Prospects of bioenergy potential in Punjab (Pakistan) under different scenarios of agricultural growth

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Abstract
Green recovery and a transition toward Renewable Energy (RE) resources are among the most critical areas being exploited for achieving the long-term sustainability of Pakistan's energy sector. RE targets (30% RE by 2030) in the backdrop of Alternate and Renewables Energy (ARE) Policy 2019 and Paris Agreement goals of Pakistan require quantification of RE sources for efficient resource harvesting. Opportunely, being an agriculture-based economy, Pakistan has a wide and diverse potential of biomass products that can assist the energy sector through the production of biofuels and power. This study performs the theoretical and technical assessment of energy generation through biomass under different scenarios of agricultural development. Bio-IRENA simulator and Long-Range Alternate Energy Planning (LEAP) models are used to calculate the potential through steam turbines (Combustion/Gasification Steam) under different technological transformations. Crop Phenology, technological penetration, feed-stock availability, farmer's willingness for selling their products are the main driving force behind the three considered scenarios. The results from the model depict that in Punjab (Pakistan), 14 billion litres of ethanol can be generated (theoretically) only through agricultural residues. However, due to the utilization of agricultural residues as a non-commercial energy source and animal fodder, the technical potential is reduced to 4.2 billion Litres. Similarly, there is a potential to generate approximately 42 TWh of electricity only through the utilization of agricultural residues. Further, the model results also depict that the generation is highly dependent on moisture contents and average yields of the crops causing the potential to change by 15 %.

Keywords
Bioenergy, LEAP, Bio-IRENA Simulator, Electricity generation, Waste to Energy

Introduction

With a constant increase in population, urbanization, and industrial development, the global energy demand has increased significantly causing worldwide energy shortage and security issues. For developing and under-developed countries, this energy shortfall combines constantly depleting resources and balloons into a huge energy crisis. On the other hand, the use of conventional resources causes environmental degradation that affects both atmosphere and human life. Figure-1 shows the constantly increasing energy demand and the resulting emissions from the energy sector around the globe.

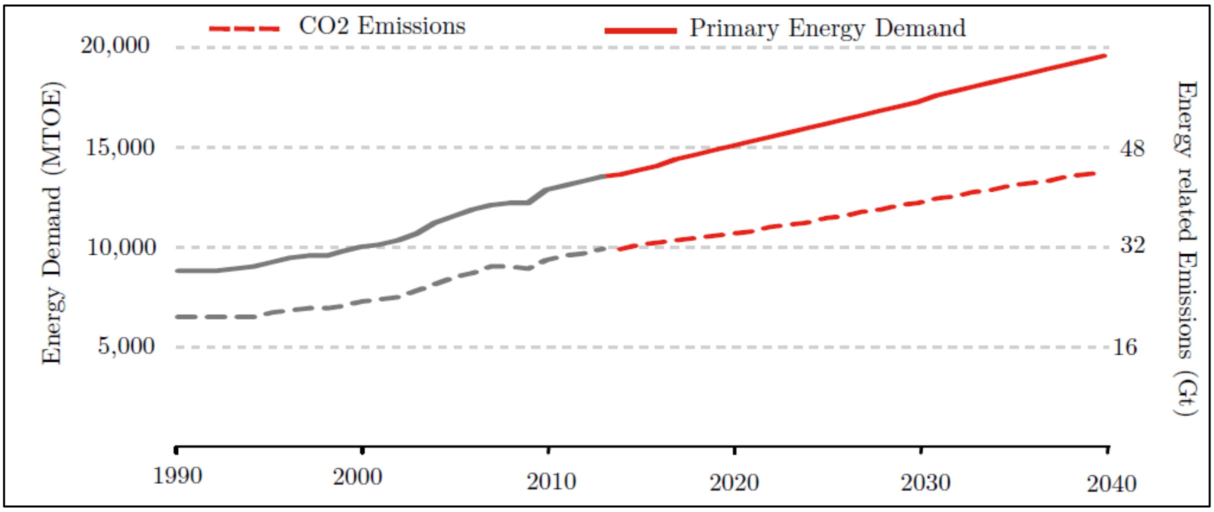

Figure 1: Increasing Energy Demand and projected emissions from the energy sector across the globe [1, 2].

