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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

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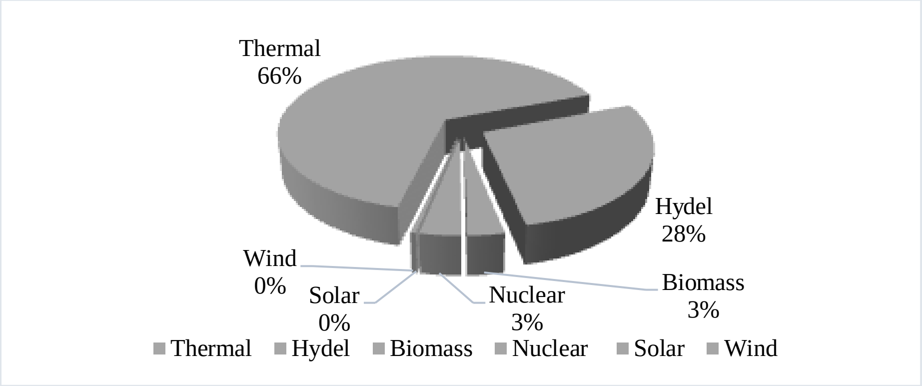
energy profile currently add up to only 1 percent of total energy stock. Other important renewable energy sources such as geothermal and ocean are totally absent. A viable energy mix in the future will not only require a radical increase in its absolute size but also substantial changes in the relative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

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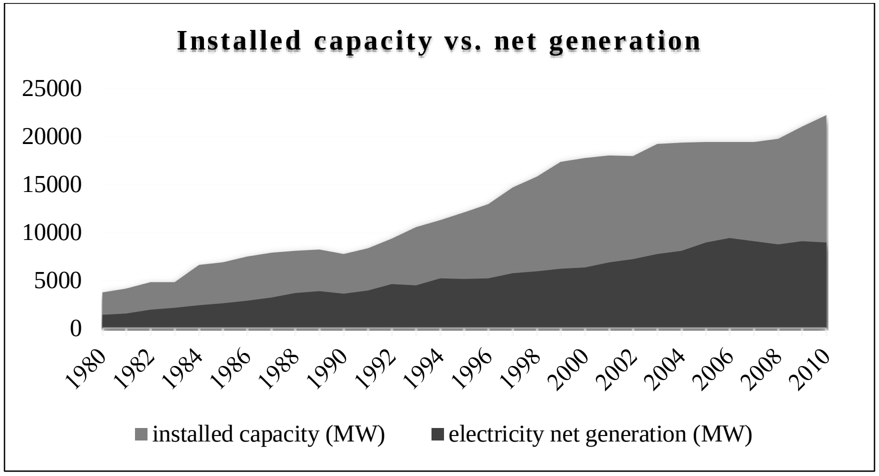
[1] http://www.dawn.com/news/1053742/power-theft-costs-rs100bn.

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.

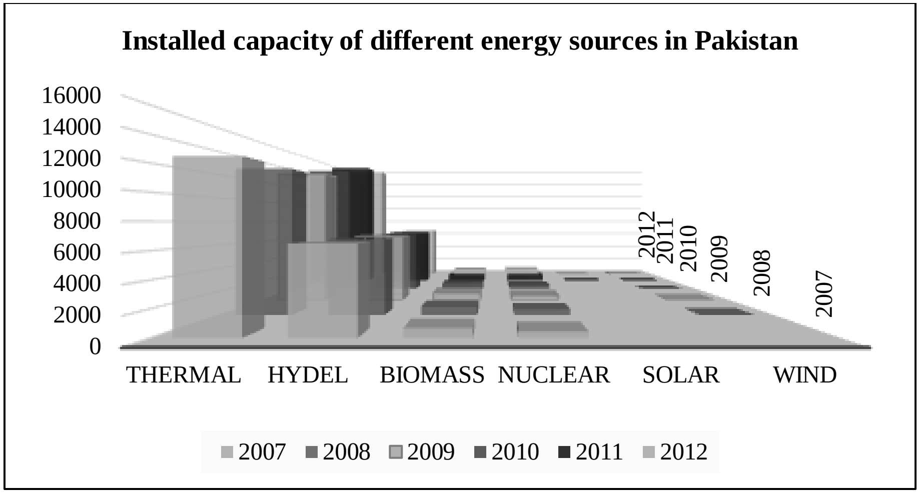
Fig.2. Installed Capacity and Net Generation.



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

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[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]

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[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).

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[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

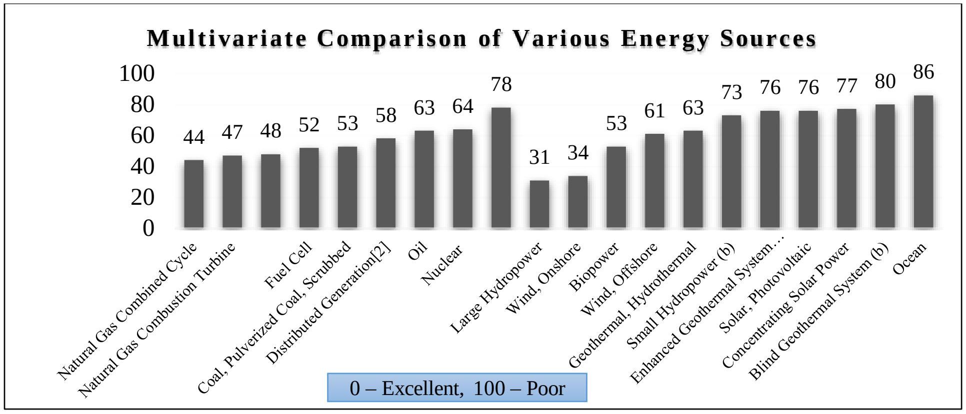
	LCOE $/kWh (a)	Overnight Capital Cost ($1000/kW USD)	Fixed Operating Cost $/kW	Capacity Factor (%)	CO_2 Emissions (g/kWhel) (c)	Expected Completion Time (Years)
Biopower	8	9	14	10	7	5
Blind Geothermal System (b)	13	19	20	1	9	18
Coal, Integrated Gasification Combined Cycle	11	13	12	11	19	12
Coal, Pulverized 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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Impact of Fossil Fuel Energy Consumption on CO_2 Emissions: Evidence from Pakistan (1980-2010)

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1. INTRODUCTION

Global environmental problems are getting more attention especially the increase in earth temperatures and change in climate. Increase in world average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level are some evidences of global warming. A CO_2 emission, which is a global pollutant is the main greenhouse gas that causes 58.8 percent of global warming and climate change [The World Bank (2007a)]. The intergovernmental panel on climate change (IPCC) reported a 1.1 to 6.4 °C rise in the world temperatures and an increase in the sea level of about 16.5 to 53.8 cm at the end of 21st century [IPCC (2007)].

Combined global land and ocean surface temperature for January 2010 on the average was 0.60°C (1.08°F) above the 20th century average of 12.0°C (53.6°F) and the average global temperature for January 2010 at the surface air was recorded 0.83°C (1.49°F) above the 20th century average of 2.8°C (37.0°F). Global warming is partly resulting from higher night temperature and partly due to rapid urbanisation. Other factors adding to global warming are the continuously changing irrigation systems, desertification and variations in the use of local lands. The developing countries need more energy consumption for economic growth that's why these economies face more environmental issues.

Rapid increase of CO_2 emissions is mainly the result of human activities (development and industrialisation) over the last decades. Earlier studies focus on estimating the growth and CO_2 emissions nexus through testing the environmental Kuznets curve (EKC) hypothesis, which proposes a U-type relationship between environmental quality and income growth to determine whether continued increase in economic growth will eventually undo the environmental impact of the early stages of economic development or not.

Financial development can promote economic growth and reduce environmental pollution. As Frankel and Romer (1999) point out, developed financial market can help to increase inflow of foreign direct investment and stimulate the rate of economic growth. Recent studies show that financial development has direct impact on energy consumption

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[e.g., Sadorsky (2010)] and thus on CO_2 emissions [Tamazian, *et al.* (2009)]. A developed financial sector lowers borrowing cost, promotes investment in energy efficient sector, and reduces energy emissions [Tamazian, *et al.* (2009); Tamazian and Rao (2010); Sadorsky (2010); Shahbaz (2009a); Shahbaz, *et al.* (2010b)]. Jensen (1996) on the other hand found that financial development increases CO_2 emissions through industrial growth enhancing-effect. Specifically, the national, regional and local governments can take advantage of lower borrowing costs to fund environment friendly projects.

Fossil Fuels are fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. Fossil fuels are hydrocarbons and include coal, oil (petroleum), and natural gas. The age of the organisms and their resulting fossil fuels is typically millions of years, and sometimes exceeds 650 million years. Fossil fuels are non-renewable resources because they take millions of years to form, and reserves are being depleted much faster than new ones are being discovered. The impact of economic growth on environment depends on the type of energy emissions, such as sulfur dioxide, carbon monoxide and nitrogen oxide have detrimental effects on health and environment. This relationship between air pollution and economic development also appears in an inverted-U shaped or monotonically decreasing form [Shafik and Bandypadhyay (1992); Hettige, *et al.* (1992); Diwan and Shafik (1992)].

2. ENVIRONMENTAL KUZNETS CURVE

The Environmental Kuznets Curve (1955) hypothesised environmental degradation and pollution increase in the early stage of economic development and after reaching a certain level of economic growth, environmental degradation will decrease. This implies that high income levels lead to improved environmental conditions. Therefore some economists believe that economic growth is a natural remedy for the environmental pollution and depletion of natural resources [Beckerman (1992)].

The Environmental Kuznets Curve (EKC) hypothesis claims that an inverted U-shaped relation exists between income and environmental pollution. Earlier empirical studies demonstrate the EKC between income and environmental pollutants such as sulfur dioxide (SO_2), nitrogen oxide (NOx), and suspended particulate matter (SPM).[1]

The EKC concept became widely popular starting in the early 1990s with background study of the World Development Report [Shafil and Bandyopadhyay (1992)] and study of potential impact of NAFTA[2] [Grossman and Krueger (1991)]. The inverted "U" shaped relationship of the environment degradation and income is supported by enough theoretical evidences. According to EKC concept, Carbon dioxide CO_2 emission (the indicator we used as environmental pollution) is expected to have a positive relationship with the level of economic growth.

Environmental Kuznets Curve and Pakistan

Pakistan is the sixth most populous country in the world. It relies on the imports of capital goods and energy resources to promote industrial growth and economic

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[1] See Grossman and Krueger (1993, 1995), Selden and Song (1994), Suri and Chapman (1998), and Agras and Chapman (1999).

[2] North American Free Trade Agreement.

development. The imports of capital goods and energy resources jointly contribute above 70 percent towards its total imports while the consumption share of manufacturing and transportation ranges between 30-35 percent [FBS (2010)]. On the other hand, agricultural products are major exports in Pakistan, which are considered to be a lower CO_2 emitting sector as compared to industrial sector. Furthermore, Pakistan is a net importer of fertiliser and other chemical products, which emit highly contaminated gases.

The government of Pakistan launched an environmental policy in 2005 to control environmental degradation with sustained level of economic growth. The main objective of the National Environmental Policy (NEP) is to protect, conserve and restore Pakistan's environment. Meanwhile, the economic growth is enhanced by agricultural, industrial and services sectors of the economy. The rising growth rate in Pakistan is led by industrial sector generally and manufacturing sector particularly.[3] This industrial sector led growth enhances energy demand and as result environmental pollutants increase in the country.

In 2002-2003, industrial sector accounted for 36 percent of total energy consumption while 33 percent is consumed by transportation. Even though total energy consumption declined to 29 percent in 2008-2009, but the consumption by industrial sector has increased to 43 percent over the period.[4] High usage of petroleum to meet transportation demand is a major reason of CO_2 emissions in Pakistan.[5] In 2005, 0.4 percent of the world total CO_2 emissions were produced by Pakistan and this "contribution" is increasing day by day.

Objectives

The main objective of the study is to analyse the impact of fossil fuel energy consumption on CO_2 emissions for Pakistan from 1980-2010. We can discuss the broad objectives as follows:

- To empirically examine the environmental Kuznet's curve for Pakistan.
- To test the robustness of environmental Kuznet's curve in the presence of other variables.
- To empirically analyse the factors that affects the fossil fuel energy consumption in short run as well as long run.
- To propose suitable policy implications based on empirical findings.

3. LITERATURE REVIEW

Shafik (1994) and Holtz-Eakin and Selden (1995) conclude that the amount of CO_2 emissions monotonically increases with per capita income. Selden and Song (1994) confirm environmental Kuznets hypothesis after investigating the relationship between economic growth and a set of energy pollutants i.e. SO_2, NOx, CO_2. Lanoie, *et al.* (1998) argue that financial market can help to decrease CO_2 emissions by providing incentives to firms for compliance with environmental regulations.

[3] In 2009, economic growth rate is 2 percent due to poor performance of the industrial and manufacturing sectors (*Economic Survey of Pakistan, 2008-2009*).

[4] *Economic Survey of Pakistan, 2008-2009,* p. 226.

[5] The transportation has been converted to compressed gas consumption after hike in petroleum prices.

Dinda, *et al.* (2000) find that the use of advanced capital intensive techniques help environment and supports EKC relation. Dasgupta, *et al.* (2004) find that the firms in Korea lose market value if their names are made public for violation of environmental regulations. Liu (2005) concludes that the EKC for CO_2 exists. Persson, *et al.* (2006) notify that the cost to improve environment will be less if developing nations implement environment friendly policies at the initial stages of economic development. Richmond and Kaufman (2006) point out that there is limited support of the EKC in the case of OECD countries, but not in the case of non-OECD countries.

Alam, *et al.* (2007) find that increase in per capita GDP and energy intensity growth leads to 0.84 percent and 0.24 percent increase in the growth rate of CO_2 and CO_2 emissions. Ang (2007) finds stable long run relation between economic growth and CO_2 emissions and argues that the EKC hypothesis is satisfied in France. He explains that causality runs from economic growth to energy consumption and CO_2 emissions in the long run but in the short run energy consumption causes economic growth. Claessens and Feijen (2007) posit that good governance and financial development make it easier to adopt advanced technology in energy sector, which helps to reduce CO_2 emissions significantly and improve environmental quality.

Chebbi and Boujelbene (2008) clear that economic growth; energy consumption and CO_2 emission are related in the long-run and provide some evidences of inefficient use of energy in Tunisia. In the short run, results shows that economic growth exerts a positive effect on energy consumption growth and results from impulse response functions do not confirm the hypothesis that an increase in pollution level brings about economic expansion.

Ang (2008) finds that causality runs from output to energy consumption not only in the short, but also in the long run, the study also reports positive link between per capita GDP, energy consumption, and CO_2 emissions for Malaysia. Wagner (2008) also argues in favour of an inverted U-relationship between economic growth and energy pollutants i.e., CO_2 and SO_2. Song, *et al.* (2008) find long run relationship between economic growth and indicators of CO_2 emissions i.e. waste gas, waste water, solid wastes etc., which confirms an inverted U relationship.

Halicioglu (2009) argues that the most significant variable in explaining the carbon emissions in Turkey is income followed by energy consumption and foreign trade. Study also explores that energy consumption; trade and CO_2 emissions are the main contributors to economic growth in the long run. Jalil and Mahmud (2009) indicate that the carbon emissions are mainly determined by income and energy consumption in the long-run and trade has a statistically insignificant positive impact on CO_2 emissions. Akbostanci, *et al.* (2009) did not find any support for the EKC with Turkish data.

Lean and Smyth (2009, 2010) find a significant positive long run relation between electricity consumption and CO_2 emissions and support the existence of EKC for ASEAN countries. Apergis and Payne (2009) give evidence in support of the EKC hypothesis by extending the work of Ang (2007) and find unidirectional causality running from energy consumption and real output to CO_2 emissions in Central American countries. Esmaeili, *et al*. (2009) find support for the EKC by using oil exploitation factors e.g., oil reserves, oil price, population, political rights, and the Gini index in the oil producing countries.

Tamazian, *et al.* (2009) argue that trade openness and financial sector reforms help to decrease CO_2 emissions in BRIC nations, the United States and Japan. Iwata, *et al.* (2009) find that the effects of nuclear energy on CO_2 emissions are significantly negative both in the short run and long-run while, the effects of trade or energy consumption are insignificant and the causality tests confirm the uni-directional relationship running from income and nuclear energy to CO_2 emissions for France.

Fodha, *et al.* (2010) find evidence in support of an EKC between economic growth and SO_2 emissions, and but not with CO_2 emissions for Tunisia. Tamazian and Rao (2010) find that institutional, economic and financial development helps to lower CO_2 emissions; the study also supports EKC for the transitional economies. Yuxiang and Chen (2010) claim that financial development induces capitalisation, technology use, income increase and regulations that affect environmental quality in China. Jalil and Feridun (2010) indicate that financial development lowers CO_2 emissions in China by investigating the impact of financial development, economic growth and energy consumption on environmental pollution.

Shanthini and Perera (2010) suggest the probable existence of a co-integrating relationship between Australia's fossil-fuel based CO_2 emissions per capita and GDP per capita. In the short-run, 1 percent increase in GDP per capita growth in the previous year leads to 0.33 percent increase in the current growth in CO_2 emission per capita. Zhang (2011) evidence reveals that financial development significantly contributes to increase in environmental degradation. Study states that Chinese enterprises have easy access to external finance and bank loans at cheaper cost to enhance investment. This leads China's economic growth and CO_2 emissions to intensify, which depend on bank asset expansion.

Saboori, *et al.* (2011) do not support the EKC hypothesis for Indonesia and long-run results indicate that foreign trade is the most significant variable in explaining CO_2 emissions followed by energy consumption and economic growth. Saboori and Soleymani (2011) do not support the EKC hypothesis for Iran and the long-run results indicate energy consumption has a significant positive impact on CO_2 emissions. Anees and Ahmed (2011) find that CO_2 affect economic growth, agriculture and industrial growth in the long run for Pakistan. It is also evident that energy consumption uni-directionally Granger causes CO_2 emissions while, industrialisation and urbanisation bidirectionally Granger cause each other.

Tiwari (2011) finds that the energy consumption, capital and population Granger-cause economic growth not the vice versa in India. IRFs and VDCs results indicate that CO_2 emissions have positive impact on energy use and capital but negative impact on population and GDP. Energy consumption has positive impact on CO_2 emissions and GDP but its impact is negative on capital and population. This implies that in the framework of production function, capital and population/labour have been rapidly substituted by energy use in the production process.

Essien (2011) suggests that there exists a long run relationship among GDP per capita, electricity per capita, natural gas per capita, crude oil per capita, fuel woods per capita and CO_2 emission for Nigeria. Results reveal that electricity and gas consumption cause economic growth both in the short and long run but only fuel woods influence it in the long run while, it provides evidence that natural gas influences carbon emissions in the long run while fuel woods influence carbon emissions in the short run.

Alam, *et al.* (2012) indicate that uni-directional causality runs from energy consumption to economic growth both in the short and the long-run while bi-directional long run causality exists between electricity consumption and economic growth but no causal relationship exists in short- run for Bangladesh. Uni-directional causality runs from energy consumption to CO_2 emission for the short-run but feedback causality exists in the long-run.

Hedi, *et al.* (2012) show that in the long-run energy consumption has a significant positive impact on CO_2 emissions but there is poor evidence in support of the EKC hypothesis for 12 Middle Eastern and North African Countries (MENA).[6] Results also suggests that not all MENA countries need to sacrifice economic growth to reduce their emission levels as they may achieve CO_2 emissions reduction via energy conservation without negative long-run effects on economic growth.

Model Specification

Environment Kuznets Curve

Following the approach adopted by Ang (2007), Acaravci and Ozturk (2010), and Lean and Smyth (2010), the long-run relationship between fossil fuel energy consumption, economic growth and carbon emissions can be specified as follows:

$$CO_{2t} = \alpha_0 + \alpha_1 FFEC_t + \alpha_2 PCRGDP_t + \alpha_3 PCRGDP^2{}_t + \varepsilon_t$$

Where CO_2 is carbon dioxide emissions, FFEC is fossil fuel energy consumption; PCRGDP is per capita real GDP and also its square used as a proxy for economic growth. The expected sign of fossil fuel energy consumption is positive. The expected sign of per capita real GDP is positive while of its square is negative in order to reflect the inverted U-shape pattern.

In order to test the robustness of inverted U hypothesis we extend our model by incorporating some other variables;

$$CO_{2t} = \beta_0 + \beta_1 FFEC_t + \beta_2 PCRGDP_t + \beta_3 PCRGDP^2{}_t + \beta_4 INDVAD$$
$$+ \beta_5 FD + \beta_6 TO + \upsilon_t$$

Where INDVAD is industrial value added that represents the industrial sector growth, while FD is financial development and TO is trade openness. Industrial value added is expected to have positive sign while financial development' sign is ambiguous. Trade openness is expected to affect the CO_2 emission positively.

Energy Consumption

To test the long run determinants of energy consumption we have specified the following equation;

$$FFEC_t = \delta_0 + \delta_1 RGDP_t + \delta_2 GFCF_t + \delta_3 POP_t + \delta_4 MX + \delta_5 MM + \varepsilon_t$$

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[6] Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, and UAE.

Where FFEC is fossil fuel energy consumption, RGDP is real GDP used as a proxy for economic growth, GFCF is investment, POP is population, MX represents manufactured exports and MM represents manufactured imports. Economic growth, investment, population and manufactures exports are expected to have positive signs while manufactured import, sign is ambiguous.

Description and Sources of Variables

Variable	Description
CO_2	Log of CO_2 emissions (metric tons per capita) *Source:* World Development Indicators (WDI)
FFEC	Fossil fuel energy consumption (% of total) *Source:* World Development Indicators (WDI)
PCRGDP	Log of Per capita real GDP *Source:* International Financial Statistics (IFS)
$PCRGDP^2$	Square of Per capita real GDP
INDVAD	Industrial value added (% of GDP) *Source:* World Development Indicators (WDI)
FD	Log of credit to private sector *Source:* World Development Indicators (WDI)
MX	Manufacture exports (% of merchandise exports) *Source:* World Development Indicators (WDI)
RGDP	Log of real GDP deflated by CPI (2005.=100) *Source:* International Financial Statistics (IFS)
GFCF	Gross fixed capital formation (% of GDP) *Source:* World Development Indicators (WDI)
POP	Log of Population (millions) *Source:* International Financial Statistics (IFS)
MM	Manufacture imports (% of merchandise imports) *Source:* World Development Indicators (WDI)
TO	Total trade as % of GDP *Source:* World Development Indicators (WDI)

4. METHODOLOGY

Univariate Analysis

(a) ***Unit Root Test***

Many variables are non-stationary for this we can use Unit Root Test in order to verify their order of integration. Then, only those variables are incorporated in the study which are stationary at 1st difference I (1).

(b) ***Augmented Dickey-Fuller Test (ADF)***

The Augmented version of Dickey Fuller Test is used for larger and complicated models, which deals with the serial correlation in the error term μt by putting lagged values of dependent variable ΔYt

Multivariate Analysis

In order to find the existence and number of long-run relationship(s) the econometric framework we used in the study for analysis is the Johansen (1998) and Johansen and Juselius (1990) Maximum Likelihood Co-integration Approach. Two or more series are co-integrated if they observe same kind of stochastic behaviour. It is statistical property of time series variables and is applied when all the variables are stationary at I (1).

The co-integration approach in a multivariate system is similar to the ADF test, but requires the use of vector autoregressive (VAR). A vector autoregressive (VAR) model with a lag length of 1 was used to test for the number of co-integrating relationships between the variables. When two series are co-integrated it suggests that even if both processes are non-stationary, there is some long run relationship linking both series.

There are two likelihood ratio test statistics in the Johansen (1998) and Johansen and Juselius (1990) Maximum likelihood Co-integration Approach and the trace and the Maximum Eigenvalue. The Trace test is a joint test with null hypothesis that the number of co-integrating vectors is less than or equal to r, against alternative hypothesis that there are more than r co-integrating vectors. The Maximum Eigenvalue test conducted separate tests on each Eigenvalue with null hypothesis that there are r co-integrating vectors against the alternative hypothesis that there are (r+1).

Vector Error Correction Model

A main quality of co-integrated variables is that their time paths are affected by the extent of any deviation from the long-run equilibrium [Anders (2004)]. The error correction mechanism (ECM) term presents the percentage of correction to any deviation in the long-run equilibrium of dependent variable in a single period and also represents how fast the deviations in the long-run equilibrium are corrected. Depending on the presence of how many co-integrating vectors, we can then test for the short run dynamics using a vector error correction model. A vector error correction model (VECM) can test how changes in trade openness in short run contributed to its long run relation with inflation.

Granger Causality

In economics, systematic testing and determination of causal directions only became possible after an operational framework was developed by Granger (1969) and Sims (1972). Their approach is crucially based on the axiom that the past and present may cause the future but the future cannot cause the past.[7] In econometrics the most widely used operational definition of causality is the Granger definition of causality, which is defined as follows:

"X is a Granger cause of Y (denoted as $X \rightarrow Y$), if present y can be predicted with better accuracy by using past values of x rather than by not doing so, other information being identical."[8]

[7] Granger (1980).

[8] Charemza and Deadman (1992).

To test the bi-variate causality relationships the following causal model is used:

$$x_t = \sum_{j=1}^{p} a_i x_{t-j} + \sum_{j=1}^{p} b_i y_{t-j} + u_t \qquad y_t = \sum_{j=1}^{p} c_i x_{t-j} + \sum_{j=1}^{p} d_i y_{t-j} + v_t$$

Where μ_t and ν_t are two uncorrelated white-noise series and p is the maximum number of lags.

5. RESULTS AND DISCUSSION

Results of Unit Root Test

We test the null hypothesis of unit root against the alternative. The results of our study comprise that all variables have a unit root at their levels indicating that the levels are non-stationary. The first differenced series however, clearly reject unit roots suggesting that the differenced variables are all stationary.

Results of Unit Root Test

	Level			1st Difference			
Variables	Intercept	Trend and Intercept	None	Intercept	Trend and Intercept	None	Order of Integration
TO	–0.763653	–2.149911	–1.65445	–5.14054*	–5.05514*	–4.6966*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	
CO_2	–0.429700	–2.684728	–1.05273	–7.27443*	–7.15370*	–4.4043*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	
FFEC	–1.282973	–2.192627	–1.63578	–5.27039*	–5.30489*	–3.8114*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	
INDVAD	–1.776672	–2.345894	–0.51290	–5.98219*	–5.85061*	–6.0549*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(1)	LAG(1)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	
MM	–2.102556	–2.170191	–0.52357	–6.03881*	–6.16942*	–6.1414*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(1)	LAG(0)	LAG(0)	LAG(0)	
MX	–2.965731	–1.208926	–0.73884	–5.33068*	–7.22322*	–5.2478*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(1)	LAG(0)	LAG(0)	LAG(0)	
PCRGDP	–0.925548	–1.320890	–1.14490	–5.40851*	–5.68580*	–3.7570*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	
RGDP	–1.232317	–0.874471	–1.49878	–4.90488*	–5.99628*	–2.7765*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	LAG(0)	
POP	–2.484547	–2.188403	–0.34365	–3.46688*	–3.587844	–3.3622*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(3)	LAG(3)	LAG(3)	LAG(2)	LAG(2)	LAG(2)	
GFCF	–2.913031	–3.189074	–0.65837	–3.36582*	–3.35304*	–3.4127*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(2)	LAG(1)	LAG(1)	LAG(0)	LAG(0)	LAG(0)	
FD	–1.105499	–3.14839	–1.45771	–4.46427*	–4.52320*	–2.6397*	I(1)
	(–2.96)	(–3.56)	(–1.96)	(–2.96)	(–3.56)	(–1.96)	
	LAG(3)	LAG(3)	LAG(3)	LAG(2)	LAG(2)	LAG(2)	

Note: *Denotes the rejection of hypothesis at 5 percent level of significance.

Environment Kuznets Curve for CO_2 Emission

As results of unit root test show that all the variables are I(1). So we use Johansson co-integration test to test the long run relationship between fossil fuel energy consumption, economic growth and carbon emissions. As the first step in co-integration we test the lag order of model. We determine the lag order through AIC (Akaike information criterion) using VAR (vector auto regressive). In the second step we test the null hypothesis of no co-integration against the alternative through maximum Eigen statistics.

