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From Energy Blues to Green Energy: Options Before Pakistan

RAFI AMIR-UD-DIN

1. INTRODUCTION

Energy crisis in Pakistan had been brewing long before it became an important national issue with the potential to significantly affect the outcome of general elections of 2013. The looming crisis of depleting non-renewable energy sources combined with a feeble economy has lent a new urgency to the search for an energy mix which is sustainable, economically viable and environmentally least hazardous. Fossil fuels with their known adverse environmental impacts dominate the current energy mix of Pakistan. The renewable energy sources remain underutilised despite being cost effective and less hazardous for the environment.

A substantial amount of literature has highlighted various dimensions of existing energy sources in Pakistan with a particular emphasis on the environmental impact, the sustainability and the efficiency of various energy sources [see Asif (2009); Basir, *et al.* (2013); Bhutto, *et al.* (2012); Mirza, *et al.* (2009, 2008, 2003); Muneer and Asif (2007); Sheikh (2010) for example]. This study analyses the environmental impact, economic feasibility and efficiency of various energy sources subject to various economic and non-economic constraints. Section 2 discusses energy security by reviewing various tapped and untapped energy sources besides analysing current energy mix and its future prospects. Section 3 highlights the interaction of energy use and environment. Section 4 discusses two approaches to assess the feasibility of an energy mix: disaggregated and aggregated. The latter approach makes a multidimensional comparison of all the energy sources discussed in this study. Section 5 consists of discussion and concluding remarks.

1.1. Energy Mix

1.1.1. *Current Distribution of Energy*

Pakistan's current energy mix is dominated by the fossil fuels. Figure 1 below shows that with the exception of hydropower, renewable energy sources remain mostly untapped. The wind and solar energy systems, which are tipped as the future of Pakistan

Rafi Amir-ud-Din <rafi.amiruddin@gmail.com> is Doctoral Candidate at the School of Economics, International Institute of Islamic Economics, International Islamic University, Islamabad.

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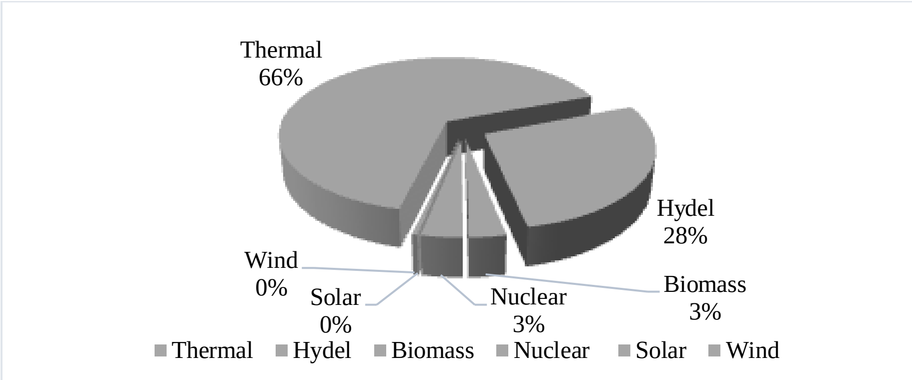
energy profile currently add up to only 1 percent of total energy stock. Other important renewable energy sources such as geothermal and ocean are totally absent. A viable energy mix in the future will not only require a radical increase in its absolute size but also substantial changes in the relative size of various energy sources.

Fig.1. Distribution of Installed Energy Capacity in 2012.



Source: HDIP (2012), Bhutto, *et al.* (2012), Renewable and Alternative Energy Association of Pakistan.

1.1.2. *Future Prospects of Energy Distribution*

Asian Development Bank in its recent report *Energy Outlook for Asia and the Pacific* (2013) presents two cases of energy demand and supply for the ADB member economies in Asia and the Pacific: (i) a business-as-usual scenario, and (ii) alternative scenario. The business-as-usual scenario reflects the impact of existing policies and current technology levels on future energy profile. The alternative scenario is based on assumed positive changes in the supply and demand through advanced and low-carbon technologies [ADB/APEC (2013)].

Table 1

Energy Outlook for Pakistan (2010-2035)

Power Generation Output	Business as Usual Scenario						Alternative Scenario					
	Share (%)			AAGR (%)			Share (%)			AAGR (%)		
	2015	2020	2035	2010–20	2020–35	2010–35	2015	2020	2035	2010–20	2020–35	2010–35
Total	100	100	100	4.9	2.8	3.6	100	100	100	3.9	2.2	2.9
Fossil Fuels	67.1	61.1	57.2	4.6	2.3	3.2	60.3	45.7	11.6	0.6	(6.7)	(3.9)
Coal	1.1	1.1	1.4	34.1	4.4	15.4	1.0	0.8	0.3	29.0	(4.9)	7.5
Oil	34.0	27.9	15.3	2.4	(1.2)	0.2	30.6	20.8	3.1	(1.5)	(10.0)	(6.7)
Natural Gas	32.0	32.2	40.5	6.6	4.4	5.3	28.7	24.0	8.2	2.5	(4.9)	(2.0)
Nuclear	3.6	6.0	4.0	10.4	0.0	4.0	7.5	13.6	30.0	18.6	7.8	12.0
Hydro	28.8	32.4	38.3	4.5	3.9	4.2	30.1	35.7	45.8	4.5	3.9	4.2
Others	0.5	0.4	0.5	–	3.7	3.6	2.1	5.1	12.6	–	8.6	–

Source: ADB/APEC (2013).
AAGR = average annual growth rate.
( ) = negative number.

