Financial Model of Levelized Cost of Electricity (LCOE) for Bioenergy Resources in Pakistan

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ABSTRACT

For agriculture-based economies, energy generation through biomass is currently among the few practical means for overcoming energy and environmental crisis. However, economic assessment for bioenergy poses significant challenges to the developing nations due to limited availability of data and existing financial models. This study therefore conducts an economic assessment for Pakistan based on Levelized Cost of Electricity (LCOE) for those bioenergy technologies which are commercially available in developing countries. These technologies vary from thermal processes such as biomass gasification or incineration in turbines to bio-chemical processes such as anaerobic digestion. LCOE modeling was performed through a mathematical set of equations driven by input parameters i.e., Feedstock price, total capital cost, auxiliary cost, operation and maintenance cost, capacity factor, and plant lifecycle. The results obtained from the modeling depicted that LCOE for bioenergy in Pakistan may vary from as low as \$0.06/kWh to as high as \$0.315/kWh. Combustion techniques like stoker boiler and Circulating Fluidized Bed (CFB) have lower cost and yield better economic value with LCOE ranging from $0.06-0.22/kWh. Further, feedstock cost is the most dominant factor that contributes to approximately 60% of the total LCOE. Hence, to make bioenergy economically viable, a sustainable biomass supply chain is essential. This will not only provide a sound energy alternative for developing countries, but it will also contribute towards social and environmental sustainability.

Keywords: Bioenergy; Biomass; Waste to Energy; Energy Generation; Energy Economics.

INTRODUCTION

Recent history of energy security issues in Pakistan have spurred a need to transition away from high cost imported fossil fuels towards sustainable energy resources. The import bill of Pakistan from oil and petroleum products have crossed $9 billion per year, while the indigenous resources of oil and gas have almost dried out **(Ubaid et al. 2020)**. Energy economics of Pakistan is further burdened by circular debt (PKR 2.4 trillion in 2021), capacity payments which are expected to cross PKR 1.5 trillion by 2023, transmission and distribution losses, and inefficiently targeted subsidies. Given this backdrop, Pakistan has recently put forward its “Alternate and Renewable Energy Policy 2019” which targets energy generation share of around 30% from renewable energy resources (Solar, Wind, and Biomass) by 2030 **(Hina et al. 2021)**. In 2021, Cabinet Council of Energy, Pakistan also approved an Indicative Generation Capacity Expansion Plan (IGCEP 2021) which targets achieving a share of around 60% generation from clean energy sources including Hydropower. While both policies have targeted a leap towards clean energy, bioenergy has been a missing piece from the landscape of Pakistan’s energy planning **(NEPRA 2021).** While ARE (Alternate and Renewable Energy) policy does not specifically define any target for bioenergy, the share in total power generation as per IGCEP (Indicative Generation Capacity Expansion Plan) by 2030 is planned to be even below 3% (ibid).

Considering that Pakistan is an agriculture-based economy, bioenergy not only make it selfenergy reliant, but it also provides significant prospects of social and environmental gains. As compared to fossil fuels, bioenergy offers more economic advantages (especially for oil-import countries), less CO_2 emissions, and more energy security which then transitions to a circular or bioeconomy. Conventionally, in Pakistan, bioenergy is only being used inefficiently in countryside to provide heat for cooking and lightening. From total energy supplies of around 90 Mtoe in Pakistan, around 12 Mtoe is being supplied through inefficient biomass use. This has caused excessive problems not only for health, but also for crop production due to excessive need of land and water to produce biomass **(Namsaraev et al., 2018)**. Apart from co-generation in some sugar plants, biomass is rarely used for any energy purpose **(Adams et al., 2018).**

In the past decade, a number of bioenergy conversion technologies have penetrated on a commercial scale which can efficiently convert biomass to energy **(Qin 2018)**. Research around this subject has highlighted that the technological advancement of bioenergy in any country depends on financial availability and its research orientation. Figure 1 highlights the capacity buildup for bioenergy across the world and their annual investments in the sector **(Destek 2017).**

