

Minimizing Environmental and Health Impacts in Developing Countries through Adoption of Sustainable Energy Options: A Case Study

Muhammad Zulfiqar Ali Khan

Civil Engineering Department, The University of Lahore, Lahore 53700, Pakistan

Abstract: An extensive review and analysis of the available global energy sources data and information from 38 countries including Pakistan, and their impacts (socio-economic, environmental, and health) shows that one of the most sustainable and environment friendly energy options (especially considering rural areas) is renewable energy (solar and wind), while other options (in descending order) are hydro, nuclear and coal. The use of “oil and gas” as energy option is not cost effective due to its serious environmental, health and financial implications. The cost of producing 1 KWh of energy from oil and gas in Pakistan is around Rs. 20 (U.S. \$ 0.19), while the same costs for hydro power and coal are 1/10th and 1/2nd respectively. Appropriate and suitable energy options are proposed in view of the current energy situation, available natural resources (water, coal, wind and sun), serious energy conservation efforts and efficient usage of available energy.

Key words: Sustainable energy options, health and environmental impacts, developing countries.

1. Introduction

Many of the developing countries, especially in South East Asia Region, are facing energy shortages due to extreme weather conditions as well as limited available financial and natural resources. The gap between energy supply and demand has been increasing in the last few years, thus resulting in serious daily power outages extending over several hours, especially in the rural areas. Very often imported costly oil and gas are used for power generation. Pakistan is one those countries facing such situation.

Pakistan, with a population of around 200 million, is the sixth most populous country in the world [1-3]. It is blessed with most of the natural (rivers, sunshine, forests, coal reserves, marine and coastline, strong winds etc) and human resources. It has made substantial progress in many sectors (telecommunications, IT,

infrastructure facilities, banking, education, etc.). However, in case of the energy sector, which is considered to be the life line and backbone of all other sectors, the progress has been the slowest and the weakest in the last two decades.

The available energy supplies have not been able to keep up with the demand due to several factors [4-7] such as excessive (e.g. 20%-30%) transmission and distribution line losses due to poorly maintained and old networks for the supply of electricity.

The gap (around 3,000-5,000 MW) between supply and demand was about 15% few years back and is now reaching to almost 50% in the current situation [7-10]. This has resulted in extended power outages (load shedding) and massive black outs as well as in serious and crippling effects on country's economy, industry and the livelihood of citizens. The power outages had more serious impacts on the rural population (which is 66% of the total population of Pakistan) as compared to the urban dwellers.

The World Bank and International Energy Agency Data [11-12] indicate that only 62.4% of the

Corresponding author: Muhammad Zulfiqar Ali Khan, Ph.D., main research fields: environmental pollution and health; water and environment.

population of Pakistan has access to electricity which is much lower than many other countries in the Region (e.g. Malaysia, India and Middle Eastern Countries). The per capita electricity available for consumption is around 432 KWh, which is much below the global average threshold level of 2,000 KWh. About 80% of the population has no access to pipeline gas and the country ranks 165 out of 218 countries in per capita access to electricity. The cost of producing 1 KWh of energy from oil and gas in Pakistan is around Rs. 20 (U.S. \$ 0.19), while the same costs for hydropower and coal are less than 1/10th and 1/2nd respectively.

Studies [12] indicate that several countries (e.g. USA, China and India) use coal as one of the major sources of energy. Even though Pakistan has one of the largest low sulfur content coal reserves (around 170 billion tons) in the world, it has until today made very little or no use of this natural resource. Similarly it also lags behind in the use of other available natural energy sources such as renewable (wind, solar, biomass fuel and geo thermal, etc.).

Energy efficiency can increase national productivity, create new economic growth and reduce energy costs for all. Under the “Global Efficient Lighting Partnership Program” [13-14] a recent joint study carried out by the United Nations Environment Program (UNEP) in conjunction with International Energy Agency (IEA) and other partners showed that Pakistan could save 35.3% energy in electricity for lighting and about 5.5% overall savings in national energy consumption. In addition, it would annually reduce 2.0 million tons of carbon dioxide emissions (equivalent to 0.5 million cars off the road) and avoiding 3.7 kg of mercury emissions.

