Energy from Anaerobic Digesters for Water Management: A Case Study of Pakistan

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***Abstract*—** The ongoing energy crisis and high energy tariffs in Pakistan has hit the farmers' community hard as these farmers are largely dependent on tube well technology for pumping ground water to supplement the deficit in canal water supplies for their agriculture. Biogas from anaerobic digestion processing of livestock manure could be a possible alternative form of energy for these tube wells. The country has a great potential for biogas generation because there is sufficient manure, construction material and human resource required for the manufacturing of biogas plants. This technology will significantly reduce farmers' spending on fuel. Besides, the biogas can also be consumed to light kitchen stoves for cooking purposes and other domestic purposes. Furthermore, this green technology will not only reduce atmospheric greenhouse gas emissions, but the nutrient value of digested effluent will also be enhanced. Consequentially, the cost of chemical fertilizers will be cut down due to these bio-fertilizers' application. Hence the soil productivity is increased and the financial constraint on resource poor farmer is reduced.

Keywords*—*tube well technology; ground water extraction; water management; biogas; alternative energy.

I. INTRODUCTION

Energy is the core element in the overall progress of human life. In day to day activities, we are heavily dependent on different sources of energy for our holistic physical, mental and socioeconomic development. In modern times, recognizing the fact that the concept of quality standard of living is built on multiple energy resources [1], efforts are accumulating all over the world to devise mechanisms for energy conservation. This is particularly true of Pakistan, which is in the midst of an ongoing energy crisis that has intensified during the previous years [2]. In 2007, Pakistan went through one of its largest power failures, seeing production fall by 6,000 Megawatt (MW). In 2008, a demand and supply gap relating to electricity was raised by 15 percent, leading to power shut downs observed at up to 16 hours a day. In 2009 on June 17, one of the major business hubs of the country, the metropolitan city of Karachi, went through a disastrous power break down that caused the entire city to remain without power for more than 21 hours. The electricity crisis was further aggravated in this year when, countrywide, there was a power shortfall of 4,500 MW. In 2010, the energy sector further suffered a setback when heavy rainfalls turned into floods that damaged the energy and fuel distribution infrastructure. In 2011, the Uch power plant was shut down as one of the pipelines transporting fuel to the power plant was destroyed in the Jaffarabad district of Balochistan province. By the mid of July 2014, it is recorded that the electricity shortfall has exceeded 7,000 MW and correspondingly, the urban parts of the country are facing 12 hours of electricity load shedding while in rural areas this duration is observed up to 18 hours a day. It seems that this crisis is not going to be resolved in the near future as inferred from the statement of the Secretary of Water and Power, Ms. Nargis Sethi, who apprised, the standing committee in the country's parliament, about the "weak and outdated electricity transmission and distribution network that cannot carry the load of more than 15,000 MW of electricity" [3].

Besides the ongoing electricity crisis, another form of energy crisis also began, as there was a shortfall of natural gas, estimated at 1.8 billion cubic feet (bcf). The shortfall resulted in severe shortages of available compressed natural gas (CNG) for consumers. The situation was further aggravated when the Oil & Gas Regulatory Authority (OGRA) raised the gas tariff by 14 percent [4]. This crucial energy crisis and price hike, consequentially, pierced the overall economy as the two major sectors, agriculture and industry, suffered through major financial losses. The agricultural production in the country has been directly affected as the energy shortage and sky rocketing energy tariffs have hampered the operating of tube wells. These tube wells over the years have become inevitable, for the agricultural growth in the country, to pump ground water for making up canal water deficits.

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A. Synergy between Tube Well Technology and Agricultural Growth in Pakistan

The existing canal irrigation system in the country is unable to meet the water distribution requirement mandated to achieve food security for a rapidly increasing population. Although the country has a large and extensive canal irrigation system designed originally during the British regime, it was primarily meant for low cropping intensity and therefore cannot satisfy demands of the increasing cropping pattern and ongoing application of hybrid seed varieties. The farmers of the Indus Basin, to meet their crop water requirement, are supplementing the deficit in canal water supplies through tube well technology used for ground water extraction [5]. Punjab province known as the food basket of Pakistan is heavily dependent on tube wells, as 60 percent of farmers are relying on this technology [6]. Use of groundwater extraction dates back to 1947 when the country was liberated. The irrigation department of the Punjab province first adopted this practice. Later on, the Water and Power Development Authority (WAPDA), in 1958, started ground water extraction on a large scale through land reclamation projects [7]. Afterwards, due to water shortages, private sector also initiated the practice.