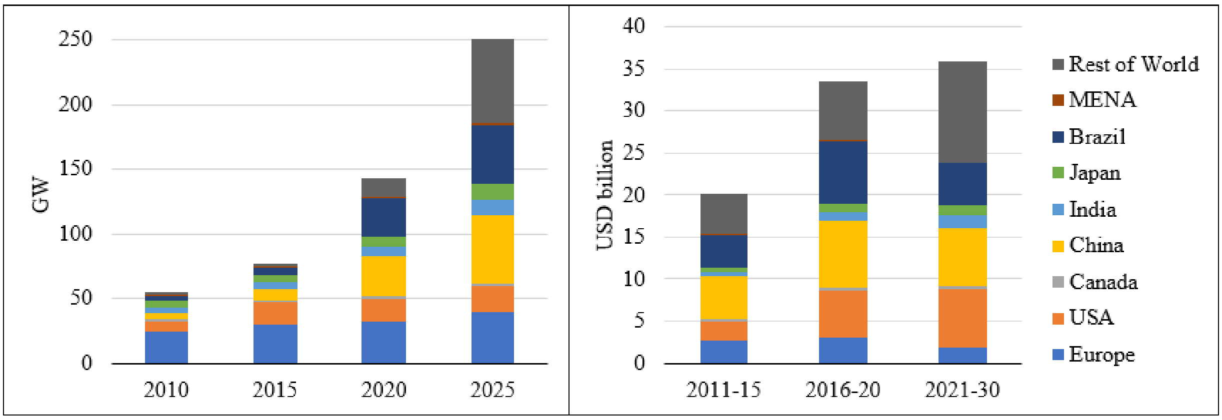

Figure 1. Annual investments and development of bioenergy capacity across the world.

Many technologies such as incineration, gasification, digestion, Combined Heat and Power (CHP) plants have now matured and are being deployed on large commercial scales. Therefore, bioenergy has a huge potential to act as an alternative source of energy in times of energy transition.

TECHNO-ECONOMIC ASSESSMENT OF BIOENERGY

Most of the current literature on bioenergy in Pakistan has focused on either calculating its technical or theoretical potential, while the literature on economic feasibilities is very limited. Study by Cambero **(Cambero et al., 2016)** showed that through bioenergy supply chains, job opportunities in rural areas can significantly increase. Gilethero **(Gilethero et al., 2012)** analyzed economic models for assessing biomass farming system in UK, while Efroymson **(Efroymson et al., 2013)** developed economic indicators for bioenergy assessment while performing techno-economic feasibility analysis for cogeneration plants based on Agro-food industry. Some studies have also coupled willingness of farmers in Pakistan to adopt while assessing the economic sustainability of bioenergy **(Robertson et al. 2008 & Solomon 2010).** For policy implications of bioenergy, studies have however revealed contradictory results which makes it difficult for analysts and policy makers to form a universal view **(Soderberg and Eckerberg. 2013).** This has been mainly due to difference in country context and demographics of the relevant areas. Fargione et al. indicated that economic viability of bioenergy is highly dependent on the current energy mix of that country, its economic status, and willingness of people to adopt a certain change **(Fargione et al., 2008).** Searchinger studied croplands and concluded that economic value of waste biomass feedstock is higher than crop-based bioenergy **(Searchinger et al.).** Mohr and Rahman discussed all the major challenges pertaining to policy making for bioenergy in developing countries **(Mohr and Rahman. 2013).**

In the decision-making process, cost-benefit analysis is one of the most reliable method. Calculation of various financial indices such as the benefit to cost ration, internal/external rate of return, payback, breakeven, and Levelized Cost of Electricity (LCOE) can provide sufficient evidence to support economic feasibility of bioenergy. Numerous methods have been utilized for adjusting CAPEX/OPEX (Capital Expenditure/Operational Expenditure) which then reflects the risks that an investor can face **(Sganzerla et al., 2021 & Yao et al., 2021).** Moreover, forecasting of decreasing/increasing cost factors, price inflation, and discount rates are some of the most widely used techniques for bioenergy economic assessment (ibid).