In the business as usual scenario presented in the Table 1, we see that with the exception of two significant changes, not much will change by the year 2035 in Pakistan's energy mix. The oil use in the power generation will be slashed by more than 50 percent while there will be around 25 percent increase in the use of natural gas. Although coal share in the total energy mix is estimated to be only about 1 percent, its growth rate equal to 15 percent will be the highest. The share of hydropower will also rise by one third.

In the business as usual scenario, there will be only a modest average change of only 4 percent in the nuclear source by 2035. The share of other renewable and environmentally friendly resources of energy like wind and solar power are expected to be not more than half a percent. What makes this scenario a particularly alarming one is that by 2030 we will have depleted our existing resources of coal and gas. Without a substantial increase in the share of alternative energy sources, Pakistan's economy will be dangerously dependent on imported power. Hydropower may also be adversely affected in case India chooses to make other large dams on water sources, which flow towards Pakistan.

The alternative scenario suggests that there will be a radical change in the share of fossil fuels in the energy mix. The share of fossil fuels will decrease almost five times. The most significant change will, however, be in the oil sector: share of oil in the total energy mix will decrease by almost nine times during the period 2015-2035 and the oil will continue to register a negative growth of about 10 percent from 2020 to 2035. The share of nuclear technology is similarly estimated to rise by 400 percent. Renewable energy sources, especially the wind and solar energy will substantially contribute to the overall energy stock besides growing at the highest rate during the period 2020-2035 according to the alternative scenario.

Nuclear energy will notably constitute 30 percent of the total energy generation in the alternative scenario, which is no small achievement as compared to its current share of only 3 percent. The hydro energy will constitute almost one half of the total energy mix, up from one third share at present. Given the intensity of opposition to Pakistan's nuclear programme and large dams due to their adverse security and environmental impacts, Pakistan must have to do a difficult tightrope walking in increasing its capacity in hydro and nuclear sources.

2. ENERGY SECURITY

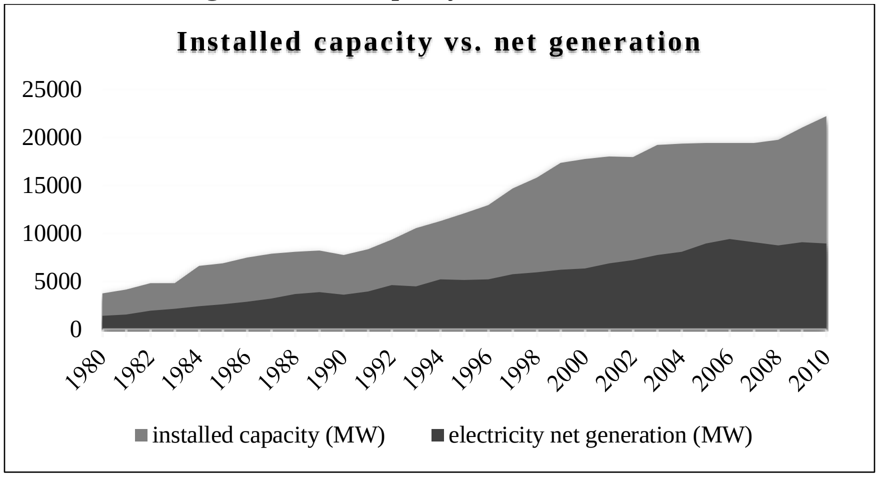
Pakistan has been facing the worst energy crisis in recent years. The issue of IPPs and RPPs and corruption scandals have considerably dented the ability of the power sector to meet Pakistan's energy needs. Electricity theft from the distribution system is yet another long-standing problem. Pakistan loses electricity because of theft worth Rs 100 billion on an annual basis.[1] The circular debt issue further aggravates the tottering energy system. The circular debt reached as high as US$2.5 billion on June 30, 2009 [Trimble, *et al*. (2011)].

It may be noted that Pakistan's energy needs are very modest. Pakistan ranked the 36th lowest country in the world in 2012 in terms of energy consumption with an average

[1]http://www.dawn.com/news/1053742/power-theft-costs-rs100bn.

per capita energy use of 43 Watts, which is one seventh of the world average [EIA (2013)]. Still there are wide gaps between the limited installed capacity and the net generation, which is increasing over time. See Figure 2 below.