To comprehend how crucial tube well technology is, in the agricultural development of the country, one can take into consideration a constant rise in the number of tube wells. In 1960 there were 160,000 tube wells [7] while in 2014 there are more than 1,000, 000 [8]. The Ministry of Water and Power and the Government of Pakistan have reported that these tube wells within the agricultural sector are extracting up to 50 Million Acre Feet (MAF) of groundwater annually [9]. The farmers in Pakistan are themselves financing the groundwater extraction for agricultural purposes. It is reported that 77 percent of these tube well owners spent their own resources for the tube well installation and operation [6]. With the ongoing energy crisis and the increasing energy tariffs, these farmers are now experiencing a financial crunch, because 30 percent of the wells are operating on electric power, consuming 2,500 MW that is approximately 15 - 20 percent of the total energy delivered through the national grid [10]. The rest of the tube wells are either diesel engine or/and tractor driven. To mitigate this energy crisis for the efficient operation of tube wells, biogas from anaerobic digestion processes of livestock manure is among one of the possible alternatives of fossil fuels and electrical energy required to sustain agricultural growth in the country.

B. Biogas Potential in Pakistan

The country has a great potential for biogas generation [11] due to the availability of: sufficient animal manure (See Table 1), suitable ambient temperature, construction materials, enough space for biogas plant installation, and human resource required for their construction. According to reports, the country has more than 78 millions of large animals [12] producing about 936 million kilogram (kg) of manure daily. Based on 50 percent manure collection, this biogas technology has the potential to produce more than 18 million cubic meter (m^3) biogas [13] that can be utilized to operate the irrigation tube wells, kitchen stoves and other farm level operations.

C. Use of Biogas in Diesel Engine Pumping Units:

Biogas-diesel engines have been applied in South and South East Asia in agriculture for many years. Single cylinder diesel compression ignition engines with direct fuel injection systems could be operated on biogas or in dual fuel mode with some modifications to the injection system [14] as illustrated in Figure 1. The primary source of fuel for these compression engines is biogas, which is ignited by pilot diesel fuel injected into the engine. The auto parts market in Pakistan is quite mature, so biogas and diesel dual fuel conversion arrangements could be made with the help of certified engine mechanics. Farmers of the Indus basin are already familiar with diesel engine operation and safety,

Table 1

Live Stock Population

Species	2010-11	2011-12 (Million Nos.)	2012-13
Cattle	35.6	36.9	38.3
Buffalo	31.7	32.7	33.7
Sheep	28.1	28.4	28.8
Goat	61.5	63.1	64.9
Camels	1	1	1
Horses	0.4	0.4	0.4
Asses	4.7	4.8	4.9
Mules	0.2	0.2	0.2

Economic Survey of Pakistan [12]

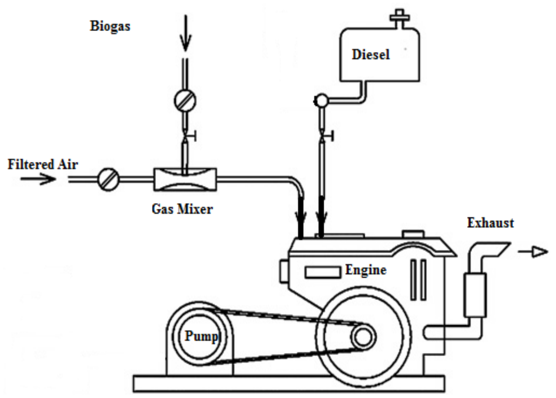

Fig. 1. Diesel Engine Dual Fuel (Biogas + diesel) Injection [14]

however, the engine does need well-trained workers for maintenance. Biogas from anaerobic digesters is at low pressure (0-2 m) and less prone to explosion hazard compared to liquid petroleum gas (LPG) and compressed natural gas (CNG). In order to reduce asphyxiation, explosion and gas poisoning, plant and diesel engines must be placed in well-ventilated areas or proper ventilation is required if located in confined spaces [15].