Among these techniques, Levelized cost of Electricity (LCOE) has extensively been used to calculate the per unit discounted cost of bioenergy. It is generally considered as the minimum cost to sell electricity to make system break even. In other words, energy price must be above its LCOE for any system that wants to generate revenue. Research studies around LCOE have concluded that it is highly sensitive to feedstock prices and discount rates. Waste categories especially agricultural residues were economically analyzed by Mizanur Rahman & V. Paatero for choosing the most appropriate option based on LCOE **(Rahman and Paatero. 2012)** They performed assessment for South-Asian countries and calculated their value to be around 0.040 Euro/kWh. Hansen performed calculations of Levelized cost of energy while discussing life cycle, discount rate, and heat value of the feedstock **(Hansen. 2019).** They constructed a model that can be used to compare different technologies.

Apart from these many other studies have identified the decommissioning cost of bioenergy to be between 33-60 Euro/MWh. Sensitivity analysis for identifying critical parameters for biomass LCOE showed that feedstock has a stronger effect on bioenergy cost than Operation and Management (O&M), and is then followed by price inflation, and economic incentives **(Korai et al., 2017).**

The main objective of this study is to fill significant gap on cost and performance of bioenergy technologies in Pakistan. No proper methodology was present to perform cumulative economic assessment for different technologies while keeping a same reference level that would assist the decision-making process. This study considers LCOE based assessment of different bioenergy conversion technologies using data sets of Pakistan which will provide much better insights for policies and decision making.

METHODOLOGY AND DATA COLLECTIONS

This section describes the data collection approach, model developed, and assumptions that were taken into consideration during mathematical modelling of LCOE. As mentioned in the Figure-2, data was collected through research publications, annual reports of Pakistan, and public surveys. Technology data that were not present in Pakistan was collected from IEA statistics, IRENA, and reports of countries with similar demographics (China, India, and IRENA reports). Figure 2 shows different research stages and how this study drew upon each analysis.

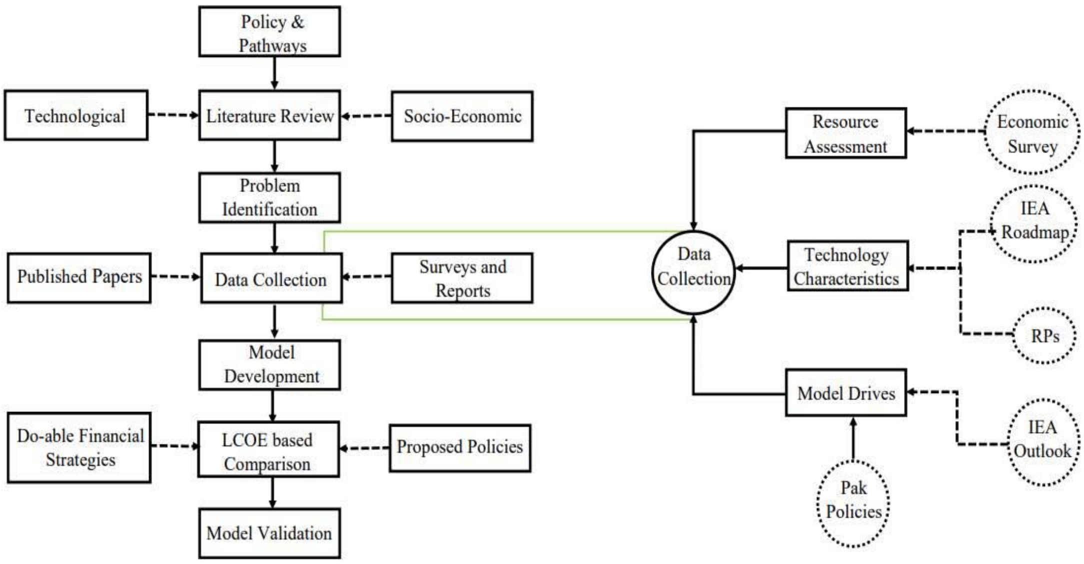

Figure 2. Research Methodology and Data Collection Process

For region specific economic assessment, credibility of feedstock data is essential. In Pakistan, biomass is available throughout the country in a wide range with different energy intensities, ash, and moisture, and oil content which directly affects the price of feedstock. Being an abundant source, it is important for feedstock to be available at a price that is market competitive. Distance from the power plant (or any other utilizing center) and its density tend to limit the feedstock availability as the resulting cost increases. Heating values of feedstock prices in Pakistan varies around 15-35 MJ/kg for agricultural residues, 18-33 MJ/kg for herbaceous crops, 18-38 MJ/kg from woody crops, 17-37 MJ/kg for forestry products, and

13-30 MJ/kg for Municipal Solid Waste (MSW) **(Ubaid et al. 2020).** These values have been further used in the LCOE assessment while entering the values of heat content.