The National Energy Security Action Plan (2005-2030) of Pakistan envisages, in the coming years, larger roles for hydropower, renewable energy technologies (in particular, windmills) and nuclear power and imported natural gas in future energy supplies. The Alternative Energy Development Board

(AEDB) created in 2003, has been mandated to achieve 5% share of power generation through renewable energies by year 2030 in collaboration with other agencies [8, 14-16].

The primary focus of this paper is to identify and recommend environmentally healthy and sustainable energy options suitable for Pakistan (especially the rural population) based on the global and national review of: (1) Energy sources (percentage contribution of each) and related factors; (2) socio-economic, environmental and health impacts of various energy sources and; (3) Current energy situation in Pakistan and the available, suitable and appropriate energy options.

2. Data Collection and Analysis Methodology

2.1 Global Quantitative Data related to Demographic, Income Level, Emissions, Sources of Energy and Environmental Sustainability

In order to get a reasonable idea about as to what sources of energy (incl. percentage contribution towards total energy use) are being utilized by various countries, globally, 38 countries (incl. Pakistan) were randomly selected representing 6 Regions (Americas, Africa, Eastern Mediterranean, European, South East Asia and Western Pacific) of World Health Organization (WHO). For each of the countries data for 5 major energy sources (coal, oil and gas, hydropower, nuclear, and renewable in percentage), 2 factors related to environmental sustainability (Environmental Performance Index Score, EPI and EPI ranking) and 1 factor each for GDP (\$/Person), Population (millions) and Total Carbon Dioxide Emissions (million tons/year), were gathered from the various technical documents [11, 15-17]. The collected data was then tabulated in Table 1.

Using the statistical analysis, the various factors (variables) in Table 1 were correlated with each other. Some of the factors showed direct (+ve) and strong correlation, while others also had strong, but indirect (-ve) correlation. Few had very weak correlation with

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Table 1 Global data for demographic, income level, CO₂ emissions, energy sources (%) and environmental sustainability.

Country	Population (Millions)	GDP(\$)/Capita	Total CO ₂ Emissions (Mt)	Coal	Oil and Gas	Hydropower	Nuclear	Renewable	EPI Score (max 100)	EPI Rank (1 to 163)
Australia	22.3	50,680	420	77.9	14.8	4.7	0	2.6	65.7	51
Bangladesh	148.7	675	53	1.7	94.2	4.2	0	0	44	139
Brazil	194.9	10,710	410	2.1	6	83.9	2.8	5.2	63.4	62
Bahrain	1.3	19,333	25	0	100	0	0	0	42	145
Canada	34.1	46,236	534	15.2	7.6	60.3	15	1.9	66.4	46
China	1,300	4,428	3,196	78.8	1.8	16.7	1.9	0.8	49	121
Denmark(EU)	502.1	32,347	3,868	26.8	26.1	10.4	28.4	8.3	69.2	32
Djibouti	0.8887	1,259	0.545	0	100	0	0	0	60.5	75
Egypt	81.1	2,698	236	0	89.9	9.3	0	0.8	62	68
India	1,200	1,475	1,921	68.6	15.3	11.9	2.1	2.2	48.3	123
Indonesia	239.9	2,846	427	41.8	44.9	7.3	0	6	44.6	134
Iran (I.R.o.f)	74	5,267	583	0.1	96.1	3.6	0	0.2	60	78
Iraq	32	2,565	105	0	93	7	0	0	41	150
Japan	127.5	42,831	1202	27.4	35.3	7.4	27.4	2.5	72.5	20
Jordan	6	4,560	23	0	99.5	0.4	0.1	0	56.1	97
Kuwait	2.7	54,512	78	0	100	0	0	0	51.1	113
Libya	6.4	14,314	61	0	100	0	0	0	50.1	117
Kazakhstan	16.3	9,136	273	74.9	16.4	8.7	0	0	57.3	92
Kyrgyzstan	5.4	860	6.72	2.8	8	89.3	0	0	59.7	79
Lebanon	4.2	9,227	16	0	95.5	4.5	0	0	57.9	90
Malaysia	28.4	8,373	224	30.9	62.7	6.3	0	0	65	54
Morocco	32	2,842	52	52.4	33.6	12.1	0	1.8	65.6	52
Nepal	30	525	3.95	0	0.4	99.6	0	0	68.2	38
North Korea	24.3	1,150	73	38.1	2.8	59.1	0	0	41.8	147
Oman	2.8	21,848	52	0	100	0	0	0	45.9	131
Pakistan	200	1,019	183	0	67.4	29.4	3	0	48	125
Qatar	1.8	71,912	83	0	100	0	0	0	48.9	122
Singapore	5.1	41,122	29	0	99.9	0	0	0.1	69.6	28
Syria	20.4	2,893	74	0	95.7	4.3	0	0	64.6	56
Sri Lanka	20.9	2,375	12	0	60.3	39.5	0	0.2	63.7	58
Tajikistan	6.9	820	3.78	0	2	98	0	0	51.3	111
Tunisia	10.5	4,199	26	0	98.9	0.6	0	0.5	60.6	74
Turkey	72.8	10,094	324	28.6	51.8	18.5	0	1.1	60.4	77
Turkmenistan	5	3,967	52	0	100	0	0	0	38.4	157
UAE	7.5	39,625	172	0	100	0	0	0	40	152
USA	309.1	47,199	5,456	45.6	24.1	6.6	20	3.7	63.5	61
Uzbekistan	28.2	1,384	124	4.19	77.2	18.7	0	0	42.3	144
Yemen	24.1	1,300	25	0	100	0	0	0	48.3	124