Lags Interval: 1 to 1

Eigen Value	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesised No. of CE(s)
0.716443	88.03858	53.12	60.16	None **
0.578956	51.48868	34.91	41.07	At most 1 **
0.534353	26.40313	19.96	24.60	At most 2 **
0.135951	4.237657	9.24	12.97	At most 3

*(**) denotes rejection of the hypothesis at 5 percent (1 percent) significance level.

L.R. test indicates 3 co-integrating equation(s) at 5 percent significance level.

Results of Maximum Eigen statistics show the evidence of three long run co integration relationships in our model. We reject the null hypothesis of two co integrating relations against alternative of three co-integrating relations.

Normalised Co-integrating Coefficients

$$CO2_t = \alpha_0 + \alpha_1 FFEC_t + \alpha_2 PCRGDP_t + \alpha_3 PCRGDP^2{}_t + \varepsilon_t$$

Dependent Variable: CO_2

Variables	Coefficients	Standard Error	t-Statistics
FFEC	0.845970	0.02760	30.6485*
PCRGDP	0.00298	0.00012	24.8333**
$PCRGDP^2$	–0.766665	0.33556	2.28473**
C	4.480726	0.16164	27.72404

Note: * show the significance at 1 and 5 percent respectively.

Fossil fuel energy consumption positively affects the CO_2 emissions as expected. A 1 percent increase in Fossil fuel energy consumption brings 0.84 percent increase in CO_2 emission. The higher level of energy consumption results in greater economic activity and stimulates CO_2 emissions. The findings are in line with Hamilton and Turton (2002), Friedl and Getzner (2003), Liu (2005), Ang and Liu (2005), Say and Yücel (2006), Alam, *et al*. (2007), Ang (2008), Halicioglu (2009), Jalil and Mehmud (2009), Nasir and Rehman (2011), Shahbaz, *et al*. (2011, 2013).

Per capita real GDP positively affects the CO_2 emission. These findings are consistent with those of He (2008) for China; Song, *et al*. (2008) for China; Halicioglu (2009) for Turkey; Jalil and Mehmud (2009) for China; Fodha and Zaghdoud (2010) for

Tunisia; Lean and Smyth, (2010) for ASEAN countries; Anees, *et al.* (2011) and Shahbaz, *et al.* (2010, 2011, 2013) for Pakistan.

The statistically significant sign of per capita real GDP square confirms the decrease in CO_2 emission at higher level of income, which provides the proof for the existence of environmental Kuznet curve. That the level of CO_2 emission initially increases with income, until it reaches maximum point, then it declines. In the early stages of the economic process, there is abundance of natural resource stock and a low production of wastes because of low economic activity.

As industrialisation takes off, resource depletion and waste production accelerate. At this phase of transition from agriculture to industry, industrialisation of the production process creates a positive relationship between per capita incomes (or else economic growth) with environmental degradation, in a general sense. At higher levels of economic development, the production process of the economy becomes more information based and the service sector is boosted. This shift in the composition of production, combined with improvements in technology and increased demand for environmental quality, results in a leveling-off and a steady decline of environmental degradation. These findings are consistent with the empirical evidence of He (2008), Song, *et al.* (2009), Halicioglu (2009), Fodha and Zaghdoud (2010) and Leanand Smyth (2010), Shahbaz, *et al.* (2011, 2013).

Error Correction Model

After Estimating long run coefficients we move toward VAR (vector error correction) model.

$$\Delta CO2_t = \alpha_0 + \alpha_1 \sum_{i=1}^{n} \Delta CO2_{t-1} + \alpha_2 \sum_{i=0}^{n} \Delta FFEC_{t-1} + \alpha_3 \sum_{i=0}^{n} \Delta PCRGDP_{t-1}$$
$$+ \alpha_4 \sum_{i=0}^{n} \Delta PCRGDP_{t-1}^2 + \lambda ECT_{t-1} + \varepsilon_t$$

Dependent Variable: ΔCO_2

Variables	Coefficients	Standard Error	t. Statistics
ECT(–1)	–0.799072	0.14648	–5.45519*
D(CO_2(–1))	0.257076	0.11794	2.17980**
D(FFEC(–1))	–3.71E–07	0.00045	–0.00083
D(PCRGDP(–1))	1.234524	0.92911	1.32871
D($PCRGDP^2$(–1))	–2.814629	1.35902	–2.07108**
C	0.030004	0.00561	5.34389
R-squared	0.714738	S.E. equation	0.014255
Sum sq. resids	0.004674	Log likelihood	85.48031

Note: *,** show the significance at 1 and 5 percent respectively.

Short run co-efficient estimates obtained from the ECM indicate that the estimated lagged error correction term (EC_{t-1}) is negative and significant. The feedback coefficient is –0.79, suggesting that about 79 percent disequilibrium in the previous year is corrected in the current year. Short run results show that previous period's carbon dioxide emission and per capita real GDP positively affect the CO_2 emission in current period. Previous period's energy consumption and per capita GDP square negatively affect CO_2 emission in current period. Most of the variables lose their significance in short run.

Robustness Checks for the Environment Kuznets Curve for CO_2 Emission

We test the null hypothesis of no co-integration against the alternative through maximum Eigen statistics.

Lags interval: 1 to 1

Eigen Value	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesised No. of CE(s)
0.880810	185.4220	131.70	143.09	None **
0.752966	123.7379	102.14	111.01	At most 1 **
0.624845	83.18928	76.07	84.45	At most 2 *
0.544144	54.75720	53.12	60.16	At most 3 *
0.477881	31.97541	34.91	41.07	At most 4
0.208002	13.12949	19.96	24.60	At most 5
0.197116	6.366808	9.24	12.97	At most 6

*(**) denotes rejection of the hypothesis at 5 percent (1 percent) significance level.

L.R. test indicates 4 co-integrating equation(s) at 5 percent significance level.

Results of Maximum Eigen statistics show the evidence of four long run co-integration relationships in our model. We reject the null hypothesis of three co-integrating relations against alternative of four co integrating relations.

Normalised Co-integrating Coefficients

We re-estimate the previous equation by including some other variables to test the robustness of environmental Kuznets hypothesis. Both the variables have expected signs but per capita real GDP loses its significance when we include some other variables. It shows that higher income is not the only factor to control the CO_2 emission, some other factors are also important. Moreover in developing countries a very small proportion of income is spent to control the environmental degradation.

$$CO2_t = \beta_0 + \beta_1 FFEC_t + \beta_2 PCRGDP_t + \beta_3 PCRGDP_t^2 + \beta_4 INDVAD + \beta_5 FD + \beta_6 TO + \upsilon_t$$

Dependent Variable: ΔCO_2

Variables	Coefficients	Standard Error	t-Statistics
FFEC	1.178385	0.10824	10.88673*
PCRGDP	0.01408	0.00144	9.7777*
$PCRGDP^2$	–0.085049	0.34868	–0.24391
INDVAD	0.011705	0.00244	4.79713*
FD	–0.006184	0.00239	–2.58744**
TO	0.003447	0.00088	3.90909*
C	5.017042	1.44981	3.46047

Note: *,** show the significance at 1 and 5 percent respectively.

Increase in the size of the economy (scale effect) is likely to increase pollution. Production and industrial activities involve energy as an essential input. Energy is one of the main resources of industrialisation. As industrial sector expands, energy consumption increases that leads to increase in environmental degradation. A 1 percent increase in the share of industrial sector increases the CO_2 emission by 0.011 percent supported by Anees and Ahmed (2011).

Developing countries are mostly net exporter of pollution-intensive goods [Grossman and Krueger (1995)] so trade openness results in the development of pollution-intensive industries and environmental degradation in developing countries. Natural resources are depleted due to international trade. This depletion of natural resources raises CO_2 emissions and causes environment quality to worsen [e.g. Schmalensee, *et al.*; Copeland and Taylor, Chaudhuri and Pfaff]. A 1 percent increase in trade openness increases the CO_2 emission by 0.003 percent supported by Nasir and Rehman (2011), Shahbaz, *et al.* (2013), Khalil and Inam (2006) who probed the hypothesis that international trade is harmful to environmental quality in Pakistan and Halicioglu (2009) who posited that foreign trade increases CO2 emissions in Turkey.

Financial development reduces CO_2 emissions through research and development enhancing effect due to economic growth. A developed financial sector lowers borrowing cost, promotes investment in energy efficient sector, and reduces energy emissions. The findings are consistent with those found by Birdsall and Wheeler (1993), Frankel and Rose (2002), Tamazian *et al.* (2009), Tamazian and Rao (2010), Sadorsky (2010), and Shahbaz, *et al.* (2009, 2010, 2013). Financial development may generally boost research and development (R & D) activities and sequentially improve economic activities, and hence, influence environmental quality [Frankel and Romer (1999)]. A1 percent increases in financial development decreases the CO_2 emission by 0.006 percent.

Error Correction Model

After Estimating long run coefficients we move toward VAR (vector error correction) model.

$$\Delta CO2_t = \alpha_0 + \alpha_1 \sum_{i=1}^{n} \Delta CO2_{t-1} + \alpha_2 \sum_{i=0}^{n} \Delta FFEC_{t-1} + \alpha_3 \sum_{i=0}^{n} \Delta PCRGDP_{t-1}$$
$$+ \alpha_4 \sum_{i=0}^{n} \Delta PCRGDP_{t-1}^2 + \lambda ECT_{t-1} + \varepsilon_t$$

Dependent Variable: ΔCO_2

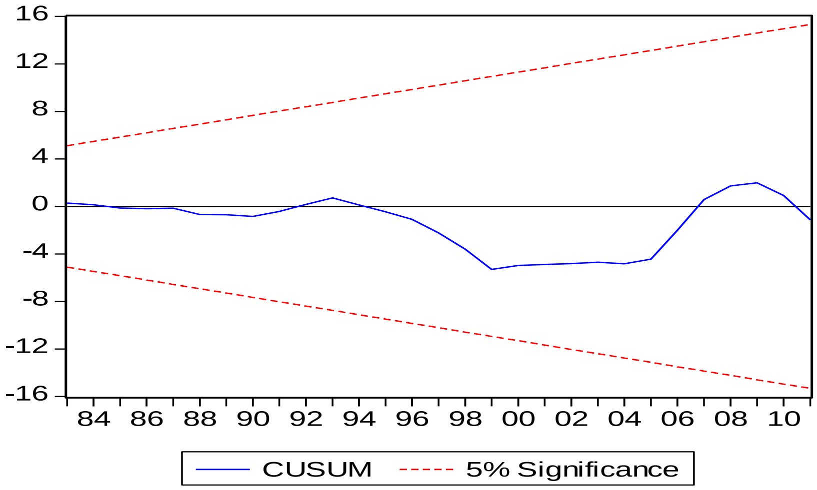
Variables	Coefficients	Standard Error	t. Statistics
ECT(–1)	–0.799072	0.14648	–5.45519*
D(CO_2(–1))	0.257076	0.11794	2.17980**
D(FFEC(–1))	–3.71E-07	0.00045	–0.00083
D(PCRGDP(–1))	1.234524	0.92911	1.32871
D($PCRGDP^2$(–1))	–2.814629	1.35902	–2.07108**
C	0.030004	0.00561	5.34389
R-squared	0.714738	S.E. equation	0.014255
Sum sq. resids	0.004674	Log likelihood	85.48031

Note: *,** show the significance at 1 and 5 percent respectively.

Short run co-efficient estimates obtained from the ECM indicate that the estimated lagged error correction term (EC_{t-1}) is negative and significant. The feedback coefficient is –0.43, suggesting that about 43 percent disequilibrium in the previous year is corrected in the current year. Short run results show that previous period's carbon dioxide emission, energy consumption, per capita real GDP and industrial value added positively affect the CO_2 emission in the current period. Previous period's financial development, trade openness and square of per capita real GDP negatively affect CO_2 emission in current period. Most of the variables lose their significance in short run.

Stability Test

The stability test is conducted by employing the commutative sum of recursive residuals (CUSUM). The CUSUM Plotted against the critical bound of the 5 percent significance level show that the model is stable overtime.



Energy Consumption

In the second step we test the null hypothesis of no co-integration against the alternative through maximum Eigen statistics.

Lags Interval: 1 to 1

Eigen Value	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesised No. of CE(s)
0.930950	195.2346	102.14	111.01	None **
0.734948	117.7199	76.07	84.45	At most 1 **
0.720810	79.21286	53.12	60.16	At most 2 **
0.497735	42.21289	34.91	41.07	At most 3 *
0.397176	22.24268	19.96	24.60	At most 4
0.229610	7.564893	9.24	12.97	At most 5

*(**) denotes rejection of the hypothesis at 5 percent (1 percent) significance level.
L.R. test indicates 5 co-integrating equation(s) at 5 percent significance level.

Results of Maximum Eigen statistics show the evidence of five long run co-integration relationships in our model. We reject the null hypothesis of four co-integrating relations against alternative of five co-integrating relations.

Normalised Co-integrating Coefficients

$$FFEC_t = \delta_0 + \delta_1 RGDP_t + \delta_2 GFCF_t + \delta_3 POP_t + \delta_4 MX + \delta_5 MM + \varepsilon_t$$

Dependent Variable: ΔCO_2

Variables	Coefficients	Standard Error	t. Statistics
RGDP	0.466306	0.05544	8.41100*
GFCF	0.675773	0.06406	10.5578*
POP	1.711502	0.12600	13.5833*
MX	0.001804	0.00034	5.30588*
MM	–0.002196	0.00039	–5.63076*
C	–3.604879	0.16052	22.4570

Note: *,** show the significance at 1 percent level of significance.

Energy consumption in developing economies, to a large extent is due to the higher growth rate of these economies. Higher growth rates put increasing pressure on energy consumption. Therefore GDP is positively related to energy consumption in developing economies. When growth rate increases remarkably, there will be an increasing pressure on resources. Therefore the demand for expert labour force, capital and equipment increases and more raw materials and energy is consumed. A1 percent increase in the real GDP increases the energy consumption by 0.46 percent.

Capital Intensive projects especially in infrastructure need high level of energy. A great amount of GFCF is related to infrastructure and transportation. A1 percent increase in investment increases the energy consumption by 0.67 percent.

As the population grows the need for energy consumption also increases. The size of population coupled with rise in GDP growth and higher per capita income creates demand for various products and this leads to increase in energy consumption. A1 percent increase in the population increases the energy consumption by 1.71 percent.

Manufactured exports to different parts of the world require higher energy consumption. The demand for these products is increasing at a faster rate and the clients being the developed economies. This is because of the availability of these products at a much cheaper rate because of the low cost resources in developing economies, especially in China. A1 percent increase in the manufactured exports increases the energy consumption by 0.001 percent.

Manufactured imports have a negative effect on energy consumption. Increase in industrial products imports will lead to decrease in energy consumption if only the domestic produced goods, which are the substitute for industrial imported goods consume higher energy levels. A1 percent increase in the manufactured imports decreases the energy consumption by 0.002 percent.

Error Correction Model

After Estimating long run coefficients we move toward VAR (vector error correction) model.

$$\Delta FFEC_t = \delta_0 + \delta_1 \sum_{i=1}^{n} \Delta FFEC_{t-1} + \delta_2 \sum_{i=0}^{n} \Delta RGDP_{t-1} + \delta_3 \sum_{i=0}^{n} \Delta GFCF_{t-1}$$

$$+ \delta_4 \sum_{i=0}^{n} \Delta POP_{t-1} + \delta_5 MX + \beta_6 MM + \delta_7 MX + \phi ECT_{t-1} + \varepsilon_t$$

Dependent Variable: ΔFFEC

Variables	Coefficients	Standard Error	t-Statistics
ECT(–1)	–0.435842	0.33946	–3.25369*
D(FFEC(–1))	0.130433	0.26023	0.50121
D(RGDP(–1))	0.018820	0.20187	0.09323
D(GFCF(–1))	0.304252	0.28620	1.06309
D(POP(–1))	–0.450279	2.43720	–0.18475
D(MX(–1))	0.000700	0.00098	0.71625
D(MM(–1))	–0.001167	0.00135	–0.86638
C	0.026462	0.06518	0.40601
R-squared	0.637470	S.E. equation	0.014948
Sum sq. resids	0.003799	Log likelihood	88.48722

Note: *,** show the significance at 1 percent level of significance.

Short run co-efficient estimates obtained from the ECM indicate that the estimated lagged error correction term (EC_{t-1}) is negative and significant. The feedback coefficient is –0.43, suggesting that about 43 percent disequilibrium in the previous year is corrected in the current year. Short run results show that previous period's energy consumption, economic growth, investment and manufactured exports positively affect the energy consumption in current period. Previous period's manufactured imports and population negatively affect energy consumption in current period. Most of the variables lose their significance in short run.

Result of Causality Test

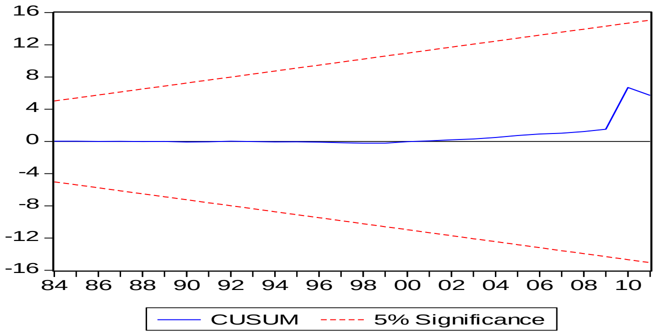
Pair Wise Granger Causality Tests
Sample: 1980–2010
Lags: 1

Null Hypothesis	Obs	F-Statistic	Probability
RGDP does not Granger Cause FFEC	30	0.07944	0.78020
FFEC does not Granger Cause RGDP		0.28508	0.59776
GFCF does not Granger Cause FFEC	30	0.19341	0.66359
FFEC does not Granger Cause GFCF		0.20836	0.65171
POP does not Granger Cause FFEC	30	**11.1012**	**0.00251**
FFEC does not Granger Cause POP		2.04059	0.16462
MX does not Granger Cause FFEC	30	**15.2334**	**0.00057**
FFEC does not Granger Cause MX		0.75407	0.39284
MM does not Granger Cause FFEC	30	0.82812	0.37087
FFEC does not Granger Cause MM		0.77980	0.38500

Results of the pairwise granger causality test provide the evidence of unidirectional causality running from population to energy consumption and from manufacture exports to energy consumption. These results are explained in the energy consumption equation.

Stability Test

The stability test is conducted by employing the commutative sum of recursive residuals (CUSUM). The CUSUM Plotted against the critical bound of the 5 percent significance level show that the model is stable overtime.



6. CONCLUSION

The main objective of the present study is to test the impact of fossil fuel energy consumption on CO_2 emissions for Pakistan from 1980-2010. Our broad objectives are to test the inverted U relationship between economic growth and fossil fuel energy consumption and also to test the impact of other factors that affect the energy consumption in Pakistan. We use the Johenson Co-integration approach to test the long run relationship between the variables while Vector Error Correction model is used to test the short run relationship.

A log linear quadratic equation is specified to test the long run relationship among CO_2 emission, energy consumption and economic growth. Energy consumption negatively affects the CO_2 emission. Results support the inverted U shaped environmental Kuznets curve for Pakistan. In order to test the robustness of EKC we re-estimate the equation by adding some additional variables; industrial value added, financial development and trade openness. Results again prove the inverted U hypothesis. Industrial value added and trade openness positively affect the carbon dioxide emission while financial development reduces the CO_2 emission.

Results of the energy consumption equation show that income, investment, population and manufactured exports positively affect the energy consumption while manufactured imports negatively affect the energy consumption.

7. IMPLICATIONS

Pakistan need to implement a wide range of environmental policies that would provide incentives to industries to adopt new technologies, which could help reduce the environmental pollution. The country also needs to give adequate boost to energy related research and development for the diffusion of cleaner technologies in the long-run. Some of the environmental damage in the form of pollution and economic growth is caused by various policy distortions such as protection of industry, energy subsidies, etc. Environmental damage can be reduced by applying property rights over natural resources and eliminating any policy distortions. Pakistan produces those products, which cause higher emissions, hence Pakistan need to emphasise on exporting those products, which cause low level of emissions. There is a need to redirect the financial sector to improve environment through issuing loans to environment friendly investment ventures, which not only increase the efficiency of all sectors but also improve the quality of life by saving the environment from degradation.

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The Role of Renewable Energy Supply and Carbon Tax in the Improvement of Energy Security: A Case Study of Pakistan

JAVED ANWAR

1. INTRODUCTION

As energy is a vital element for sustained economic growth and development, therefore energy consumption is used as a basic indicator of people's living standards. Due to technological and industrial development, the demand of energy in Pakistan is increasing more than the total primary energy supply; therefore, it is confronting the severe energy deficit today. So there should be a serious concern for the government about the energy security and should take actions for the development of indigenous alternative and renewable energy resources.

Renewable portfolio supply (RPS), and carbon tax are the two indirect policy options used for the improvement of energy security. Renewable Energy Promotion is used to reduce greenhouse gas emission, promote local energy sources and improve energy security through reducing energy dependency and diversification of energy sources. Carbon tax is an indirect policy option for energy security enhancement through emission reduction. Imposing tax on carbon emission will alter the primary energy supply mix, more efficient fuel and technologies will be substituted for less efficient fuel and technologies. This will reduce the primary energy demand and lead to improved energy security.

Energy security, particularly security of oil supply, has become a key political, and economic issue in recent years. Energy security in simple words means the security of energy supply. From economic point of view, energy security refers to the provision of reliable and adequate supply of energy at reasonable prices in order to sustain economic growth.

Pakistan as an energy deficient country is facing the challenge of energy security. A few papers analysed this issue highlighting just the energy situation of the country, ignoring the analytical side of the issue. Sahir and Qureshi (2007) gave an overview of the energy security issues in the global and regional perspectives and presented the specific implications and concerns for Pakistan. Moreover, the global and regional energy

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security is not vulnerable to shortage of energy resources but may be exposed to energy supply disruption, non-availability of tradable resources and threatened by growing terrorism and geopolitical conflicts.

Due to limited fossil fuel resources and poor economy, a huge portion of the population in Pakistan still have no access to modern day energy services such as electricity [see Mirza, *et al.* (2003); Mirza, *et al.* (2007a); Mirza, *et al.* (2007b)]. To overcome energy shortage, Pakistan should develop its indigenous fossil energy resources and alternative renewable resources such as mini-hydro, solar and wind resources [see Mirza, *et al.* (2007a); Mirza, *et al.* (2007b)]. Pakistan has a vast potential of mini-hydro, solar and wind energy resources, the exploitation of these resources could produce a enough electricity, which could be provided to the northern hilly areas and the southern and western deserts. This will help in reducing dependency on fossil fuels imports and also improve energy security.

Pakistan recorded a shortfall of 40 percent between demand and supply of electricity in 2008 [see Asif (2009)]. To overcome this shortfall, Pakistan has many sustainable energy options including hydro, biomass, solar, and wind resources. The total estimated hydropower potential is more than 42 GW and so for only 6.5 GW has been utilised. Although biomass is another conventional resource of energy in Pakistan but still it is not commercialised. Solar and wind options are also identified as potential energy resources but still these are not in operation on a vast scale.

This paper is aimed at analysing the effects of policies of renewable portfolio supply (RPS), and carbon tax on diversification of energy resources, technology mix in energy supply side and demand side; energy efficiency and energy conservation; and energy security during the planning horizon 2005-2050. A MARKAL-based model for an integrated energy system of Pakistan was developed to accomplish the research.

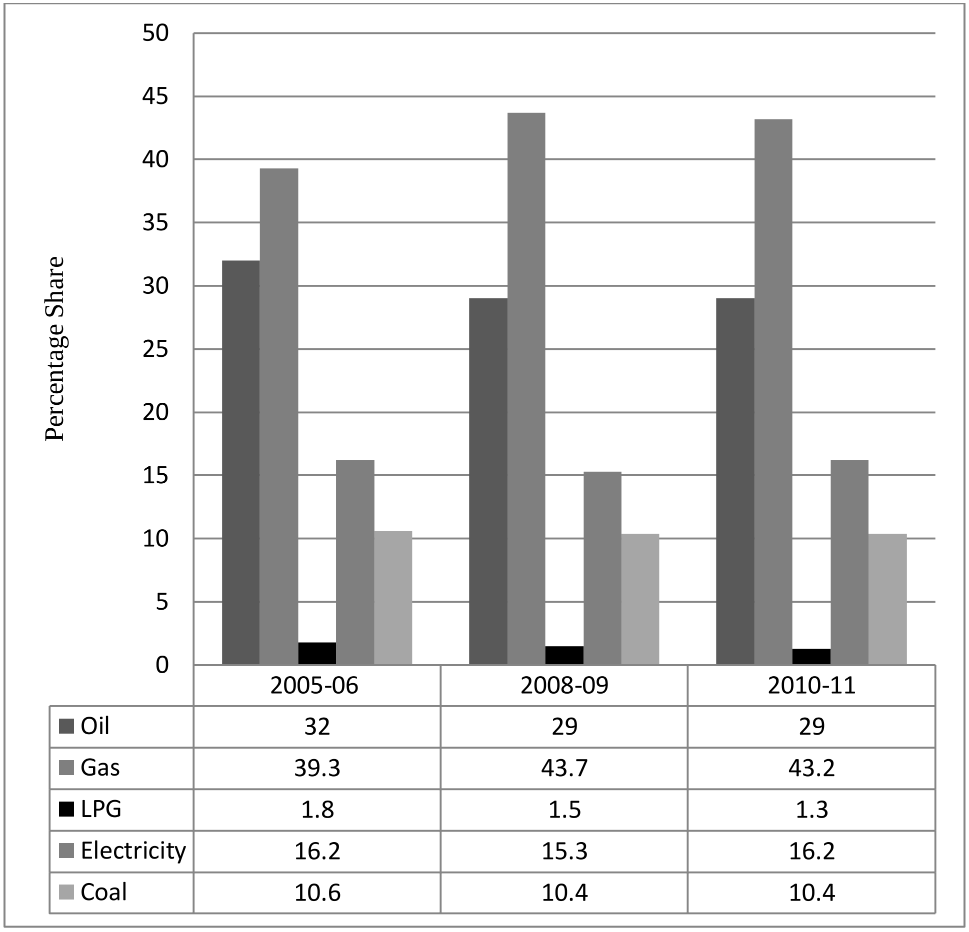
The paper is structured as follows. Section 2 gives an overview of Pakistan energy outlook. Section 3 provides the methodology and model formulation. Section 4 gives a brief description of the scenarios while analysis of the base case, renewable portfolio supply case and carbon tax case is given in Section 5. Finally, Section 6 presents the main conclusions.

2. PAKISTAN ENERGY OUTLOOK

Pakistan energy sector consists of electricity, gas, petroleum and coal. Oil and gas are major contributors to the Pakistan’s primary energy supply mix. (Fig. 1.) The primary energy supply mix of Pakistan consists of 78 percent oil and gas, 13 percent hydro, 8 percent coal and 1 percent nuclear (see Pakistan Economic Survey, 2006-07). The most interesting feature of Pakistan’s primary energy supply mix is that share of oil decreases from 32 percent in 2005-2006 to 29 percent in 2010-2011, and share of gas increases from 39 percent in 2005-2006 to 43 percent in 2010-2011, while the shares of other resources remained almost constant over the same period. It shows that Pakistan energy sector is switching from oil to gas and other resources.

Pakistan indigenous oil production meets only one-sixth of the current oil demand while imports one-third of the total energy demand. This implies that Pakistan is unable to meet energy demand from its internal resources, and is a net importer of energy.

Fig. 1. Primary Energy Supply Mix (2005-2010)



	2005-06	2008-09	2010-11
■ Oil	32	29	29
■ Gas	39.3	43.7	43.2
■ LPG	1.8	1.5	1.3
■ Electricity	16.2	15.3	16.2
■ Coal	10.6	10.4	10.4

Source: Pakistan Economic Survey 2011-12.