Table 1 shows feedstock prices in Pakistan against their density and moisture content level **(PBS 2020).**

Table 1. Composition and Price of Biomass Feedstock in Pakistan

Sr #	Feedstock	Density	Moisture Content	Cost of Feedstock*	
		(kg/m3)	%	Pakistan $/ton	Europe $/ton
1	Cotton Stalk	100 - 110	5-20	64	20-50
2	Maize Stalk	50	10-15	66	20-50
3	Rice Husk	150	10-12	87	20-50
4	Rice Straw	125	10-12	64	20-50
5	Wheat Straw	55	10-20%	66	20-50
6	Bagasse	110	20-50	32	15-30
7	Sugarcane	100	15-30%	40	20-30
8	Forest Residues	-	-	19-38	15-30

This cost is highly case specific and depends on the distance between area of harvest and utilization. The cost may vary by 10-20% if the feedstock has relatively very high density. On the other hand, a long-time during storage and transportation degrades the bioenergy which results in a cost deduction. For Forest residues, the cost includes harvesting and chipping, loading, and unloading along with its transportation fee. For agricultural residues, the value is only the purchase cost, and total travelling cost may differ based on the distance from power plant.

Further, for economic and technical viability of bioenergy, technology cost is equally an essential component. More efficient technologies generally require a high investment and trade-off must be made between cost and energy requirements. Moreover, the scale of energy generation also limits the technological availability. In most cases, as the capacity increases, the cost of producing electricity from that plant decreases. For commercial technologies available in developing countries, Figure 3 and Figure 4 shows the estimated range of equipment cost calculated from NEPRA proposed models and IRENA renewable energy costing series.