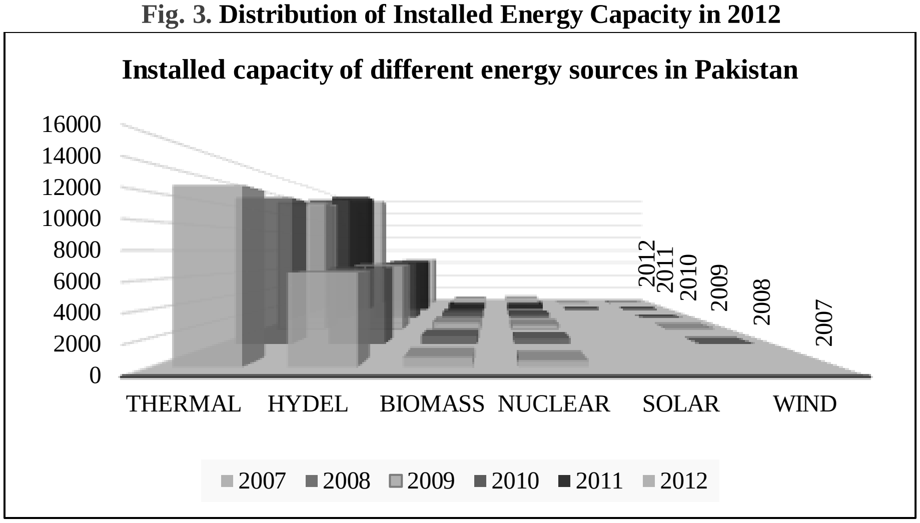
Fig.2. Installed Capacity and Net Generation.



Source: U.S. Energy Information Administration.

As the Figure 2 above shows, we see a noticeable shift in the installed capacity in the last decade of 20th century, but the generation capacity shows a predictable path. How the successive governments could have overlooked the widening gap during the period, which saw a significant increase in the installed capacity requires closer scrutiny. During the years 2008-2012, depressed growth in the energy sector set the tone for what had to come later. There was only a modest growth of only 3 percent in the installed capacity over the period of 6 years.

Fig. 3. Distribution of Installed Energy Capacity in 2012



Source: HDIP (2012), Bhutto, *et al.* (2012), Renewable and Alternative Energy Association of Pakistan.

In this section, we shall review both the tapped and untapped energy sources in Pakistan. We shall also review both the current mix of energy and the distribution of the expected energy mix in the long run.

1.2. Renewable Energy Sources: Tapped and Untapped

1.2.1. *Biomass*

Biomass currently meets substantial energy needs of rural and low-income urban households in Pakistan [Mirza, *et al.* (2008)]. It contributes 36 percent of the total supplies in the primary energy mix [Asif (2009)] but it is primarily used as unprocessed fuel for cooking and household heating [Pakistan (2006)]. Although sugarcane bagasse, an important biomass material, can be used to generate 2000 MW of electric power [Mirza, *et al.* (2008)], a few sugar mills using bagasse for cogeneration purposes are allowed to sell surplus power to the grid up to a combined limit of 700 MW so far [Pakistan (2006)].

Pakistan Council for Renewable Energy Technologies (PCRET) has started some groundwork by installing 60,000 energy-conserving, improved cooking stoves all over the country. Research on biodiesel production and use of municipal and industrial waste for power generation is underway. Biogas can also become a reliable energy source in rural areas through a network of community biogas plants [Mirza, *et al.* (2008)].

1.2.2. *Hydropower*

The total hydroelectric potential in the country has not been fully investigated, but some conservative estimates put the potential up to 45,000 MW. "Pakistan has an installed hydroelectric capacity of only 5928 MW of large (>250Mw), 437 MW of medium (>50 MW and <250 MW), and 253 MW of small to micro (<50 MW) plants, mostly in the northern parts of the country. This amounts to 6608 MW of total capacity, or less than 15 percent of the identified potential" [Pakistan (2006)].

Water is a crucial issue in Pakistan primarily because its allocation remains a critical factor in inter-provincial politics. The proposed construction of Kalabagh dam, the third large-scale storage and hydroelectric reservoir after Mangla and Tarbela, became controversial right from its inception and led to large-scale protests in Sindh, where it was seen as an encroachment by the Punjab upon the lower riparian's water entitlements [Gazdar (2005)]. Water is also an important issue between Indo-Pak bilateral relations and Baglihar dam issue has further vitiated the atmosphere between the two neighbours.

1.2.3. *Solar*

Pakistan is amongst the richest countries in the world in terms of solar energy, having an annual global irradiance value of 1900–2200 kWh/m^2 [Asif (2009)]. The estimated solar energy potential in Pakistan is over 100,000 MW" [Basir, *et al.* (2013)]. In 2012 Pakistan inaugurated the first ever solar power on-grid power plant in Islamabad with the total generation capacity of 356.16 kW of electricity.[2] Recently Siemens has been proactively pursuing solar energy projects by installing many standalone solar

[2]http://www.jica.go.jp/pakistan/english/office/topics/press120529.html.

power systems in the country [Mirza, *et al.* (2003)]. According to another estimate, 50 to 100 MW of photovoltaic is expected to be installed by the end of 2013, and at least 300 MW in 2014.[3]

1.2.4. *Wind*

Pakistan has a large wind corridor stretching from southern Sindh to coastal Balochistan and parts of KPK valleys. Monthly average wind speed exceeds 7-8 m/s[4] at some sites along the Keti Bandar-Gharo corridor [Bhutto, *et al.* (2012)] and there is potential for 20,000 MW of economically viable wind energy [Sheikh (2010)]. According to Alternative Energy Development Board estimate, only Jhimpir, which falls in the Gharo-Keti Bandar Wind Corridor can potentially generate up to 50,000MW of electricity.[5]

Pakistan installed two major wind farms as late as in 2012, with a total capacity of 100 MW. Given the present energy crunch and a feed-in tariff scheme in place, further projects are expected to get online in the year 2013 and beyond.[6] Offshore wind energy is another important renewable energy source, which refers to wind turbines inside the water bodies. The offshore wind energy, however, depends on the depth of the water and its potential in Pakistan has to be explored yet.