Due to a constantly increasing demand, increasing energy supplies at a faster pace is needed to reach the goal of universal energy access. As of today, approximately 1.2 billion of the global population (i.e. 17%) is without access to energy and approximately 38% are still at health risk due to the use of inefficient sources [3], [4]. To account for this increase and environmental considerations, a paradigm shift is needed toward sustainable energy sources where renewables are the centre of transition for attaining a low carbon-intensive system. International Energy Agency (IEA) predicted that currently, renewables supply a share of 23.9%, 10/3%, and 3.4% in the power, heat, and transport sector of the country respectively. In the coming years, this value is expected to increase to a total value of 12.4% in the overall worldwide energy mix [5]–[7].

According to reports of the IEA, bioenergy constitutes almost half of the renewable energy that was consumed in 2017. This value is four folds larger than the energy supplied by solar and wind combined [Renewables 2018]. Similarly, according to the International Renewable Energy Agency (IRENA), half of the energy consumption today is based on biomass. However, this half also includes the non-commercial use of bioenergy sources which is non considered a sustainable form [8], [9].

Compared to wind and solar, biomass is more favorable for the energy sector of Pakistan and its penetration will provide more sustainable energy and economic outlook. Since biomass can be converted to three different forms of fuels, it can provide a better energy outlook and consequently economic stability. The Gross Electricity production of major bioenergy utilizing countries is shown in figure 2.

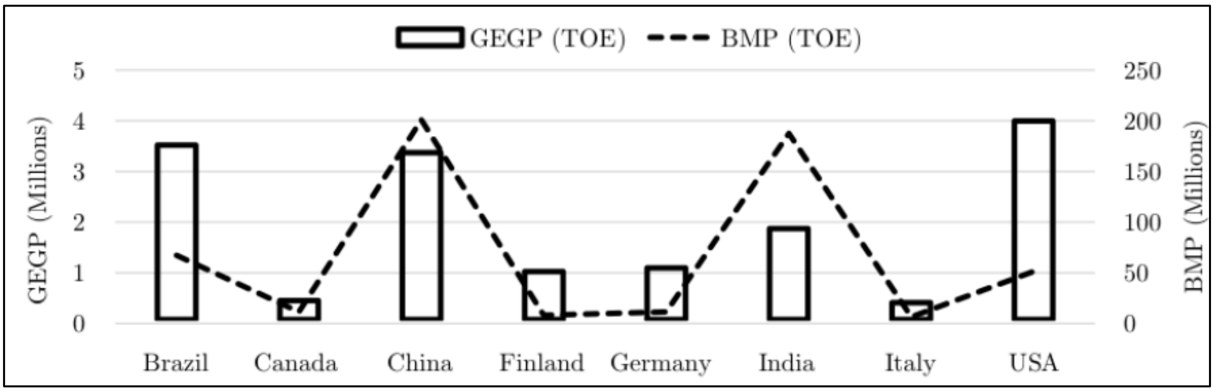

Figure 2: Gross potential of power production from biomass in different countries [GEGP = Gross Electricity Generation Potential, BMP = Biomass potential] [3,7]

Biomass-related studies being conducted in Pakistan are described below [10].

Alternate Energy Development Board Studies (AEDB): Currently, the bioenergy market in Pakistan includes Independent Power Producers (IPPs), Combined Heat and Power (CHP) plants, Power Captives, and some off/on Grid systems. Three sugar plants are working under IPPs that generate approximately 50 MW through cogeneration of bagasse.
Quality Standards: AEDB in assistance with United Nations Industrial Development Organization (UNIDO) described technical criteria for promoting bioenergy projects under various government schemes. The common conversion technologies considered were Combustion and Gasification plants and various specifications of technology, as well as feedstock, is presented.
Policy on biomass energy technology: The government of Pakistan with assistance from UNIDO and funding from the Global Environment Facility (GEF) promoted efficient and market-based BETs in industries of Pakistan. The report reviews the current status of ARE barriers and challenges, success stories around the globe, and annually provides policy recommendations. Energy Sector Management Assistance Program (ESMAP) bioenergy resource mapping also provides useful insights on the technical and theoretical potential of biomass across the country from different sources.

This study quantifies bioenergy under different scenarios of agricultural growth for analyzing the potential socio-economic impacts in the long term. This would provide a clear indication of the technical and theoretical potential of bioenergy based on agricultural development in the country.

