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Future of Renewable Energy Use in Pakistan in the Context of Agrifood-Energy Nexus

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Abstract:

Pakistan is facing a serious energy supply problem due to lack of energy that results in a shortfall of power supply from 6–10 hours/day, especially outside the big cities. The energy demand is expected to increase in every sector such as industrial, agricultural, household and transport in the years ahead due to population growth, economic development and modern lifestyle. Agricultural sector plays a vital role in the country's economy contributing around 20% share in GDP. At present the direct energy consumption in the agricultural sector is 2%. To avoid a worse situation in the future years renewable energy resource potential exploitation is needed. This requires also proper planning and implementation of energy policies. In this work present and future electrical energy consumption, demand and supply gap of the country is presented. A sustainable agricultural productive system has become a major priority to maintain food security for the increasing population. Both direct and indirect electrical and energy consumption has emerged in agrifood sector with farm machinery, production, packing and transport of fertilizers, food processing and transport, crop production, animal product production, poultry production, etc. In addition to this excel based model is developed to integrate the renewable energy into the agrifood – energy nexus supply chain and to fulfil the current and future energy demand of the sector.

Keywords: Renewable Energy Technologies, Energy-Food Nexus, Electricity, Powering Agriculture

1 Introduction to the Energy Supply Status-quo in Pakistan

World energy consumption has been in an increasing trend continuously over the past years due to population growth and modern life style. In today's carbon constrained world 40% of the global CO_2 emission is from electricity generation from coal, natural gas and oil [1]. With the awareness of the high risks of climate change since the past few years, many countries' governments are focusing on alternative energy sources such as wind, hydro, biomass, solar energy that are sustainable, environment friendly and provide energy security.

Currently Pakistan is facing a huge shortfall in electrical energy supply with demand due to the rapid economic and population growth, and this is resulting in frequent power cuts over the day. The country has a shortage in electricity supply of around 25-50% with respect to the demand and it is causing load shedding of around 10-12 hours in urban areas and 14-20 hours in the rural areas. Pakistan's total primary energy supply during the year 2011 – 2015 is shown in Figure 1. The share of petroleum products in the primary energy supply is around 22.15 MTOE in the year 2015 as shown in Figure 2.

Figure 4 shows the consumption of petroleum products in different sectors over five consecutive years 2010-2015. It is clear from Figure 4 that over the last five years there is a slight increase in the petroleum consumption in the transport sector as compared to other sectors.

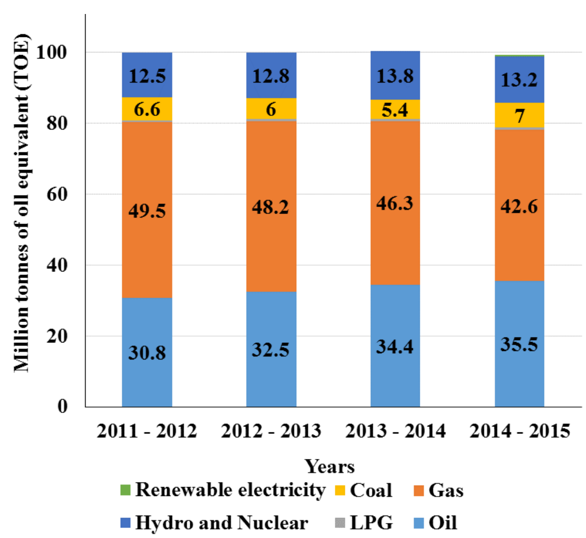

Figure 1: Contribution of different energy sources into the primary energy consumption [2,3]

Figure 3 represents the consumption of natural gas by other sectors and its share into primary energy supply which is around 25.6 MTOE in 2015. It can be seen from