Biogas produced during anaerobic digestion of bovine manure contains hydrogen sulfide ranging between 1000 – 3600 part per million (ppm) and needs to be purified up to acceptable limit before injecting into the diesel engine to avoid corrosion [16]. In terms of combustion engines tolerances, hydrogen sulfide concentrations should be reduced to 200-500 ppm. Water scrubbing and use of iron rich soil as filter media could be used to reduce the hydrogen sulfide concentration in biogas [17].

II. Theoretical Framework

The foundations of this review paper is built on the three pillar model of Sustainable Development [1] in which the technology is analyzed as if it is beneficial from economic, social and environmental aspects. Some researchers, however, also include the technical dimension of the technology in the sustainable development [18]. The economic factor generally deals with the concept of Life Cycle Costs (LCC) that revolves around whether or not the technology is economically feasible in terms of its maintenance and operation. With particular reference to biogas technology, its construction and maintenance is cost effective. In terms of affordability, it not only pays for itself by generating numerous benefits but also reduces the cost to be incurred on the purchase of fuel. Among the social factors, it is examined as if the direct impact of technology is building a pool of stakeholders. In this context too, biogas technology has a wide network of stakeholders inclusive of the government, farmers' community, and the overall country's population—as among several purposes of the technology, running the tube wells for a flourishing agriculture that leads to improving food security is also inclusive. The environmental dimension takes into account as if the greenhouse gases (GHG) emissions are reduced as a direct outcome of the technology utilization. Biogas has proven efficient in preserving the environment [19]. Last but not least, the technical aspect deals with the power rating and generating capacity of the technology [18].

This review paper is, therefore, an effort to estimate the national potential of biogas generation from bovine manure that can compensate for the amount of power required for operating tube wells in Pakistan. Besides, it is also assessed as if there are any benefits that can be accrued from biogas generation in terms of savings from fuel cost and protection of the environment. A humble effort is also made to assess what impact biogas can create on the lives of rural women.

III. Methodology

In order to estimate biogas potential in Pakistan for water management, a bottom up approach is adopted for selecting an appropriate model of utilizing a biogas digester to power a typical irrigation pump unit installed in the Indus basin. An average farming household is evaluated as a sample. Farming households considered in this case study are assumed to meet the selection criteria of: holding at least 2 - 5 hectare (ha) of land, having an operational pumping unit, owning a livestock barn on the same piece of land, and willingness to sell water to nearby farms. The baseline data, inclusive of household information, livestock, agricultural land holding, and expenditure on running a pump system used for analysis, is derived from government census reports and other research studies. The national potential for biogas generation is estimated, stepwise, in the following paragraphs;

A. Tube-well Operation Time and Power Requirement:

The number and operating hours of private tube wells, for irrigation in a hydrological zone, depend on the type of crop grown, cropping intensity, nature of agro-climatic zone, groundwater quality, and average area that needs to be irrigated. During the Kharif (summer) season, tube well operating time is more as compared to the Rabi (winter) season, due to increased water demand from crops such as rice and sugarcane. Typical tube wells operated in the Indus basin require a 12 - 25 horsepower (hp) diesel engine and/or 50 - 85 hp tractors that are extracting water from a 6 - 15 meter (m) deep aquifer [20]. Based on a research study in Pakistan, the average fuel consumption of a typical shallow tube well operating with local/Chinese pumps and/or slow speed diesel engines is about 1.5 - 2.5 liters per hour [6]. The average utilization of a diesel engine driven tube well in terms of its operating hours is given in Table 2. In the regions of Punjab, Sindh and Khyber Pakhtunkhwa, the area irrigated from a single diesel is about 11, 8 and 14 ha respectively with an average value of 11 ha.