Methodology

This section describes the modeling approach used to calculate and analyze the potential of biomass under different scenarios. Each scenario is driven by the use of different technologies and the growth of demand drivers. The most critical drivers considered in this study are the Agricultural Gross Domestic Product (GDP), its linkage with Overall GDP, urbanization, and population growth.
Long Range Energy Alternatives Planning (LEAP) model (Projections) and Bio-IRENA simulator have been used to assess the varying potential under different scenarios. The modeling framework for the study is described in figure 3.

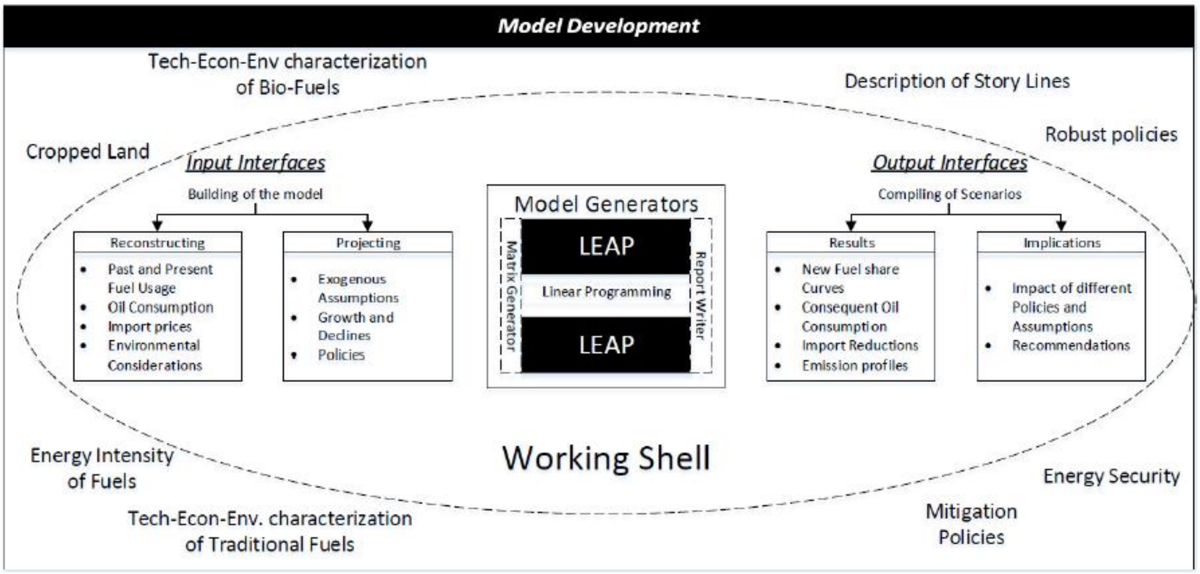

Figure 3: Modeling framework of the Study

The modeling framework depicts that the processing of both the base year and the post scenario analysis. Technological, Economic, and Environmental considerations (parameters) are entered into the model as base year along with energy intensity of different crops (used in the study), their harvesting area and cropper land, and characterization of end uses and output products. The output obtained from this model is used to analyze the robust policies that can be used to improve the outlook of bioenergy in the energy mix of Pakistan. Based on these policies, a sustainability framework has been created for Pakistan.

Data Collection

The data collection process mainly involved the crop seeds, their moisture contents, crop cycle, agricultural growth, and its linkage with the GDP of the country. The major crops used in this analysis are shown in the table below.

Table 1: Major Crops used in the analysis and their annual production along with end-use [T = Transport, El = Electricity, H&P = Combined Heat and Power]

Sr. No	Crop	Yield (t/ha)	Cropped Area(ha)	Total production (t)	End Use
1	Maize	3.99	689,000	2,749,110	T
2	rapeseed	0.806	151,000	121,706	T, El, H & P
3	Sugarcane	55.22	757,000	41,801,540	T
4	Barley	0.91	36,000	32,760	T, El, H & P
5	Rice	2.395	1,809,000	4,332,555	T, El, H & P
6	Wheat	2.713	6,901,000	18,722,413	T, El, H & P
7	Groundnut	0.919	82,200	75,541.8	T, El, H & P
8	Jatropha	1.2	1,000,000	1,200,000	T, El, H & P
9	Sunflower	1.3	46,200	60,060	T, El, H & P

Apart from this data collection further includes:
1. Cost of Biomass Feedstock
2. GDP growth and interconnection with Agriculture
3. Crop Rotation and Cycle.