each other. The positive correlation coefficient (r^2) varied from 0.2063 to 0.6939, while the negative correlation coefficient (r^2) varied from 0.2185 to 0.6890. Review of all the variables indicates that 3 variables, namely EPI ranking, total carbon dioxide emissions,

and EPI scores are dependent variables, while other 8 are independent variables. Therefore EPI ranking and score of a specific country can be improved by changing its sources (percentage towards total energy use) of energy. For example increasing renewable energy

source share in the total energy use and reducing the source contributing towards total carbon dioxide emissions will result in higher ranking and score.

2.2 Global Qualitative and Quantitative Data related to Socio-Economic, Environmental and Health Impacts of Energy Sources

Considering the 5 major sources of energy namely coal, oil and gas, hydro power, nuclear and renewable (e.g. wind, solar, biomass and geo thermal), an extensive literature search was made at global, regional and national levels to compile the available qualitative and quantitative data related to the impacts of each of the energy sources on social, economic, environmental, and health aspects of the population. The collected

qualitative and quantitative data [18-23] were, then, compiled in Tables 2 and 3. For assessing qualitative impacts, the data was divided into two categories, namely negative (-) and positive (+) impacts. Thus considering the information in Tables 2 and 3, an energy source with the least negative but maximum positive impacts was considered most sustainable, environment friendly and healthy.

2.3 National Data of Pakistan Related to its Energy Sources Capacities, Demands, Gaps and Challenges

The most recent estimates were made by WAPDA and other national agencies [7, 8] regarding the potential reserves of fossil fuels (e.g. oil, natural gas and coal). While the coal reserves may last for many

Table 2 Quantitative socio-economic, environmental and health impacts of various energy sources.

Energy source	Impacts	
	Positive	Negative
Coal	1-Employment and job opportunities	1-GHG emissions, air, water and land pollution 2-Serious health effects 3-Global warming/climate changes
Oil and gas	1-Employment and job opportunities	1-Environmental pollution 2-Global warming/climate changes 3-Human exposure and Health effects due to emissions. Dependency due to imports of costly source. 4-Adverse health effects due to emissions.
Nuclear	1-Employment and job opportunities	1-Long-Term radiation hazards on environment and humans 2- Nuclear waste highly radio-active, and hazardous needing costly disposal options 3-Potential damage and destruction of eco-system
Hydro power	1-Employment and job opportunities 2-Potential increase in recreation facilities 3- Potential increase in land-value around the facility	1-Disruption of traditional social life value and cultural heritage 2-Change in surrounding ecosystems 3-Effect on fish, wild life and hydrologic pattern 4-Dependent on rainfall and V/s activities
Renewable sources • Solar • Wind • Others - Bio-mass - Geothermal	1-Employment and job opportunities 2-Absolutely reliable cheap and clean energy 3-No hazardous by products 4-Very little/no CO2 emissions 5-Intergrated socio-economic benefit 6-Reduced GHG emissions	1-Limited visual impact on building aesthetics due to solar panels.
	1-Elimination/reduction of transmission lines 2-Accelration for rural electrifications 3-Non-exhaustable source of energy	1-Limited injury on killing of flying birds and bats in wind farms. 2-Some source noise due to wind farms in the surroundings
	1-Very reliable and offers independence in power ownership 2-Ideal for poor and isolated communities e.g.rural 3-Low maintenance and operational costs. 4-Reclamation of marginal and degraded land Geo-Thermal	