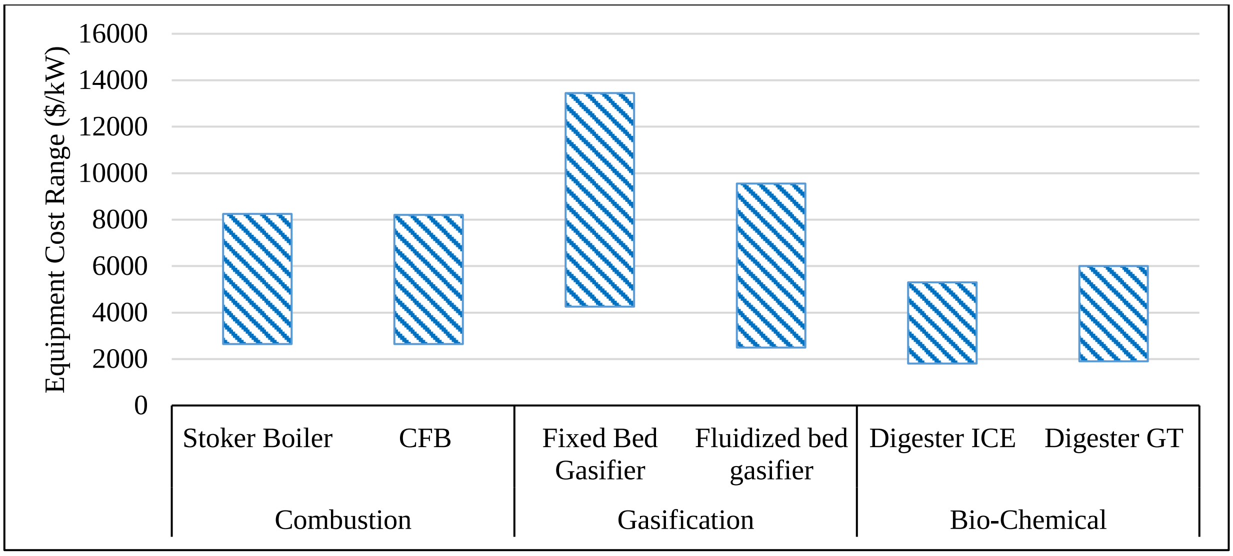

Figure 3. Equipment cost of simple bioenergy plants

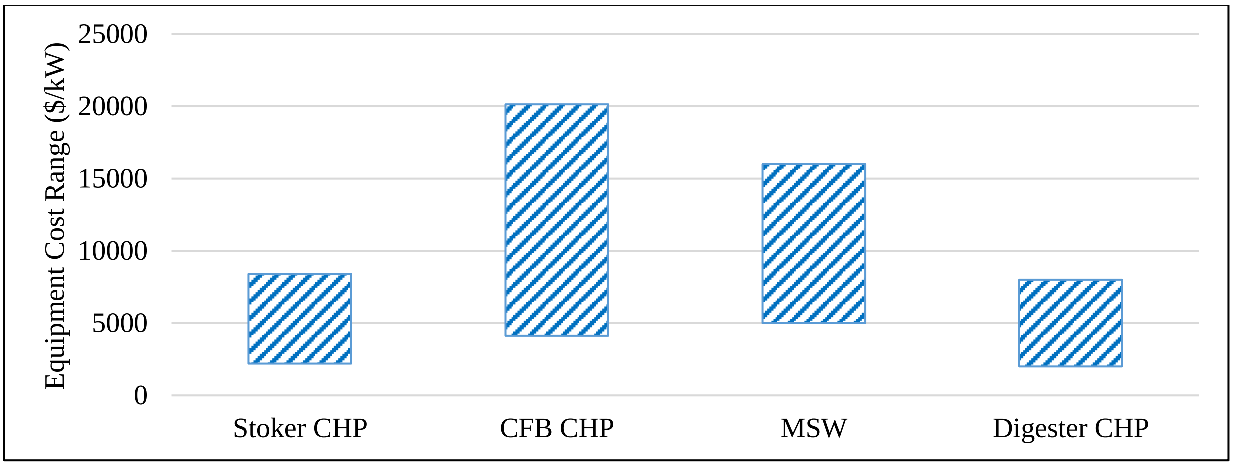

Figure 4. Equipment cost of combined heat and power (CHP) biomass plants

As evident from the case of CFB-CHP, the value ranges from $4000 to almost $16000. This system with a generation capacity of 0.5 MW will lie in upper limit of the range ($15000/kW) while the same system with a generation capacity of 9 MW will only cost $4000/kW. The remining technologies however are not greatly affected by the scale. Total capital cost includes CAPEX, consultancy and engineering services, planning, grid connections, and the cost of preparatory machineries. Figure 5 shows the dominating factors for each classification of waste to energy conversion technologies. The value ($/kW) for total capital cost is calculated by combining all the previous values according to the given share.