Details on water table bore depth and power rating of shallow tube well pump units are provided below in Table 3. Most of the diesel engines installed in the Indus basin are of a 12 hp rating. The fuel consumption of a diesel engine is mainly dependent on the tube well design and operating conditions. A poorly tuned engine with a blocked filter and high throttle will consume more than the manufacturer's rated consumption. Usually the shallow tube well pump with 12 hp rating consumes 1.5 liters per hour. These pumping units can be operated with biogas by injecting a mixture of diesel and biogas into diesel engine carburetor [21].

B. Selection of Biogas Plant:

Based on experimental work carried out by the Pakistan Agricultural Research Center, diesel engines of 12 hp rating used for pumping groundwater for irrigation will consume 0.56 liters of diesel and 2 m^3 of biogas when operated on dual fuel mode i.e. Diesel + Biogas [21]. On average in Indus basin, shallow tube wells run by diesel engines are operated 6 hours every third day in Kharif season, while every fifth day during the Rabi season to irrigate 11 ha of land.

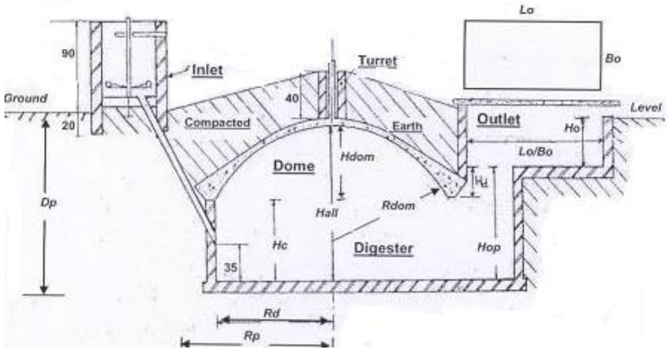

Fig. 2. Fixed dome biogas plant [13]

In order to meet the biogas demand for operating the pumping unit, ideally a fixed dome biogas plant of 10 m^3 capacity, with 50 days retention time is appropriate [13]. The dome of the biogas plant has the capacity to store 60 percent of gas produced on daily basis. If the pumping unit is not operated daily, an auxiliary storage tank will be needed to store the biogas of 4 m^3 on daily basis during peak season of Kharif. During the Rabi season both the water demand and gas production is low due to crop type grown and ambient temperature. If the irrigation is not required the biogas can be utilized for domestic purposes.

Table 2

Utilization of Diesel Driven Shallow Tube Well Pumping Units operated in Indus Basin

Region	Operating hours per day	Area Covered (ha)	Average days per year		
			Rabi Season	Kharif Season	Annual
Punjab	5	11	47	71	118
Sindh	9	8	36	54	90
Khyber Pakhtunkhwa	4	14	57	86	143
Average	**6**	**11**	**47**	**70**	**117**

Source: IWMI Working Paper 64 [6]

Table 3

Pumping Units Diesel Engine Horse Power Rating installed in Indus Basin

Bore Depth (meter)	Water Table Depth (meter)	Power Requirement (hp)	Most Commonly Installed Engines in Field (hp)
< 15	<3	3-16	12
15-30	3-5	6-22	12
30-45	5-12	6-24	12
45-60	12-18	14-25	16
60-75	>18	16-24	20

Source: IWMI Working Paper 64 [6]

Table 4

Technical details of Biogas plant of 10 m^3 capacity

		Min	Max	Ave
Feeding	[Dung in kg/day]	96	120	108
Water requirement	[liter water/day]	96	120	108
Cattle (night stabling only)	[heads]	8	10	9
Gas production	[m^3/day]	3.84	4.8	4.32

Source: National Program on Domestic Biogas in Pakistan [13]

C. National Potential of Biogas Generation for Water Management in Pakistan:

In Pakistan there are more than 2 million households with a herd size of seven and above. Most of the time, this herd is comprised of rearing buffalo and cattle [22]. On average, dung droppings of medium-sized animals are estimated to be 10 - 12 kg/day. This manure flow can supply enough manure for a biogas plant of 10 m^3 size and that is sufficient to run a12 hp diesel engine. According to a report, six percent of the buffaloes and cattle are grazing in open meadows while the rest of the 94 percent are either on stall feeding or night stabling [23]. For further details, please see Fig. 3.