Table 3 Quantitative environmental and health Impacts of main energy sources.

Energy source	Quantitative impacts			
	Environmental (Green House Gas emission) (g/kwh)			Health
	CO ₂	SO ₂	No _x	Total human deaths per year
Coal	955	11.8	4.3	218,730
Oil	818	14.2	4.0	706,892
Natural gas	430	--	0.5	35,987
Nuclear	--	--	--	369
Hydro-electric	--	--	--	818
Small	9	.03	.07	--
Large	3.6-11.6	.009-.0201	.003-.006	--
Renewable				
Wind	--	--	--	305
Solar	--	--	--	812
PV	98-167	0.2-0.34	0.18-0.30	--
Thermal	26-38	0.13-0.27	.06-0.13	--

decades, the oil and gas reserves are estimated to be depleted in the next 10-15 years. If renewable energy sources are not utilized, then Pakistan will be forced to purchase foreign oil and gas at high prices, pushing the cost of per unit of electricity to unaffordable levels for citizens.

The total installed capacity of electricity, as of 2007, is 19,505 MW, which is primarily coming from fossil fuels i.e. oil and gas (67.4%), hydropower (29.4%) and nuclear (3%) and other sources including renewable (0.2%). However the active generation capacities (MW) of all energy sources during the summer and winter months respectively are 17,878 and 13,832, while the demand peak loads may reach 19,257 during extremely hot and drought conditions. Thus the gap between supply and demand may exceed 5,000 MW during peak demands thus creating serious daily energy crisis situation and extended power outages, sometimes lasting for 14-16 hrs daily, especially in the rural areas.

2.4 Data about Renewable Energy Sources

The available information and data such as wind and sol radiation maps was primarily gathered from AEDB, USAID and the Pakistan Meteorological Department (PMD). At present, total Renewable Energy produced in the country stands at 40MW which accounts for

about 0.2% of total installed generation capacity from all the energy sources. The renewable energy potentials (MW) from wind, solar, mini and small dams, bio-gas and others are estimated to be 0.346 million, 2.9 million, 2,000 million, 1,800 million, and 500 million respectively.

Review of wind maps indicates that the coastal belt of about 1,000-1,200 km, with a depth of about of 100-150 km into the land is quitesuitable for wind energy, both for on-grid as well as for off grid systems.

3. Data Analysis and Discussion

3.1 Global Analysis

Review of global data (Table 1) indicates that the energy mix of countries with larger populations (e.g. China, India, Indonesia and USA) includes more than 40% coal and are also major contributors to the total amount of carbon dioxide emissions, which eventually contributes to the climate change and global warming and their Environmental Performance Index (EPI) scores (except USA) are quite low. However countries (e.g. Brazil) with greater percentage of hydel power, low percentage of oil and gas, and higher percentage of renewable energy in their energy mixes have higher EPI scores and have more sustainable environments. This is further confirmed by the higher correlation coefficients of 0.4-0.6.

3.2 Energy Mix and Impacts

Countries (low or non- oil producing) with higher GDP (e.g. Japan, European Countries and USA) have larger percentage of share in the energy mix due to the nuclear power, while in case of oil producing countries (e.g. Gulf countries), mix is contributed mainly by oil and gas sources. In case of Pakistan, the major share in the energy mix is primarily due to the imported and costly oil and gas, followed by hydel and nuclear sources but with very little or no contribution of renewable energy and coal sources. While most of the energy development projects have positive impacts on the socio-economic (Table 2 and 3) conditions of the population, some of them may have serious short and long term impacts both on the environment (incl. eco-systems) as well as on the human health. Review of available global, regional and national data indicates that the renewable energy sources have minimum adverse environmental impacts, almost no GHG emissions, and have least number of human fatalities, followed by hydro power, nuclear and coal sources. The highest GHG emissions, adverse environmental impacts and human fatalities are from oil and gas energy sources.