4. Production Potential
5. Environmental Consideration

The following schematic shows the inputs of data into the modeling framework.

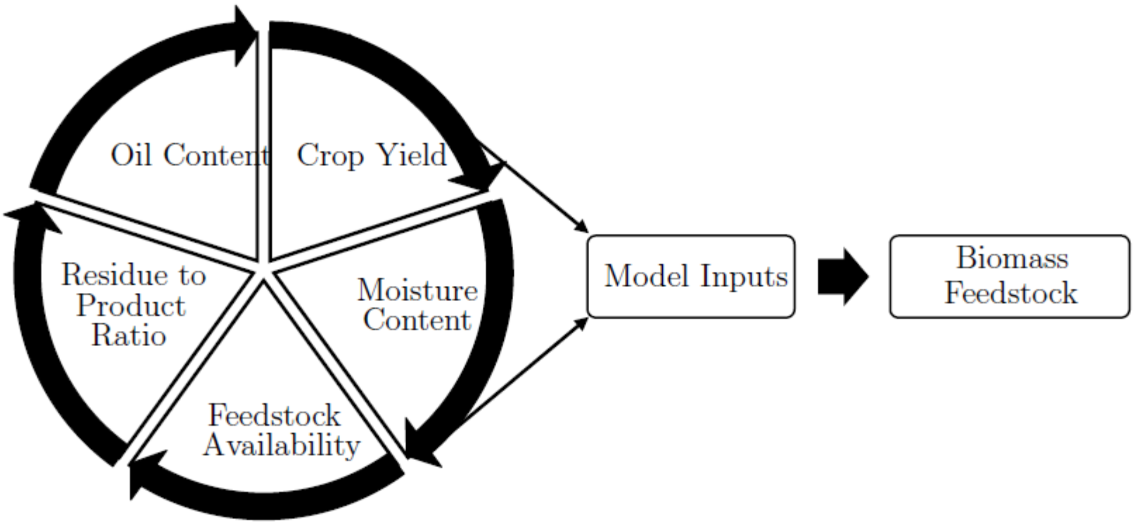

Figure 4: Data Inputs into the Model

Modeling Cases

Each simulation in the model is run based on a particular technology and an energy end-use sector. The technology efficiency of a particular process is kept the same for all crops. However, thermal efficiency does vary for each technology considered. Apart from technological consideration, two different scenarios of fuel utilization are considered i.e i) substitution considering an increase in oil import based on historical trend, and ii) substitution without considering an increase in oil import.

Results and Discussion

The results obtained from our study are classified into different groups, a few of which are presented here.

Technological Potential (Scenario based on production through different technologies)

Potential through biomass can vary significantly depending on the technology used for its conversion. Currently, Pakistan has limited availability of waste-to-energy conversion technologies that are deployed on a commercial scale. Waste management plants are present, but one-two power plants in the country are using this waste to convert it into energy. However, the country has significant potential as depicted in the next sections.

Biofuel generation potential (Transport sector as the end-use) through different technologies analyzed through Bio-IRENA simulator for different crops is shown in figure 5. Technologies used for analyzing this potential are Ethanol 1st and 2nd Generation engines and biofuel engines.