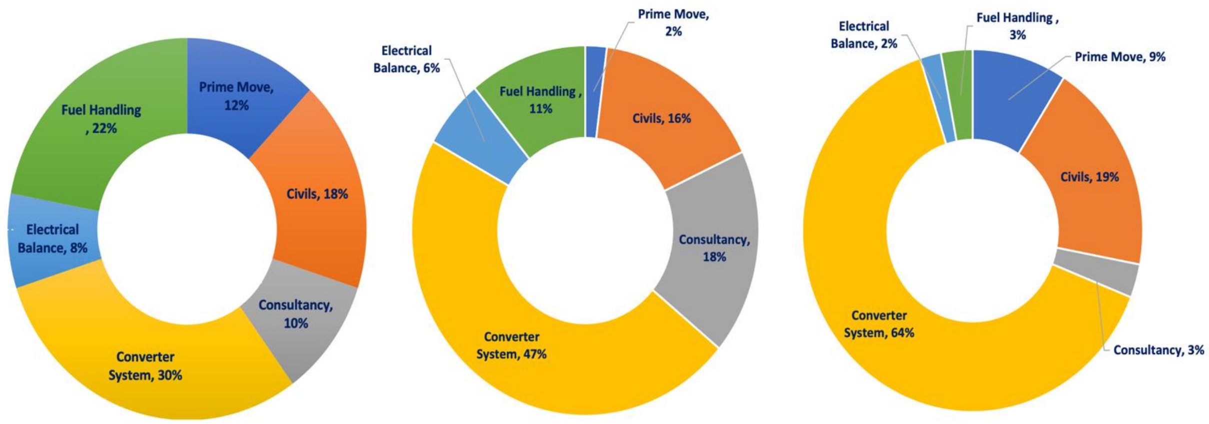

Figure 5. Share of different parameters in total investment cost (Anaerobic Digestion, Combustion, Gasification respectively from left to right)

For LCOE calculation, all financial and economic considerations mentioned above are discounted over the lifetime with a rate of 11.2%. This includes capital costs, fuel costs and other O/M cost factors. Generally, LCOE is described in USD/kWh or PKR/kWh. For Renewable Energy Technologies, LCOE vary based on technologies, resources, cost factors, and performance of a system. The equation used for LCOE assessment is mentioned below:

$$LCOE = \frac{Capital\ Cost \times CRF \times Fixed\ Cost}{8760 \times Capacity\ Factor} + (Fuel\ Cost\ \times\ Heat\ Rate) + Variable\ \frac{O}{M} \quad (1)$$

Where, CRF is the capital recovery factor that was calculated using the following formula:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (2)$$

Where "i" gives the "discount rate" while "n" is the "lifetime" LCOE calculations are also verified using NREL tool that uses the below-given formula:

$$LCOE = \frac{FCR \times TCC \times FOC}{AEP} + VOC \quad (3)$$

Where FOC is the fixed annual operating cost, TCC is the capital cost, FCR is the fixed charge rate, and AEP is the annual electricity production.

RESULTS AND DISCUSSION

This section describes the LCOE results obtained from model under different sets of input values and the key takeaways of the study. Table 2 shows the calculated total installed capital cost of different technologies incorporating all cost parameters. Further, as compared to other countries, especially European, the cost of available technologies in Pakistan is slightly higher. The result obtained for our model were significantly close to the values of some technologies that were also proposed by National Electric Power Regulation Authority (NEPRA).

Table 2. Upper and Lower Limit of Capital Cost for biomass conversion technologies.

Sr #	Technologies	Upper Limit ($/kW)	Lower Limit ($/kW)
1	Stoker	4400	1950
2	Bubbling/circulating fluidized beds. boilers	4650	2150
3	Gasifier	5800	2200
4	Stoker CHPs	7150	3900
5	Gasifier CHP	6950	5800
7	Digester	6500	2800
8	Co-firing	1150	700

LCOE results from different technologies are represented in Figure 6.