3. ENERGY AND ENVIRONMENT

In this section we analyse the impact of various renewable energy sources on the environment. In view of the 'rage' for the renewable energy sources, it is easy to forget that large dams once created the same kind of 'rage' before falling from grace. Abbasi and Abbasi (2000) recount the interesting history of the virtual "rise and fall" of the large dams and conclude that we must be clear about the environmental hazards of the renewable energy sources to avert the "sad euphoria-turned-despair history of hydel power projects."

3.1. Biomass

Biomass is biological material derived from living, or recently living organisms, biomass refers to both animal and vegetable derived material [BEC (2013)] and is used as an important source of energy. Biomass energy is extremely demanding in terms of water and land resources [Abbasi and Nipaney (1993)]. Removal of biomass from land and water degrades soil and water, may cause floods and remove important nutrients essential for organisms [Pimentel, *et al.* (1984)]. Nutrient-rich run-off also harms the water channels through the process of eutrophication. Converting natural ecosystems into energy crops, a fundamental requirement of a viable biomass energy system, reduces the habitat and food supply of certain wildlife species besides reducing the diversity of vegetation [Abbasi and Abbasi (2000)].

[3]http://www.nation.com.pk/pakistan-news-newspaper-daily-english-online/business/31-Oct-2012/punjab-german-firm-ink-solar-energy-mou.

[4]7-8 m/s refers to the wind speed which is 7-8 meters per second.

[5]http://tribune.com.pk/story/483543/alternative-energy-in-jhimpir-lies-the-future-of-wind-farming/

[6]http://tribune.com.pk/story/483543/alternative-energy-in-jhimpir-lies-the-future-of-wind-farming/

3.2. Solar Energy

Contrary to the popular perception that solar energy is the cleanest renewable energy source, it pollutes the atmosphere through a massive use of materials like primary steel, glass and cement. It is estimated that solar thermal system requires more material per unit of energy than the fossil fuel plants [Siddayao and Griffin (1993)]. Solar energy generation systems also pollute water by releasing antifreeze agents, rust inhibitors and leaching heavy metals. Large scale photovoltaic power generation systems consume more water for cooling purposes and may disrupt the ground and surface water flow patterns. Such systems may also destroy desert habitats for burrowing animals and desert wildlife such as endangered species [Abbasi and Abbasi (2000)].

As regards the dispersed solar energy systems, it is considered the most benign source of energy. However, locating the solar home heating near evergreen trees could pose certain dangers to the atmosphere. Similarly concentrating rooftop collectors in a given area might change the albedo, which is ratio of reflected to incident light, and change the weather [Abbasi and Abbasi (2000)]. As regards greenhouse gases, solar energy system causes more greenhouse gas emissions initially than nuclear and fossil-energy systems [Bezdek (1993)] but in later stages it emits negligible greenhouse gases.

3.3. Wind Energy

Drewitt and Langston (2006) conducted a literature survey to find that birds, sometimes rare species such as raptors in U.S, collide with the wind turbines. Wind turbines may also disturb or even displace the birds or damage their habitat. Both Lloyd [ETSU (1996)] and Colson (1995) suggest that wind energy system installation can minimise the danger to birds by avoiding their migration corridor doors. Some other measures include the construction of tubular turbine towers and fewer large turbines with adequate space [Burton, *et al.* (2011)].

Wind energy generation is also believed to produce infrasound noise, at frequencies below the audible range, which causes the neighbouring buildings to vibrate. Large scale wind generation facilities can reduce wind speeds, increase temperatures of the lakes located down the windmills because of reduced evaporation, and increase the soil moisture [Abbasi and Abbasi (2000)]. Wind turbine can also interfere with electromagnetic signals, which are used by a wide range of communication systems. Electromagnetic Interference (EMI) affects certain ranges of radio system, television broadcasts and microwave links. Researchers continue to investigate the impact of EMI on the civil and military radar systems [Burton, *et al.* (2011)].

3.4. Hydropower

Environmental experts agree that large hydroelectric projects adversely affect environment, worsen water quality and could be the most damaging energy source for the environment [Abbasi and Abbasi (2000)]. Large hydropower generation installations affect catchment areas through increased deforestation. In the artificially created lakes, they obstruct movement of aquatic life by changing sediment and nutrient levels and also damage terrestrial habitat. They increase eutrophication and affect the behaviour of riparian organism in the downstream areas as a result of altered river flow. They affect the estuary into which river flows by disrupting the natural mix of salt water and inflowing freshwater [Kandpal, *et al.* (1994)]. Some studies suggest that large manmade water reservoirs emit greenhouse gases, especially methane, to levels, which is comparable to emissions of fossil-fuelled power plants [Rosa and Schaeffer (1994)].

Small hydropower systems also affect the river habitat by interrupting water flow, obstructing movements of aquatic organisms and causing water evaporation. The small hydro systems convert parts of riparian area into wilderness and are too demanding in terms of roads. As storage is an important issue in small hydropower systems, construction of a large number of low head systems tend to create problems of siltation and eutrophication. Shallow reservoirs also substantially emit methane gas [Lindau and Bollich (1993); Wang, *et al.* (1993)].