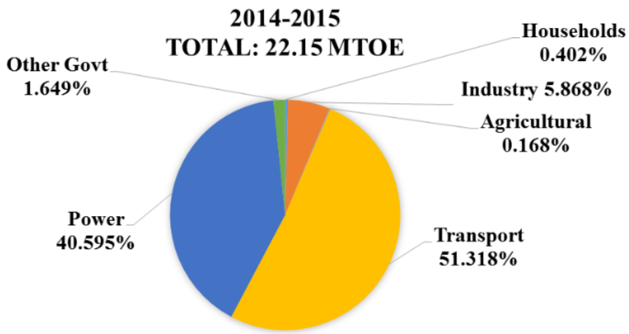

Figure 2: Consumption of petroleum products by different sectors in 2014-2015 [3]

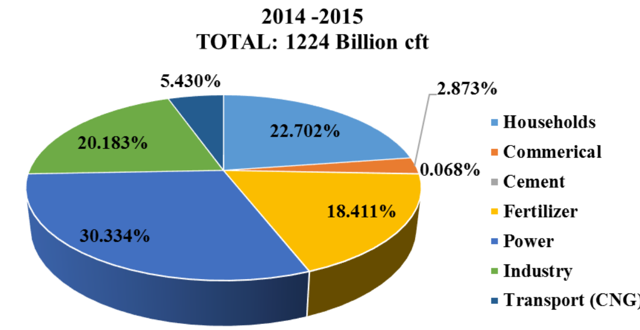

Figure 3: Share of natural gas into various sectors for 2014-15 (total: about 35 Billion m^3) [3]

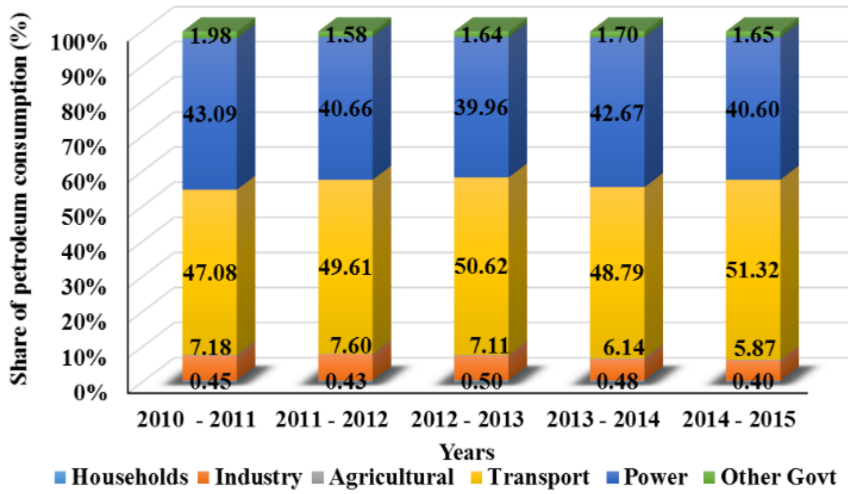

Figure 4: Five years trend of petroleum products consumption among different sectors [3]

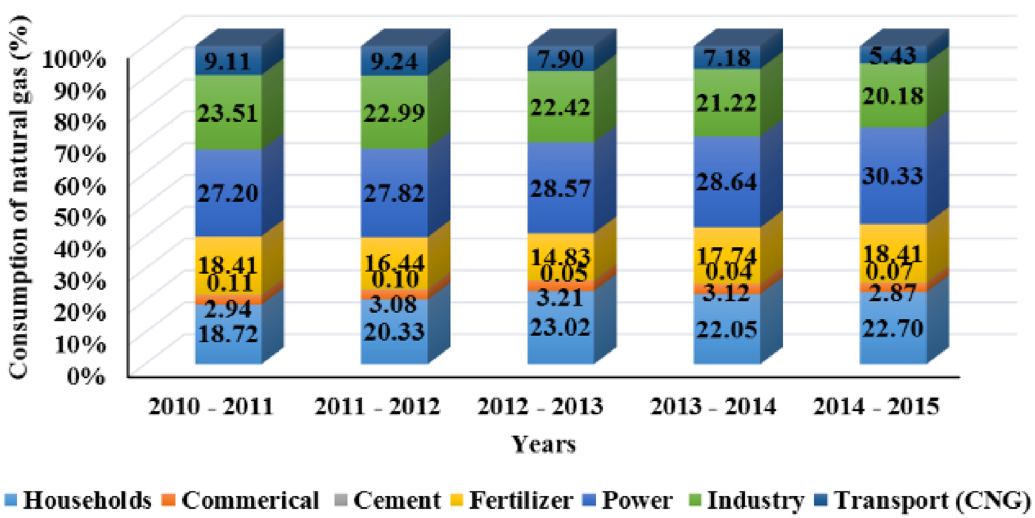

Figure 5: Five years trend of natural gas consumption by different entities [3]

