main contributor to energy consumption. Moving to alternative options that should be considered and graphical futuristic outcome of considering these technologies. Biodiesel and Solar Water Pumping technologies are the main discussed.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

This research underscores the high necessity for Pakistan to thoroughly reassess its energy framework, notably characterized by oil centric methodologies such as the use of fossil-fueled based agricultural machinery. Projections of energy demand in agriculture sector emphasize the increasing dependence, compelling the need for strategic shifts away from unsustainable paths. The analysis facilitated by the VEDA-TIMES model yields invaluable insights into the forthcoming trajectory of Pakistan's agricultural energy sector. The evident upward trajectory in emissions, particularly attributable to high-speed diesel usage, focuses on the imperative for immediate and transformative interventions to mitigate environmental degradation. By visualizing into the intense dynamics of the energy landscape, this study acts as an emergency call for the nation to adopt sustainable practices, thereby shifting a course towards a more environmentally friendly and resilient future.

As visualized above in the reference case the evolving emissions trajectory defines the evolving nature of agricultural sector and their linked energy consumption. In about 30-40 years these emissions are set to be increased by a huge number, even if this number is possible if well maintained and timed retirement of machinery takes place. Otherwise, these emissions could be a lot higher than expected. This all reinforces the narrative, underscoring the urgency for targeted interventions that address both technological inefficiencies and the pressing need for prompt maintenance practices within the agricultural sector. The prevailing situation in Pakistan's agricultural landscape, marked by a lack of adequate maintenance facilities, is particularly pronounced in regions with intensive agricultural activities. This inadequacy poses an increasing challenge to ensuring the timely upkeep of machinery. The prospect of transformative change becomes apparent with the provision of proper maintenance facilities in this sector, promising enhanced efficiency for machinery reliant on fossil fuels. A symbiotic relationship emerges between efficient machinery and reduced greenhouse gas (GHG) emissions, presenting a promising avenue for fostering sustainability in agriculture. This holistic strategy is imperative, as it not only tackles the overreliance on high-speed diesel but also addresses systemic challenges associated with delayed maintenance and inefficient technologies, thus paving the way for a more sustainable and resilient agricultural sector.

5.2 Recommendations

- Resource conservation technologies (RCTs) like precision land leveling and high efficiency irrigation systems are essential. These technologies will greatly reduce water dependency and ultimately helps in energy savings, ultimately addressing to both issues like water scarcity and energy shortage.
- Policy makers should consider giving subsidies on biodiesel and solar water pumping technologies. As inclusion of both will highly contribute to county's sustainability goals and economic capacity building. These both technologies will help run the agriculture sector much faster, ultimately contributing to food security challenges.
- Stakeholders should ensure the availability of nominal and authorized dealerships/ workshops near to agricultural areas, as discussed above the loss of hours due to machine failure, maintenance needs and accessibility of dealerships is quite an issue for timely cultivation of agricultural land. Timely maintenance will lead to efficient engine running and less fuel consumption. Both help reduce overall emissions from the sector.
- Community awareness campaigns are essential to the effective implementation of sustainable practices. The advantages of renewable energy technologies and the significance of resource-efficient farming methods must be communicated to farmers and other stakeholders. Formulating integrated strategies that holistically address the multifaceted challenges faced by these sectors is essential for fostering sustainable development. This collaborative approach ensures that policies are coherent, synergistic, and capable of generating positive outcomes across various interconnected aspects.
- Investment in research and development (R&D) emerges as a critical factor in shaping the evolution of sustainable technologies that cater to the unique requirements of Pakistan's agriculture. The continuous exploration of innovations in energy-efficient machinery, the seamless integration of renewable energy sources, and the advancement of precision agriculture practices can pave the way for long-term sustainability. R&D investments play a pivotal role in fostering technological advancements that are not only tailored to the existing challenges but also anticipate and address future needs. By promoting a

culture of innovation, Pakistan can position itself at the forefront of sustainable agricultural practices, enhancing productivity while minimizing environmental impact.

Appendix- Publication

Paper ID: ICETEMS-23-238

REDUCING THE ENVIRONMENTAL IMPACT OF AGRICULTURE SECTOR IN PAKISTAN THROUGH HYBRID SOLAR-POWERED IRRIGATION SYSTEM

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Abstract: This research paper addresses the challenges posed by Pakistan's heavy reliance on fossil fuel-based energy consumption, particularly within the agriculture sector. Despite notable progress in other sectors transitioning to renewable energy, the agriculture sector is not progressing at the same pace and is facing a severe energy shortage. The study aims to identify areas for improvement and propose measures to reduce dependence on costly fossil fuel-based energy. Using the Veda-TIMES modeling approach, the research develops scenarios considering energy demand and fossil fuel consumption in agriculture. Two scenarios, the reference, and solar hybrid technology scenarios, highlight key areas for improvement. Water pumps are identified as critical areas where informed decisions and technological advancements can alleviate energy shortages and reduce greenhouse gas emissions. Aligned with the Sustainable Development Goals (SDGs), the paper emphasizes the significance of Affordable and Clean Energy (SDG 7) and Climate Action (SDG 13). Transitioning to sustainable energy sources in agriculture can enhance accessibility, and affordability, and contribute to reducing GHG emissions. The study offers tangible solutions rooted in renewable energy technologies, advocating for a sustainable and resilient future. By integrating hybrid solar-powered irrigation systems, Pakistan can achieve energy efficiency, cost-effectiveness, and environmental sustainability in agriculture. This research provides a comprehensive analysis of Pakistan's energy challenges and proposes actionable recommendations. Embracing renewable energy and aligning with the SDGs and the Paris Agreement will enable a greener and more sustainable agricultural system, contributing to socio-economic development and global climate change mitigation efforts.

Keywords: SDGs, Water Pumps, GHGs, Veda-TIMES, Hybrid Solar

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