3.5. Ocean Energy

The power plants, which convert the ocean thermal energy displace massive amount of water from the surface and deep ocean, and discharge them in some surrounding areas about 100 to 200 meters deep. This adversely affects the ocean water quality by changing salinity gradients and amounts of dissolved gases as well as other nutrients. Increased amount of nutrients in aquatic ecosystem leads to eutrophication. Some of the discharges from the power plants such as chlorine may irritate the organisms or may even be toxic. The disasters of accidental ammonia leak are also well-documented. Similarly, the discharge of effluents from the cold water pipes could lower the sea surface temperatures in the vicinity of the ocean energy power plants. [Abbasi and Abbasi (2000)].

3.6. Geothermal Energy

Geothermal energy, which is harnessed from the heat of the earth is not without its fair share of environmental issues. Various means of geothermal energy may disturb the surface of the land by massive fluid withdrawal, create noise and thermal pollution and release offensive chemicals [Armannsson and Kristmannsdottir (1992)]. Withdrawal of hot water or steam form underground fields emits several pollutants such as hydrogen sulfide and arsenic. It may be noted that geothermal energy system is highly site-specific and therefore the real impacts can be analysed only on site-by-site basis.

4. FEASIBLE ENERGY MIX

Pakistan has so far no reliable data on the cost of various energy sources, nor data on the precise environmental impact of various energy sources and their efficiency is available The data on the expected project completion time of different energy technologies is extremely sketchy and is mostly not available for Pakistan. Open Energy Information (OpenEI), an online platform of United States Department of Energy, maintains a large historical data on various indicators such as cost, CO_2 emissions, efficiency and sustainability. We chose seven indicators: levelised cost of energy, overnight capital cost, fixed operating cost, variable operation cost, capacity factor, CO_2 emissions and expected project completion time for our multivariate comparison.[7]

[7]Although various energy sources adversely affect the environment in a variety of ways, the choice of CO_2 emissions as a sole measure of environmental degradation is an expedient choice because it makes direct comparison across a range of energy sources possible.

We have carried out two types of assessments: aggregated and disaggregated. The disaggregated assessment allows us to compare various energy sources within indicators and aggregated assessment allows us to compare various energy sources across multiple indicators.

Table 2

Multivariate Comparison of Various Energy Sources

	LCOE $/kWh (a)	Overnight Capital Cost ($1000/kW USD)	Fixed Operating Cost $/kW	Variable Operating Cost $/MWh	Capacity Factor (%)	CO_2 Emissions (g/k Whel) (c)	Expected Project Completion Time (Years)[8]
Wind, Onshore	0.05	1.57	10.95	6.45	38	10	1
Wind, Offshore	0.08	3.05	14.28	21.18	43	9	5
Solar, Photovoltaic	0.26	5.1	32.03		21	32	0.5
Concentrating Solar Power	0.19	5.74	55.72	0.1	31.16	13	2
Geothermal, Hydrothermal	0.05	2.82	159.41		85	38	6
Blind Geothermal System	0.1	6.85	222.98		95	38	6
Enhanced Geothermal System (EGS)	0.11	7	199.69	30	84.6	38	3
Small Hydropower (b)	0.13	4.5	130		50	13	2
Hydropower	0.02	1.32	13.14	3.2	93.2	10	5
Ocean	0.22	6	100		25.5		4
Biopower[9]	0.06	2.62	66.63	4.61	84.04	24.5	1.5
Distributed Generation[10]	0.12	1.8	16.58	7.37	75		1
Fuel Cell	0.14	4.64	5.65	47.92	95	664	1
Natural Gas Combined Cycle	0.05	0.88	13.71	2.86	84.6	443	4
Natural Gas Combustion Turbine	0.07	0.6	10.53	3.57	80	443	3
Coal, Pulverized Coal, Scrubbed	0.05	1.92	27.5	3.7	84.6	960	3
Coal, Pulverized Coal, Unscrubbed	0.04	1.1	27	4.45	84.6	1050	3
Coal, Integrated Gasification Combined Cycle	0.08	3.17	38.67	7.25	80.96	1050	3.25
Nuclear	0.05	3.1	85.66	0.49	90	66	6
Oil	0.07	0.396	25.26	3.46	79.27	948 (d)	5

Source: Open Energy Information (OpenEI)/DOE.

(a) The values of five indicators LCOE, Overnight capital cost, fixed operating cost, variable operating cost and capacity factor represent the median values based on the data from several studies.
(b) The Blind Geothermal System (BGS) and small hydropower data are based on one observation each.
(c) *Source:* EIA.
(d) *Source:* Sovacool (2008).

[8]The data on this variable is based on various public sources such as World Nuclear Association, US Department of Energy, United States Agency of International Development and Renewable Energy World.

[9]The technologies used to obtain energy (biopower) from different types of biomass are different and the resulting energy products are different too. Biopower technologies convert renewable fuels of biomass into heat and electricity by using equipment, which is similar to the one used for fossil fuels.

[10]Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power. http://www.dg.history.vt.edu/ch1/introduction.html

4.1. Disaggregated Assessment

In this sub-section, we will compare various energy sources individually.

4.1.1. *Levelised Cost of Energy*

Levelised cost of energy (LCOE) is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital, and is very useful in calculating the costs of generation from different sources [NREL (2013)].