Figure 5 that the share of consumption of natural gas in household and power sector increased by 4% and 3.1%, respectively in the year 2015 as compared to the year 2010.On the other hand, in other sectors such as transport and commercial industries, there is a slight decrease in the natural gas consumption in 2015 as compared to 2010.

Figure 6 presents the share of electricity consumption by different sectors in the year 2015. It can be seen here that household, industry and agricultural sectors are the three highest electrical energy consumption sectors with a share of 48.3%, 29.11% and 9.36% respectively. Five years consumption trend of electricity by different sectors in the country is shown in Figure 7. It is evident here that in Pakistan the demand for electricity is on the rise every year in every sector but there is a slight change in the pattern of electricity consumption by different sectors as no new power plant were built to fulfill the actual rising demand. According to data compiled from [3] the current electricity mix supplies during the year 2011-2015 from conventional and non-conventional sources are presented in Figure 8. Total installed power generation capacity increased by 4.22% in the year 2015 followed by year 2011 due to increase in thermal and hydro power as well as adding renewable energy into it. No independent power producers are added into Figure 8 due to unavailability of the data.

Due to modern life styles, increase in the use of electrical devices, high growth in income and urbanization, the demand for electricity has been increasing continuously over the past few decades. On the other hand, the installed power capacity is not growing at the same rate as the demand. Therefore, there is a gap of 5000 MW between the supply and demand as shown in Figure 9 [4,5,6]. Rauf et al. [7] projected the future electrical demand to be around 45 GW by 2030. Consequently, a sustainable and secure electricity supply is required to fulfill the demand and economic growth of the country.

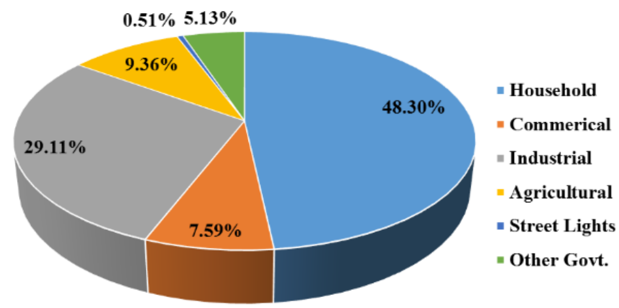

Figure 6: Total electricity supply in 2014 -2015 and its share among different consumers (~86 TWh) [3]