Historical data shows that Pakistan has been dependent on oil imports from the Middle East since it came into being. The crude oil imports for the year 2005-06 were about 8.56 mtoe as compared to local production of crude oil of 3.24 mtoe and the imports of petroleum products were about 5.85 mtoe. The cost of all these oil and petroleum products was equivalent to US$ 4.6 billion, which is roughly equal to 25-30 percent of the total import bill. This huge import bill put enormous pressure on the economy [Pakistan (2005)]. On the other hand, the primary energy demand has increased significantly but the primary energy supply remained at the same level, which created a huge gap between demand and supply. As a result, the country is facing huge energy shortage.

Pakistan imports about 29 percent of total primary commercial energy. Although Pakistan has a variety of energy resources, but approximately 80 percent of the energy supply is from oil and natural gas. The dependence on imported fuels especially on imported oil is likely to increase, which will affect Pakistan's economy adversely. To avoid this negative impact, we should explore opportunities for untapped large renewable energy resources in the form of mini-hydro, solar and wind projects so that Pakistan can fulfil its energy needs and keep up its economic growth.

Table 1 displays the annual trends of primary energy supplies and their per capita availability from 1996-97 to 2005-06, which indicates that the primary energy supply has increased by 50 percent and the per capita availability by 26 percent in the last 10 years.

Table 1

Primary Energy Supply and Per Capita Availability

Year	Primary Energy Supply (Tons of Oil Equivalent)	% Change	Per Capita Availability (Tons of Oil Equivalent)	% Change
1996-97	38.515	–0.6	0.295	–3.0
1997-98	40.403	4.9	0.305	3.3
1998-99	41.721	3.3	0.313	2.7
1999-00	43.185	3.5	0.317	1.2
2000-01	44.404	2.8	0.319	0.6
2001-02	45.068	1.5	0.315	–0.1
2002-03	47.056	4.4	0.324	2.7
2003-04	50.831	8.0	0.341	5.3
2004-05	55.533	9.3	0.363	6.7
2005-06	57.855	4.2	0.372	2.2

Source: Pakistan Economic Survey 2006-07.

3. METHODOLOGY

3.1. Model Formulation

This study makes use of bottom up MARKAL-based least cost energy system model[1] as an analytical framework for the analysis of energy security in case of Pakistan [Loulou, *et al*. (2004)]. It models the flows of energy in an economy from the source of primary energy supply, conversion of primary energy into secondary energy, and finally the delivery of various forms of energy to the end-use services. In the model, these flows of energy are described through detailed representation of technologies providing an end-use demand. Figure 2 shows the simplified structure of the MARKAL modelling framework through reference energy system.

Basically, Pakistan energy system model consists of four modules; primary energy supply, conversion technologies, end-use technologies and demand for energy services. Primary energy supplies are hydro, crude oil, natural gas, imports of oil, nuclear, solar wind etc., while conversion technologies module consists of power generation and transmission systems, oil refineries, natural gas processing and transmission systems. Service energy demand is grouped into five sectors: agriculture, residential, commercial, industrial, and transport sector (see Figure 2).

End use demands are a measure of the useful energy output provided by the demand technologies in each end use demand category. It is assumed in MARKAL that

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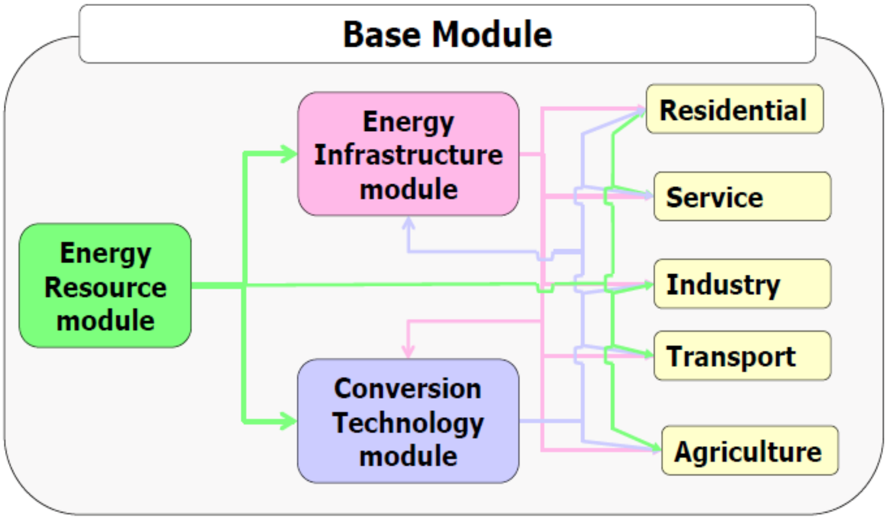
[1] Model formulation is described in Appendix-C.

the essential energy demand is for some service (an amount of cooking or heating), while the basic service is fixed, it can be provided by different mixes of devices and fuels. End-use demand technologies and conversion technologies are described in detail in Appendix A&B.

The objective function of the least cost energy system is to minimise the total discounted cost during the planning horizon; the total cost comprises of capital cost net of salvage value, fuel cost, operation, and maintenance costs. The optimal solution given by the model must satisfy energy demand, capacity and energy demand-supply balance constraints.

Fig. 2. General Reference Energy System



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3.2. Service Demand Projection

Service energy demand is projected through three different techniques using econometric models as well as using identity relating service energy demand in particular sector to GDP and Value Added of the particular sector. In the econometric approach, the dependent variables are number of energy devices, passenger kilometres, ton kilometres etc. The independent variables are Gross Domestic Product (GDP) and population. The other approaches consider the service demand of particular sector in particular year as dependent on the service demand of sector in base year multiplied by the ratio of the current year GDP and base year GDP; the service demand of particular sector in particular year depends on the service demand of sector in base year multiplied by the ratio of the current year value added and base year value added.

The econometric approach was used to project the service energy demand in transport and residential sectors, while the service energy demand in industrial, commercial and agriculture sectors was projected through economic value added and GDP approach.

Service demand projection for fans, air conditioners and cooking is based on the GDP growth through the following formulation:

$$SD_{i,k,t} = SD_{i,k,0} \times \frac{GDP_t}{GDP_o}$$

Where $SD_{i,k,t}, SD_{i,k,0}$ are service demand of sector i sub-sector k, in year t and base year respectively, GDP_t and GDP_0 represent Gross Domestic Product in year t and Gross Domestic Product in base year.

Service demand projection for agriculture, commercial and industrial sectors is based on the following formulation:

$$SD_{i,k,t} = SD_{i,k,0} \times \frac{VA_{i,k,t}}{VA_{i,k,0}}$$

Where $SD_{i,k,t}$ is service demand of sector i subsector k in year t, $SD_{i,k,0}$ is service demand of sector i subsector k in base year, $VA_{i,k,0}$ is the i_{th} sector k_{th} subsector value added in the base year and $VA_{i,k,t}$ is the i_{th} sector k_{th} subsector value added in the year t.

Electricity-related service demand and supply were considered in six time slices along with two seasons (summer and winter) and two periods (peak and off-peak) so that the variation of electricity loads on the energy system can be reflected.

3.3. Energy Security Indices

The prime objective of this research is to classify policy options for the improvement of energy security of Pakistan. The fundamental and suitable criterion for the classification of policy options are the calculation of energy security indices for the whole planning horizon 2005-2050. In this study, four energy security indicators are used, i.e. Net Energy Import Ratio (NEIR), Shannon-Wiener Index (SWI), Diversification of Primary Energy Demand (DoPED), Vulnerability Index (VI) and Energy Intensity (EI). These indicators are estimated by using the MARKAL model which is energy-system model depicting long-term development of the energy-system. The indicators are explained as follows:

$$NEIR = \frac{Net\ Imports}{(Domestic\ Production + Net\ Imports)}$$

The value of NEIR close to 1 indicates that the energy system of that country is to a large extent dependent on energy imports.

$$SWI = -\sum_i x_i \ln(x_i)$$

where x_i represents the share of energy supply from each source. A higher value of SWI means well diversified energy sources ultimately leading to improved energy security while a lower value implies low diversification of energy sources and poorer energy security [Grubb, *et al*. (2006)].

$$DoPED = \frac{\sqrt{Coal^2 + Oil^2 + Hydro^2 + Biomass^2 + Other^2}}{Total\ Primary\ Energy\ Demand}$$

Where the value of DoPED close to 1 indicates that the economy is reliant on one energy resource while a value close to zero (0) means that the energy sources in the economy are uniformly spread among several energy resources.

Vulnerability may be linked to strong energy import dependency i.e. it may also be linked to the high level of energy import value in GDP. It refers both to the quantity and cost of energy imports.

$$VI = \frac{EEI}{GDP}$$

where; EEI is expenditure on energy import and GDP is Gross Domestic Product.

$$EI = \frac{TPES}{GDP}$$

Where EI is Energy Intensity, TPES is Total Primary Energy Supply and GDP is Gross Domestic Product.

4. SCENARIOS DESCRIPTION

Three scenarios were studied: (i) Base case, (ii) renewable portfolio supply (RPS) case, and (iii) carbon tax case. Details of the scenarios are explained as follows.

4.1. Base Case

In this case, Pakistan GDP growth rate was assumed to grow at an annual growth rate of 7.0 percent and the growth rate of population was estimated at an annual growth rate of 1.9 percent based on the GDP and population data for the period of 2000-2013 [Pakistan (2006-07), World Economic Outlook Database (2008)].

Under the base case, the maximum available stock of fossil energy resource (e.g., coal, oil and petroleum products, and natural gas) was estimated as the sum of proven reserve of the resource, its probable reserve and its possible reserve. In the power sector, renewable energy options (hydro, wind, and solar), natural gas-based power plants as well as nuclear power plants were included in the model (see Appendix B). The options considered for the transportation sector include road, water and air transports.

4.2. Renewable Portfolio Supply Scenario

Renewable Energy Promotion is used to reduce emissions, promote local energy sources and improve energy security through reducing energy dependency and diversification of energy sources. To assess the effects of renewable portfolio supply (RPS), we implemented five different constraints and calculated energy security indicators for the whole planning horizon 2005-2050. The constraints are:

(a) **RPS10-** Total renewable based electricity generation is set to be 10 percent of total electricity generation (excluding large hydro) during period of 2005 to 2050.

(b) **RPS20-** Total renewable based electricity generation is set to be 20 percent of total electricity generation (excluding large hydro) during period of 2005 to 2050.

(c) **RPS30-** Total renewable based electricity generation is set to be 30 percent of total electricity generation (excluding large hydro) during period of 2005 to 2050.

(d) **RPS40-** Total renewable based electricity generation is set to be 40 percent of total electricity generation (excluding large hydro) during period of 2005 to 2050.

(e) **RPS50-** Total renewable based electricity generation is set to be 50 percent of total electricity generation (excluding large hydro) during period of 2005 to 2050.

4.3. Carbon Tax Scenario

Carbon tax is an indirect policy option for energy security enhancement through emission reduction. Imposing tax on carbon emissions will alter the primary energy supply mix, more efficient fuel and technologies will be substituted for less efficient fuel and technologies. This will reduce the primary energy demand and lead to improved energy security. To assess the effects of carbon tax on energy security, we implemented different constraints in the model. The constraints are:

(a) **CO_2-10-** Impose a tax of 10US$/t$CO_2$ until 2050.
(b) **CO_2-15-** Impose a tax of 15US$/t$CO_2$ until 2050.
(c) **CO_2-20-** Impose a tax of 20US$/t$CO_2$ until 2050.
(d) **CO_2-25-** Impose a tax of 25US$/t$CO_2$ until 2050.
(e) **CO_2-30-** Impose a tax of 30US$/t$CO_2$ until 2050.

5. ANALYSIS OF THE BASE CASE

Energy system development of Pakistan during the planning horizon of 2005–2050 under the base case is discussed as follows:

5.1. Primary Energy Supply in the Base Case

As can be seen from Figure 3, the primary energy supply in the base case under the renewable portfolio supply scenario shows an increasing trend over the whole planning horizon 2005–2050 indicating the rising energy supply and per capita energy availability. The primary energy supply in Pakistan is found to increase from 2475 PJ in 2005 to 35,559 PJ in 2050. Results from model simulation show that oil and gas are the major parts of primary energy supply in the base case, while coal and renewables are also contributing to primary energy supply. Over the time, primary energy supply mix is changed and the cheap resources (renewables and coal) dominate the primary energy supply mix.

As can be seen from Figure 4, the primary energy supply in the base case under the carbon tax scenario shows an increasing trend over the whole planning horizon 2005–2050. The primary energy supply is estimated to increase from 2475 PJ in 2005 to 22,684 PJ in 2050. Results from model simulation show that oil and gas have major contribution to primary energy supply in the base case, while coal and renewables are also contributing to primary energy supply. Over the time, primary energy supply mix is changed and the cheap resources (renewables) and oil dominate the primary energy supply mix.

Sector wise fuel consumption in both scenarios is presented in Figure 5 and Figure 6. In the renewable portfolio supply scenario, industrial sector, residential sector and transport sector dominate the sectoral fuel consumption in 2005, while the shares of industrial sector and transport sector have increased considerably while the share of residential sector has declined in 2050. Similarly under carbon tax scenario, transport sector holds the largest share in the sector wise fuel consumption followed by industrial sector and residential sector in 2005, while the share of residential sector has declined and shares of transport sector and industrial sector have grown significantly in 2050.

Fig. 3. Primary Energy Supply in Renewable Portfolio Supply Scenario in Base Case

(PJ)

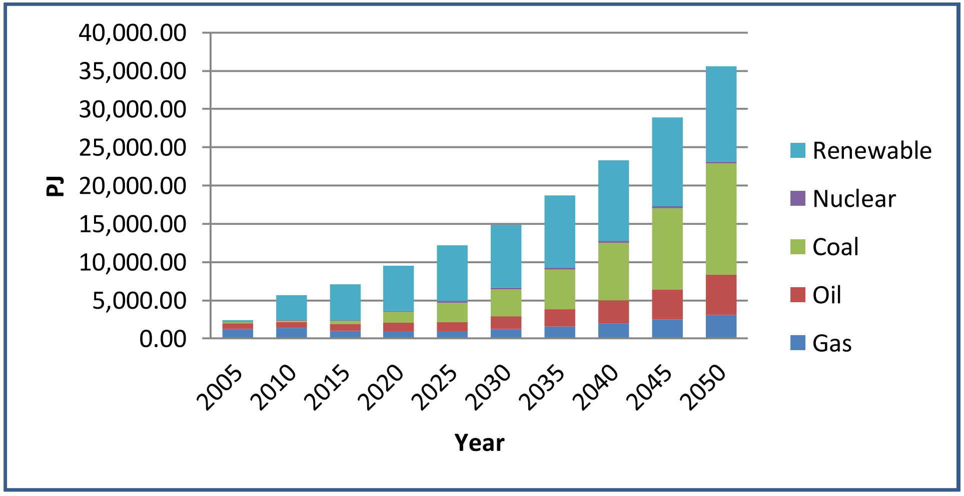


Fig. 4. Primary Energy Supply in Carbon Tax Scenario in Base Case

(PJ)

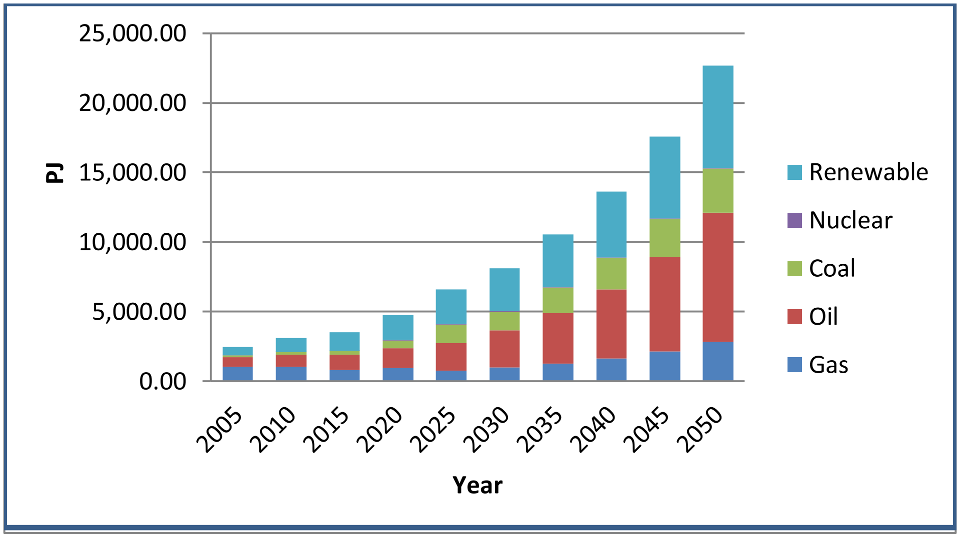


Fig. 5. Sectoral Energy Consumption in Renewable Portfolio Supply Scenario (Percentage Share)

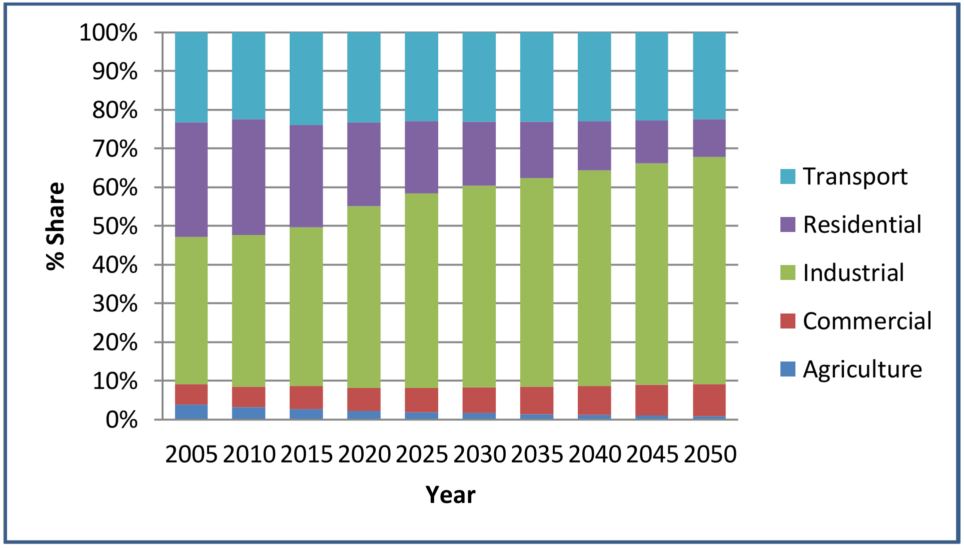
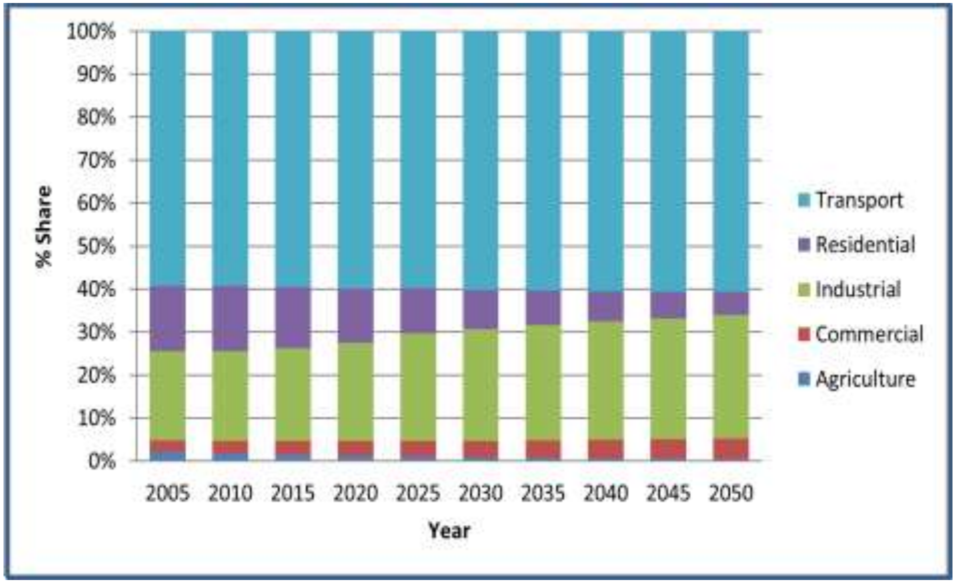


Fig. 6. Sectoral Energy Consumption in Carbon Tax Scenario (Percentage Share)



5.2. Results and Discussion

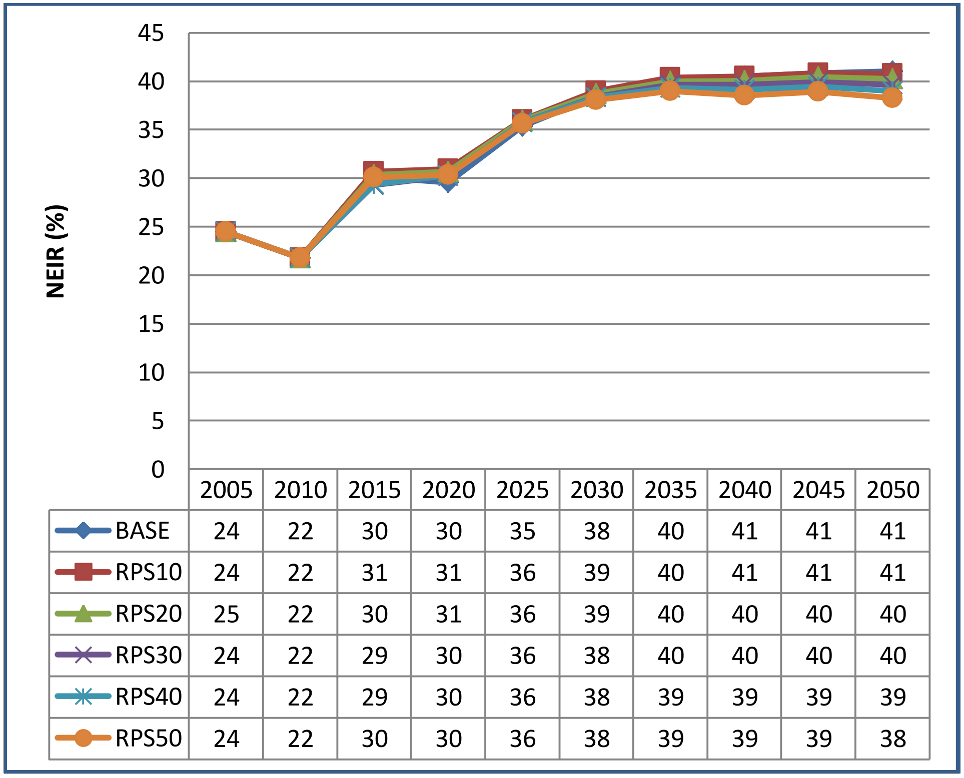
5.2.1. *Energy Security under Renewable Portfolio Supply and Carbon Tax Scenarios*

For the classification of policy options for the improvement of energy security of Pakistan, we imposed five different types of Renewable Portfolio Supply and Carbon Tax constraints (These constraints are briefly explained in section-4.2 and 4.3) in the MARKAL model for Pakistan. On the basis of these constraints, we analysed import dependency, diversification of energy resources, vulnerability, and energy intensity for the whole planning horizon.

5.2.1.1. *Energy Import Dependency under Renewable Portfolio Supply and Carbon Tax Scenario*

Energy Import Dependency is one of the key aspects of energy security that can be calculated as a percentage of net energy imports in total primary energy supply. Energy security indicator based on net energy import ratio (NEIR) is shown in Figure 7 and Figure 8. As can be seen from Figure 7, the net energy imports from the rest of the world indicated by NEIR would increase from 24 percent in 2005 to 41 percent in 2050 under renewable portfolio supply scenario indicating higher energy import dependency, but as more renewable energy resources are exploited and enter in the energy system, the energy import dependency decreases from 41 percent in base case to 38 percent in RPS50 scenario, which is a considerable reduction in energy import dependency. The main factor behind the reduction of energy import dependency is the share of renewable resources based electricity generation in the total electricity generation, which increases significantly as compared to the base case and that is a signal towards energy security improvement in Pakistan.

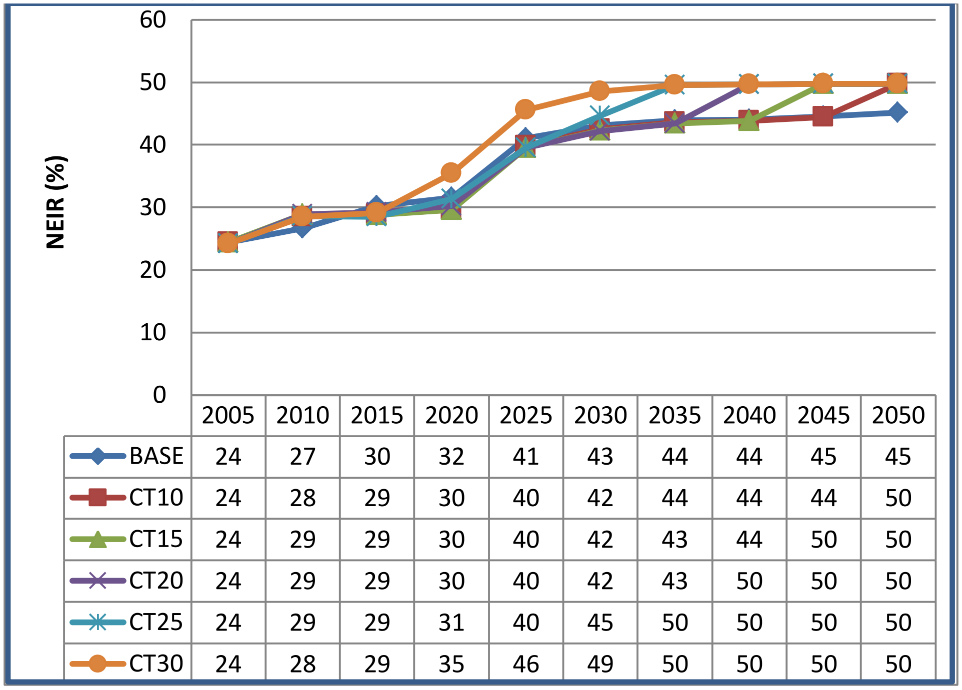
Fig. 7. Import Dependency under Renewable Portfolio Supply Scenario



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
◆ BASE	24	22	30	30	35	38	40	41	41	41
■ RPS10	24	22	31	31	36	39	40	41	41	41
▲ RPS20	25	22	30	31	36	39	40	40	40	40
× RPS30	24	22	29	30	36	38	40	40	40	40
✳ RPS40	24	22	29	30	36	38	39	39	39	39
● RPS50	24	22	30	30	36	38	39	39	39	38

On the other hand, energy import dependency under carbon tax scenario would increase from 24 percent in 2005 to 45 percent in 2050 as shown in Figure 8. Energy import dependency in carbon tax scenario has a mixed trend, but as more and more carbon tax is imposed, import dependency increases. The main reason behind the increased energy import dependency is the increased shares of imported oil in the primary energy supply in 2050 under carbon tax scenario.