Levelised cost of the energy sources analysed in this study display wide differences. The solar PV is 13 times more expensive than the hydropower. Fuels cells almost cost three times more than the coal and natural gas. Three geothermal energy sources have wide disparities in terms of cost. The fossil fuel based energy is the least expensive and small wonder that coal, oil and gas form a major chunk of Pakistan's energy mix.

Hydropower despite being the least expensive, and with a huge untapped potential [Asif (2009); Bhutto, *et al.* (2012)] constitutes only 28 percent of the present energy mix. Nuclear energy constitutes only 3 percent of the total installed capacity. Nuclear energy is a sensitive issue because its security and safety are genuine concerns but it also touches many raw nerves in the international community because of the fear that it might be misused in the hands of the non-state actors.

A substantial literature suggests that Pakistan's future belongs to the wind and solar energy [see Basir, *et al.* (2013); Bhutto, *et al.* (2012); Mirza, *et al.* (2003); Solangi, *et al.* (2011) for example]. But the fact that solar technologies (both PV and CSP) are among the most expensive options puts a lot of questions marks on the viability of the solar technology in a country like Pakistan with faltering economy.

4.1.2. *Overnight Capital Cost*

Overnight capital refers to the cost of building a power plant overnight. The term is useful to compare the economic feasibility of building various plants. The overnight capital cost does not take into account financing costs or *escalation*, and hence is not an actual estimate of construction cost [RMI (2013)].

The overnight capital cost of the energy sources discussed in this study is not much different from LCOE except that the cost of non-renewable resources like oil and natural gas is markedly less than the least expensive renewable resources like hydropower and wind. The hydropower is three times more expensive than the least—cost non-renewable energy source, that is, oil. Both types of solar technologies, though still much expensive as compared to hydropower, are not the most expensive; they are around 30 percent less costly than the geothermal energy source, which is the most expensive energy source. Similarly, the nuclear energy is a prohibitive eight times more expensive than oil.

Similar to the LCOE, the cost differentials between the small hydropower (of 10 MW or less in size) and a large-scale hydropower of average capacity are very high: the small hydropower project costs over 300 percent more than the hydropower of an average capacity, indicating that small hydropower installations are not feasible. However, the atmosphere in Pakistan is presently not favorable towards large dams partly because of political dispute over the Kalabagh Dam and partly because Pakistan is getting less than its due share because of construction of large dams like Baglihar Dam in India. It may be noted that India is considering a lots of other dams.

4.1.3. *Fixed Operating Cost*

The fixed operating cost of geothermal energy system is an astronomically 40 times higher than the fuel cell. Fuel cells are the most expensive non-renewable energy source, but it requires the least fixed cost. The nuclear energy, though least expensive in terms of LCOE, has the highest fixed operating cost among the non-renewable energy sources explaining one of the constraints of successive Pakistani governments to go ahead with nuclear energy installation in a big way. The average fixed cost of potential renewable resources available in Pakistan with the exception of geothermal and solar energy is almost the same as the fixed cost of non-renewable sources. The implication is that if we manage to make an initial investment in the renewable energy sector, it will pay larger dividends in terms of environmental safety.

The average fixed cost of fossil fuels is slightly higher than the most promising renewable energy sources: wind and hydropower. It may be noted that the fixed cost of small hydropower is about ten times higher than the hydropower. Similarly there is also a significant difference in the cost of solar PV and concentrating solar power (CSP): the latter being much more capital intensive technology because of the additional lenses used to concentrate the solar energy.

4.1.4. *Variable Operation Cost*

Variable costs refer to the cost which may increase or decrease depending on the volume and method of production. Most of the non-renewable and renewable energy sources have almost the same amount of variable cost on average with some exceptions. Among the non-renewable sources, fuel cell has the highest variable cost, which is an astronomical 100 times higher than the nuclear energy. Geothermal and offshore wind energy are disproportionately more expensive as compared to other renewable energy sources. It may be noted here that given the present level of technology, offshore wind energy system does not seem to be a realistic goal at least in the near future. The cost effective renewable energy is again hydropower followed by biopower and onshore wind.

Interestingly the concentrating solar power, which is on the higher end of LCOE and fixed cost spectrum requires the lowest variable operating cost. An extremely low variable cost of CSP would offset the high initial fixed cost in the long run. Concentrating solar power is for a number of technical reasons a much better option, and going by its low variable cost, it means that only one time high investment should be enough to harness the solar energy in an effective way.

4.1.5. *Capacity Factor*

Capacity factor is the ratio of actual generation to maximum potential output, expressed as a percent. The renewable and non-renewable energy sources display wide disparities in terms of capacity factor. Abysmally low capacity factor of the renewable energy sources like solar and wind is no match for the fossil fuels with capacity factor above 80 percent. Nuclear energy and fuel cells are remarkable in terms of their efficiency with regard to capacity factor of above 90 percent on average. The renewable energy sources, which match the non-renewable energy are only biopower, hydropower and geothermal. As in previous indicators, hydropower is among at the most efficient sources. Although the efficiency of CSP is 10 percent higher as compared to solar PV, the poor efficiency of solar energy in general despite its high cost puts a question mark on its feasibility. Similar is the case with wind energy which with an efficiency factor of around 40 percent is not a viable option.