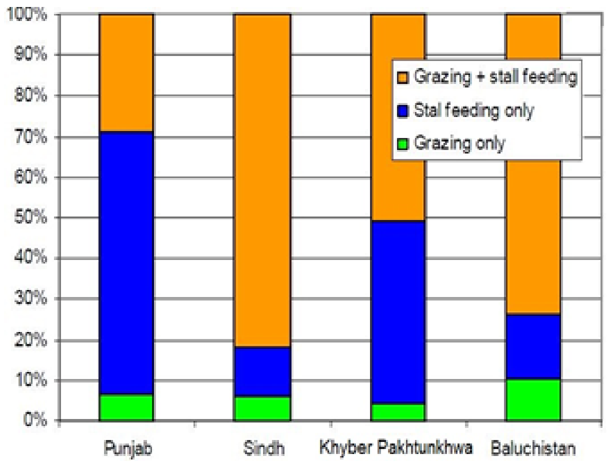

Fig. 3. Feeding Practices of large ruminant [10]

Based on regional distribution, Punjab has the largest cattle and buffalo population of 57 percent, followed by Sindh and Khyber Pakhtunkhwa with 25 percent and 14 percent, respectively [23]. Baluchistan has the least quantity of herds up to 5 percent of the total herd population. The number of households qualifying for biogas plant suitability is further reduced by a factor of 20 percent, due to insufficient water, land and/or ambient temperature. Based on these estimates, about 1.5 million households are deemed to be the potential sites for biogas plant installation as shown in Table 5.

IV. BENEFITS OF BIOGAS GENERATION

A. Fuel Saving

Development and utilization of biogas sources not only provide a sustainable solution to energy crises, but will also help farmers to reduce their spending on diesel fuel without compromising agricultural production. On average, a single biogas plant running a diesel operated tube well covering about 11 ha of irrigated land can save 660 liter of diesel fuel worth Rs. 71,000 (Rs. 107.97 per liter) over the entire season. At a national level, if the identified potential number of 0.7 million diesel engines operating tube wells are run on biogas, the country could save as much as 2.9 million barrels of diesel fuel per year, significantly reducing the cost spent on the import of fossil fuels.

B. Environmental Benefits

This technology also controls the atmospheric emissions and the digested materials can be used as bio-

Table 5

Potential Number of Agricultural Household for Biogas Plants

Description	**No. of Households**
Total households with cattle/buffalo	12 million
Households with only 7-10 or greater cattle and buffalo	2 million
Household unsuitable for biogas plant due to;	
a. *Open range grazing*	5 Percent
b. *Low temperature, insufficient water and land availability*	20 Percent
Total biogas Potential Sites	1.5 million

fertilizers. Bio-fertilizer applications help in reducing the costs of chemical fertilizers and increase soil productivity. Consequently, the environment is protected and the financial constraints on resource poor farmers in the region will be reduced.

i. Greenhouse Gases Emission Mitigation:

Use of biogas as an alternative to fossils fuels minimizes the emission of GHG that are threatening the environment. GHG mitigation is estimated as per the guidelines of the Clean Technology Development Mechanism, United Nations Framework Convention on Climate Change (CDM-UNFCCC) [24]. According to method AMS I.B Version 11, GHG emission reduction is calculated as follows;

$$ER_y = BE_y - PE_y - LE_y$$

Where;

ER_y = Emission reductions in year y (T CO_2)
BE_y = Baseline emissions in year y (T CO_2)
PE_y = Project emissions in year y (T CO_2)
LE_y = Leakage emissions in year y (T CO_2)

In dual fuel operation (diesel and biogas mixture) these pumping units are saving 62 percent of the diesel fuel. Hourly fuel consumption of 1.5 liter per hour is thus reduced to 0.56 liter of diesel per hour [21]. Leakages could be determined following the Pakistan Domestic Biogas Program (PDBG) criteria by multiplying a gross net adjustment factor of 0.95 to base line emission. Calculations are also based on 6 hours average daily operation for 117 days per year with a default value of emission coefficient of 3.2 kg of Carbon Dioxide (CO_2) per kg of diesel fuel as suggested by CDM of UNFCCC [24]. Calculation results show GHG reductions per plant of 1.7 tons (T) of CO_2 per year. Hence if the aforementioned figure is integrated for 70,000 irrigation pumping units that are operated on dual fuel mode, then at a national level the CO_2 emission will be reduced up to nearly 1,168 million metric tons (MMT).