Fig. 8. Import Dependency under Carbon Tax Scenario



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
BASE	24	27	30	32	41	43	44	44	45	45
CT10	24	28	29	30	40	42	44	44	44	50
CT15	24	29	29	30	40	42	43	44	50	50
CT20	24	29	29	30	40	42	43	50	50	50
CT25	24	29	29	31	40	45	50	50	50	50
CT30	24	28	29	35	46	49	50	50	50	50

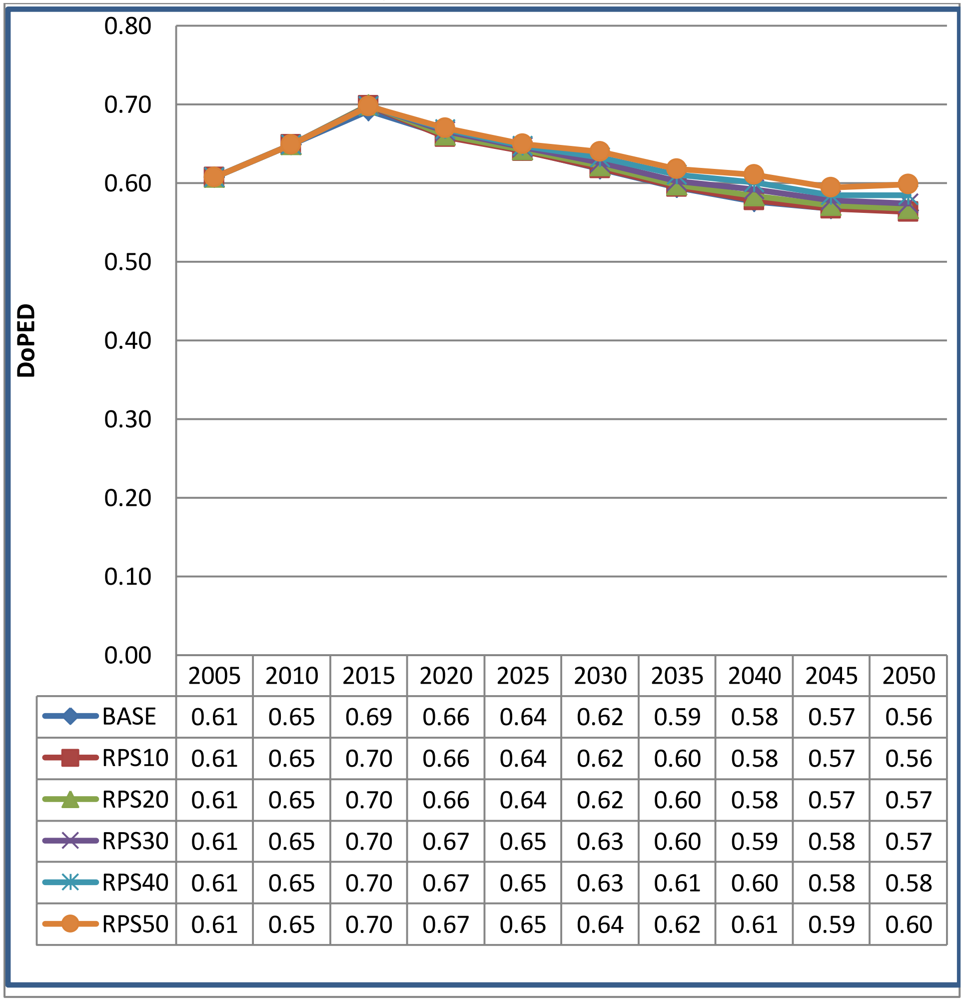
5.2.1.2. *Diversification under Renewable Portfolio Supply and Carbon Tax Scenario*

Diversification of primary energy sources is another important factor of energy security. DoPED and Shannon-Wiener Index (SWI) illustrate the diversification of the primary energy supply mix of the future energy system. As can be seen from Figure 9, the value of DoPED drops from 61 percent in the 2005 to 56 percent in 2050 in the base case implying better diversification among different energy resources under the renewable portfolio supply scenario. Diversification decreases up to 2015 and then in the long run, it increases up to 2050 in all renewable portfolio supply scenarios. On the other hand, diversification under carbon tax scenario reflected somewhat mixed trend (Figure 10). First, diversification of energy resources improves up to 2025 in the base case and then it deteriorates up to 2050. While in case of all carbon tax scenarios, diversification improves up to 2035 and then starts to deteriorate up to 2050.

Diversification can also be examined through Shannon-Wiener Index (SWI); higher value of SWI implies better diversification among different energy resources. Figure 11 and Figure 12 depicts the model simulated values for SWI under the renewable portfolio supply and carbon tax scenarios. As can be seen from Figure 11, the value of SWI increases from 51 percent in the 2005 to 55 percent in 2050 in the base case implying better diversification among different energy resources under the renewable portfolio supply scenario. Diversification index does not perform well up to 2015 and then in the long run, it shows improved performance up to 2050 in all renewable portfolio supply scenarios. On the other hand, diversification under carbon tax scenario demonstrates a mixed trend in different time periods (Figure 12). First, diversification of energy resources improves up to 2025 in the base case and then it drops up to 2050. While in case of all carbon tax scenarios, diversification shows better performance up to 2035 and then starts to worsen up to 2050.

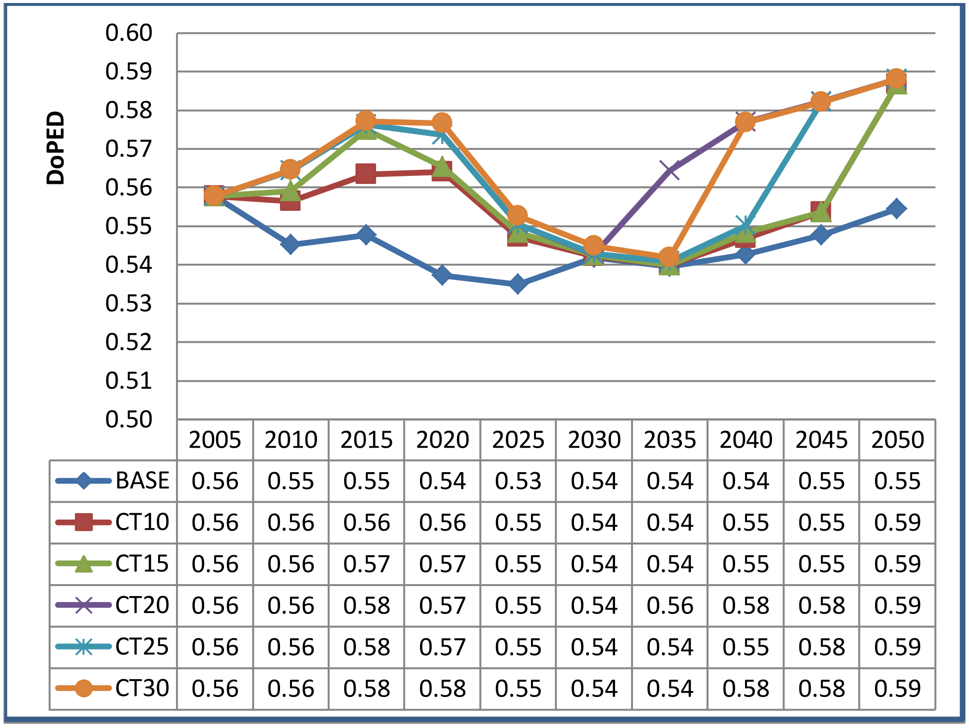
Both the indices ultimately imply better diversification of energy resources by 2035 as compared to 2005 that leads to energy security improvement in Pakistan by 2035.

Fig. 9. Diversification of Energy Resources under Renewable Portfolio Supply Scenario



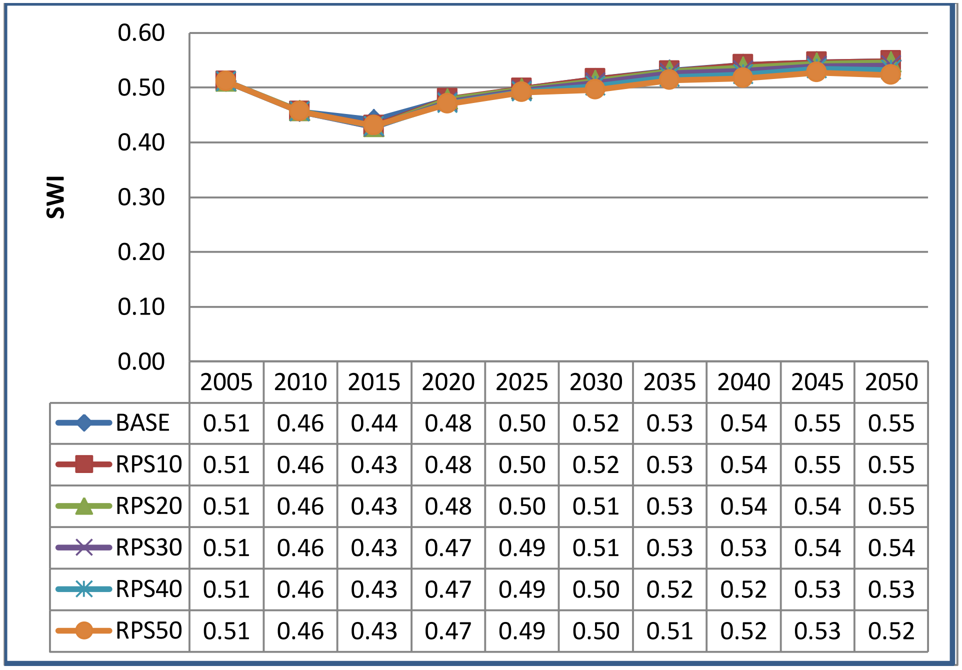
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
◆ BASE	0.61	0.65	0.69	0.66	0.64	0.62	0.59	0.58	0.57	0.56
■ RPS10	0.61	0.65	0.70	0.66	0.64	0.62	0.60	0.58	0.57	0.56
▲ RPS20	0.61	0.65	0.70	0.66	0.64	0.62	0.60	0.58	0.57	0.57
× RPS30	0.61	0.65	0.70	0.67	0.65	0.63	0.60	0.59	0.58	0.57
✳ RPS40	0.61	0.65	0.70	0.67	0.65	0.63	0.61	0.60	0.58	0.58
● RPS50	0.61	0.65	0.70	0.67	0.65	0.64	0.62	0.61	0.59	0.60

Fig. 10. Diversification of Energy Resources under Carbon Tax Scenario



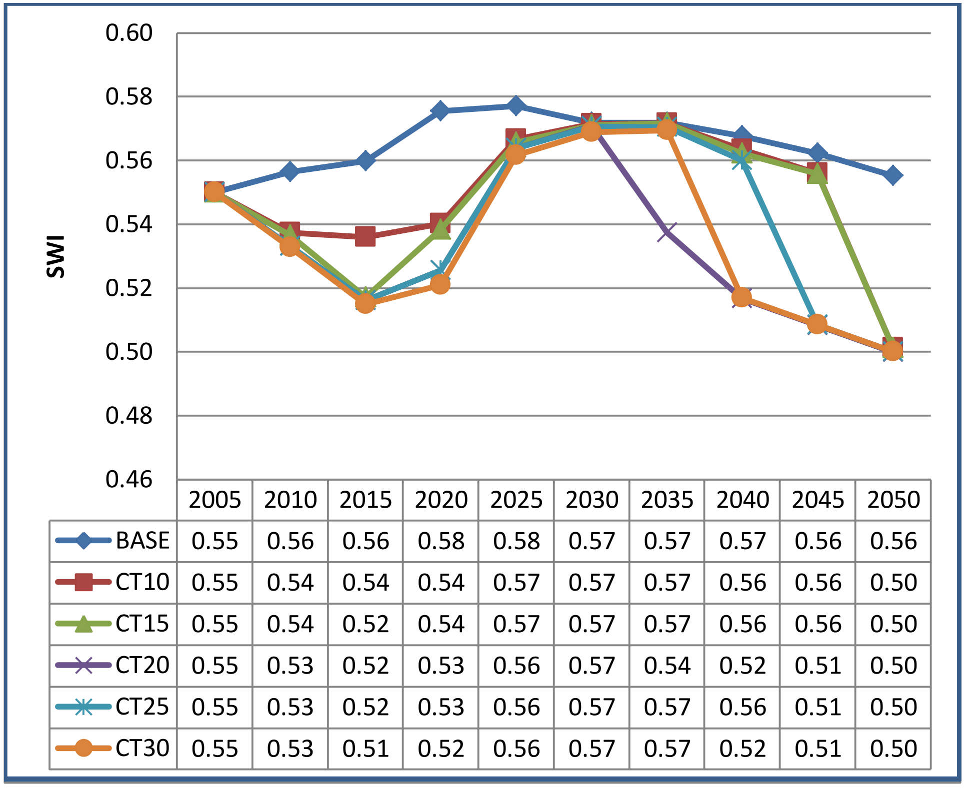
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
◆ BASE	0.56	0.55	0.55	0.54	0.53	0.54	0.54	0.54	0.55	0.55
■ CT10	0.56	0.56	0.56	0.56	0.55	0.54	0.54	0.55	0.55	0.59
▲ CT15	0.56	0.56	0.57	0.57	0.55	0.54	0.54	0.55	0.55	0.59
× CT20	0.56	0.56	0.58	0.57	0.55	0.54	0.56	0.58	0.58	0.59
✳ CT25	0.56	0.56	0.58	0.57	0.55	0.54	0.54	0.55	0.58	0.59
● CT30	0.56	0.56	0.58	0.58	0.55	0.54	0.54	0.58	0.58	0.59

Fig. 11. Diversification of Energy Resources under Renewable Portfolio Supply Scenario



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
◆ BASE	0.51	0.46	0.44	0.48	0.50	0.52	0.53	0.54	0.55	0.55
■ RPS10	0.51	0.46	0.43	0.48	0.50	0.52	0.53	0.54	0.55	0.55
▲ RPS20	0.51	0.46	0.43	0.48	0.50	0.51	0.53	0.54	0.54	0.55
× RPS30	0.51	0.46	0.43	0.47	0.49	0.51	0.53	0.53	0.54	0.54
✳ RPS40	0.51	0.46	0.43	0.47	0.49	0.50	0.52	0.52	0.53	0.53
● RPS50	0.51	0.46	0.43	0.47	0.49	0.50	0.51	0.52	0.53	0.52

Fig. 12. Diversification of Energy Resources under Carbon Tax Scenario



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
BASE	0.55	0.56	0.56	0.58	0.58	0.57	0.57	0.57	0.56	0.56
CT10	0.55	0.54	0.54	0.54	0.57	0.57	0.57	0.56	0.56	0.50
CT15	0.55	0.54	0.52	0.54	0.57	0.57	0.57	0.56	0.56	0.50
CT20	0.55	0.53	0.52	0.53	0.56	0.57	0.54	0.52	0.51	0.50
CT25	0.55	0.53	0.52	0.53	0.56	0.57	0.57	0.56	0.51	0.50
CT30	0.55	0.53	0.51	0.52	0.56	0.57	0.57	0.52	0.51	0.50

5.2.1.3. *Vulnerability and Energy Intensity under Renewable Portfolio Supply and Carbon Tax Scenario*

The energy security indices NEIR, SWI, and DoPED quantify the physical availability of primary energy supply to the economy ignoring the monetary significance of energy imports. To capture the economic significance of energy imports, we used vulnerability index.

As can be seen from Figure 13, vulnerability under renewable portfolio supply scenario shows a declining trend up to 2020 and then reflects rising trend up to 2050 in the base case as the amount of imports in the total primary energy increase over the time. Under all renewable supply portfolio scenarios, vulnerability index exhibits the increasing trend, however, it declines as more and more renewable energy enters into the system over time. The declining behaviour of vulnerability index (Figure 13) implies that vulnerability will decrease in the long run as compared to short run in all cases that will lead to enhanced energy security of Pakistan under the renewable portfolio supply scenarios.

Under carbon tax scenario, vulnerability decreases up to 2020 in base case as well as in all carbon tax scenarios and then it increases up to 2050 (Figure 14). The main reason for increasing vulnerability is the rising shares of energy imports from the Middle East.

The other energy security indicator such as energy intensity (Figure 15 and Figure 16) is a measure of the energy efficiency of an economy. It is calculated as units of energy per unit of GDP. High energy intensities indicate a high price or cost of converting energy into GDP and low energy intensity indicates a lower price or cost of converting energy into GDP. In case of renewable portfolio supply scenario, energy intensity has a rising trend showing economic inefficiency in the base case (Figure 15), while energy intensity decreases with the inclusion of renewable energy in the system that reflects economic efficiency of the energy system under all renewable portfolio supply scenarios. This is an indication of energy security enhancement in the renewable portfolio supply scenarios.

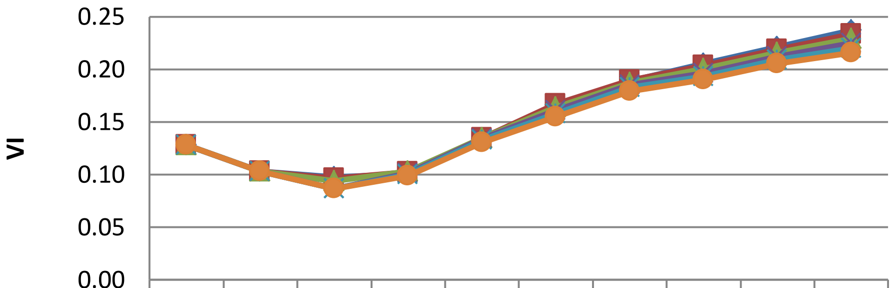
In case of carbon tax scenario (Figure 16), energy intensity decreases up to 2020 in the base case, which is a sign of economic efficiency as more efficient technologies are put in place under carbon tax scenario and after 2020, energy intensity shows a mixed trend up to 2050 in the base case as well as in all carbon tax scenarios.

5.2.1.4. *Green House Gases Emission under Renewable Portfolio Supply and Carbon Tax Scenario*

Environmental emissions are decomposed into green house gases emissions e.g. CO_2, CH_4 CO, SO_2, NO_x, and PM_{10}. According to Figure 17, total cumulative green house gases emissions decrease from 165 million tons in base case to 151 million ton in RPS50 scenario i.e. there is 9 percent reduction in green house gases emissions under renewable portfolio supply scenario, which is quite significant. As can be seen from Figure 18, total cumulative greenhouse gases emissions is reduced from 72 million tons in base case to 19 million ton in CT30 scenario, which is a significant reduction in greenhouse gases emissions under carbon tax scenario.

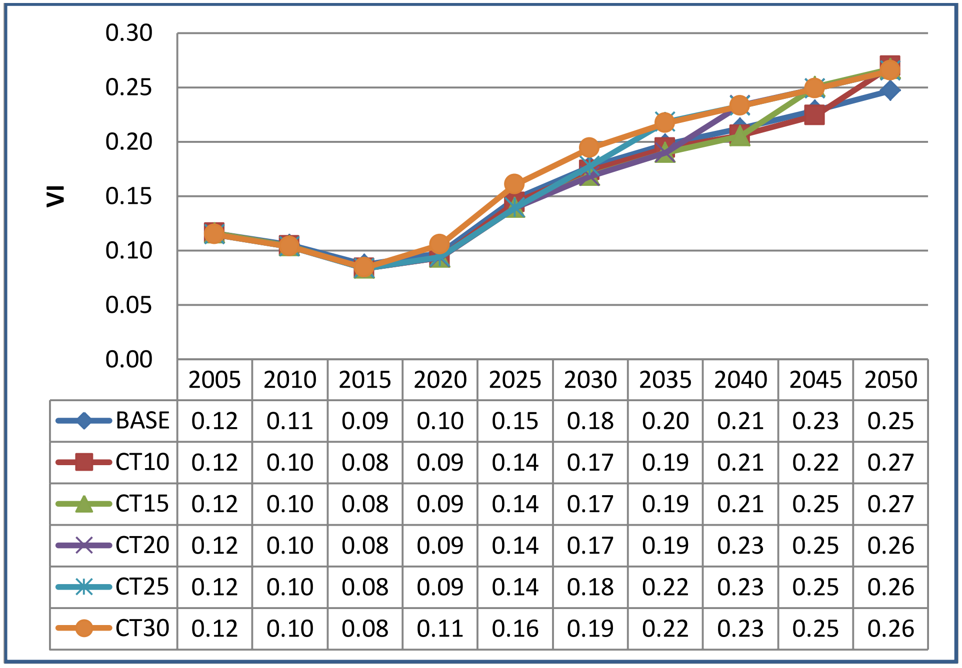
All these facts imply that renewable portfolio supply and carbon tax policies can be used as combined policy options for the enhancement of energy security in case of Pakistan.

Fig. 13. Vulnerability under Renewable Portfolio Supply Scenario



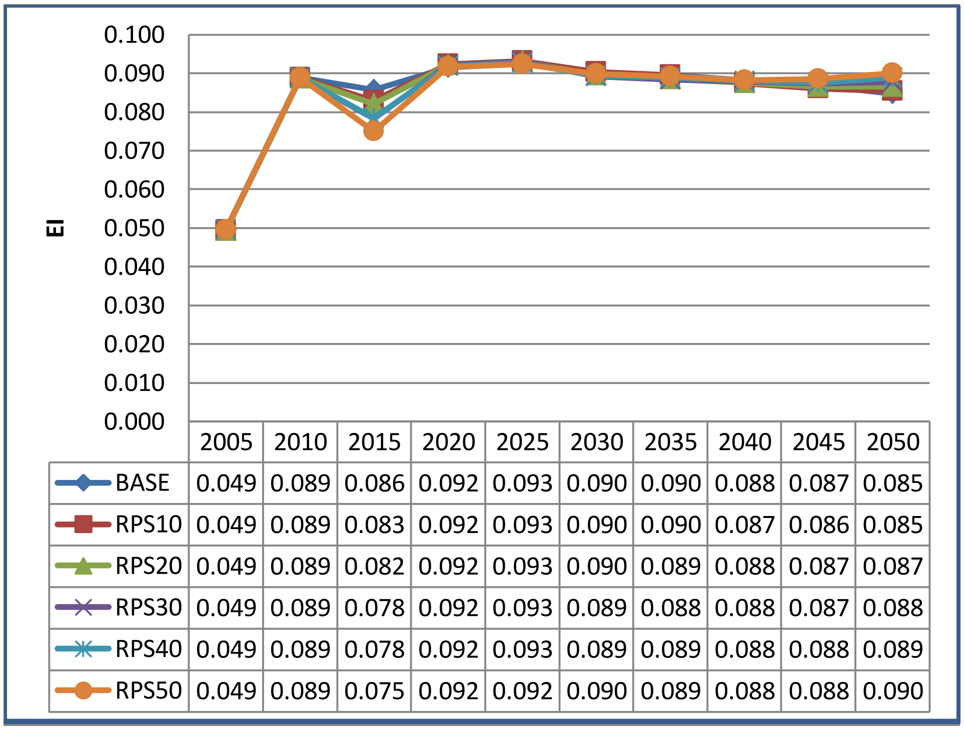
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
◆ BASE	0.13	0.10	0.10	0.10	0.13	0.17	0.19	0.21	0.22	0.24
■ RPS10	0.13	0.10	0.10	0.10	0.13	0.17	0.19	0.20	0.22	0.23
▲ RPS20	0.13	0.10	0.09	0.10	0.13	0.16	0.19	0.20	0.22	0.23
× RPS30	0.13	0.10	0.09	0.10	0.13	0.16	0.19	0.20	0.21	0.22
✳ RPS40	0.13	0.10	0.09	0.10	0.13	0.16	0.18	0.19	0.21	0.22
● RPS50	0.13	0.10	0.09	0.10	0.13	0.16	0.18	0.19	0.21	0.22

Fig. 14. Vulnerability under Carbon Tax Scenario



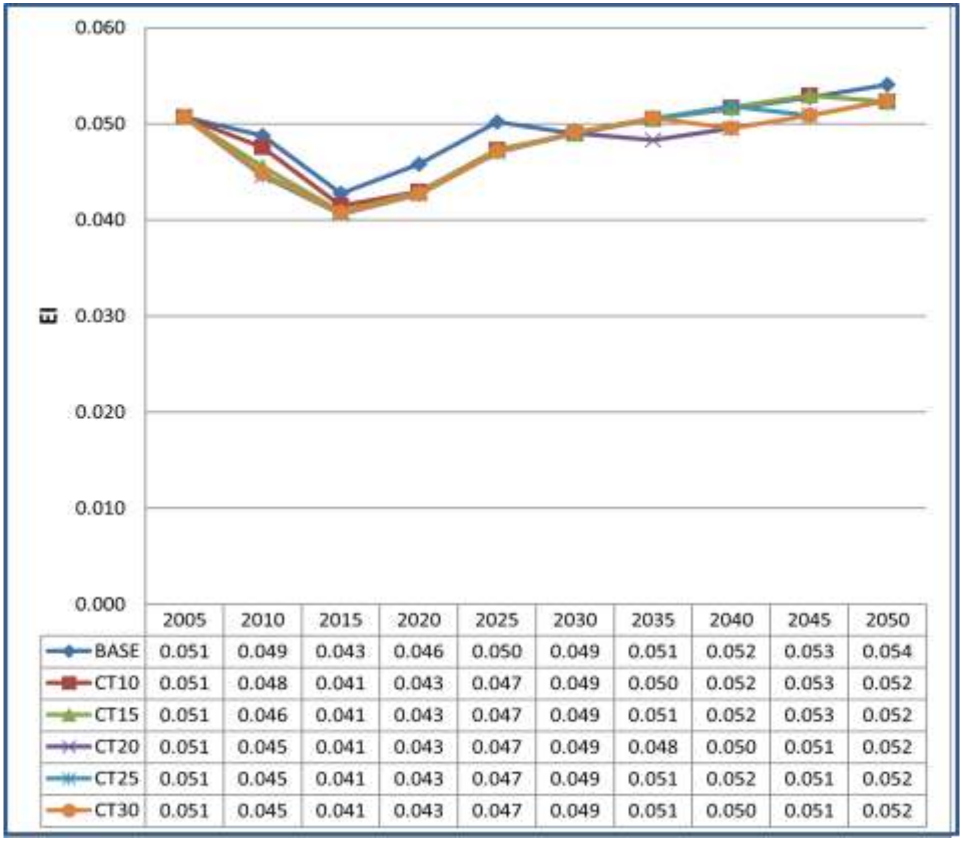
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
BASE	0.12	0.11	0.09	0.10	0.15	0.18	0.20	0.21	0.23	0.25
CT10	0.12	0.10	0.08	0.09	0.14	0.17	0.19	0.21	0.22	0.27
CT15	0.12	0.10	0.08	0.09	0.14	0.17	0.19	0.21	0.25	0.27
CT20	0.12	0.10	0.08	0.09	0.14	0.17	0.19	0.23	0.25	0.26
CT25	0.12	0.10	0.08	0.09	0.14	0.18	0.22	0.23	0.25	0.26
CT30	0.12	0.10	0.08	0.11	0.16	0.19	0.22	0.23	0.25	0.26

Fig. 15. Energy Intensity under Renewable Portfolio Supply Scenario



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
BASE	0.049	0.089	0.086	0.092	0.093	0.090	0.090	0.088	0.087	0.085
RPS10	0.049	0.089	0.083	0.092	0.093	0.090	0.090	0.087	0.086	0.085
RPS20	0.049	0.089	0.082	0.092	0.093	0.090	0.089	0.088	0.087	0.087
RPS30	0.049	0.089	0.078	0.092	0.093	0.089	0.088	0.088	0.087	0.088
RPS40	0.049	0.089	0.078	0.092	0.093	0.089	0.089	0.088	0.088	0.089
RPS50	0.049	0.089	0.075	0.092	0.092	0.090	0.089	0.088	0.088	0.090

Fig. 16. Energy Intensity under Carbon Tax Scenario



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
BASE	0.051	0.049	0.043	0.046	0.050	0.049	0.051	0.052	0.053	0.054
CT10	0.051	0.048	0.041	0.043	0.047	0.049	0.050	0.052	0.053	0.052
CT15	0.051	0.046	0.041	0.043	0.047	0.049	0.051	0.052	0.053	0.052
CT20	0.051	0.045	0.041	0.043	0.047	0.049	0.048	0.050	0.051	0.052
CT25	0.051	0.045	0.041	0.043	0.047	0.049	0.051	0.052	0.051	0.052
CT30	0.051	0.045	0.041	0.043	0.047	0.049	0.051	0.050	0.051	0.052

Fig. 17. Green House Gas Emission under Renewable Portfolio Supply Scenario

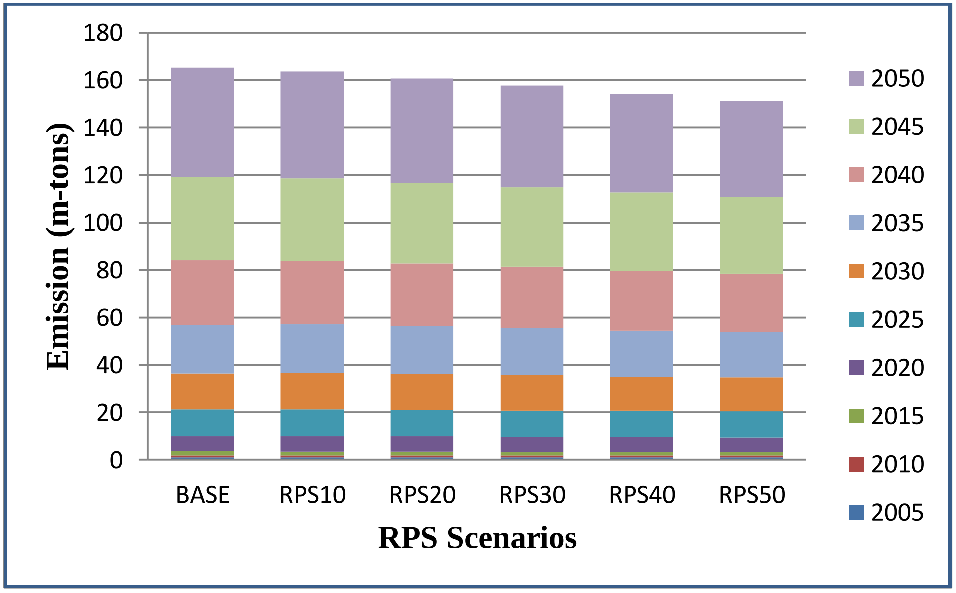
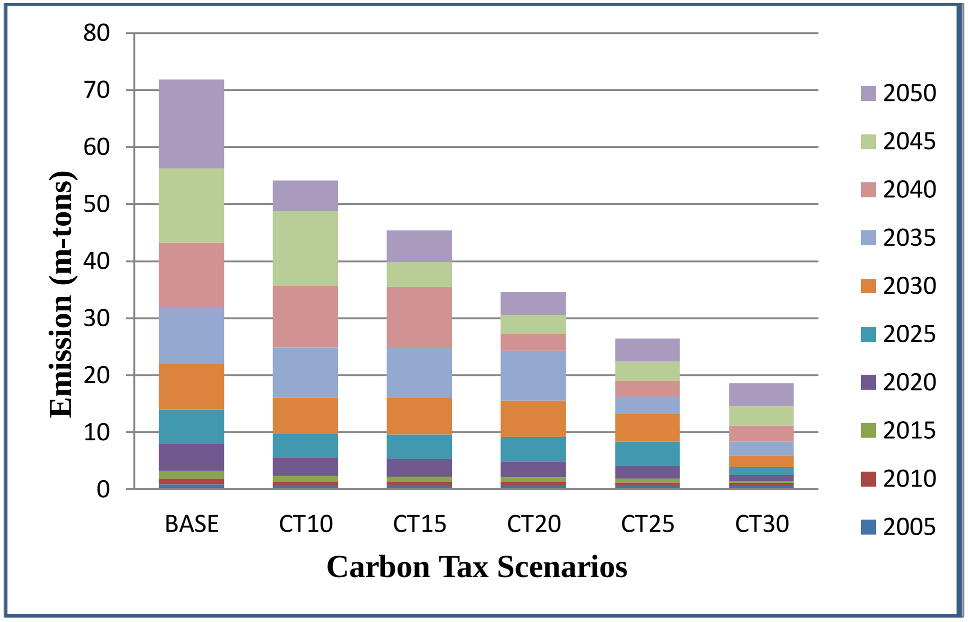


Fig. 18. Green House Gas Emission under Carbon Tax Scenario



6. CONCLUSIONS

This paper investigates the effects of renewable supply portfolio and carbon tax policies on diversification of energy resources, technology mix in energy supply side and demand side; energy efficiency and energy conservation; and energy security during the planning horizon 2005-2050. A MARKAL-based model for an integrated energy system of Pakistan was developed for this cause.