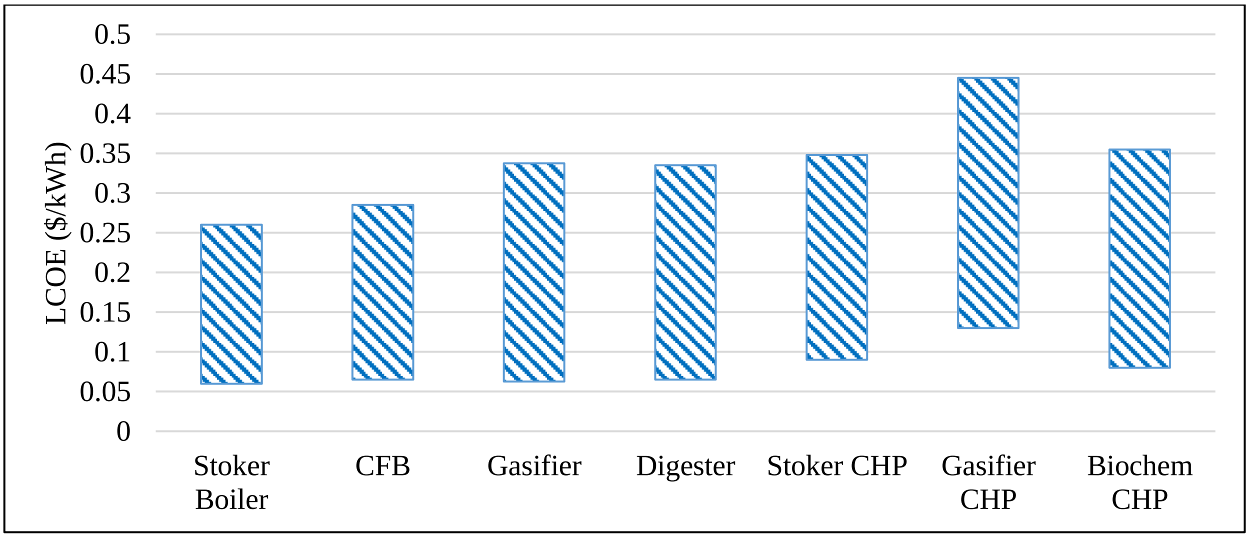

Figure 6. LCOE of bioenergy in Pakistan through different technologies.

Comparatively, LCOE range for gasification technology is wider due a broad range of feedstock cost (pre-treated feedstock is used) and more importantly because gasification in Pakistan is not a commercially mature technology and thus the sub-equipment can vary substantially. Therefore, the economic feasibility of bioenergy is highly dependent on the supply chain process. At low feedstock price, bioenergy can be a market competitive for generating electricity. But with a comparatively higher capital cost and feedstock prices, bioenergy will not be able to match other generating sources without subsidies and incentives. Hence, it is essential for bioenergy utilization on a large scale that a working competitive supply chain is established first. As further depicted in Figure 7, feedstock costs contribute to a significant portion of this overall LCOE.

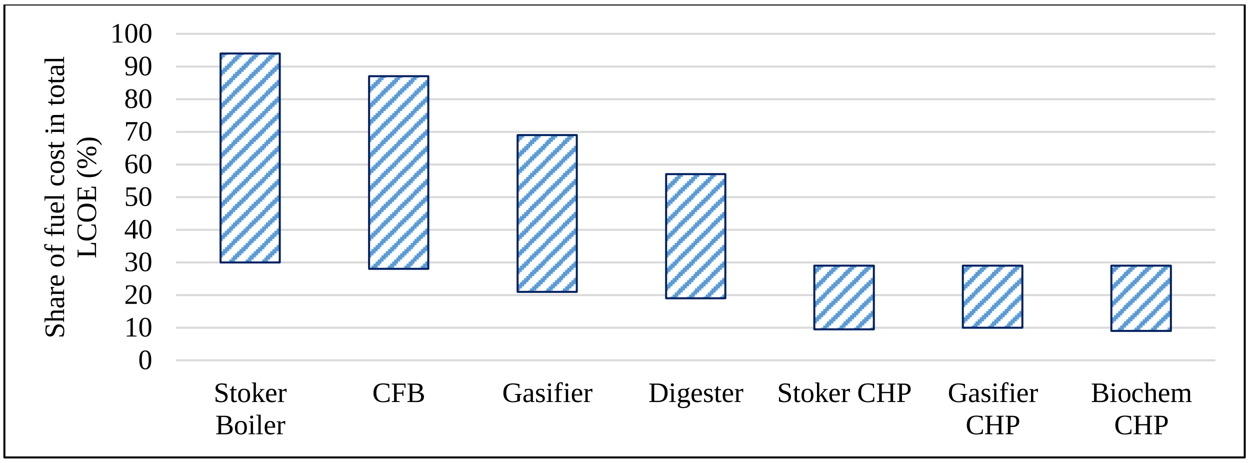

Figure 7. Share of fuel cost in total LCOE

This value is significantly close to the results obtained from different studies. Even as per the international studies, the feedstock share in total cost may go as high as 60%. The share of feedstock cost may be even higher for countries which have to import biomass or feedstock. But since Pakistan is an agriculture-based economy, feedstock availability for use as an energy source is not an equally essential challenge.