3.3 Environment Friendly Energy Options

Under the current energy situation in Pakistan, the rural population is more effected and vulnerable to power shortages than the urban population. The percentage of rural population in the various provinces varies from 50% to 97% (except the Islamabad territory) which can be easily served by the natural renewable energy sources (e.g. wind and solar) thus releasing

other sources of energy (e.g. hydro, coal and nuclear) for the urban dwellers and high energy consuming sectors, such as industrial, commercial and institutional .

In view of the global average energy mix (Table 1), considering the energy mix of some of most developed as well as neighboring countries, it seems very clear that for Pakistan in order to have sustainable and environment friendly energy options, it needs to focus more on the available resources within Pakistan and slowly reduce its reliance on the imported oil and gas. The share of renewable energy sources (especially solar and wind), hydro and coal must be substantially increased in the energy mix in the “National Energy Plan” in coming 20 years. A proposed energy mix for Pakistan is presented in Table 4.

4. Sustainable Energy Options and Measures for Pakistan

In view of the extensive literature search (global, regional and national levels) for the available data and information related to the energy sources and their socio-economic, environmental and health effects, the following options and measures (short and long term) are proposed for Pakistan.

4.1 Short Term Options and Measures (1-10 years)

4.1.1 Energy Efficiency and Conservation

According to the “Pakistan Vision 2025”, the Government of Pakistan is making a concerted effort to solve the energy crisis through increased spending and building new infrastructure and energy projects in the coming years. However it also needs to focus on improving the existing energy systems through the following steps:

Table 4 Proposed share (%age) of energy sources in the energy mix for Pakistan.

Year	Source of energy (%age)				
	Nuclear	Hydel	Coal	Renewable	Oil and Gas
2010 (Global)	6.9	2.3	22.6	18.7	57.1
2010 (Pakistan)	3.0	29.4	0.2	---	67.4
2018	3	30	3	3	61
2022	4	32	6	10	48
2026	4	35	12	15	34
2030	5	40	20	20	15

(a) Requiring all building codes (residential, commercial, industrial, institutional) to have energy saving lighting systems, which could result in about 35% energy savings in lighting sector as well as about 5% energy savings in the national energy demand;

(b) Reduction of the current average electricity transmission and distribution lines losses from 25% to about 10% (the global average being 7%) through improved maintenance and operational facilities and practices as well as strengthening/upgrading existing infrastructure (transmission and distribution network);

(c) Reduction of “un accounted for losses (10%-30%)” in electricity due to illegal electrical connections and thefts to less than 5% by developing and implementing comprehensive surveillance and monitoring systems through well trained and well paid technical and administrative staff.

In order to ensure the sustainability of the existing electricity generation, transmission and distribution systems, it is very critical and important that immediate and urgent improvements be made in the power sector through improved policies and procedures for better revenue collection and cost recovery of current revenue loss of 25%-30%.

4.1.2 Use of Solar Energy

Pakistan, with its average of 8-9 hours/day of sunshine and annual insolation values of more than 1,700 kilowatt hours per square meter, is ideally suited for solar energy. The use of solar energy, so far, has been very limited. It needs to make full use of the available solar energy, (estimated potential of 2.9 million MW) through installation and operation of the “Solar Panel Packages”, where appropriate and feasible in all the non-residential sectors e.g. commercial, industrial and institutional, for meeting requirements related to the basic lighting and light load machines. It is equally suitable for most of the rural population (especially the unserved, underserved and the poorest of the poor) in all the provinces to have, own, and maintain their individual home solar energy producing units (e.g. 2-4 lights and

1-2 fans) mounted on roof tops subsidized by the Federal and or Provincial Government of Pakistan.