Renewable Portfolio Supply (RPS) is an important policy option to improve energy security. Renewable energy promotion is used to reduce emission, promote local energy sources and improve energy security through reducing energy dependency and diversification of energy sources. As more renewable energy resources are exploited and entered into the energy system, the energy import dependency decreases by 3 percent in RPS50 scenario, which is a considerable reduction in energy import dependency. Diversification of primary energy sources measured through DoPED and Shannon-Wiener Index (SWI) demonstrate 5 percent increase in diversification of the primary energy supply mix of the future energy system. Declining vulnerability and intensities in RPS Scenarios reflect enhanced energy security in long run. All the energy security indicators reflect better position under renewable portfolio supply scenarios; therefore Renewable Portfolio Supply (RPS) is a suitable policy option for energy security improvement in the long term in case of Pakistan.

Carbon tax is an indirect policy option for energy security enhancement through emission reduction. Imposing tax on carbon emission will alter the primary energy supply mix, more efficient fuel and technologies will be substituted for less efficient fuel and technologies. This will reduce the primary energy demand and lead to improved energy security. Under carbon tax, import dependency has reflected an increasing trend, while diversification of energy resources, vulnerability and energy intensity show better energy security up to 2035. Therefore Carbon Tax Policy may be a suitable policy option for energy security improvement in the long term.

Under Renewable Portfolio Supply (RPS) and Carbon Tax scenarios, Green House Gases (GHG) emissions are reduced by 9 percent, which is a significant reduction. This reduction in GHG emission is a sign of environmental security. So these two policy options not only enhance energy security, but also ensure environmental security.

Appendices

APPENDIX-A

End-use Demand Technologies

Sector		**End-use Demand Technologies**
Agriculture		Tractors and Electric Motors
Commercial		AC, Lighting, Refrigerators, Thermal Use and Other Electric Appliances
Industrial		Cement, chemical, electricity, equipment, food, paper, steel, sugar, textile, others.
Residential		Air-conditioning, cooking, fan, iron, lighting, refrigerator, TV and other electric appliances.
Transport	Air Passenger	Air plane
	Air Freight	Air Plane
	Water Freight	Ship
	Rail Passenger	Locomotive rail
	Rail Freight	Locomotive rail
	Road Passenger	Car, bus, van, pickup, taxi, three-wheelers, two-wheelers
	Road Freight	Trucks, Tankers, Pickups

APPENDIX-B

Conversion Technologies

Technology	**Fuel Type**
Power Generation	
Hydro	
a) Hydro	Reservoir
b) Hydro	Canal
Fossil Fuels	
a) Fluidised bed combustion(FBC)	Coal
b) Gas Turbine	Gas and HSD
c) Combine Cycle	Gas and HSD
d) Gas Turbine	Gas
e) Steam	Dual Fuel Combustion (Gas + FO)
f) Oil Fired	Fuel Oil
g) Gas Turbine Combine Cycle	Gas and FO fired Gas and HSD oil Fired
Nuclear	
a) Nuclear Power Plant	Uranium
Renewable	
Solar Photovoltaic, Solar Thermal, Wind Turbine, Mini Hydro	
Process Technologies	
a) Oil refinery	Crude Oil
b) Gas Processing Plant	Natural Gas

APPENDIX-C

Model Formulation

Objective Function of the Integrated Energy System Cost Model

The objective function is the sum over all of the discounted present value of the stream of annual costs incurred in each year of the horizon (no reference for this?). Therefore:

$$NPV = \sum_{r=1}^{R}\sum_{t=1}^{t=NPER}(1+d)^{NYRS.(1-t)}.ANNCOST(r,t).(1+(1+d)^{-1}+(1+d)^{-2}+\cdots+(1+d)^{1-NYRS} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where, *NPV* is the net present value of the total cost for all regions, *ANNCOST(r, t)* is the annual cost in region *r* for period *t*, *d* is the general discount rate, *NPER* is the number of periods in the planning horizon, *NYRS* is the number of years in each period *t*, *R* is the number or regions.

In order to minimise total discounted cost, the MARKAL model must satisfy a number of constraints. These constraints show the physical and logical relationships to describe the associated energy system.

(a) Satisfaction of Energy Service Demands

For each time period *t*, region *r*, demand *d*, the total activity of end-use energy technologies must be at least equal to the specified demand. Hence:

$$\sum_{k}^{all\ d} CAP(r,t,k) \geq D(r,t,d) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where *CAP*(*r*, *t*, *k*) is the installed capacity of technology *k*, in period *t*, in region *r*, *D*(*r*, *t*, *d*) is the energy demand for end-use *d* in region *r*, in period *t*.

(b) Use of Capacity

In each time period, the model may use some or all of the installed capacity according to the technology availability factor (AF) i.e. the model may utilise *less* than the available capacity during certain time-slices, or even throughout one whole period. Therefore, the activity of the technology may not exceed its available capacity.

$$ACT(r,t,k,s) \leq AF(r,t,k,s)\ CAP(r,t,k) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where *ACT*(*r*, *t*, *k*, *s*) is the activity level of energy technology *k*, in period *t*, in region *r*, for time slice *s*, *AF*(*r*, *t*, *k*, *s*) is the availability parameters.

(c) Demand-Supply of Energy Balance

For each commodity *c*, time period *t*, region *r*, this constraint requires that the disposition of each commodity may not exceed its supply.

$$\sum_k Output(r,t,k,c)\ ACT(r,t,k,s) + \sum_l MINING(r,t,c,l) + \sum_l FR(s)IMP(r,t,c,l)$$
$$\geq \sum Input(r,t,k,c)ACT(r,t,k,c,s) + \sum_l FR(s)\ EXP(r,t,c,l) \quad \ldots \quad (4)$$

where *Output*(r, t, k, c) is the amount of energy commodity c, produced per unit of technology k in region r in period t, *MINING*(r, t, c, l) is the quantity of energy commodity c extracted in region r at price level l in period t, *FR*(s) is the fraction of the year covered by time-slice s, *IMPORT*(r, t, c, l) is the quantity of energy commodity c, price level l, exogenously imported or exported by region r in period t, *Input*(r, t, k, c) is the amount of energy commodity c required to operate one unit of technology k, in region r and period t, *EXPORT*(r, t, c, l) is the quantity of energy commodity c, price level l, exogenously imported or exported by region r in period t.

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Energy Smart Buildings: Potential for Conservation and Efficiency of Energy

AJAZ AHMED

1. BACKGROUND

Energy is the basic ingredient for economic growth and development [Lorde, *et al.* (2010)]. Presently demand for energy has significantly increased due to the overall expansion of economic and industrial activity in all important economic sectors e.g. industry, agriculture, and services. In addition to the expansion of economic activity and subsequent increase in energy demand at industrial level, population growth and increased consumption are also adding to the demand for energy [OECD (2011)]. In other words, modern economy has become highly dependent on energy resources. In order to meet the increased energy demand and ensure its sustainable supply, there is a need to have strong and robust plans with all options to consider at various levels.

Pakistan is going through the severe energy crisis [Javaid, *et al.* (2011); Masood, *et al.* (2012)] which has seriously hampered the economic growth and development progress of the country. Aziz, *et al.* (2010) estimated that, due to power shortages in the industrial sector alone, the loss was over $3.8 billion in 2009 that was approximately 2.5 percent of the gross domestic product (GDP). Therefore, it is crucial to resolve the present energy crisis to avoid the further economic problems and social unrest in the country. In order to manage the present energy crisis, concerned departments and agencies are trying to reduce the current shortfall. There are two sets of strategies, which are being used by the authorities; demand management and production expansion.

In this context, potential of energy conservation cannot be neglected as it can yield significant results in demand management. One important avenue of energy conservation is buildings, where large amount of energy can be conserved to achieve the energy conservation and efficiency. Buildings consume a lot of energy especially in heating and cooling systems. This consumption can be reduced by modifying the building structures and making them energy smart. Because energy smart buildings have relatively reduced energy demand and more energy efficiency, which can play a vital role in achieving the goal of energy conservation.

Around the world countries have adopted energy conservation policies in buildings, for instance Dutch government aims at reducing the energy use by 50 percent in the existing housing stock by 2020 [Hoppe, *et al.* (2011)]. Similarly European Union

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has the goal to reduce 20 percent of the total building energy consumption by 2020 [European Commission (2011)]. The European Commission also estimated that the energy saving potential for residential and commercial buildings is up to 30 percent [European Commission (2006)].

It has also been estimated that the energy smart buildings can save 30 percent or even more in energy costs over a conventional building designed [Zainordin, *et al.* (2012)]. Present research aims to investigate the energy conservation and efficiency potential of energy smart buildings, their monetary benefits, and likely impact of improved thermal performance to increase the energy in the light of government's proposed conservation strategies and building energy code of Pakistan.

2. DATA AND METHODOLOGY

2.1. Data

Data for the present research was collected from two sources. One source is National Energy Conservation Centre (ENERCON), which is an organisation that deals with energy conservation at domestic as well as commercial level in Pakistan. Second source is UN-HABITAT guidelines on energy efficient housing, which was formulated by UN-HABITAT along with the Ministry of the Environment Pakistan, ENERCON, and the Capital Development Authority Islamabad Pakistan. These guidelines are specifically about the improved rooftop thermal performance and its potential for conservation of energy. This data was generated from an experiment, which was conducted on few houses of Islamabad.

2.2. Methodology

Present research is a policy paper which highlights the importance, scope, and potential of energy smart buildings in terms of energy saving and associated gains. Study followed the descriptive analysis method to highlight the energy efficiency and conservation potential of energy smart buildings. Descriptive analysis is an approach that provides the simple summaries of the variables and their features in the form of Tables and graphs, which present data and information in such a way that any phenomena can easily be observed and analysed. With descriptive statistics we can simply describe what the data shows.

3. ENERGY CONSERVATION AND EFFICIENCY SYSTEMS

A building is classified in a number of energy systems presented in the following (Table 1). Each of these energy systems has the potential for energy efficiency and conservation that can be achieved by various ways such as; altering the designs and structures of the systems, introducing the new technologies, which are more energy efficient, and reducing the consumption of energy. In Pakistan, to date, no significant work has been done to adopt any of the aforementioned techniques to achieve the energy efficiency and conservation.

Table 1

Buildings Energy Systems
Building Envelope (Type, Geometry and Location)
Lighting
Heating, Ventilation and Air Conditioning
Mechanical and Electrical Systems
Service Water Heating

Source: ENERCON (2013).

Construction industry in Pakistan is still following the old traditional designs and structures, which are highly energy inefficient. This energy inefficiency is found in almost all systems ranging from building envelope, lighting, mechanical, to electrical systems. It increases the consumer demand for energy and subsequently puts burden on the energy supply sources. It is worthwhile to mention that government has the energy building code of Pakistan prepared in 2010 by a number of government departments, which deals with the energy and buildings. A significant amount of energy can be conserved by following the energy building code of Pakistan for new buildings. Moreover, UN-HABITAT guidelines can also be instrumental to improve the thermal performance of rooftops of traditional buildings.

4. POTENTIAL CONSERVATION AREAS

A number of areas of energy efficiency and conservation are presented in (Table 2) along with their efficiency and conservation potential. This possible energy conservation potential has been estimated by the ENERCON after identification of a number of potential areas. In this regard first prospective area in buildings is building envelope, which consists of building type, geometry, location, walls and roof specifications, and windows. Building envelope has 40 percent energy conservation potential, which means that almost 40 percent energy can be conserved or saved if standard building energy code is followed in buildings envelope.

Table 2

Potential Energy Conservation Areas

Conservation Areas	Saving Potential
Building Envelope	40%
Overall Lighting Potential	29%
High Efficiency Lighting (LEDs)	72%
Fluorescent Tube Ballasts	83%
Lamp Fixtures or Luminaries	50%
Air Conditioner	18%
Printer	19%
Heaters	17%
Copier	10%
Fan	5%
Computer	2%

Source: ENERCON (2013).

Next potential area of energy conservation and efficiency in buildings is lighting. Overall energy conservation potential of lighting is about 29 percent that means there is still lot of room for improvement and technological advancement in the area of lighting. Majority of the people still use the energy inefficient lights at domestic as well commercial level, which puts burden on energy demand as well as electricity bills.

Next area of energy saving potential is Air Conditioner (AC) usage which has increased with improved incomes and changed lifestyles. AC has 18 percent energy conservation potential, which means that use of inefficient AC is also putting burden on household energy demand that can be reduced by adopting the recommended technologies for energy efficient buildings. Heaters are a big source of energy inefficiency and losses, which can also be improved by adopting better technologies to reduce the demand of energy. Potential for energy conservation of heaters is approximately 17 percent that can be unleashed by choosing appropriate technologies. In the same way fans' energy conservation potential is 5 percent and computers' energy conservation potential is 2 percent.

Above presented Table of potential areas of energy conservation shows that these areas can contribute significantly to the energy demand management. In this regard energy smart buildings have great importance as their structure and design can yield lots of energy saving at domestic and commercial level.

5. SENSITIVITY ANALYSIS OF ENERGY CONSERVATION AND MONETARY SAVING

The energy conservation potential presented in preceding section (Table: 2) gives an idea of overall energy saving potential of energy smart buildings in terms of reduced consumption and demand. In order to translate the energy efficiency and conservation potential into monetary incentives, some extrapolations have been done by using few hypothetical values of electricity bills. The purpose of the exercise is to highlight the monetary savings, which can be generated from energy smart buildings.

Following (Table 3) presents the sensitivity analysis approach, which has been used to assess the monetary savings from energy conservation. Overall savings of aforementioned three potential energy conservation areas is 29 percent that means roughly 29 percent of the energy consumption can be reduced and saved. Therefore, same percentage of the energy cost can be saved in terms of electricity bills.

Table 3

Energy Conservation and Monetary Saving Sensitivity Analyses

Electricity Bills in Traditional Building	Monetary Value of 29% Energy Conservation	Electricity Bills in Energy Smart Building
1000	290	710
2000	580	1420
3000	870	2130
4000	1160	2840
5000	1450	3550

First column of Table 3 presents different hypothetical amounts of electricity bills of various dwelling units, which are traditional buildings. Second column illustrates the monetary savings in terms of reduction in electricity bills due to energy conservation potential of the energy smart buildings. And last column of the Table demonstrates the electricity bills of energy smart buildings and the amounts of bills in energy smart buildings are significantly less than those in the first column. Hence, this sensitivity analysis shows that energy smart buildings can yield the monetary savings, in addition to the energy conservation and efficiency.

6. IMPROVEMENT OF ROOFTOPS THERMAL PERFORMANCE

Improvement of rooftops thermal performance means maintaining the temperature inside the buildings by modifying the rooftops of the buildings. In building envelope, it is a useful method to conserve the energy. There are various techniques, which are used to improve the thermal performance of rooftops. The techniques are based on the application of different solutions on roofs. These techniques are divided into following categories; insulative techniques, reflective surface techniques, and radiant barrier techniques.

(a) Insulative Techniques

Insulative techniques are effective in maintaining heating and cooling both in summer and winter. These technologies reduce the heat transfer from the top by slowing down the conduction of heat. Following are the some of the insulative techniques, which have been tested and applied; stabilised mud (cement stabilisation), mud with high density styrofoam (thermo pole), brick tiles with stabilised mud, polystyrene (jumbolon) with plain concrete screed, concrete wizard insulating tiles, cellular light weight concrete (CLC) tiles, smart concrete tiles (aerated concrete with thermo pole used as sandwich between concrete layers), terrazzo mixed white apoxy with thermo pole sheet, fired clay extruded hollow tiles, and green netting.

(b) Reflective Techniques

These techniques are used to reflect the sun radiations and reduce the absorption of heat into the rooftops. According to technical guidelines [UN-HABITAT (2010)] reflection of the sun radiations depends upon the color of the slab. The reflective techniques, which are applied to reduce the heat of rooftops include; lime wash, white enamel paint, weather shield white paint, OCEVA-MOL chemical, aerosol heat reflective paint etc. It is advised that the surfaces must be cleaned frequently in order to attain maximum efficiency of the technologies. The durability of the reflective surfaces varies according to the conditions of weather and material reliability.

(c) Radiant Barrier Techniques (False Ceiling)

Radiant barrier techniques reflect the direct sun radiations. When the rooftops become hot, these technologies radiate the heat directly into the room below and a radiant barrier stop this heat from coming into the inside of the buildings. Radiant barrier is usually an additional layer of false ceiling provided underneath the roof to stop the heat from radiating into the building. The false ceiling may either absorb the heat, or play the role of reflection of the heat. According to the UN-HABITAT guidelines there should be an adequate and ventilated air gap between the slab and the radiant barrier to be most effective. Radiant barriers techniques consist of; gypsum board false ceiling, gypsum board with aluminum foil on the back, paper board false ceiling, and thermo pole false ceiling. These techniques can be used as a decorative finish and solutions are more appropriate if the room height is adequate.

7. REDUCED TEMPERATURE AND IMPROVED THERMAL PERFORMANCE

UN-HABITAT conducted an experiment on improvement of the rooftops thermal performance, in collaboration with Capital Development Authority (CDA), and ENERCON. The experiment was conducted on few selected households in Islamabad, where a number of thermal performance techniques were applied to examine the results in from of reduced temperature.

Analysis of the data on temperature changes due to the use of the technologies revealed that there is significant difference in temperature after the application of these solutions. Following Table 4 present the temperatures in control and treated scenarios. Control is the condition of temperature before the application of the solutions (insulation technologies were not applied) and treated is after the application of different solutions (insulation technologies were applied). The top highlighted row is of control condition that presents the normal temperature of the building inside before the use of any technology to improve the thermal performance.

Table 4

Reduced Temperature and Improvement in Thermal Performance

	Without Solution	**Temperature**
Control	Normal Temperature (Inside)	36.2
	Solution	
Treated	Stabilised mud	35.3
	Mud with thermo pole	33.6
	Brick tiles with stabilised mud	33.1
	Extruded Polystyrene (Jumbolon)	32.2
	Concrete wizard tiles	34.7
	Sachal CLC tiles	34.0
	Smart concrete tiles	33.7
	Munawar AC tiles	33.0
	Alnoor tile	34.1
	Green netting	35.1
	Lime wash	33.1
	Weather shield paint (white)	33.7
	White enamel paint	33.1
	Aerosol heat reflecting paint	34.2
	OCEVA-MOL chemical	34.7
	Gypsum board false ceiling	34.6
	Gypsum board with aluminum foil	34.9
	Paper board false ceiling	32.2
	Thermo pole false ceiling	34.4

Source: UN-HABITAT (2010).

After the treatment of the rooftops with different insulation techniques average temperature has significantly decreased. The temperature of the houses where insulation techniques were applied has decreased by 2 to 3 degrees, which is a significant change in temperature due to improved thermal performance. It is worthwhile to mention that this change in temperature has occurred only due to arrangements made for rooftops insulation. And if we apply the same techniques to the walls, the temperature may further reduce by enhancing the energy conservation and efficiency of the buildings.

1. Cost Estimates

In order to assess the efficiency and effectiveness of the improvement of rooftops thermal performance, per unit cost of the insulation material has been computed. Table 5 presents the initial costs of the each insulation technique used in enhancing the energy efficiency of the buildings. However, some of these techniques are relatively more cost effective than others. Moreover, suitability of the adoption of these technologies also depends on a number of factors such as; average temperature, nature of material and its life, type of rooftop, building type etc.

Table 5

Cost Estimates of Different Solutions

Solution	Initial Cost Rate/ Sft (PKR)
Stabilised mud	32
Mud with thermo pole	52
Brick tiles with stabilised mud	39
Extruded polystyrene (jumbolon)	76
Concrete wizard tiles	78
Sachal CLC tiles	80
Smart concrete tiles	70
Munawar AC tiles	80
Alnoor tile	81
Green netting	60
Lime wash	30
Weather shield paint (white)	80
White enamel paint	80
Aerosol heat reflecting paint	39
OCEVA-MOL chemical	35
Gypsum board false ceiling	44
Gypsum board with aluminum foil	45
Paper board false ceiling	22
Thermo pole false ceiling	30

Source: UN-HABITAT (2010).

Apparently the most economical insulation technique is paper board false ceiling (Rs 22 per square foot), and it is due to its material being relatively less expensive. On the other hand, paints insulation is the most expensive solution (Rs 80 per square foot) in above presented options for insulation to enhance the thermal performance of the rooftops. It is worth mentioning that the presented costs were estimated in 2010 and one may expect the effect of inflation due to increased material costs. However, because of lack of technical information the relative effectiveness of each technology could not be ascertained.

2. Benefits

Energy efficiency and conservation is undeniably a crucial business for domestic as well as commercial consumers. Following are some of the direct and indirect benefits of energy efficiency and conservation in energy smart buildings. The direct benefits of energy smart buildings are as follows; the reduced energy consumption and demand due to potential for conservation, monetary saving in terms of reduced electricity bills, and demand management. In addition to this there are a number of indirect benefits of energy smart buildings such as less carbon footprint due to reduced energy consumption.

In this way these buildings can qualify for carbon credits, as they are the source of reduction in carbon emissions and pollution. Moreover, due to reduced carbon emissions and exposure to extreme weather conditions energy smart buildings are environment and climate friendly or climate compatible.

3. Missing Link in National Housing Policy

National Housing Policy 2001 is the main document of government on housing sector in Pakistan. This housing policy provides detailed and comprehensive course of action based on strategies and guidelines on different aspects of housing. However, this document has not been revised since its formulation in 2001. Due to which the present issues and problems such as energy and climate change aspects are not reflected or could not receive adequate attention of the policy makers. Specifically, there are no policy guidelines in housing policy for newly constructed housing schemes on energy conservation and efficiency.

Although ENERCON has produced some guiding material but Ministry of Housing and Works Pakistan has no strategy for energy efficient housing. However in present energy crisis situation in Pakistan, there should be greater emphasis on energy efficient housing and it must be reflected in the national housing policy of Pakistan. Present research presents the policy recommendations in the following section, which can be instrumental to produce the guidelines for energy efficient housing.

8. CONCLUSION AND POLICY IMPLICATIONS

Present research concludes that a significant amount of energy can be conserved and saved if building structures are modified according to the standard policy guidelines for energy efficient or energy smart buildings. In Pakistan UN-HABITAT has developed the guidelines on building envelope in collaboration with Capital Development Authority and ENERCON to improve the thermal performance of already constructed houses. There are a number of insulation technologies, which have the potential to reduce inside temperature of the buildings by 2 to 4 C^0. Findings of the present research have revealed that insulation technologies are instrumental in improving the thermal performance of buildings. These technologies have the potential to maintain the temperature of the buildings. Use of such technologies helps in energy conservation and yields monetary saving in terms of reduced electricity bills. Lastly energy smart buildings play important role in reducing the carbon emissions and problems associated with emissions.

Following are some of the policy implication emerging from present analysis of energy smart buildings;

- There are standard guidelines on energy smart buildings formulated by relevant departments; however, there is lack of implementation due to a number of factors such as lack of information. In this regard awareness can play very important role.
- Rewards for conservation and efficiency of energy should be given in terms of reduced electricity bills to attract the people for energy conservation.
- Government should set the annual targets for energy conservation in buildings and prepare the action plan to achieve them.
- Media should promote the idea of energy smart buildings as it can play a crucial role in sensitising people about their responsibilities on energy conservation in buildings.
- Energy conservation and efficiency aspects and their effective implementation should be included into the construction bylaws.
- There should be strict criteria for monitoring of energy consumption in the domestic as well as commercial buildings to implement the guidelines on energy smart buildings.
- Energy efficient structures of the buildings should be encouraged by introducing the incentives for energy conservation in buildings. Moreover, violation of regulations and guidelines should be punished.
- Finally research should be encouraged on different energy systems within the buildings to promote the energy conservation.

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Comments

The idea is very interesting and if implemented then can help to overcome Pakistan energy crises.

(1) The issue is not properly introduced in the introduction. Further the argument is built without proper references support. After the first two paragraphs the author suddenly comes to the issue without giving the proper specific background.

(2) This is a policy paper and “Building Envelop” is suggested by the author. But in a developing country like Pakistan, where almost one third population is spending their lives on or below the poverty line, building envelop is not a good suggestion. This is a good suggestion but for a developed country.

(3) In a policy paper it is more important to know that how this policy will be implemented. The author suggested a policy but the implementation process is missing which is the only significance of a policy paper.

   (i) How the policy will be formulated and implemented?
   (ii) Who are the main stakeholders and how to deal the obstacles (if any) for the implementation?

(4) Annual shortage of energy (Difference of Demand and Supply of Energy) is not given.

(5) The source of Table 3 is missing. Whether the author has made his own calculations are this table is taken from sum source.

(6) The author claims that these buildings are environmental friendly but did not estimate or explained that how much it will benefit the environment in terms of CO_2 reduction etc.

(7) The author has not provided the cost benefit analysis of the phenomenon and did not further analyse the feasibility of these building in Pakistan.