ii. Nutrients Availability:

Nitrogen (N) in the cattle dung enters an anaerobic digester mainly in two forms: ammonium or organic N. Ammonium is produced mainly from the enzymatic hydrolysis of the urea in the urine. Ammonium is not destroyed during the digestion process but rather organic N is converted to ammonium during protein degradation. Hence, the ammonium level in the digester effluent is typically higher than the influent. It is found that the total ammonium nitrogen (TAN) to total kjeldahl nitrogen (TKN) ratio increased from 50 percent to 67 percent [25]. A 10 m^3 digester is fed with 108 kg dung/day as shown in Table 4. According to a research study conducted in Pakistan, TKN in cattle manure was about 0.57 percent [26]. Based on these statistics, total ammonium nitrogen (TAN) in the manure will increase from 0.54kg/day to 0.72kg/day post the anaerobic digestion process. If integrated for 0.7 million plants this is an additional 0.4 MMT of urea fertilizer. Since part of the ammonium in the dung or digester effluent is in a gaseous form of ammonia, the current system of surface gravity application favors reduced losses as compared to sprinkler irrigation systems utilized in Europe and United States of America. When digested effluent is applied into the field, microorganisms can convert the ammonia to nitrite that is then rapidly converted into nitrate, the form of nitrogen, most readily taken up by plants.

iii. Pathogen Reduction:

Anaerobic digestion is well known for its ability on reductions of most pathogens in manure, such as Escherichia coli O157:H7, Salmonella, and Cryptosporidium. It has been shown that a 95% pathogen reduction can be achieved from a 20 day retention time in mesophilic digester at 95 to 105°F temperature range. Higher rates of pathogen reduction are achieved with thermophilic digestion [27]. Based on the literature searched, no evidence of harmful bacteria strains (Vibrio genus found in human excreta, mainly coming from sea life) were found that supports the existence of any kind of harmful bacteria strain in healthy livestock manure effluent from a biogas plant, however special planning for dung disposal are required for animal diagnosed with infectious diseases.

C. Biogas and Rural Women

Promoting biogas generation at a large scale has a direct impact on ameliorating the status of the rural women who are the most disadvantaged section of the population for being vulnerable to hunger, malnutrition, illiteracy and poor health. These all are direct outcomes of the poverty that these women have to suffer through because of either poor agricultural growth or some other reasons such as water scarcity that hamper agricultural development. To fight poverty and elevate their living standards, these rural women are, therefore, compelled to work the whole day in completing agricultural field tasks besides performing household chores.

Pakistan has a total population of 188.02 million out of which 115.52 million are living in rural areas [12]. Despite the reality that the majority of the population is residing in rural areas; the fact is that the rural infrastructure is very under developed. Access to fundamental utilities of life like electricity, gas and piped water connections is severely limited. In 2013, 68.6 percent of the country's total population is noticed to have access to electricity [28]. Countrywide, 91 percent of households, of this population that has access to electricity [29], are using electricity for lighting purposes while some are using oil or gas to light the lamps and the rest are yet relying on candles. For the last couple of years, this access to electricity has merely become an eyewash as the country is passing through one of the worst load shedding crisis in its history.

The percentage of population having access to gas is also not very high. It is found that across Pakistan, in 2011, there were only 35 percent of households that are using gas for cooking purposes. In rural areas, only 11 percent of households have gas utility. As there is an overall energy crisis, these meager gas supplies have also become deficient. Consequently, 65 percent of the total households in the country have no other option except burning wood or charcoal to fulfill the cooking needs. The percentage using charcoal in rural areas is recorded to be 89 percent [29].