Substantial energy savings could be made by requiring that the solar residential lighting and lighting systems in urban areas should cater for at least 25% of the total lighting and emergency electricity requirements. In addition, all large size housing societies and authorities (e.g. Defense Housing Authority) in urban areas should be required to meet at least 25% of their electricity requirements through its society managed and operated solar units. Also regulations should require that all street lighting and publicity posters lighting in urban and rural areas to be powered 100% by solar units.

4.1.3 Capacity Building and Strengthening of AEDB and Private Sector in Renewable Energy Technologies (RET)

The Alternative Energy Development Board (AEDB) was established in 2003 in Pakistan to facilitate, promote and encourage development of Renewable Energy in Pakistan and with a mission to introduce Alternative and Renewable Energies (AREs) at an accelerated rate. The AEDB has been fully functional, however the rate of implementation of planned projects has been slow due to its limited financial and human resources. Therefore there is an urgent need to further build/strengthen the human, financial and technical capacity of AEDB for developing, promoting and facilitating of RET, as well as for the formulation of plans, policies and developing technological base for manufacturing and promoting renewable energy (RE) equipment to the private sector.

4.2 Long Term Options and Measures (10-30 years)

For sustainable and appropriate energy solutions, Pakistan needs to reduce its current share of oil and gas (i.e. 67%) in the energy mix to about 15% by increasing the percentage shares of the other renewable energy sources: hydro power, nuclear and coal (Table 4). It should also make use of all available wind energy (estimated potential of 0.346 million

MW) through installation and operation of the “wind farms” in all the districts, falling in the coastal areas and some in the Northern (mountainous) areas of Pakistan. The energy needs can be supplemented by the hydro power energy (available and planned) from major dams (e.g. Tarbela, Mangla and others) with the construction and operation of micro and mini dams (e.g. 200 MW). Making use of the available coal reserves (around 170 billion tons) can provide long term energy solution by increasing its share in the energy mix to 20% through acquiring and adopting clean coal technologies (e.g. coal bed methane capture, CBMC; integrated coal gasification combined cycle power generation, IGCC and CO₂ capture and storage, CCS). The increase in the use of hybrid systems and CNG can provide relatively clean and environment friendly fuels for the urban (public and private) transport systems.

There is an urgent need to revise the “Pakistan Energy Security Action Plan 2030” developed and approved in 2005 to reflect the current realities, constraints and increasing in the energy mix, the share of abundantly available hydro, natural renewable sources (e.g. solar and wind) and extensively available coal reserves.

5. Summary and Conclusions: Some Recommended Sustainable Energy Options

After having reviewed and analyzed all the available sources of energy (in global, regional and national perspective) and their impacts, it is very clear that the most sustainable and environmentally healthy energy source is the renewable energy (RE) i.e. solar and wind, which is available in abundance throughout the year in Pakistan. The other sustainable options, followed by RE (in the descending order) are hydro power, nuclear and coal.

The last and the least cost effective energy source option to be considered for Pakistan is the oil and gas, which is resulting in the highest carbon dioxide emissions (GHG emissions) as well as in the number

of human fatalities. This source is very costly, mostly is imported and is very much affected by global market price fluctuations.

The most appropriate energy option for all the rural areas of Pakistan is solar, followed by wind for the coastal rural areas and to some extent bio-mass for the farming communities.

The currently available energy can be extended and enhanced as much as 40%-60% by reducing line losses (transmission, distribution), illegal and unaccounted for electricity thefts, using high efficiency and energy efficient power generation systems, and upgrading/replacing old electrical networks and systems. Also additional 5%-15% energy can be saved/conserved in the national grid by using “energy saving lights/bulbs and home appliances”. Huge coal reserves in Pakistan need to be developed, which can significantly contribute to the energy sector and also offer a long term and sustainable solution to its energy needs and problems. Conservative estimates indicate an energy potential of more than 100,000 MW of power generation. Primarily the base load capacity for industrial sector (high power consumption) needs to be based on hydro, coal and nuclear.

The “Pakistan Energy Security Action Plan 2030” needs to be updated to reflect major share of RE, hydro power, and coal in the energy mix, while progressively decreasing the share of oil and gas to about 15% in the energy mix by the year 2030 or sooner. This will not only result in national cost savings, but also ensure sustainability and continuity of energy supply to all sectors, ensuring improved quality of life and higher global EPI Ranking and Score for Pakistan.

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