(8) Very few references are available. More intensive review of literature on the subject can improve the paper.

(9) The reader is lost to know about the data, the type of buildings, the location of the buildings etc.

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Energy, Emissions and the Economy: Empirical Analysis from Pakistan

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1. INTRODUCTION

It is now an established fact that the most important environmental problem of our era is global warming.[1] The rising quantity of worldwide carbon dioxide (CO2) emissions seems to be escalating this problem. As the emissions generally result from consumption of fossil fuels, decreasing energy spending seems to be the direct way of handling the emissions problem. However, because of the possible negative impacts on economic growth, cutting the energy utilisation is likely to be the "less preferred road". Moreover, if the Environmental Kuznets Curve (EKC) hypothesis applies to the emissions and income link, economic growth by itself may become a solution to the problem of environmental degradation [Rothman and de Bruyn (1998)]. Coondoo and Dinda (2002), however, argue that both developing and developed economies must sacrifice economic growth. Still, countries may opt for different policies to fight global environmental problems, mainly depending on the type of relationship between CO2 emissions, income, and energy consumption over the long run [Soytas and Sari (2006)]. Hence, the emissions-energy-income nexus needs to be studied carefully and in detail for every economy, but more so for the developing countries. In this paper, we investigate the relationship between energy consumption, CO2 emissions and the economy in Pakistan from a long run perspective, in a multivariate framework controlling for gross fixed capital, labour and exports by employing ARDL bounds testing approach.

Pakistan can be a good case study for the analysis because it needs to adjust her infrastructure, economy, and government policies (including environmental, energy, and growth policies) to make them in line with the global requirements of this era. Secondly, amid industrialisation, there has been increasing trend in CO2 emissions in Pakistan since 1990s.

The organisation of the study is as follows: after this brief introduction of the study, in Section 2 we present some background literature relating to theoretical and empirical model; in Section 3 we design the model and methodology; Section 4 discusses some facts about energy sector in Pakistan; Section 5 comprises the empirical findings and the discussion of the results, Section 6 presents the implications of the model for Pakistan economy and conclusions.

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[1] Report by Intergovernmental Panel on Climate Change [IPCC (2007)].

2. THE THEORY AND THE MODEL

2.1. Background Literature

There are quite a few theoretical studies that formally model a direct link between the environment and growth, energy and growth, and energy and environment. The empirical literature appears to be richer. Initially we underpin some of the theoretical concerns. Then, we introduce the empirical surveys that relate to the transmission mechanisms within the energy-environment-economy (E-E-E) nexus. The theoretical work on economic growth mostly relies on the Solow growth model. More recently growth models depend heavily on the endogenous growth theory. There are a significant number of studies that model the relationship between the natural resource management, environment and economic growth [for review see Xepapadeas (2005)]. Whereas Jorgenson and Wilcoxen (1993) selectively cover the theoretical work that models intertemporal general equilibrium framework to develop the interrelationships between energy, the environment, and economic growth. As claimed by Xepapadeas (2005) early works on the growth failed to take into account of the environmental issues of growth. Reviewing the recent literature, he argues that, "there is a necessity for growth theory to delve deeply into the analysis of the interrelationships between environmental pollution, capital accumulations and the growth of variables which are of central importance in growth theory." p. 1221).

Kolstad and Krautkraemer (1993) point out that the resource use (particularly energy) cede instant economic benefits, its negative blow on the environment may be observed in the long run. Since, most of the theoretical work is dynamic; the empirical studies are mostly static in nature, entailing the need for dynamic empirical analysis. Jorgenson and Wilcoxen (1993) find out that the common feature of the models is relying on the effect of policies on capital accumulation in modelling the relationships between the economy, energy and environment. Theoretically, there may be several transmission mechanisms through which environmental policy and economic growth may relate; partly due to some models considering pollution as an input to production; and partly, as a negative by-product [Ricci (2007)]. Generally, environmental policies are considered to have negative impact on growth, due to their role as additional constraints in the models. Certainly, Dudek, *et al.* (2003) show that the additional benefits from reduction of emissions will exceed the average cost. Hence, the methodology for empirical analysis should base on the dynamic effects in the energy-environment-economy nexus. Theoretical studies mainly believe that any effective policy should take the dynamic nature of the relationships and long run perspective.

The mismatch between theoretical work and empirical studies about the relationship between growth, energy and environment is pointed out by Brock and Taylor (2005) who argue that the key is the so-called Environment-Kuznets-Curve (EKC) literature. Brock and Taylor (2005) find a tighter connection between theory and data. The focus of many empirical studies has been on the relationship between the environment and economic growth [see Dinda (2004); Stern (2004) to review]. The EKC studies that analyse linear [Shafik and Bandyopadhyay (1992); de Bruyn, *et al.* (1998)], plus quadratic and cubic [Canas, *et al.* (2003); de Bruyn, *et al.* (1998); Heil and Selden (1999); Roberts and Grimes (1997)] connection between GDP per capita and CO2 emissions, could not confirm agreed-upon findings. Dinda (2004) find a dynamic link between CO2 emissions and income and CO2 emissions may lead to economic growth. It may still be possible to observe the emissions to lead to energy use if the energy production process of a county is responsible for a major portion of emissions.

In another line of empirical research, there are a sizeable number of studies that examine the bond between energy use and economic growth. Since Kraft and Kraft (1978), the literature has tested the Granger (non) causality between energy and income with miscellaneous results [Akarca and Long (1980); Yu and Hwang (1984); Erol and Yu (1987); Hwang and Gum (1992); Glasure and Lee (1997)]. Most of these studies faced a numerous methodological setbacks; particularly the omitted variables bias. In this regard the first significant study is Stern (1993) who supports using a multivariate analysis. Following Stern (1993), many studies employed recent and powerful time series techniques, [see for example, Stern (2000); Asafu-Adjaye (2000); Yang (2000); Sari and Soytas (2004); Ghali and El-Sakka (2004); Lee (2006)]. Nevertheless, this line of research also failed to accomplish common objectives. For instance, Soytas, *et al.* (2007) study the long run Granger causality between emissions, energy use, and growth for US economy, with additional variables such as labour and capital. Though they do not find any evidence of causality between carbon emissions and income; and energy consumption and income, but verify that energy use is the foremost source of emissions.

In both directions of literature, and particularly in the EKC literature, the large size of the work is on developed economies. There is still very limited literature that studies the link between energy use, economic development and environmental degradation in Pakistan, yet alone the dynamic link between CO2 emissions and income. Siddiqui (2004) in this regards is one of the pioneer studies that analyses the link between energy and economic growth. According to the results of her model, energy is a major source of economic growth and indicates the possibility of inter-fuel substitution, which may be a result of changes in price structure, Recently, for Pakistan economy some other studies are done, e.g., Nasir and Rehman (2011), who find mixed results and do not support the idea of EKC in the short run. Shahbaz, *et al.* (2010) study suffers from the theoretical issues of endogeneity and multicollinearity.

2.2. Model

In this paper we investigate the dynamic relationship between energy use, CO2 emissions and GDP [as suggested by Xepapadeas (2005); Kolstand and Krautkraemer (1993); and Jorgenson and Wilcoxen (1993)] in an emerging Asian economy, accounting for possible effects of labour and fixed capital formation.[2] The paper attempts to make a contribution to the existing empirical literature by combining the two lines of empirical research in a developing, economy using relatively new time series techniques that cater to some of the methodological issues of the past studies. Besides, the choice of the variables is not random or arbitrary but relies on theory,[3] which may be missing from many empirical studies. We hope the empirical results of this study may be helpful in guiding policy makers to devise long run sustainable policies.

[2] To account for capital accumulation as suggested by Jorgenson and Wilcoxen (1993).

[3] As proposed by Brock and Taylor (2005).

$$Y = f(E, CO2, K, L, X) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

Where Y is log of real GDP in Rs Million,

E is log of energy consumption, converted to Giga-watt-hours.
$CO2$ is the log of emission of carbon dioxide per capita measured in tons,
K is the log of gross fixed capital formation, in Rs. Million,
L is log of employed labour force in Million persons and
X is the log of exports in Rs Millions.
The econometric specification of the model will be;

$$Y = \alpha_0 + \alpha_1 E + \alpha_2 CO2 + \alpha_3 K + \alpha_4 L + \alpha_5 X \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

Where expected signs of the parameters are: $\alpha_1 > 0, \alpha_2 < 0, \alpha_3 > 0, \alpha_4 > 0, \alpha_5 > 0.$

3. METHODOLOGY AND DATA

3.1. Methodology

For this model we develop a methodology based on the Pesaran, *et al.* (2001), that provides a bounds test approach to find out the short and long run relationships among the variables of interest. It would also be based on the results of the unit root test. *A priori*, we can assume different order of integration of the variables of the model. This is made clear in Section 5.1.

The Pesaran, *et al.* (2001) methodology is based on the Autoregressive Distributed lag model. The ARDL approach involves two steps for estimating the long-run relationship. The first step is to examine the existence of a long-run relationship among all variables in the equation under examination. Conditional upon the confirmation of cointegration, in the second stage, the long-run coefficients and the short-run coefficients are estimated using the associated ARDL and ECMs. To test for cointegration in model (2) by the bounds test, the following conditional Unrestricted Error Correction Model (UECM), is constructed

$$\begin{aligned} \Delta y_t = {} & \alpha_0 + \Sigma\, \alpha_i \Delta y_{t-i} + \Sigma\, \alpha_j \Delta E_{t-j} + \Sigma\, \alpha_k \Delta CO2_{t-k} + \Sigma\, \alpha_m \Delta K_{t-m} + \Sigma\, \alpha_n \Delta L_{t-n} \\ & + \Sigma\, \alpha_s \Delta X_{t-s} + \theta_0 y_{t-1} + \theta_1 E_{t-1} + \theta_2 Co2_{t-1} + \theta_3 K_{t-1} + \theta_4 L_{t-1} + \theta_5 X_{t-1} + e_t \quad \dots \quad (3) \end{aligned}$$

Notice that this is almost akin to traditional Error-Correction Model. The alphabets *i,j,k,m,n* and *s* in the subscript of each variables define the lag structure of that variable. If the optimal lag length is found one using Schwarz criterion, then this lag length is used for each variable. To investigate the presence of long-run relationships among the Y, E, $CO2$, K, L and X, under the bounds test approach formulised by Pesaran, *et al.* (2001), after regression of Equation (3), the Wald test is applied. The Wald test can be conducted by imposing restrictions on the estimated long-run coefficients of Y, E, $CO2$, K, L and X, The null hypothesis is H_0: $\theta_0 = \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0$ where there is no cointegration among the variables. The F-stat is computed and compared with the critical value (upper and lower bound) given by Pesaran, *et al.* (2001). If the F-computed exceeds the upper critical bound, then the hypothesis of no cointegration will be rejected. However, if the F-computed is less than the lower critical bound, then H_0 cannot be rejected, concluding that there is no cointegration among the variables. If the F-computed falls between the lower and upper bounds, then the result is inconclusive.[4]

The empirical evidence for the existence of an EKC has been found in various studies. These studies share some common characteristics with respect to the data and methods employed. Most of the data used in these studies are cross-sectional/panel data. The following reduced form model is used to test the various possible relationships between pollution level/environmental pressure and income:

$$\log (co2/capita) = \beta_0 + \beta_1 \log(GDP/capita) + \beta_2 \log(GDP/capita)^2 + \beta_3 \log(GDP/capita)^3 + \log E + u \quad \ldots \quad (4)$$

Here all the variables are self-explaining. Model (4) provides us to test several shapes of environment-economy development relationships where energy demand is used an intervening variable. It follows;

I. $\beta_1 = \beta_2 = \beta_3 = 0$. A flat pattern or no relationship.
II. $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$. A monotonically increasing relationship or a linear relationship between environment and economy.
III. $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$. i.e., monotonically decreasing relationship between both.
I. $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$. An inverted-U-shaped EKC.
II. $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 = 0$. A U-shaped curve.
III. $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$. A cubic or N-shaped curve.
IV. $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$. Opposite to N-shaped curve.

3.2. Data

Our empirical findings are based on the data from different sources. We obtained GDP, exports and CO2 emission data from World Bank (WB); Employed Labour Force from Pakistan Economic Survey (PES) and SBP website; Gross Fixed Capital Formation (GFCF) from IFS; and energy from PES and WB. The data are used in log form. The currency unit of the GDP, exports and GFCF is Rupees in Million. Since we are using aggregate data of energy, these are converted into single unit by applying scientific formulae of the measurement of energy. The tons of fuel consumption, the million cubic feet of natural gas, and metric tons coal consumption are used to convert each energy source into Giga-watt Hour (Gwh) of energy it could produce. The electricity consumption is already measured on Gwh. There could be many other units of energy, e.g., joules, calories, etc., but the measureable values of these units would have increased enormously, which would be difficult to use. This calculation method and data can be obtained from the authors upon request. The time period of the study is 1973–2012. It is the post-separation period, however, considering the issue of degrees of freedom for time series analysis we have tried to use 40 years' annual data.

4. PAKISTAN: SOME ENERGY FACTS

Table 1 shows the energy highlights of supplies in Pakistan energy sector, which include both imported and exported sources of the supplies. The issue of utilisation of resources remains typical. The demand of energy resources mainly originates from: households, industry, agriculture, transport power and government.

[4] This perhaps reminds of the *old DW* test for serial correlation.

Table 1

Highlights of Energy Sector in Pakistan

Highlights	Units	Energy Supplies 2011-12
Crude Oil Production	000 barrels	24,573
Production of Gas	Mcf	1,558,959
Production of Coal	000 tonnes	3,472
Import of Coal	000 tonnes	3,850
Electricity	MW	
Hydel	MW	6,557
Thermal	MW	15,392
Nuclear		787
Total Capacity		22,736

This table is copied from Statistical Bulletin of Pakistan Economic Survey, 2013.

Over the years the demand of energy has increased manifold, particularly for transportation and industrial sectors. Figures, A1–A5 in the appendix present analysis of demand sources for energy. The consumption share of natural gas for house hold and industrial use increased during last twenty years, while the share of power sector decreased during this period. The cement sector has substituted the energy use from gas to coal. The fertiliser sector has also shown a decrease in its percentage share of the use of gas. Transportation has increased its share in use of natural gas, but during last two years, it shows a downward trend in its growth. Transportation and power sectors are the major consumers of the oil products throughout the period of analysis, and their share has increased over time. The household, agricultural and industrial consumption of oil products has decreased during last twenty years. Households are the largest consumer of electricity. The share of industrial sector decreased about 10 percent over the last two decades. This reflects that the resource substitution by the industrial sector from relatively costly (electricity) to cheaper (gas) one. Coal being the least technically applied source has never been preferred by the industrial sector before 1990s. The major user (about 90 percent) has been brick kilns. The cement sector started using coal in 2001 and now its share of total use has increased to 61 percent, which reflects resource substitution. Households and power sector reduce use of coal. Power sector peaked its use of coal in late 1990s. Figure A5 shows the growth rate of the energy demand. The demand for coal has shown huge oscillations whereas gas consumption has been steady. The use of coal and electricity have shown similar trends, while the use of gas and oil products has shown the same pattern. The consumption of electricity has also been volatile during past forty years.

5. EMPIRICAL FINDINGS

5.1. Unit Root Test

Table 2 presents the results of the unit root test using ADF test. The series of CO2 emissions, GDP growth rate, exports and population are significant at level, i.e., they do not exhibit stochastic trend. Both GDP and GDP growth have significant intercept, despite different orders of integration. The result of exports (ex) has shown interesting feature: Pakistan's export are stationary at level; but with significant trend and intercept. This is deterministic trend, not the stochastic one. The distinction between a deterministic and stochastic trend has important implications for the long-term behaviour of a process: (i) time series data with deterministic trend always revert to the trend in the long run (the effects of shocks are eventually eliminated) the intervals for forecasting comprise constant width; (ii) time series with a stochastic trend never recover from shocks to the system (the effects of shocks are permanent). Forecast intervals grow over time. Thus the stochastic trend in GDP, energy demand, energy supply and imports show that these series are difference stationary.

The maximum order in integration is one in this model while minimum is 0, so we cannot apply general cointegration technique [e.g., Johansen and Juselius (1990)] on this model. We confirmed that none of the variables in the model is I(2) using KPSS test. So the mixture of order of integration confirms the use of autoregressive distributed lags (ARDL) model and long run causality test. We apply ARDL model.

Table 2

Test of the Stationarity of the Variables

Variable	Parameter	ADF cal	5%	Lag	Trend/ Intercept	Inference
CO2	–0.053303	–4.54	–1.95	1	None	Level
GDP	–0.673	–4.30	–2.93	0	Intercept	1st Dif
Energy	–0.49	–3.42	–1.95	0	None	1st Dif
Growth	–0.700	–4.52	–2.93	0	Intercept	Level
Exports	–0.56	–3.59	–3.53	1	Both	Level
Labour	–0.452	–4.01	–3.53	0	Both	Level
Capital	–0.36	–4.21	–3.53	0	Both	Level

On the basis of SC we have selected one lag for this model. So this lag length will be used to estimate the unrestricted ECM for the bounds test.

5.2. The Long run

The long run analysis of our E-E-E model[5] is based on the UECM used in econometric literature. The evidence of such modeling procedure is Narayan (2004), Altinay (2007) and Sultan (2010). Most of the individual coefficients are statistically significant at 5 and 10 percent level of significance. Here our objective is to compute F stat using Wald test of joint significance of this unrestricted model to test the hypothesis of long run relationships among the variables. To compute F–state for bounds testing, we applied Wald test of joint significance of coefficients θ_0, θ_1, θ_2, θ_3, θ_4 and θ_5. Table 3 presents the estimates of *Autoregressive Distributed Lag Model* of Equation 3.

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[5] Energy-Environment-Economy Model.

Table 3

Unrestricted Error Correction Model for Pakistan Economy

Variable	Coefficients	Standard Error
Constant	–2.2463	1.286**
Δy_{t-1}	–0.042	0.019*
ΔL_{t-1}	–0.112	0.07***
ΔK_{t-1}	–0.048	0.027**
ΔX_{t-1}	–0.0127	0.009
ΔE_{t-1}	–0.0369	0.024
$\Delta CO2_{t-1}$	0.0188	0.13
y_{t-1}	–0.197	0.121**
E_{t-1}	0.3361	0.107*
$CO2_{t-1}$	–0.237	0.131**
K_{t-1}	0.0689	0.026*
L_{t-1}	0.088	0.066
X_{t-1}	0.0263	0.021
R–sq	0.622	

*,** means individual coefficients are significant at 5, and 10 percent.

Diagnostic Tests

In dynamic time series analysis the selection of variables for a model is critical. Almost all individual time series, which show trend, are supposed to have serial correlation and specification problem. But to use a time series model we have to perform some diagnostic tests on the model of unconstrained/unrestricted error correction model. Table 4 shows that our specified UECM passes all the diagnostic tests, i.e., (i) The residuals are normally distributed, because we fail to reject the null of Normality in JB test; (ii) the F-stat in Ramsey RESET test shows that model is correctly specified; (iii) For serially independent residuals, we used BG LM test and failed to reject the null hypothesis of no auto correlation.; and (iv) and the variance of residuals is persistent, as pointed by ARCH LM test for the estimated model.

Table 4

Diagnostic Tests

Diagnosis	Test	Stats
Normality Test	Jarque Bera	JB Stat: 2.31 (0.31)
Specification Test	Ramsey RESET	F-Stat: 0.232 (0.635)
Serial Correlation Test	B-G LM Test	Chi-sq: 2.74 (0.11)
Hetroskedasticity	ARCH LM	F: 0.095(0.76), Chi-sq: 0.099 (0.75)

For the dynamic stability of the UECM model, the inverse roots before and after differencing (Figure A6 and A7 in the Appendix) are confirmed. The before differencing inverse root exhibits the instability, thus differencing is required. After differencing none of the roots lay on the X-axis, it's clear that we have three complex pairs of roots. Accordingly, the short-run dynamics associated with the model are quite complicated.

For the bounds test, the F-stat 4.48 is compared with lower bound at 5 percent level of significance from the Pesaran, *et al.* (2001) in case III in the Table the relationships are tested at level, which show drift but no intercept at $k = 5$.

Table 5

Cointegration Properties

Dependent Variable	F-Statistics	Critical Bound Bottom I(0)	Top I(1)
Δy_t	4.48	2.62	3.79

The statistics in Table 5, shows that the computed F-stat is greater than the upper bound, indicating the existence of long run relationships between variables of the model. Thus cointegration exists and the estimated coefficient of Equation 3 can be used to calculate the long run elasticities of the model. The long run elasticities can be computed as:

$\xi_{y, E} = -(\theta_1 / \theta_0) = 1.70$
$\xi_{y, co2} = -(\theta_2 / \theta_0) = -1.20$
$\xi_{y, K} = -(\theta_3 / \theta_0) = 0.35$
$\xi_{y, L} = -(\theta_4 / \theta_0) = 0.447$
$\xi_{y, X} = -(\theta_5 / \theta_0) = 0.133$

In the long run one percentage increase in energy use leads to 1.7 percent increase in GDP. The energy is positively linked with aggregate demand. On the contrary, the effect of carbon emissions on economy is negative. These absolute values of the two elasticities are greater than unity. Thus reflecting, the negative externality produced from the use of energy (particularly use of fossil resources) in the shape of CO2 emission can retard economic growth. Nevertheless, the net effect of energy is positive (i.e., 1.70–1.20 = 0.5) and less than unity. This implies that for Pakistan still we can use the energy resources with positive output effect.

Similarly the positive elasticities of capital and labour reflect that both have standard theoretical interpretation, but interestingly, in the presence of externalities, these results imply decreasing return to scale production function. The exports elasticity of demand is very low and statistically insignificant. This result contradicts theory, yet, due to the presence of the factors that directly affect the economy, the effect of exports on GDP remained insignificant.

5.3. The Short Run

For short run we estimated the error correction model of Equation 3, by estimating the logged model at levels then used error term as an explanatory variable in the error correction model. The Results are presented in Table 6. We can notice that the coefficient of error term Z_t is negative and statistically significant, which also confirms the existence of cointegration between the variables of the model. The magnitude of the coefficient implies that about 16 percent of the disequilibrium is corrected in one period of time.

Table 6

Short Run Properties

Variable	Coefficients	Standard Error
Constant	0.03596	0.0108*
Δy_{t-1}	0.398859	0.203*
ΔL_{t-1}	–0.04671	0.066
ΔK_{t-1}	–0.05193	0.03**
ΔX_{t-1}	–0.00461	0.03
ΔE_{t-1}	0.117681	0.0630**
$\Delta CO2_{t-1}$	–0.17135	0.104**
Z_t	–0.161	0.090**

*,** Means individual coefficients are significant at 5, and 10 percent respectively.

5.4. Environmental Kuznets Curve

Our model so far has shown important implications for the Pakistan economy. This E-E-E model is now being used under the methodology discussed in the end of section 3.1, where we developed seven hypotheses to be tested for Equation 4. The estimated version of this equation is given below;

$$\log(\text{co2/capita}) = -2.165 - 1.58 \log(\text{GDP/capita}) + 0.18 \log(\text{GDP/capita})^2 - 0.0067 \log(\text{GDP/capita})^3 + 0.517 \text{ Log } E + u$$

(*Note:* all the coefficients are statistically significant at 1 percent level of significance.)

According to our setting in section 3.1, we find that hypothesis (iv) which reflects EKC does not hold in case of Pakistan's data. Rather it is a cubic and opposite to an *N*-shaped curve as assumed in hypotheses (iv). Hypotheses (i) is rejected through Wald test.[6] In nutshell, we can declare that the EKC is not in place in Pakistan, given the energy use data. This cubic function also elaborates that at the early stages of economic growth, Pakistan has been an agrarian economy, with less use of fossil fuels and had not any environmentally negative impact. But with the wave of industrialisation, over the long run the emissions grow and after some point in time when a certain level of GDP per capita is achieved, the environmental degradation increases. Thus this curve, which is monotonically decreasing at early stages of growth, starts increasing at higher income levels; and after some turning point, it will look like an EKC. Since, EKC have been used as an argument that economic growth and increased environmental quality go hand in hand, this may not be true for the case of developing countries [Richmond and Kaufman (2006)].

6. CONCLUSIONS AND POLICY IMPLICATION

In this study we have used an ARDL approach to find the long run nexus between E-E-E and found some robust results after estimating the long run elasticities. The demand elasticity of energy is positive and greater than unity, but the negative externality produced due to the use of energy, may reduce this effect. The elasticities of capital and Labour show that due to negative by-products of energy use, the production function

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[6] To conserve space and time, we do not present these Wald test results here.

exhibits decreasing returns to scale (this hypothesis needs further investigation). We also estimated the model to test the EKC in the presence of energy demand and find no such evidence. The energy substitution behaviour is found as claimed by Siddiqui (2004), particularly industrial/ cement sector has switched from the use of other resources to the coal. In summary we can derive the following implications of our analysis.

Implications

It is found that the energy use has positive impact on economy. There is an urgent need to explore more sources of energy which can be helpful in meeting the increasing demand of energy.

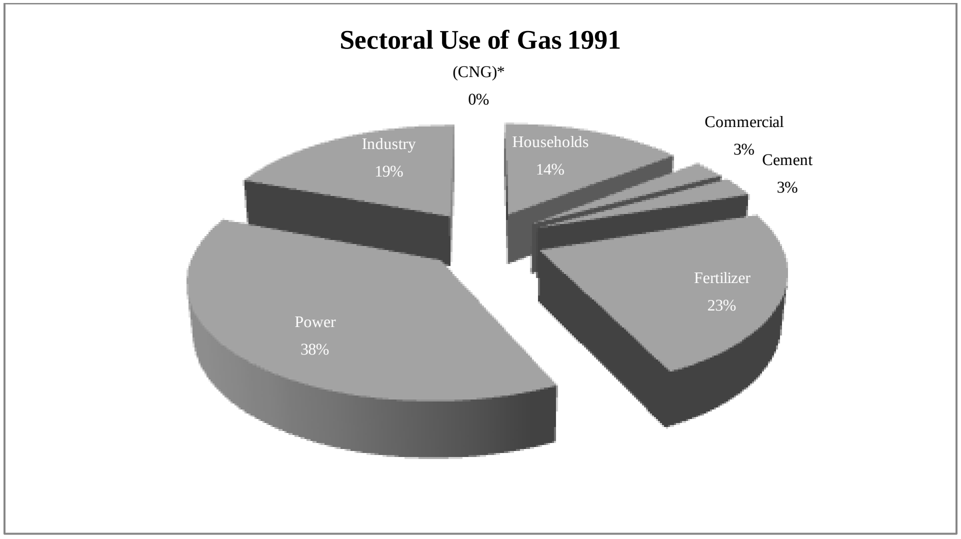
The fuel substitution from costly to cheaper one should be monitored by the government and carbon tax should be imposed on the industries that produce more pollutants. The green technologies can reduce these pollutants.

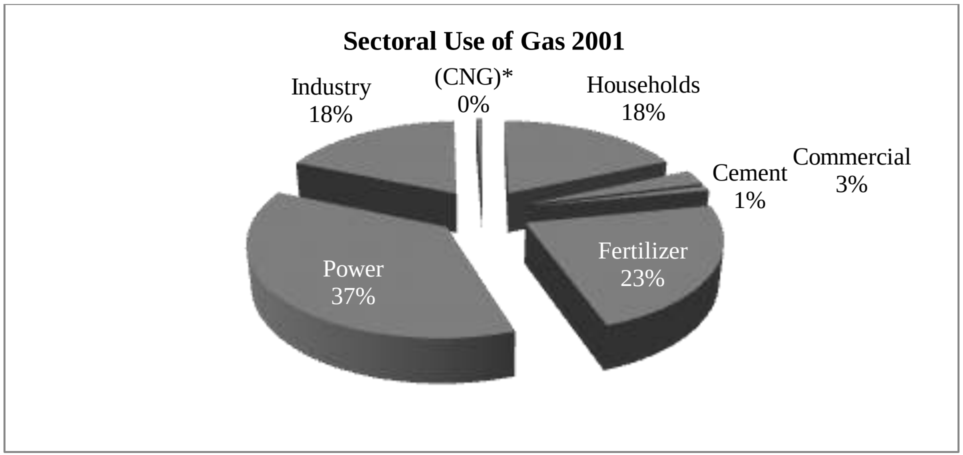
The EKC is used to support *do nothing* policy, which unfortunately cannot happen for the case of Pakistan. This also may not be useful due to turning points that make us to think of the factors that explain it, before making assessments about the necessary components of environmental policy. After an initial stage of economic development we have to take serious measures to tackle the issues of environmental degradation (as a result of energy use). The scale effect suggests that in the beginning of industrialisation and urbanisation, Pakistan should improve the factors' productivity. However, considering energy a separate factor of production, energy efficiency may also increase the efficiency of labour and capital.