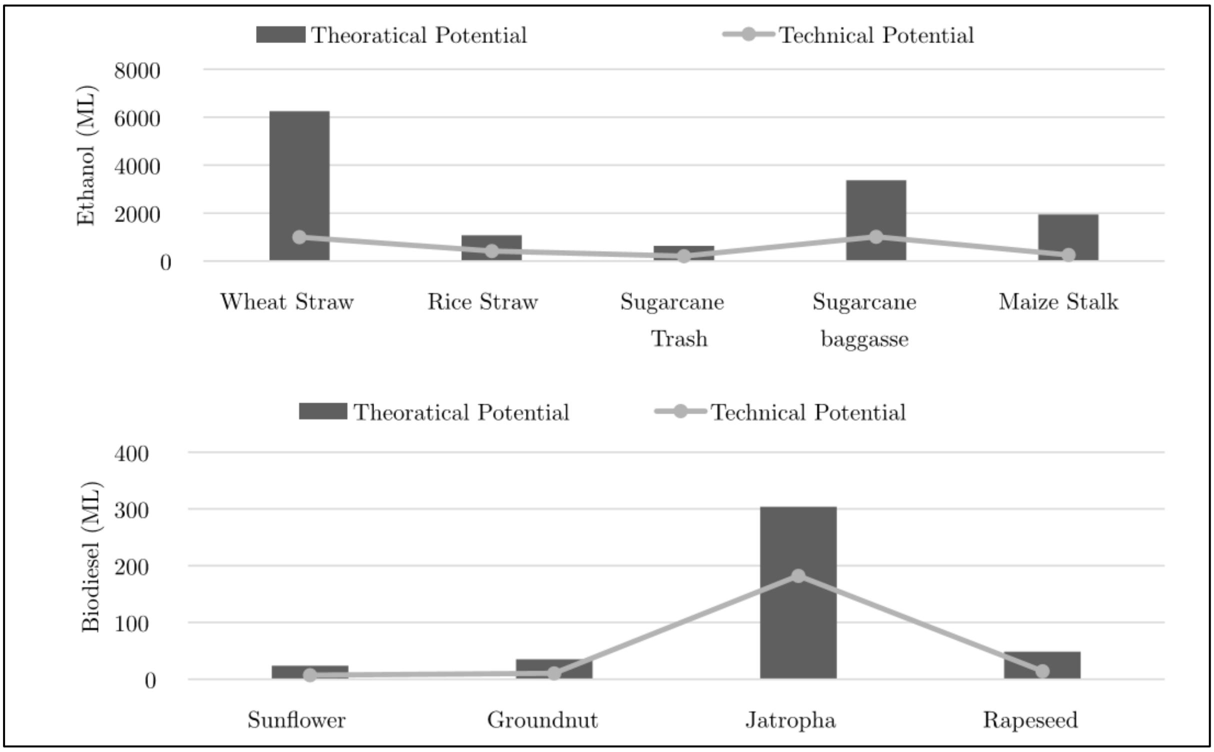

Figure 5: Production potential of different biofuels from respective crops in Pakistan

In Pakistan, biomass is being majorly used on a non-commercial scale in rural areas where it is used inefficiently resulting in environmental hazards and emissions. This also leads to fatal diseases in those areas and hence a commercial scale utilization is significantly important. The figure depicts that only through Jatropha, Pakistan has the potential of producing around 300 ML of biodiesel every year. Similarly, wheat straw can be used to produce around 6000 ML of ethanol each year. However, it should further be analyzed that the above-mentioned values are for the theoretical potential. Apart from energy utilization, biomass waste is used in large plenty of products which limits its technical potential. For Example, the major use of wheat straw is for animal fodder. Ethanol produced from bagasse is also extensively used in the cosmetic industry. In figure 5, the line for technical potential represents the availability of that source to be used in the energy sector.

For power generation, technologies that can be deployed in Pakistan along with their production potential are presented in figure 6 generated from the Bio-IRENA simulator.