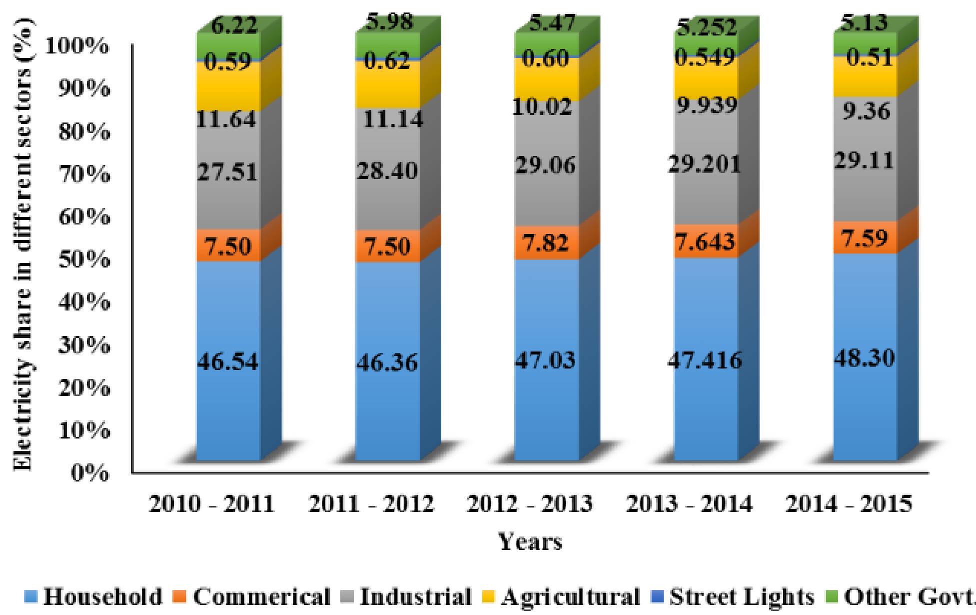

Figure 7: Five-year orientation of electricity supply into various sectors

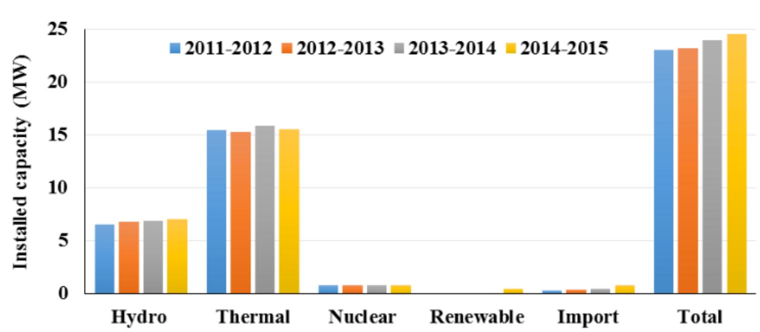

Figure 8: The installed electrical capacity growth rate during the years 2011 -2015 [3]

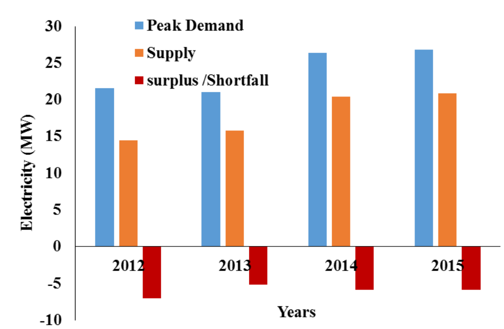

Figure 9: The gap between the supply and demand of electricity in Pakistan [4, 5, 6]

2 Energy use in Agriculture

Agriculture is a continuous process of energy conversion. One of the forms of energy conversion is from solar to food, feed and fiber through photosynthesis. Old agricultural techniques consisted of scattering seeds often unevenly, resulting in an unprepared field. On the other hand, modern agriculture utilizes a well-planned energy application for achieving desirable results [8]. Pakistan is a water- and energy- scarce country and both are very important in agricultural production. Agriculture is considered as the backbone of country's economy, contributing 21% to its GDP, accounting for nearly 43.7% of its work force and providing a livelihood to more than 67% of its population. Water and energy conservation plans are directly related to poverty reduction and living standards [9].

Indicators of agricultural growth are often spared the relative success of livestock, fisheries and secondary crops. The variation in these numbers is not a good indicator of the production of crops due to the numerous forces that affect the commodity prices and the market. The increase in added value (after considering the direct and indirect costs) is unstable, due mainly to major corps such as wheat, rice, sugarcane, gram and maize as shown in Table 1.

Agricultural sector of Pakistan is mainly dependent on fossil fuel inputs through fertilizers, pesticides and mechanization, which is a global trend. The years 1960 and 1970 were marked by a significant increase in productivity due to improved varieties, such as oil-containing fertilizers and pesticides, irrigation and diesel tractors [14]. The use of Nitrogen fertilizers (N) in Pakistan increased from 36,000 in the years 1960-1963 to 326,000 tonnes in the years 1970-1973 and it went up to 876,000 tonnes in the years 1980-1983 [15]. Energy analysis is not new to agriculture. The literature shows a significant amount of research on energy analysis, especially for crops (ethanol) such as sugarcane, wheat, maize and rice. Many authors have performed energy analyses on agricultural systems [16]. Due to growing population the food demand is increasing and to fulfill that agricultural production increased aggressively, in turn increasing demand of energy in direct and indirect ways.