4.1.6. *CO_2 Emissions*

A comparison of different energy source explains why the fossil fuels are roundly condemned as the main culprit behind the environmental degradation. The pulverized coal based energy system emits 116 times higher CO_2 in the atmosphere than offshore wind for example. The renewable energy sources, on the other hand, emit quite modest amounts of carbon. All the fossil fuels do not however contribute to carbon emission in equal measure: natural gas is a much better option with carbon emission level about half of other fossil fuels such as oil and coal. Nuclear energy is uniquely placed in that it mimics the renewable energy sources thanks to a very modest (though no amount may be considered modest in the final analysis!) carbon emission. Nuclear energy minus the safety and security issue can become an important constituent in our energy mix in the coming years.

4.1.7. *Expected Project Completion Time*

Pakistan lost from 3 to 4 percent of GDP in 2011 because of the electricity and gas shortages [NEPRA (2012)], which is roughly equal to $13.5 billion.[11] If this loss continues for a number of years, the modest achievements in other sectors of economy will be neutralised by the massive loss of GDP caused by energy crisis. Assuming that we have to fulfill our energy needs from indigenous resource, it is critical to assess the expected time required to put in place new projects.

Geothermal and nuclear energy sources are the most time consuming with each requiring 6 years to complete.[12] Large hydropower and offshore wind energy systems are also long-term enterprises requiring 5 years or more. Photovoltaic solar system, onshore wind and fuel cell could be most readily put in place within a year only. The small hydropower projects and concentrating solar power are medium term projects requiring about two years and should be particularly useful as a stop-gap arrangement. See Table 2 above.

4.2. Aggregated Assessment of Energy Sources

Comparison of different energy sources in terms of a single indicator is relatively a straightforward affair. But such a comparison is not quite helpful when one has to

[11]http://www.globaltimes.cn/NEWS/tabid/99/ID/838289/Energy-ensures-stability-for-Pakistan.aspx

[12]Since the data is not based on project completion in Pakistan, is based on diverse resources, there may be wide differences in the actual completion time in Pakistan partly because of less developed infrastructure and complex issues related to inter-provincial differences over water distribution. Caution is therefore required in interpreting these numbers.

consider multiple indicators to reach a conclusion. Such a 'multidimensional' comparison is inherently problematic. The moment we make comparison among different energy sources across multiple dimensions, the picture becomes complicated and a whole range of assumptions and value judgments become inevitable.

Here we assume that all the dimensions analysed in the study are equally important. We rank each measure according to its desirability in ascending order (least cost getting the highest rank, highest capacity factor getting the highest rank) and sum them to see how they compare. Even if considering all the variables may not be a plausible assumption because different things may mean different things to different stakeholders, an aggregate number has the virtue of easy interpretation. A substantial amount of literature on multivariate comparison is based on the assumption of equal weight for different dimensions of a desirable goal.[13]

Table 3

Multivariate Comparison of Various Energy Sources

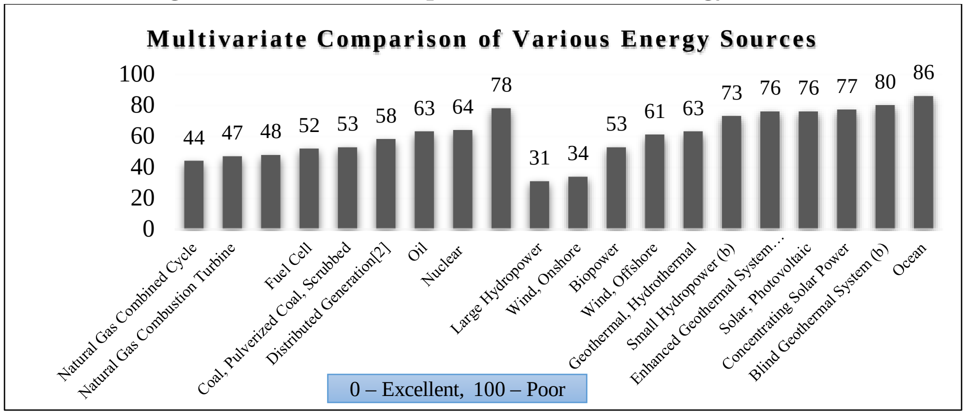
	LCOE $/kWh (a)	Overnight Capital Cost ($1000/kW USD)	Fixed Operating Cost $/kW	Capacity Factor (%)	CO_2 Emissions (g/kWhel) (c)	Expected Completion Time (Years)
Biopower	8	9	14	10	7	5
Blind Geothermal System (b)	13	19	20	1	9	18
Coal, Integrated Gasification Combined Cycle	11	13	12	11	19	12
Coal, Pulverized Coal, Scrubbed	3	8	10	6	18	8
Coal, Pulverized Coal, Unscrubbed	2	4	9	6	19	8
Concentrating Solar Power	18	17	13	18	5	6
Enhanced Geothermal System (EGS)	14	20	19	6	9	8
Fuel Cell	17	15	1	1	16	2
Geothermal, Hydrothermal	3	10	18	5	9	18
Large Hydropower	1	5	4	3	3	15
Natural Gas Combined Cycle	3	3	5	6	14	13
Natural Gas Combustion Turbine	9	2	2	12	14	8
Nuclear	3	12	15	4	12	18
Oil	9	1	8	13	17	15
Small Hydropower (b)	16	14	17	15	5	6
Solar, Photovoltaic	20	16	11	20	8	1
Wind, Offshore	11	11	6	16	2	15
Wind, Onshore	3	6	3	17	3	2
Distributed Generation [2]	15	7	7	14	13	2
Ocean	19	18	16	19	1	13

As shown in the Table 3, there is no energy source which is superior to another energy source in all dimensions. Pulverized coal is an excellent energy source in terms of cost-effectiveness and efficiency but it hurts the environment most grievously. Fuel cell is a perfect choice in terms of fixed operational cost and efficiency but it is one of the most expensive options. Photovoltaic solar panels can be installed in the shortest possible time but they are among the least efficient.