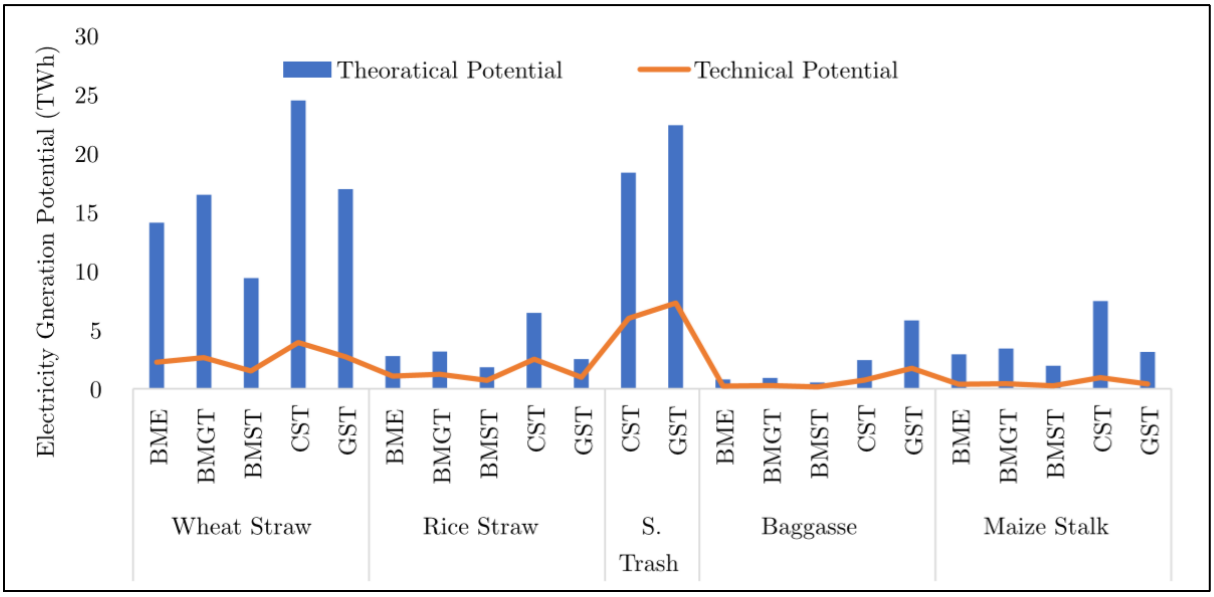

Figure 6: Electricity generation potential through different technologies for respective resource [BME = Biomethane Engine, BMGT = Biomethane Gas Turbine, BMST = Biomethane Steam Turbine, CST = Combustion Steam Turbine, GST = Gasification Steam Turbine]

Figure 6 represents that base on crop phenology in Pakistan, combustion steam turbine has the potential to generate the largest quantity of electricity. The figure also presents both the theoretical and technical potential of generating power.

Economic Assessment

The second critical thing in bioenergy utilization and agricultural growth is the pricing framework for this technology. The pricing framework generated after careful analysis is shown in the table below. The table represents the basis for calculating the Levelized Cost of Energy for bioenergy power plants in Pakistan. Based on different assumptions from National Electric Power Regulation Authority (NEPRA), the Levelized cost of bioenergy is around PKR 7.08/kWh.

Table 2: Pricing Framework for biomass technologies in Pakistan

Component	1-10 years	11-30 Years	Levelized (Rs/kWh)	WACC Levelized
Fixed Capital Cost	4.7186	4.7186	4.7186	4.7186
Variable O&M (F)	0.1646	0.1646	0.1646	0.1646
Variable O&M (L)	0.1646	0.1646	0.1646	0.1646
Fixed O&M (L)	0.2195	0.2195	0.2195	0.2195
Insurance	0.1096	0.1096	0.1096	0.1096
COWC	0.0968	0.0968	0.0968	0.0968
ROE/WACC	0.5614	0.5614	0.5614	1.0701
Debt Servicing	1.607	-	1.607	0.4572
Total (Rs/kWh)	7.642	6.035	7.08	7.0011
Revised				
Component	1-10 Years	11-30 Years	Levelized	-
Fixed Capital Cost	6.54	6.54	6.54	-
Variable O&M (F)	0.0736	0.0736	0.0736	-
Variable O&M (L)	0.1104	0.1104	0.1104	-
Fixed O&M (L)	0.2759	0.2759	0.2759	-
Insurance	0.115	0.115	0.115	-
COWC	0.1255	0.1255	0.1255	-
ROE/ROEDC	0.5575	0.5575	0.5575	-
Debt Servicing	1.3661	-	0.8904	-
Total (Rs./kWh)	9.1713	7.8	8.69	-

Environmental Emissions and Biofuel substitution (LEAP Modelling results)

The detailed analysis from the LEAP model depicts that annual fuel consumption in the transport sector of Pakistan is expected to increase beyond 17 billion liters in 2015 to approximately 34 billion liters in 2030. This represents an Annual Compound Growth Rate (ACGR) of around 4.5%. Now substituting biofuels produced from these crops can significantly limit the use of imported gasoline and diesel. In this scenario, the consumption of imported products will only increase from14.5 a billion to 16.6 billion liters. Although the value has still increased, this is lower than the scenario with no biofuel substitution (where the consumption was expected to go beyond 28 billion liters). Now under different scenarios, the production potential increase from biomass can be depicted in figure 7 below where an increase is observed with an ACGR of 4.5%.