3 Methods

The present study was carried out to determine the energy demand in agricultural sector using direct and indirect ways. Due to unavailability of data only five major crops are considered to determine the energy demand per crop. The direct energy includes human labor, diesel, and water for irrigation. Two main sources of the energy directly used in agriculture are petroleum products (3.71 Million TOE) and electricity (~8 TWh) as can be seen from Figures 2 and 6 respectively. The indirect and direct energy comprises of human labor, machinery, seeds, chemical fertilizer, fuel for transportation, storage, production, pesticides, field management, farm structure and operation characteristics. Empirical data such as seeds, fertilizers, sowing, electricity, pesticides, and machinery has been collected for five major crops such as rice, wheat maize, sugarcane and cotton and their energy equivalent units are shown in Table 2 [17]. Later, the total land available in the country for agriculture is defined and out of that, irrigated land is determined. For each crop land

Table 1: Value-added growth in the agricultural sector change in (%) in Pakistan, 2001 to 2010.

Year	Agricultural	Major crops (%) *	Minor crops (%) **
2001	−2.2	−9.9	−3.2
2002	−0.1	−2.5	−3.7
2003	4.1	6.8	1.9
2004	2.4	1.7	3.9
2005	6.5	17.1	1.5
2006	6.3	−3.9	0.4
2007	4.1	7.7	−1.0
2008	1.0	−6.4	10.9
2009	4.0	7.3	−1.7
2010 (provisional)	2.0	−0.2	−1.2

**** Cotton, sugarcane, rice, wheat, pearl millet, rapeseed, mustard, maize, barley, gram;***
***** Oilseeds, pulses, potato, onion, chilies; Data from [10, 11, 12, 13]***

Table 2: Energy input per ha for five different crops [17] in the year 1982

Inputs	Rice	Wheat	Maize	Sugarcane	Cotton
Seed rate (kg/ha)	10- 12	70-75	30-35	2300-3000	7-9
Fertilizer (kg/ha)	1148	1160	420	1470	540
Harvesting (kcal)	2×10^3	1.2×10^3	-	20×10^3	1×10^3
Threshing (kcal)	40×10^3	1.2×10^3	20×10^3	1.0×10^3	4.4×10^3
Sowing (kcal)	2×10^3	4.4×10^3	-	16×10^3	4.4×10^3
Pesticides (kcal/ha)	$360 – 480\times10^3$	-	480×10^3	480×10^3	240×10^3
Tractor (tac/ha)	2.24×10^{-3}	2.24×10^{-3}	2.24×10^{-3}	2.24×10^{-3}	2.24×10^{-3}

Table 3: Availability of total irrigated land for different crops in Pakistan in 2017 [18]

	Rice (000 ha)	Wheat (000 ha)	Maize (000 ha)	Sugarcane (000 ha)	Cotton (000 ha)
Irrigated Land available	2724	9052	1300	1218	2498

availability was determined using the information available for irrigated land as shown in Table 3.

4 Results and Discussion

The research results determine the indirect energy cover for five main crops; namely rice, wheat, maize, sugarcane and cotton. Among those rice is the most labor intensive crop. The total land available in the country for agriculture is around 23.7 Million hectares. Table 3 describes the share of irrigated land available for these five major crops. Unfortunately, due to unavailability of data, energy calculation for some inputs is not considered. Table 3 shows the energy required for different input parameters in kWh/ha for these five crops. Input data from Table 3 is used to determine the energy required in kWh/ha for different inputs for all five crops (the calculation has been made using 1 kcal = 0.00116222 kWh). Assumption has been made to estimate the energy required for the fertilizer applied as 0.174 kWh/ha. It can be concluded from Table 4 that sugarcane requires more energy in the seed rate (1046 kWh/ha) as compared to others crops.