This analysis is limited in many ways. For future research the EKC can be tested for the turning points. This would be interesting to find out (numerically) the income per capita that limits the relationship between E-E-E.

APPENDIX

Figure A1: The Consumption of the Natural Gas by Different Sectors





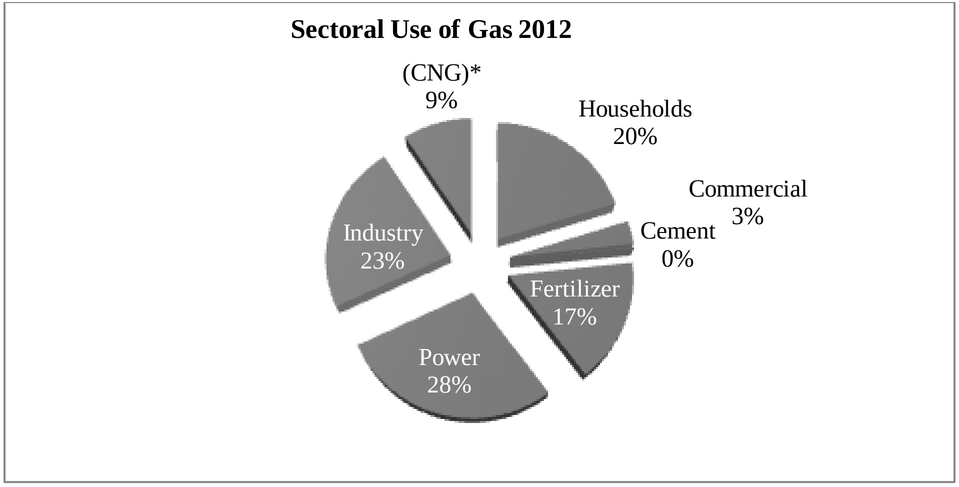
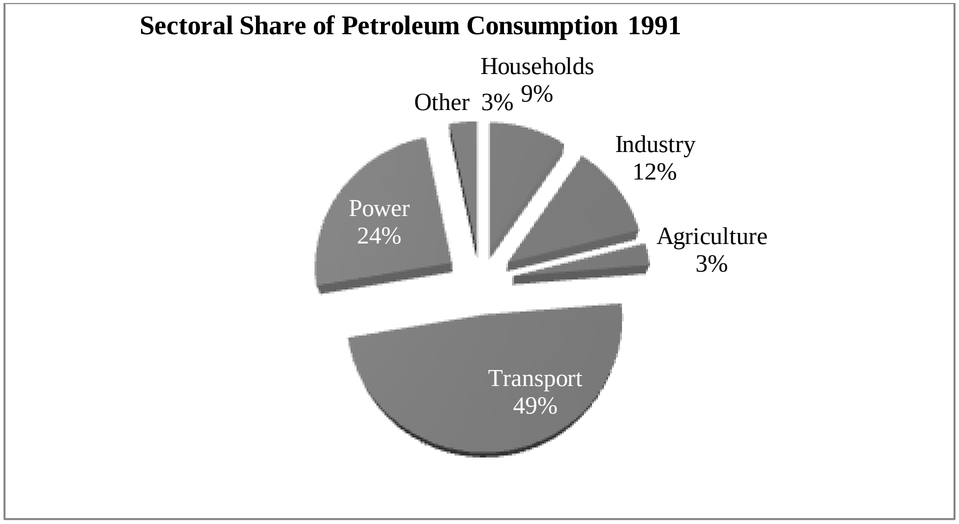
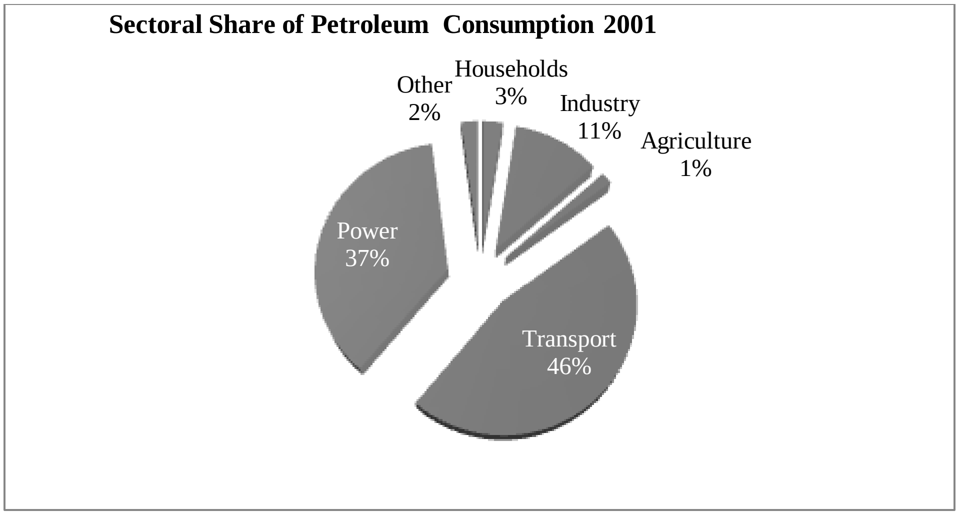


Fig. A2. The Consumption of the Petroleum Products by Different Sectors





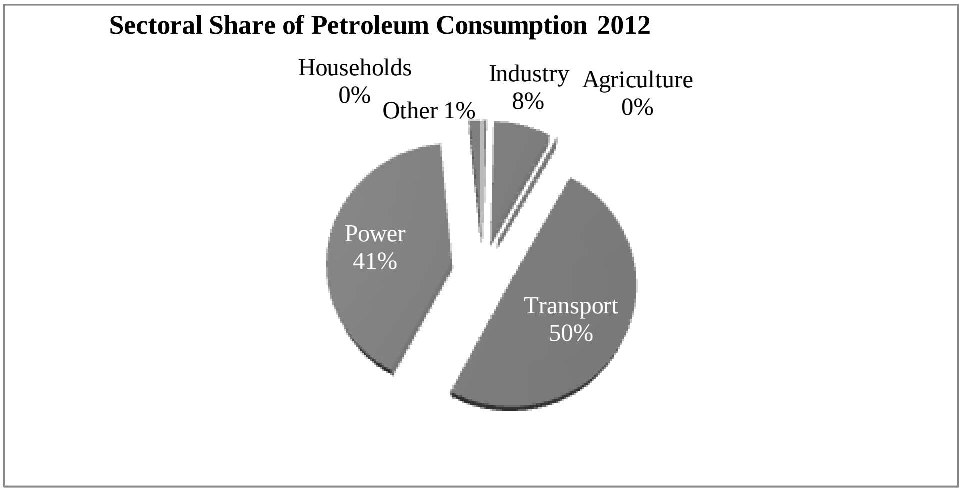
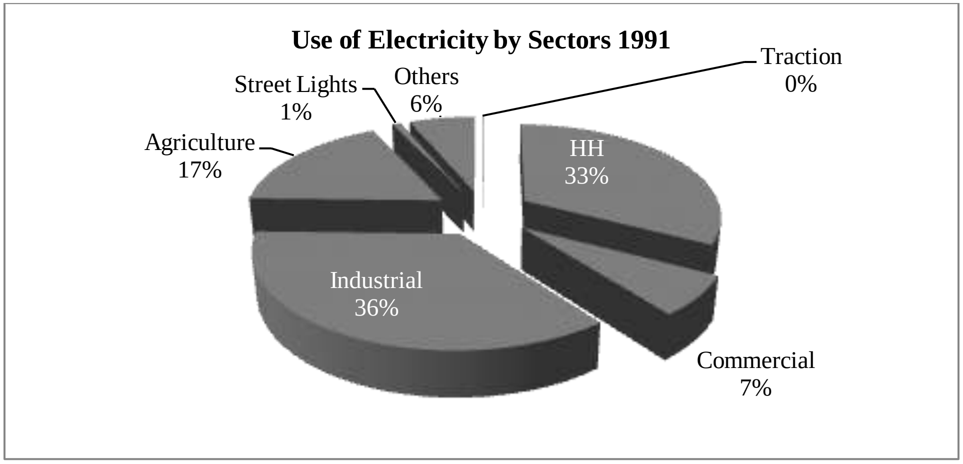
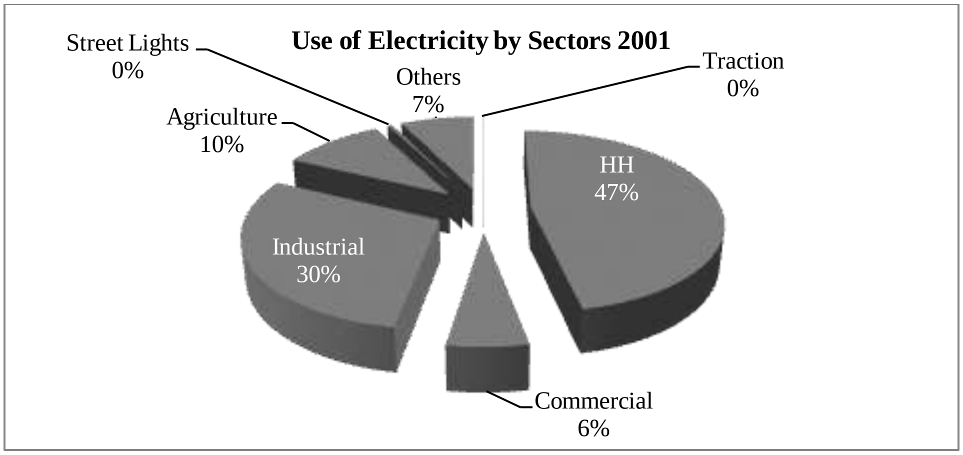


Fig.A3. The Consumption of the Electricity Gas by Different Sectors





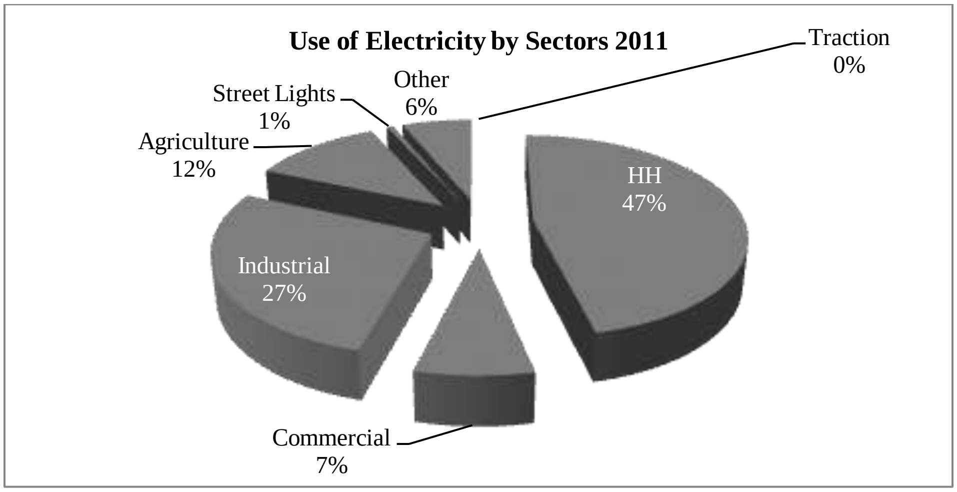
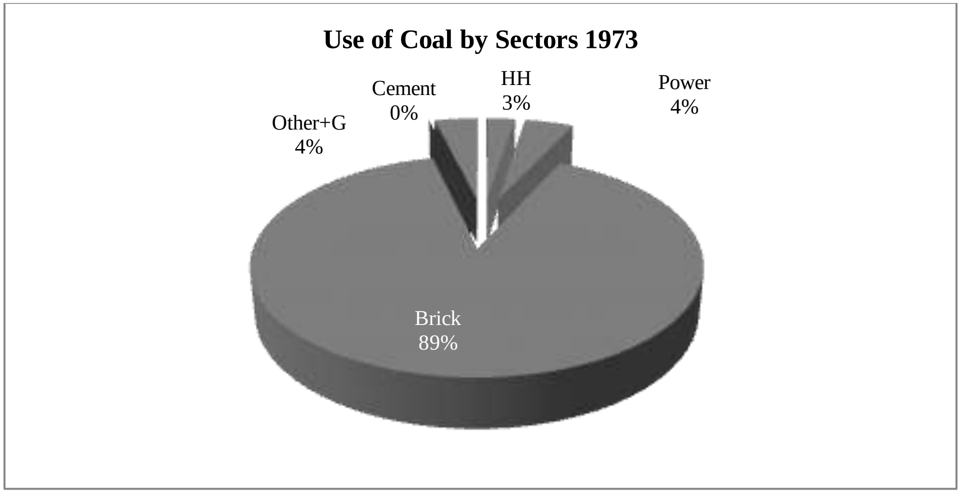
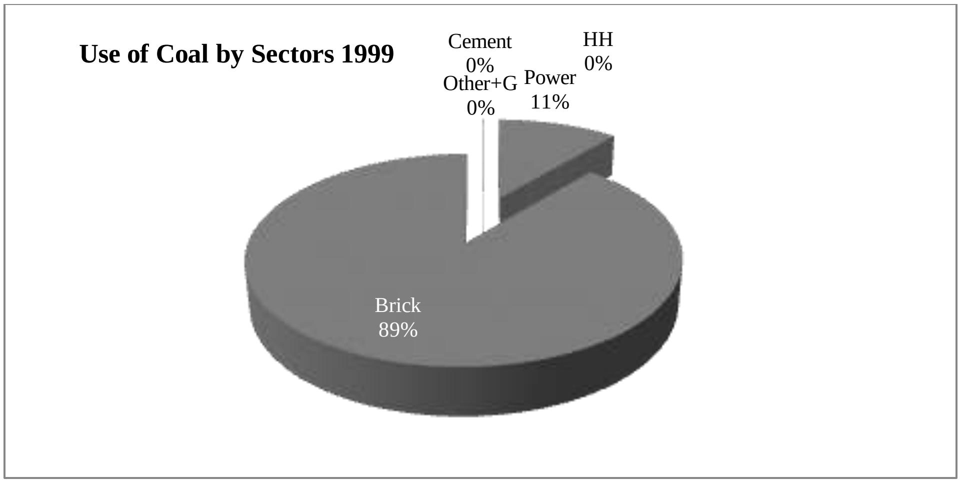
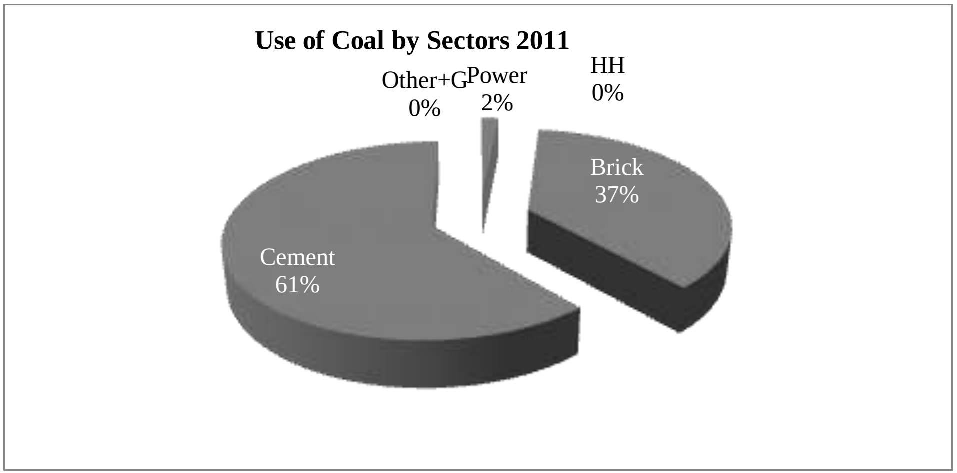


Fig.A4. The Consumption of the Coal by Different Sectors





Use of Coal by Sectors 1999



Use of Coal by Sectors 2011

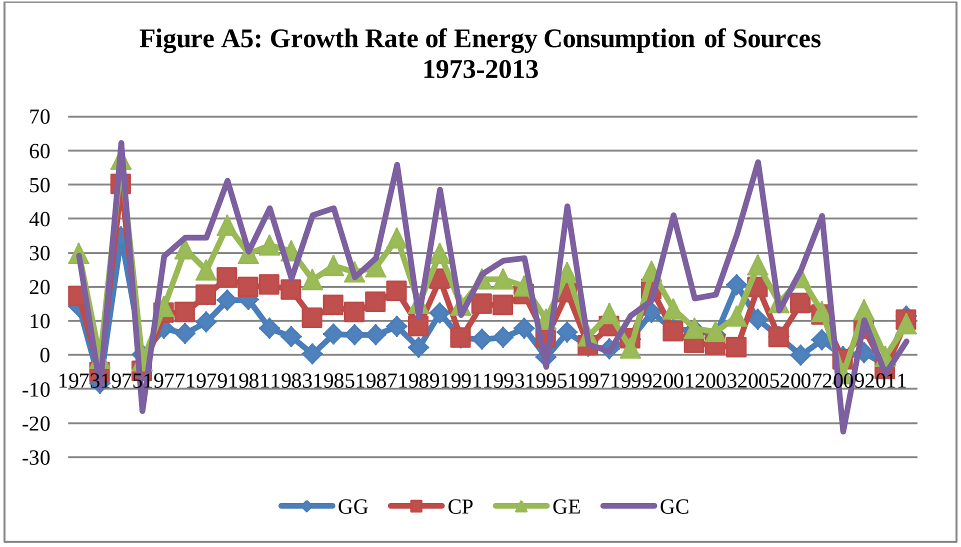


Figure A5: Growth Rate of Energy Consumption of Sources 1973-2013

Figure A6

Inverse Roots of AR Characteristic Polynomial

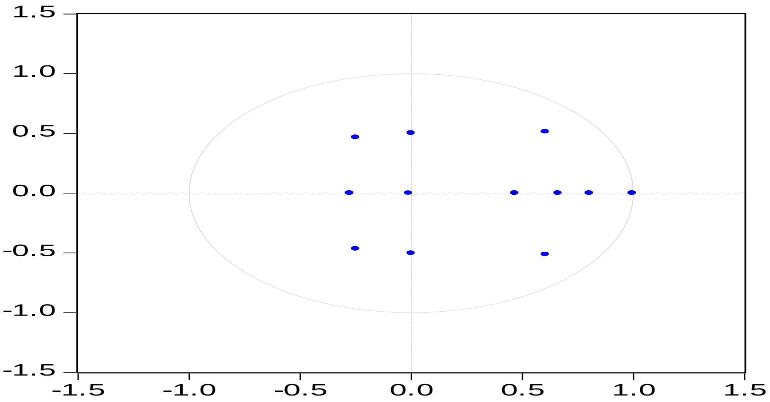
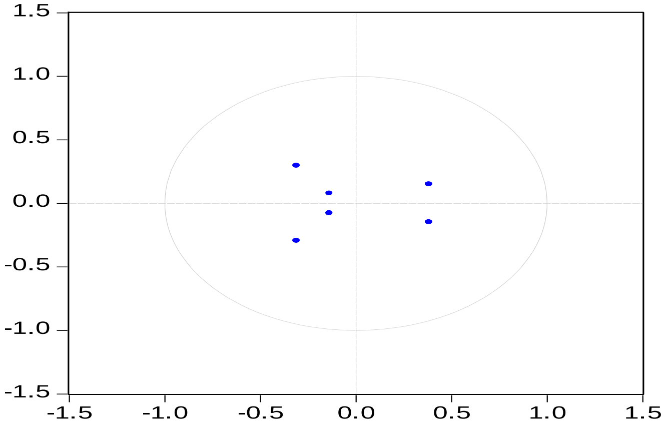


Figure A7

Inverse Roots of AR Characteristic Polynomial



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Comments

The authors have done a good analysis of the issue. However, I have the following minor comments.

(1) Very old review of literature- no reference is available after the 2007. This may be the reason behind the claim that this phenomenon has not been tested so for. I wonder why the writer did not quote more recent studies on the same topic in case of Pakistan. For example Shahbaz, *et al.* (2010), Nasir and Rehman (2011) and Ahmad (2012) have analysed the EKC for Pakistan. The three studies find the existence of the phenomenon in Pakistan. The author could not explain that how their study is different from these studies. These studies have also used ARDL approach.

(2) The author has not explained what the methodological issues of the past studies faced that the ARDL will cater for. Moreover the author is not sure about the variables selection that was missed in the previous studies.

(3) The ARDL is the standard methodology and the author has given unnecessary detail of the methodology that can be avoided. For example if Fc is greater than tabulated than rejected or accepted. This does not make sense.

(4) I could not find the data span in the paper as author has not given any detail that for how many years' data has been used.

(5) Implications or suggestion are insufficient and ordinary, they should be specific to the study objective.

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Dynamic Effects of Energy Sector Public Investment on Sectoral Economic Growth: Experience from Pakistan Economy

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1. INTRODUCTION

The successive economic and financial crisis in recent time has reemphasised the importance of fiscal policy. Modern literature has also revisited the debate regarding the effectiveness of fiscal policy in influencing growth. The issue of the impact of public investment on growth is debated in economic literature since seminal work of Solow (1955). The issue is tackled from different angles. Some have used production function approach [Ligthart (2002), Otto and Voss (1994, 1996), Sturm and de Haan (1995) and Wang (2004)]. Then another seminal work by Aschauer (1989) led a series of work on this issue once again in empirical literature (1989a, 1989b). These approaches used single equation method for estimation and captured only the direct effects of public investment on growth. Periera (2000) gave another twist to this literature by highlighting the indirect effects of public investment on output through its effects on other inputs like private investment and employment. Periera's works (1999, 2000, 2001, 2003, 2005, 2007 and 2011) also contributed empirically to this literature by using vector autoregressive (VAR) technique. This work accounts for both the direct and indirect effects of public investment on growth and also considers the feedback effects of each input to other and finally their effects on output.

The classical school believes that an increment in public spending slows down growth and crowd out the private investment. Since higher spending requires higher taxes at individual or corporate level, it creates distortion in the choice of economic agents and increases interest rate. Barro (1991) in his most famous work associated with government size found a negative relationship between growth and government size. Razzolini and Shughart (1997) in the case of United States found a negative relationship between growth rate and relative size of government. Parker (1995) in case of India found crowding out effect of overall public investment while infrastructure investment crowd in private investment. Alesina, *et al.* (2002) measured the effect of fiscal spending in case of OECD countries in a Tobin's Q model and confirmed a crowding out phenomena. Many other empirical studies found evidence of crowding out effect of government

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expenditures including [Ganelli (2003), Voss (2002), Engen and Skinner (1992), Folster and Henrekson(2001), Devarajan, *et al.* (1996), Milesi and Roubini, (1998) and Majumdar (2007)].

The Keynesians on the other hand, consider government spending as a key variable for economic growth. They argue that development expenditures on health, education and infrastructure increase labour productivity and reduce cost of business, which motivates private investment. Many empirical studies support this view. For instance like Chakraborty (2007) examined the real and financial crowding out effect in India using data from 1971 to 2003 through a VAR model and found that public and private investment are complementary. Easterly and Rebelo (1993) in their work found a positive growth effect of public investment, specially transport and communication. Baotai (2004) analysed the effect of public investment through cointegration model during the period 1961 to 2000 for Canada and found mixed results; some public expenditure such as health and education have a positive effect while infrastructure and social security have a negative growth effect. Bose, Haque and Osborn (2007) using data for 30 developing countries found out that government capital expenditures have a positive effect on growth, while at the disaggregate level only education expenditures are positively correlated with growth.

Pereira (2000) investigated the effects of aggregate public investment and infrastructure investment at a disaggregate level by using the VAR model for U.S and found that both at aggregate and disaggregate levels, public investment positively affects output and crowd in private investment. This study estimated a marginal productivity of 4.46 indicating that a one dollar investment will increase private output by about $4.46 and found out that the highest rate of return is in electric, gas, transit system and airfield sectors.

Pereira and Oriol (2001) analysed the marginal productivity of private investment, output and employment with respect to public infrastructure investment in the case of Spain by using VAR methodology. The study used five VAR models, one for aggregate level and remaining four for agriculture, services, manufacturing and construction. The results indicate that at aggregate level public infrastructure investment has positive marginal productivity for each variable while at sectoral level manufacturing, services and construction have positive output, private investment and employment marginal productivity but in the case of agriculture there is negative marginal productivity of output, private investment and employment. The highest output marginal productivity was found in the case of manufacturing being 2.43 indicating one peseta of public investment will generate 2.43 pesetas of output.

Pereira and Andraz (2005) analysed the effect of aggregate public transportation infrastructure investment and its components (national roads, municipal roads, highways, ports, airports and railways) on aggregate private investment, aggregate output and employment in Portugal by using a VAR approach on annual data from 1976 to 1998. They found out that in the long term, aggregate public infrastructure investment of one euro will generate an output of 9.5 euros and also have a positive effect on private investment and employment. At a disaggregate level, they found similar trends for output, employment and revenue. Pereira and Sagales (1999) using the VAR model for Spain found a crowding in effect of public capital on private output and employment.

Pina and Aubyn (2006) examined the rate of return of public investment in the case of U.S economy using VAR model for a period of 1956-2001. The four variables used were real private investment, real public investment, private employment and real GDP and found a positive Partial-cost dynamic feedback rate of return of 7.33 percent while the total or Full-cost dynamic feedback came out to be 3.68 percent.

Pereira and Pinho (2011) using the data of twelve euro-zone countries for 1980 to 2003 employed the same methodology and found diverse results. For example, they established that public investment has a positive effect on private investment and employment in all countries except Austria, Belgium Luxembourg and Netherland, while public investment has a positive effect on output in all countries except Luxembourg and Netherland. They also concluded that in the case of Austria, Belgium, Luxembourg and Netherland the public investment has a negative output affect. But in Finland, Portugal and Spain public investment has a positive growth effect; still it is unable to generate sufficient tax revenue. While in case of France, Greece and Ireland public investment pays for itself and finally in the case of Germany and Italy, public investment not only pays for itself but also generates extra tax revenue.

Afonso and Aubyn (2008) utilised accumulated impulse response function of VAR model, which consists of real interest rate, real output, real taxes, real public investment and real private investment for 14 European Union countries and some non-European countries including Japan, Canada and the United States. The results show that output elasticity of private investment is higher than public investment. Further in most of the countries they found a positive marginal productivity accompanied with a crowd-in effect. Voss (2002) investigated the crowding in or out effects in case of Canada and U.S using quarterly data through a VAR model, using real GDP, real interest rate, and share of public and private investment in the GDP. In both countries he found a negative effect of public investment on private investment. Mittnik and Neumann (2001) examined the relationship between public investment, private investment and output using the VAR model for six industrial countries. Results reveal that public investment crowd in private investment in three countries only; however the public investment has a positive output effect in all six countries.

Kamps (2005) measured the elasticites of private investment, employment and output with respect to public investment using a VAR estimation technique based on the variables: “net public capital stock”, “number of employed persons”, “real GDP” and “private net capital stock”. The study was based on 22 countries and showed that public capital stock has a positive effect on output in majority of the countries excluding Japan and Portugal. Further public investment and private investment are complementary and crowding in exists except for Belgium, Japan and U.S. However in the case of employment there is no significant role of public capital.