[13]See World Bank's Human Development Index, Human Poverty Index and Alkire and Foster's Multidimensional Poverty Index for example.

In the Figure 4, we present the sum of the ranks across all variables and sort them after dividing them into two distinct categories: renewable and non-renewable.

Fig. 4. Multivariate Comparison of Various Energy Sources



As it is shown previously, hydropower and the wind energy are the most promising technologies followed only by the natural gas and nuclear energy sources. Contrary to the common perception that small hydro dams hold the key to energy blues, they are much less efficient than large hydropower energy generation systems. Large hydropower systems are almost twice as efficient as the small hydropower systems. Even if some of the coal based technologies are not much different from natural gas, some coal based energy production technologies are the worst possible choice. Growing concern about the environment would not allow much leeway to resort to coal in a big way. Following the discovery of new gas fields, a shift away from coal to natural gas must make a perfect sense.

Comparing the non-renewable and renewable energy sources as distinct categories, hydropower and wind energy are distinctly better options. Non-renewable resources like nuclear and coal energy systems are only slightly better than wind and biopower. Oil, some varieties of coal and geothermal energy sources are the least efficient choices. Ocean energy may deservedly be called the no-go area for cash-starved Pakistan at least for the foreseeable future. Interestingly, the solar power, which is tipped as the most promising candidate for the future years is found to be much inferior option to both non-renewable resources like fossil fuels and renewable sources like hydropower.

5. DISCUSSION AND CONCLUDING REMARKS

This study finds that hydropower is the most feasible energy source in terms of environmental safety, cost effectiveness, efficiency and sustainability. However this important energy source cannot be fully utilised without a strong political will to develop a consensus on the distribution of water, location and size of new reservoirs, and sorting out the avoidable adverse environmental effects. The controversy over Kalabagh Dam goes beyond the technical issues and has become an emotive political issue. Rapid melting of the glaciers in Himalaya may also reduce water supply by 40 percent in the next 40 years [Husain (2010)].

Among other renewable energy sources, wind energy and biopower are second only to hydropower while ocean, solar and geothermal energy are the least efficient. It is predicted that R&D will bring down the prices of photovoltaic solar energy to the level of fossil/nuclear levels [Husain (2010)]. Among the non-renewable energy sources, natural gas is the most feasible option followed by coal and fuel cell. Nuclear energy and oil are almost similar while some coal based energy systems (combined cycle integrated gasification) are the worst possible options.

Some of the underlying assumptions in the recent literature on the role of renewable energy sources in Pakistan include: (i) wind and solar energy is the future of Pakistan's energy mix, (ii) it is a matter of time before the non-renewable resources will become irrelevant, (iii) a shift to renewable energy is a simple process. However, this study finds that non-renewable energy sources, especially the fossil fuels will continue to stay with us in the foreseeable future and will continue to make a sizable chunk of our energy mix because of their cost effectiveness and efficiency. The reasons why a rapid shift to the renewable energy sources seems improbable include the relative inefficiency and high cost of wind and solar energy. Discovery of massive shale gas reserves must also provide a breathing space for some time to come at least because natural gas is efficient, cost-effective and relatively cleaner energy source.

A major limitation of this study is the assumption that cost, efficiency and environmental safety are equally important concerns. The choice among environmentally clean but inefficient energy source like solar and wind energy and environmentally adverse but extremely efficient energy source like fossil fuels will not be at best an easy choice in any case and will largely depend on the exigencies of economic health of Pakistan.

Some of the other limitations of this study are that we have not factored in the projected decrease in the long run cost of energy types. Similarly, generalising the costs estimates based on studies unrelated to Pakistan may be problematic but we have chosen median values to hedge against wide discrepancies in our results. The variable on the expected project completion time draws heavily on the publicly available data, which is unrelated to Pakistan. As infrastructure in Pakistan is not fully developed, the time required for the setting up of new energy projects might well be higher than expected.

Failure to put in place a reliable energy system would spell disaster for our economy in the form of reduced agricultural yields, lower growth rates and further increase in poverty and deprivation. If we fail to choose a suitable energy mix, the coming generations will have to bear the brunt of the hazards of many types. Pakistan being vulnerable to several challenges can hardly trifle with misguided energy policies.

Finally, hydropower, wind and biopower (in the same order) are the most promising alternative reliable energy sources. But a rapid shift away from the non-renewable fossil fuels is not possible for various economic, political and strategic reasons. An ideal energy mix could be dominated by the renewable energy sources, while the non-renewable energy sources especially natural gas may substantially supplement the renewable energy sources.

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