Calculations have also been made to determine the total indirect energy demand for the agricultural land available for five major crops and values are shown in Table 5. The requirement of different inputs (like seed rate, fertilizer applied, etc.) varies based on the type of crop, soil, climatic conditions and water availability. Total energy required per hectare is higher for the sugarcane than all the other crops because of the high input of seed rate for sugarcane. The total indirect energy consumed by all inputs is highest for the wheat (18 GWh) compared to all the other four because land available for wheat (~9 million ha) is higher than all the others, as can be seen in Figure 10.

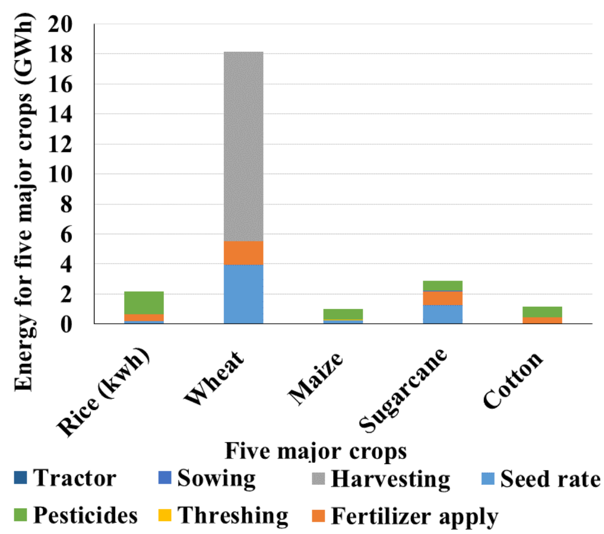

Figure 10: Total energy required for total irrigated land for five crops

4.1 *Potential for the integration of renewable energy with agriculture*

Pakistan has abundant renewable energy resources to fulfill the country's energy demand. Therefore, steps need to be taken to explore, develop and establish sustainable and secure energy supply to combat the gap in energy supply and demand [19]. The cumulative installed solar, wind and bioenergy capacity is around 100 MW, 360 MW 200 MW respectively [20]. The renewable energy potential of the country is 8 times higher than the total demand of around 168 GW. Energy is a vital part of the agricultural system and to make agriculture more

Table 4: Energy calculation kWh/ha for various crops

Inputs	**Rice** (kWh/hec)	**Wheat** (kWh/hec)	**Maize** (kWh/hec)	**Sugarcane** (kWh/hec)	**Cotton** (kWh/hec)
Seed rate	69.7	435	203.3	1046	52.3
Fertilizer applied	0.174	0.174	0.174	0.174	0.174
Harvesting	2.324	1.394	-	23.24	1.162
Threshing	46.48	1.39	23.2	1.162	5.11
Sowing	2.32	5.113	-	18.6	5.113
Pesticides	557.8	-	557.8	557.8	278.93
Tractor	-	-	-	-	-

Table 5: Total indirect energy required for five crops

Inputs	Rice (kWh)	Wheat (kWh)	Maize (kWh)	Sugarcane (kWh)	Cotton (kWh)
Seed rate	189862	3937628	264290	1274028	130174.7
Fertilizer applied	473.976	1575.048	226.2	896.652	433.086
Harvesting	6319.68	12618.488		28306	2892.21
Threshing	126611.52	12582.28	30160	1415.3	12718.79
Sowing	6319.69	46282.8		22533	12718
Pesticides	1519447		725140	679400	694256
Tractor	854.72	174.5	-	-	-

sustainable and for low carbon emissions a renewable source of energy can be used. The agricultural sector has a great positive impact on climate change as it helps mitigate the impact of greenhouse gas emissions. At the same time, it is strongly influenced by the effects of climate change as agricultural activities depend directly on the climatic conditions. The agricultural sector itself contributes significantly to the greenhouse effect because of the use of fossil fuels and agricultural practices that reduce the ability of the soil, e.g. fertilizers and agrochemicals that cause greenhouse gas emissions, methane emissions and other greenhouse gases from livestock creation. Good agricultural practices can help offset the global contribution of agriculture to the climate change. The major goals of a sustainable and eco-friendly agricultural system combine [21, 22]:

1. Reduced dependency on conventional fuels
2. Improved soil capacity
3. Reduced greenhouse gas emissions
4. Reduced agricultural inputs such as fertilizers, pesticides and other chemicals
5. Providing a more profitable farm income

Many forms of renewable energy are produced in rural areas and in many small and medium-sized installations, the facilities provide opportunities for new co-operation in production and distribution of renewable energy. On farm many technologies are or could be deployed to meet energy use for heating, cooling, traction and other energy functions such as bioenergy (heat, power, biogas, biofuels such as vegetable oils or bioethanol), solar (electricity and heat) and wind. These can also include geothermal heat and heat recovery systems from e.g. cooling systems and manure storage. In various settings, farmers combine different technologies and can deliver renewable energy to power or gas grids [21].

4.1.1 Solar energy for agriculture

For many agricultural needs one alternative energy source is solar energy. A modern and well-designed solar system can provide the necessary power in a certain place and for a certain period of time. These are globally proven and certified systems that are economical, reliable and have already increased the productivity of agriculture around the world [23]. Solar energy can cover and/or supplement a large part of the energy demand. Motor power generation is the primary use of solar photovoltaic systems (PV) on farms. Water pump, one of the simplest and most commonly used system, provides irrigation, water for livestock and pond management. Portable or grounded photovoltaic systems can be used to pump out water from underground wells or surfaces (e.g. ponds, streams). Photovoltaic water systems may be the most economical option for pumping water in locations where there are no grid connections available. Solar drying is another important application.

4.1.2 Wind energy for agriculture

The use of wind farms can improve the living standards of the rural population by increasing agricultural productivity. Wind turbines have significant advantages in areas with shorter rainy seasons, and thus the high demand for pumped water. When the wind turbine water pumps are installed, it is possible to grow the most valuable plants throughout the year and also supply water to the cattle. Local farmers need proper training for wind turbine driven water pump irrigation. Today in most of the agricultural practices fossil fuels and their derivatives are widely used. However, very few wind-powered water pumps are installed in some parts of the world. Wind power can be used to grind legumes and vegetables. Before the invention of electricity, the first wind turbines have done a very useful job of grinding. During the last several centuries, windmills in Europe have been used in many places for the use of expensive granite slabs, so-called mills. Mills were used to crush dry grains such as wheat, barley and corn, cakes or flour. This method can be used on farms to produce flour

5 Conclusions

Agricultural land is mainly irrigated using both surface and groundwater. Approximately 94% of farmland in Pakistan is viable for irrigation. The countryside has a large irrigation system relying on rivers, dams, trays and canals. However, irregular monsoon models, increased melting temperature of clay, low water capacity, and continuing disputes between border zones cause uncertainty about water availability and affect production standards. The country is highly rich in renewable energy resources but they are not yet completely exploited and developed. However, till 2008 no renewable energy based electricity was integrated into power grid due to lack of capable grid network. The energy demand is increasing over the past two decades but power generation capacity was not growing enough simultaneously to fulfill the demand. One way to overcome the energy demand is by optimizing demand based management, reducing line losses and minimizing energy theft. Direct energy use in agriculture is higher than the indirect use due to water irrigation and fertilizers. Sugarcane has a higher energy demand in comparison with rice, wheat, maize and cotton. Land availability for wheat crop in Pakistan is more than that for the other four aforementioned crops. Hence the total indirect energy required for wheat crop is 18 GWh, which is comparatively higher than that for all the other four crops. The input data on fertilizer processing, fertilizer transport, agricultural machinery is currently unavailable and these can be included in future to identify more additions to the indirect energy demand. Further the input data from food processing and food transportation can also be included to more correctly estimate the complete indirect agro-food energy demand in Pakistan.

Acknowledgments

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