It is again quite startling to take into account that altogether there are only 32 percent of households, nationwide, having access to piped water connections. In rural areas, only 19 percent of households have this facility [29]. After knowing the state of fundamental amenities of life such as access to electricity, gas and piped water connections, it can easily be comprehended how hard life is for rural women in Pakistan. They spend most of their day in undertaking their agricultural related duties and their daughters are supposed to collect wood/charcoal to use as fuel for cooking purposes, fetching water for drinking purposes and other household needs and if the women themselves are performing these tasks then these daughters have to take care of their younger siblings at home because the Total Fertility Rate (TFR) in Pakistan is 3.8 [30]. Hence, attending school for such girls is merely a dream. In 2012, the overall literacy rate in Pakistan is found to be 49 percent and when segregated in terms of gender, the men and women literacy rate is 64 and 35 percent respectively [12].

Agriculture is the major contributing sector of the economy holding a 21.04 percent share of Gross Domestic Product (GDP). This sector is also retaining a large chunk of the country's total labor force. For 2012 -13, it is found that 43.7 percent of the labor force are engaged in agriculture. Of this 43.7 percent, women constitute of 75.7 percent while men make only 34.5 percent [12], hence demonstrating that agriculture in Pakistan, like many other developing countries of the world, is a women dominated sector. There is a long list of agricultural chores that women perform in Pakistan [31] around the year inclusive of pre and post harvesting and thus it can be said that sustaining agriculture in Pakistan without these rural women's contribution is unimaginable [32]. Anaerobic digestion and development of biogas plants hold potential for managing the ongoing crisis of water and energy, the two indispensable components of the agricultural development. The trickling down impacts of the biogas generation will ease rural women’s lives. Air pollution, emerging as a product of combusting wood and charcoal for cooking directly affects the health of the rural women and children. Biogas will help curtail this problem too. The issue of lighting bulbs/lamps at household level and in the village streets can also be resolved as another byproduct of biogas generation. Lighting the streets of the village will reduce the night crime. The amount of money spent on the purchase of fuel to run the tube wells for water management will be reduced and this in turn can be utilized for sending girls to schools and buying other facilities for life. The biogas production can thus become a precursor for the welfare of overall rural life in Pakistan besides sustaining the country’s economic growth.

V. CONCLUSION

Taking into account the several benefits of biogas that are evident from the aforementioned analysis, this green technology is strongly recommended to be introduced at a wider scale to sustain agriculture and ensure food security in the country. Pakistan is among the world’s most arid countries with average rainfall of 240 millimeters per year (mm/yr) [33], yet agriculture is the single largest sector of the economy [34]. This sector consumes 96 percent of country's fresh water resources and is heavily dependent on the Indus River with water driven from the glaciers of Himalayas and the neighboring countries of India and Afghanistan. Since it has been established that the farmers living in the Indus basin are relying heavily on tube well technology to fix the canal water deficits; biogas is among the most viable alternate energy solutions to operate these either diesel or tractor driven tube wells. Besides, anaerobic digestion increases the ammonia concentration in slurries, thereby reducing the cost of fertilizer inputs. Also compared to solids, farmyard manure nutrient slurry is easy to handle, usually mixed with irrigation water, and reduces the labor cost required to spread manure over the fields.

Besides being a form of renewable energy, biogas production is also notable for being compatible with socio cultural enhancements. Rural women are already engaged in collecting animal dung that is afterwards dried, by pasting on the outer walls of houses in villages, to be utilized for burning in kitchen stoves. It, therefore, needs to be processed on scientific lines for better outcomes.

Alternative Energy Development Board of Ministry of Water and Power, Government of Pakistan being the apex body has to, therefore, coordinate and facilitate the Provincial On Farm Water Management Directorates to promote biogas technology to run farm level operation. This initiative will be helpful to achieve the Planning Commission of Pakistan’s vision, of 5 percent share of power generation through renewable energies, set by year 2030.

AUTHORS' CONTRIBUTION

The authors share the work contributed in the following sequence;

Tariq Mahmood Khalil is the first author while Leena Maqsood and Quanbao Zhao are the second and third author respectively. The name of the third author is, however, appeared in the first column as per the IEEE guidelines for holding the same affiliation as that of the first author.

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