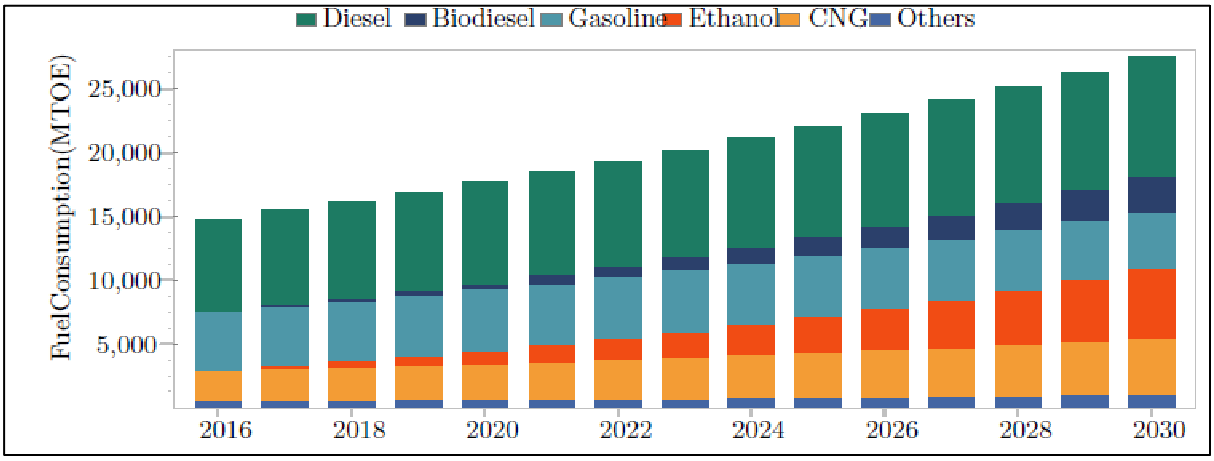

Figure 7: Growth in fuel consumption from 2015-30

CO2 Emissions

Along with energy generation, import reduction, biofuel substitution has much better environmental aspects. The results obtained from the LEAP model are depicted in figure 8 where adopting biofuels in the transport sector of Pakistan can significantly reduce the emission.

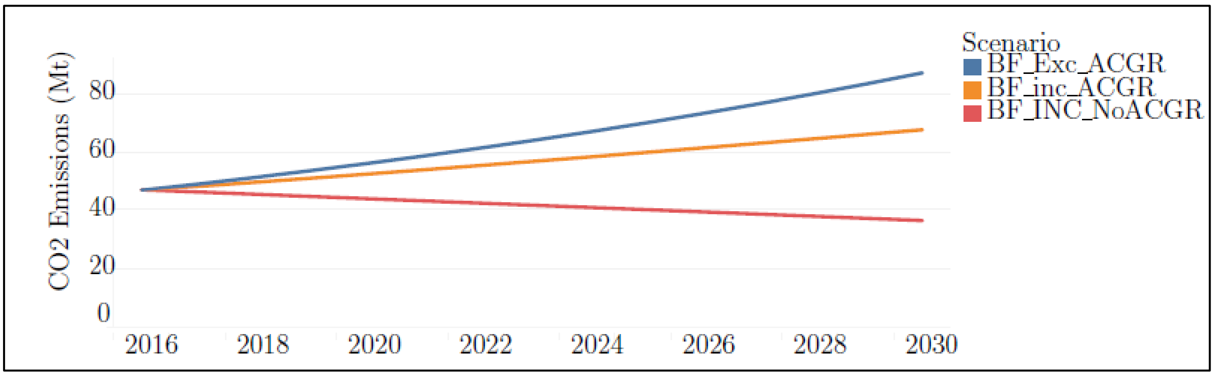

Figure 8: Emission control under different scenarios.

Based on the above-mentioned results, there is a major potential in Pakistan to harness bioenergy. Pakistan needs to come up with proper policies and plans to harness this potential.

Conclusions

Based on the agricultural potential of Pakistan, a significant amount of energy can be generated through the use of agricultural residues on a commercial scale. This can assist Pakistan in both its power and transport sectors. However, efficient harvesting of this energy would require a proper supply chain mechanism since currently the larger amount of agricultural residues generated is utilized for non-energy or non-commercial use. This study identifies different technologies that are commercially available for waste to energy conversion and then identifies both technical and theoretical potential that can be generated using residues available in the province of Punjab, Pakistan.

Acknowledgments

The authors would like to acknowledge the support from the University of Engineering and Technology, Taxila for providing technical guidance and assistance in carrying out the research.

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