The LCOE of stoker boiler varies from $0.06-$0.2/kWh and on an average slightly less than half of it accounted for fuel cost while 30-35% is accounted for investment cost. For instance, since bagasse is a cheap residue available in Pakistan, a stoker boiler fired with bagasse will be near the lower end of spectrum. In this case, the larger portion of LCOE will be due to the equipment or CAPEX cost. Same goes for other combustion technologies and an anerobic digestor. However, for CHP plants, the share of feedstock in overall LCOE is comparatively lower. This is due to a comparatively higher investment on equipment and maintenance side. Table 3 represents some case-specific plants and their resulting LCOE broken down into its components.

Table 3. Breakdown of LCOE for specific bioenergy power plants.

Sr #	Bioenergy plants with specific conditions	Feedstock $/kWh	OPEX $/kWh	CAPEX $/kWh	Total* $/kWh
1	Stoker Boiler plant with 50 MW capacity and using Bagasse	0.06	0.012	0.042	0.114
2	Circulating fluidized bed with 30 MW of capacity and use of Forestry residues	0.065	0.016	0.06	0.141
3	Anaerobic digestor producing 1 MW and using agricultural residues	0.05	0.01	0.06	0.12
4	CHP stoker with bagasse	0.06	0.02	0.12	0.2

A comparative assessment of results obtained for bioenergy with levelized cost of current electricity generation resources in Pakistan indicates that LCOE of bioenergy is market competitive and provide comparatively more benefits in terms of social and environmental sustainability. This includes off-setting carbon footprints from thermal fuels to creation of local employment in rural settings. Most technologies discussed in the study were commercially proven in many regions across the world. Those who are still in R&D stages currently have higher economic values but even for them, the potential of cost reductions is very heterogenous. This study also lead to implications for other countries as discussed below:

- For all agriculture-based countries, reliance on biomass is a better alternative as opposed to fossil fuels with high import cost. Along with making country’s energy sector self-reliant, the feedstock cost is significantly low which leads to a lower LCOE.
- Feedstock price may account for up to 50% of total LCOE and hence an efficient supply chain must be established to ensure cheap production and supply of feedstock.
- For biomass to be used as an energy source, it does not have to necessarily compete with food or export sector of the country. Food waste, agricultural or forestry residues and waste materials, livestock waste, and MSW can also be used in waste to energy plants. Further, researchers have also identified many energy crops that along with providing a cheap energy source can also revitalize the soil which further increases its economic value make it even a more suitable option.

LCOE has been used broadly for decision making across the European countries for justifying subsidy schemes as well. A higher LCOE suggests that the technology is economically viable only if sufficient subsidies or incentives are provided. However, while LCOE provides a good tool for comparison, it should not be used alone as a deciding factor since it does not provide any information based on the availability of the resource.

Clear description of each technology and its relevant cost components are essential for providing useful insights. At the same time, it is also critical to differentiate between the quality of renewables power generation system being investigated. Other issues such as grid connections, T&D losses must also be incorporated. An LCOE model does not account for these two parameters and hence dataset for each alternative must be directly comparable. Strength of the economic model presented in this study can be further developed by conducting ground research on the type of technologies that are currently under use in Pakistan. However, as of today, there are only two commercially waste to energy conversion plants in Pakistan, which limits the data access.

CONCLUSION

This study has economically assessed various bioenergy conversion technologies. Levelized cost of electricity (LCOE) model has been used to model electricity generation cost for each commercially available technology. Due to absence of any reliable bioenergy assessment study, this study can be used extensively in decision making process. The results obtained from the model depicts that the LCOE of bioenergy is highly case specific and depends on the process specifications. Based on the use of technology or feedstock, the cost may vary from as low as $0.06/kWh to as high as $0.315/kWh. Combustion technologies (stoker boiler and CFB) are the technologies with least economic cost with LCOE ranging from $0.06-0.22/kWh. Further, this study has identified the breakdown structure of LCOE which depicts that the feedstock cost is the most critical component of LCOE. Share of feedstock cost in total LCOE may be as high as 60% and hence a sustainable supply chain system must be developed to make it economically viable. For a developing country like Pakistan, India and Bangladesh, infrastructure advancement and technological availability is a big hurdle that might render a non- subsidized bioenergy plant infeasible. Investment on filling this technological gap will further bring down the LCOE, while at the same time providing environmental and social benefits.

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