Pereira (2001) estimated the VAR model using private gross domestic product; private investment, public investment and private employment for U.S economy and both private and public investment are further disaggregated into highways and streets, electric and gas facilities, sewage, water supply, education, hospital building and development structure. At aggregate level he found that public investment has a positive effect on private investment, the marginal productivity was $4.5 with an annual rate of return of 7.8 percent. Pereira and Andraz (2003) examined the effect of aggregate public investment on aggregate private output, employment and investment in the case of U.S using VAR impulse response methodology and found at aggregate level, public investment exerts positive effect on all variables. The study found that an investment of one million dollars will generate 27 new jobs in the long term and one dollar investment of public investment will create $1.112 of private investment and $4.991 of output with an annual rate of return of 8.4 percent. Pereira and Andraz (2003) further analysed the effect of aggregate public investment at disaggregate level and found in six out of twelve industries public investment has a positive employment effect; in five industries crowding in prevailed, while in eight out of twelve industries, public investment has a positive effect on output.

Hyder (2001) examined the effect of real public investment on private investment and growth through a VEC model during 1964 to 2001 and found a complementary relationship between public and private investment and positive growth effect. Saeed et. al (2006) examined the effect of public investment at aggregate and disaggregate level in a VAR model using the variables i.e. public investment, employed labour force, GDP and private investment. The study reveals that in agriculture there is crowding in effect while in manufacturing there is crowding out effect and at the aggregate level the evidence is inconclusive. For example Hussain, *et al.* (2009) found that defense and debt servicing crowd out investment while development expenditures crowd in investment. Naveed (2002) showed that public capital formation has a crowding in effect. Haque and Montiel (1993) found a crowding out effect in case of Pakistan.

The impact of aggregate public investment on growth is examined vastly in the economic literature. This paper captures both the direct and indirect effects of public investment in energy sector on sectoral output, private investment and employment. This will highlight first the size of the impact of public energy investment on sectoral output and second its impact on private investment. This study also indicates which sector of Pakistan's economy is getting most benefit of energy investment. This will be useful information for the policy-makers.

The remaining study is organised as follows: Section 2 illustrates methodological framework, Section 3 gives data and diagnostic test, Section 4 is based on empirical results and finally conclusions and policy implications are presented in Section 5.

2. METHODOLOGICAL FRAMEWORK

The selection of the methodology and the variables for the present study are based on the empirical studies such as Pereira (2000) and Kamps (2005); where a Vector Auto Regressive (VAR/VECM) technique is used for measuring the dynamic effects of public investment. This methodology significantly differs from the one used in the previous studies related to Pakistan, although some studies applied Vector Auto Regressive (VAR/VECM) models, yet their findings are based on error correction term; other studies measured causality among public investment, private investment and output or their results are merely based on impulse response graphs for measuring the nature of effects either positive or negative. For our analysis, we have divided Pakistan's economy into the following sub sectors; Agriculture, Manufacturing (large and small scale), Mining and Quarrying, Construction, Electricity and Gas Distribution, Transport Storage and Communication, Finance and Insurance plus Ownership of Dwellings and Public

Administration, Defence and Community Services. Hence, total eight VAR models are estimated; one for each of eights sectors. The VAR model corresponding to each sector is specified as follow:

$$X_t = C + \sum_{i=1}^{p} A_t X_{t-i} + \varepsilon_t \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.1)$$

Where *X* is the vector of (4x1), *C* is the intercept vector also (4x1), *A* is the matrix of coefficient (4x4) and ε is the vector of error term. Each VAR model consists of Public sector energy investment, Private investment, Output and employment for each sector. The linear form of the model is

$$Xt = \Delta log\ \mathrm{l}pub, \Delta log\ \mathrm{l}priv\ , \Delta log\ Y, \Delta log\ Emp \qquad \ldots \quad \ldots \quad \ldots \quad (2.2)$$

Where l*pub*, l*priv*, *Emp* and *Y* are *log* of real public investment, *log* of real private investment, *log* of real output and employment respectively.

Dynamic Feedback Effects

For measuring the effect of public investment on other variables, an impulse response function for each VAR model was generated. By definition an impulse response function measures the effect of a shock in an endogenous variable due to other variables in the model. It is known that residual of the VAR are contemporaneously correlated. For measuring the effect of shock in one variable due to other variable, these residuals should be uncorrelated. The VAR model is modified in such a way that contemporaneous correlation among the residuals is diagonal, called orthogonalisation. To attain these uncorrelated residuals, Choleski decomposition is used and accumulated impulse response is calculated to measure the cumulative response of all variables due to innovation in policy variables i.e. Public investment in energy. The outcome of accumulated impulse response function provides the accumulated long term elasticity of the selected variables due to shock in policy variable where the long term is defined as the time period in which shock disappeared.

Long Term Accumulated Marginal Productivity

The long term accumulated marginal productivity of policy variable measures the unit change of the dependent variable due to one unit change in policy variable. This concept of marginal productivity is different from the conventional concept. One of the main distinctions is that it is not based on the assumption of ceteris paribus; it refers to the accumulated marginal product and captures all the dynamic feedback among the variables. The value of marginal productivity is obtained by multiplying the accumulated long term elasticity with the ratio of policy variable to the response variable.

$$\varepsilon_{IPUB} = \frac{\Delta \log Y_i}{\Delta \log IPub_i} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.3)$$

The above Equation (2.3) is the long term elasticity, which is obtained directly from an accumulated impulse response function against each sector; which measures the accumulated change in growth rate of different variables. The numerator is the accumulated change in output growth rate of the *i*th sector, while the denominator is the accumulated change in growth rate of public investment in the *i*th sector.

The above elasticity is transformed into long term marginal productivity by using following formula

$$MP \equiv \frac{\Delta Y}{\Delta IPub} = \varepsilon_{IPUB} \frac{Y_i}{IPub_i} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.4)$$

In this fashion for each sector; marginal productivities of private investment, output and employment (in terms of number of jobs creation) are measured.

3. DATA SOURCES AND DESCRIPTION

This study is based on annual time series data from 1981 to 2011 obtained from the State Bank of Pakistan Annual Report, 50 Years of Pakistan Economy and various issues of Economic Survey of Pakistan. All variables are converted into real terms based on 1999-2000 prices[2] and their first differences in log form are used in the analysis.

Univariate Analysis

Stationarity of each variable is one of the necessary conditions for forecasting using the VAR model and if there is cointegration then the order of integration must be the same. Augmented Dickey-Fuller (1979) and Philips Perron (1988) test are used to check the order of integration. The final decision based on Philips Perron test results reported in Table 1 show[3] that all the variables are non-stationary at levels using a 5 percent confidence interval, except three variables, which are level stationary. However, at first differences, all the variables are stationary.

VAR Order Selection

Appropriate number of lags is a crucial decision for VAR estimation. There are different information criteria available for choosing a more parsimonious model and we have applied Schwarz (1978) information criterion (SC) and Akaike (1974) information criterion (AIC). For each model lag selection was made on the basis of Schwarz information criterion. The results reveal[4] that in most cases one lag is showing minimum information criterion value while maximum of four lags were incorporated to avoid too many parameters.

Diagnostic Test

The results of the diagnostic tests are given in Table 2. The results indicate that there is no Heteroskedasticity in any model. The results of LM test also support no serial correlation in all the cases except services sector model. The assumption of Normality is also tested in all the cases and the results do not support the normality assumptions in five out of eight cases, but we can ignore this issue as Lutkepohl (1991) discussed that the VAR parameters estimators do not depend on the normality assumption.

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[2] The data is available in real terms at different base years. For this study as suggested by the discussant we have used a common base of 1999-2000, for the conversion of the nominal variables into real variables.

[3] Due to lack of space just Philips Perron results are reported, but the complete results are available on demand.

[4] Due to lack of space results are not reported, but available on demand.

Table 1

Unit Root Test

	Phillips-Perron Test Statistic							
	Level				First Difference			
	Without Trend		With Trend and Intercept		Without Trend		With Trend and Intercept	
Variable	t-Statistic	Prob.*	t-Statistic	Prob.*	t-Statistic	Prob.*	t-Statistic	Prob.*
LAgr_IPub	–0.544194	0.8729	–1.961717	0.6065	–9.31261	0	–9.993371	0
LAgr_IPrv	–0.771485	0.8178	–2.679558	0.2494	–6.833569	0	–6.749098	0
LAgr_Emp	1.355936	0.9986	–2.668833	0.2537	–8.362981	0	–8.815865	0
LMing_GDP	–0.487884	0.8843	–2.191037	0.4833	–6.817256	0	–6.751895	0
LMing_IPrv	0.053368	0.9585	–1.956587	0.6092	–7.043074	0	–7.235855	0
LMing_Emp	–2.396637	0.1481	–2.754807	0.2207	–5.685598	0	–5.644688	0.0001
LMfg_GDP	–0.292774	0.9181	–2.522159	0.3166	–5.750705	0	–5.68134	0.0001
LMfg_IPrv	–0.657962	0.8472	–1.986704	0.5933	–5.112176	0.0001	–5.053197	0.0008
LMfg_Emp	–0.321594	0.9136	–1.962546	0.6061	–6.843413	0	–6.833039	0
LConst_GDP	–2.153902	0.2254	–1.578453	0.7865	–5.429063	0	–5.744962	0.0001
LConst_IPrv	–1.263144	0.6389	–3.388271	0.0652	–10.32539	0	–10.17403	0
LConst_Emp	–3.485632	0.0127	–5.753265	0.0001	–15.32939	0	–16.14105	0
LElec_GDP	–3.033429	0.039	–1.417099	0.843	–7.213615	0	–9.89615	0
LElec_IPub	–1.954775	0.3053	–1.363139	0.8589	–7.555604	0	–13.90007	0
LElec_IPrv	–1.212813	0.6613	–1.613274	0.7726	–5.892388	0	–6.015573	0
LElec_Emp	–2.104588	0.2439	–3.762389	0.0277	–12.33055	0	–12.90363	0
LTranp_GDP	–0.911304	0.776	–3.171151	0.1027	–6.598544	0	–6.506002	0
LTranp_IPrv	–0.737195	0.8271	–2.069132	0.549	–4.622056	0.0005	–4.566332	0.0034
LTranp_Emp	–3.044822	0.038	–18.15966	0	–31.51532	0.0001	–33.01162	0
LFinc_GDP	–0.907251	0.7724	–2.47431	0.3375	–5.001994	0.0003	–4.92316	0.0021
LFinc_IPrv	–1.352439	0.5923	–2.562142	0.2987	–5.476395	0.0001	–5.471944	0.0005
LFinc_Emp	–1.937825	0.3114	–2.648321	0.2634	–6.564159	0	–6.570572	0
LSrv_GDP	–1.509704	0.5201	–2.513062	0.3208	–7.695887	0	–7.932222	0
LSrv_IPrv	–0.310469	0.9154	–2.38316	0.3832	–6.381415	0	–6.31137	0
LSrv_Emp	–0.072283	0.9464	–6.040012	0	–16.19263	0	–15.71361	0
LAgg_GDP	–1.01663	0.7399	–3.168162	0.1033	–10.29256	0	–9.94885	0
LAgg_IPrv	–0.246937	0.9247	–2.376024	0.3868	–5.751953	0	–5.703555	0.0001
LAgg_Emp	1.100535	0.997	–1.926615	0.6249	–6.48744	0	–6.597266	0

LAgr is representing the log of agriculture sector, Lming is representing the log of mining sector, LMfg is representing the log of manufacturing sector, Lconst is representing the log of construction sector, Lelec is representing the log of electric and gas sector, LTranp is representing the log of transport and communication sector, LFinc is representing the log of finance and insurance sector, LSrv is representing the log of services sector and LAgg is representing the log of Aggregate economy.
EMP is representing the employment, IPub is representing the public investment, Iprv is representing the private investment.

Table 2

Diagnostic Test: Dynamic impacts of Public Energy Spending

Sectors/Model	Numbers of Lags	Autocorrelation Test (p-value)^1	Normality Test (p-value)^2	Heteroskedas-ticity Test (p-value)^3
Agriculture(Major and Minor Crops, Livestock, Fishing and Forestry)	1	0.1958	0.1381	0.6523
Mining and Quarrying	2	0.5828	0.9435	0.5831
Manufacturing	1	0.3933	0.145	0.9859
Construction	1	0.1936	0.978	0.8569
Electricity and Gas Distribution	1	0.8288	0	0.9359
Transport, Storage and Communication	1	0.5089	0.766	0.8618
Finance and Insurance	1	0.5292	0.001	0.5744
Services (Community Services, Public Administration and Defense and Ownership of Dwellings)	1	0.0019	0.0017	0.1813

1. Based on VAR residual serial correlation LM test with null no serial correlation.
2. Multivariate Jarque-Bera residual normality test. For the null hypothesis of normality.
3. VAR Residual Heteroskedasticity Tests. For null hypothesis of no Heteroskedasticity.

Cointegration Analysis

Finally, to decide whether to use Vector Autoregressive Model (VAR) or Vector Error Correction (VEC), a cointegration test is applied to all the models by using Engle-Granger (1987) and Johansen (1991, 1995) approaches. The cointegration results based on Engle-Granger test [5],in all the models reject the existence of cointegration, while in a few models only Johansen test shows the existence of cointegration. The reason for using Engle-Granger approach is based on the finding of Gonzalo and Lee (1998) and Gonzalo and Pitarakis(1999) who mentioned that Johansen approach has small sample bias for cointegration when it does not exist. These findings are similar to other related studies e.g. in the case of Portugal, Pereria and Andraz (2005) and in the case of U.S, Pereria and Andraz (2003) did not find any cointegration.

4. EMPIRICAL RESULTS

This section discusses the empirical effects of public energy investment on sectoral output, private investment and employment. These effects are based on accumulated impulse response function. The effect of a shock in public energy investment on sectoral GDP is traced in terms of output elasticities. The effect of a shock in public energy investment on sectoral private employment is traced in terms of private investment elasticities, similarly the effects of a shock in public energy investment on employment are measured in terms of employment elasticities.

Table 3

Long Term Accumulated Impulse Response Effects of Public Energy Investment

Sectors	On Output	On Private Investment	On Employment
Agriculture(Major Crops, Minor Crops, Livestock, Fishing and Forestry)	+	+	+
Mining and Quarrying	+	+	–
Manufacturing	+	+	–
Construction	+	+	+
Electricity and Gas Distribution	–	+	+
Transport, Storage and Communication	+	+	–
Finance and Insurance	+	–	–
Services (Community Services, Public Administration and Defense, Ownership of Dwellings)	+	+	–

Table 3 gives summary of results of the impact of public investment on output, private investment and employment and detailed graphs are given in Appendix-A which are based on accumulated impulse response function with a time horizon of 20 years. These unit shock effects of public energy investment on output show that public energy investment has a positive effect on the output of all sectors except electricity and gas

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[5] For the sake of brevity results are not reported, but available on demand.

distribution sector. In case of private investment the impulse response functions indicate that public energy investment also has a positive effect on private investment in all the sectors except finance and insurance, while in case of employment the impulse response function graphs show that only three sectors out of eight have a positive employment effect with respect to public energy investment. One more important feature of these graphs, which is worth mentioning here is that in all the cases the shocks effect dies out after five years, except three sectors.

Measuring the Long-term Accumulated Effect of Public Capital Formation

The Effects of Public Investment on Output

The effect of public investment on sectoral output is presented in Table 4. The results indicate that public investment has positive output effects for all the sectors except electricity and gas distribution. The result shows the sum of marginal productivities across the sectors is 3.57 i.e., one rupee public investment will collectively generate the output of rupees 3.57, which is low as compared to the relatively advanced countries, such as in Spain; Pereira and Oriol (2001) found the aggregate marginal productivity for output of 5.5, similarly in the case of Portugal; Pereia and Andraz (2007) found aggregate marginal productivity of output of 8. On the sectoral level, the public investment's highest benefit share goes to manufacturing followed by mining and quarrying, transport and communication, services, agriculture, finance and insurance and then construction. The share distribution is 24 percent, 21 percent, 17 percent, 11 percent, 10 percent and 3 percent respectively.

The Effects of Public Investment on Private Investment

Table 4 also discusses the impact of public investment on private investment. The empirical results show that public investment has a positive impact on private investment supporting the hypothesis of crowding-in; in seven out of eight sectors i.e. except the services sector. The results show the sum of marginal productivities of private investment across the sectors is 1.35 indicating one rupee public investments will increase private investment by Rs 1.35. These results show that overall impact of public investment on private investment is also low in Pakistan as compared to the other countries. In the case of Spain Pereira and Oriol (2001) found the aggregate marginal productivity of private investment is 10.18, similarly in the case of Portugal, Pereia and Andraz (2007) found aggregate marginal productivity is 9.45. On the sectoral level, the highest benefit share of public energy investment goes to manufacturing followed by agriculture, services, transport and communication, mining and quarrying, electricity and gas and then construction. The share distribution is 47 percent, 11.5 percent, 11 percent, 6 percent, 6 percent and 5 percent respectively.

The Effects of Public Investment on Employment

The employment effect of public investment is presented in Table 4. On the sectoral level, public investment has positive employment effect in agriculture, construction and electricity and gas. The one million rupees public investment will create

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Table 4

Effects of Public Energy Investment on Output, Private Investment and Employment

	Share Contribution			Elasticities			Marginal Productivity			Shares of Benefits (%)		
Sectors	% of total Output	% of total Private Investment	% of total Employment	Output	Private Investment	Employment	Output	Private Investment	Employment	Output	Private Investment	Employment
Agriculture	21.38	12.09	43.82	0.0085	0.0640	0.0061	0.3892	0.2107	3.0902	10.79%	13.81%	74.65%
Mining and Quarrying	2.93	4.66	0.17	0.1220	0.0766	–0.1831	0.7666	0.0971	–0.3669	21.25%	6.36%	–
Manufacturing	18.09	25.55	13.42	0.0227	0.1025	–0.0190	0.8830	0.7132	–2.9306	24.48%	46.73%	–
Construction	2.35	1.45	6.24	0.0214	0.1884	0.0142	0.1080	0.0746	1.0190	3.00%	4.89%	24.62%
Electricity and Gas Distribution	2.33	2.62	0.7	–0.0074	0.1268	0.0038	–0.0370	0.0903	0.0302	–	5.92%	0..73%
Transport, Storage and Communication	12.67	18.65	5.51	0.0227	0.0325	–0.0219	0.6172	0.1650	–1.3880	17.11%	10.81%	–
Finance and Insurance	4.48	4.70	0.91	0.0372	–0.1371	–0.0245	0.3576	–0.1756	–0.2560	9.91%	–	–
Services	18.02	27.22	14.23	0.0125	0.0237	–0.0356	0.4850	0.1754	–5.8241	13.44%	11.49%	–
Sum	82.27	96.95	85				3.57	1.35	–6.63			

Source: Authors' own estimation.

Table 4

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highest employment in agriculture sector followed by construction and then electricity and gas. In comparison with other studies such as in the case of Portugal, Pereia and Andraz (2007) found the highest benefit share of infrastructure investment in the case of construction followed by finance, services, and real estate. These results show in many sectors it is negative, however these results are also consistent with other studies. For example Pereira and Andraz (2007) found negative employment effect of public infrastructure investment in agriculture, food, textile, other manufacturing and real estate sectors in the case of Portugal.

5. CONCLUSION AND POLICY IMPLICATION

The objective of this study is to find empirical evidence of the effectiveness of public energy investment in Pakistan. In literature, usually the production function approach is applied for such analysis while this study uses the VAR methodology which allows capturing dynamic feedback effect of public investment on private investment, employment and output.

The study is one of the pioneer attempts on the subject by estimating the long term marginal productivities of public investment at sectoral level. The study uses data of eight sectors of Pakistan economy from 1981-2011. The study estimates eight elasticity coefficients to investigate the impact of public investment on sectoral private investment and confirms crowding-in phenomenon in seven out of eight sectros in Pakistan’s economy. This overwhelming evidence confirms that public investment has positive a effect on private investment. The three out of eight elasticity coefficients show public investment has increased labour absorption and the remaining five show labour is substituted by capital as a result of increased public investment. The highest marginal productivity is 0.88 in manufacturing followed by 0.766 and 0.61 in mining and quarrying and transport and communication sectors. This implies one rupee public investment in these sectors will generate rupees 0.88, 0.766 and 0.61 in these sectors respectively. Generally the marginal productivity is lower as compared to several developed countries like Portugal and Spain where such analysis has been conducted.

The results of this study provide the answers to some important policy questions and also help in formulating future policy. This study calculates the marginal productivities, which are useful in project evaluation and investment decisions. The positive output effect indicates that public energy investment is growth stimulating through its direct effect and indirect effects.

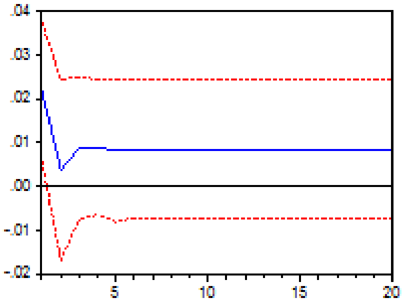
APPENDIX-A

Impulse Response Graphs

Fig. 1. Accumulated Impulse Reponses of Sectoral GDP Due to Change in Sectoral Public Investment

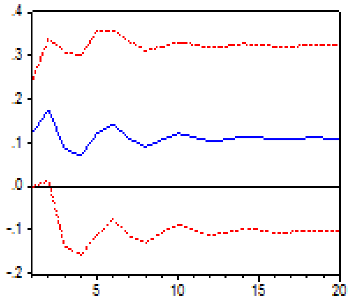
1A

Accumulated Response of D(AGR_GDP) to D(ELEC_IPUB)



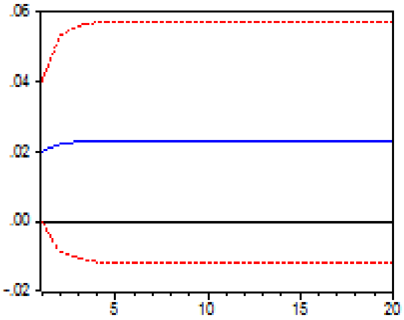
1B

Accumulated Response of D(MING_GDP) to D(ELEC_IPUB)



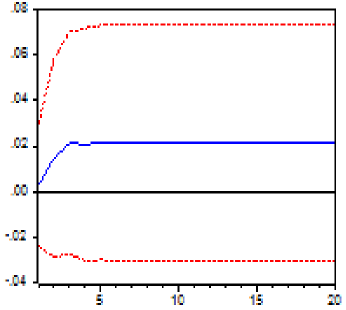
1C

Accumulated Response of D(MFG_GDP) to D(ELEC_IPUB)



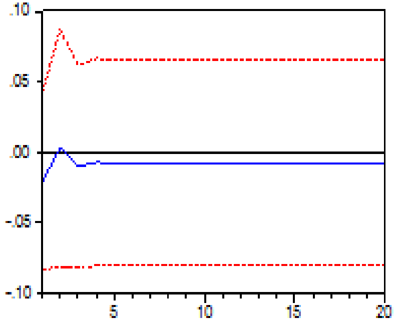
1D

Accumulated Response of D(CONST_GDP) to D(ELEC_IPUB)



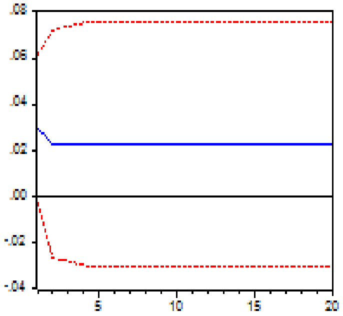
1E

Accumulated Response of D(ELEC_GDP) to D(ELEC_IPUB)



1F

Accumulated Response of D(TRANP_GDP) to D(ELEC_IPUB)



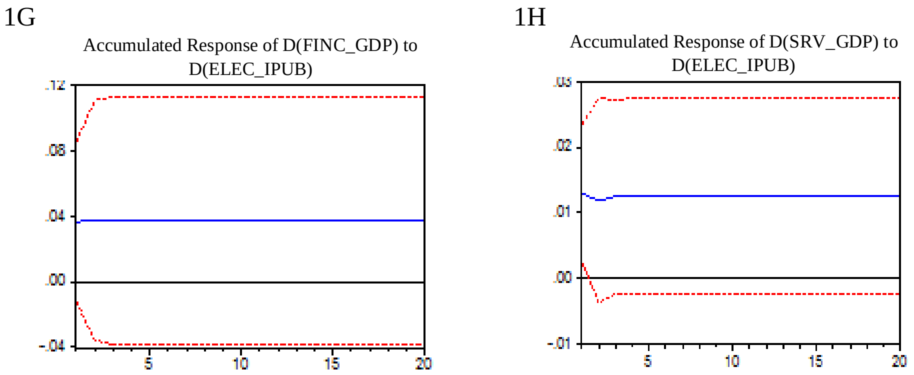
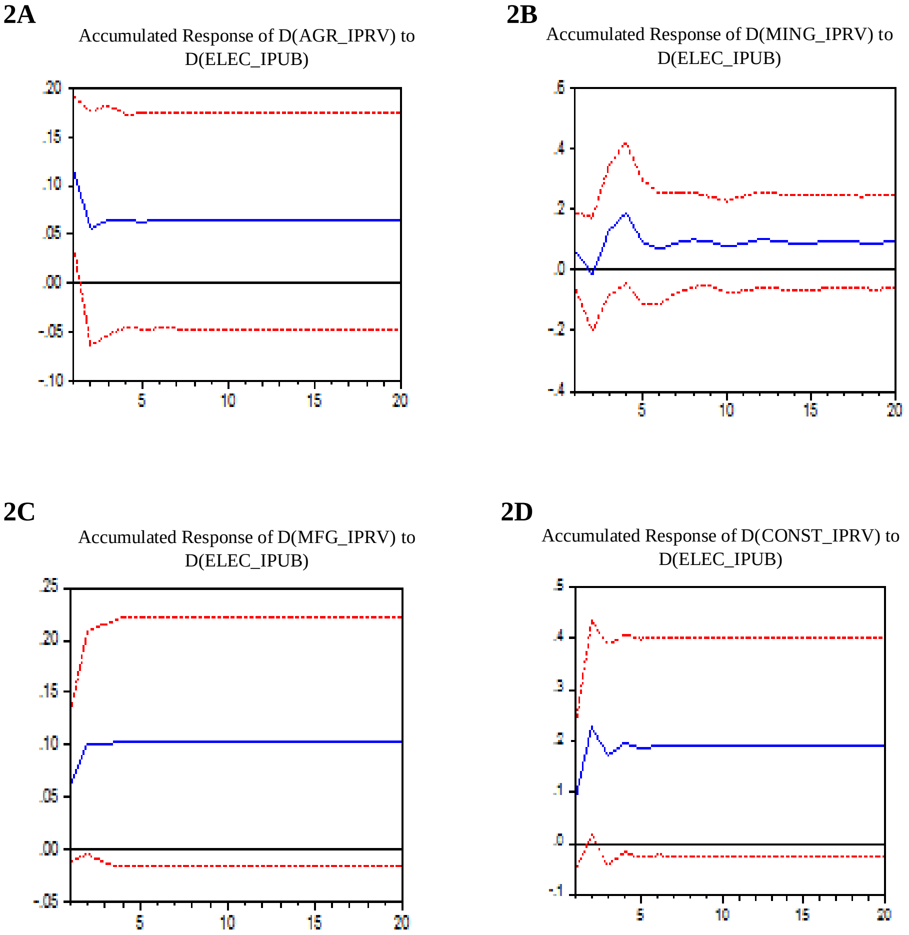
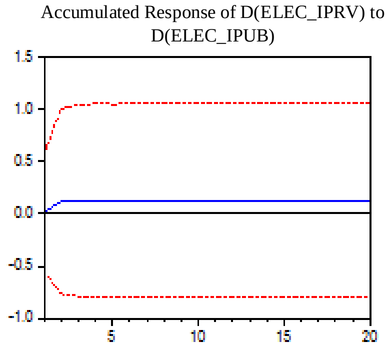


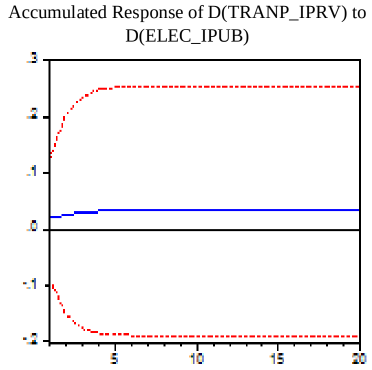
Fig. 2. Accumulated Impulse Reponses of Sectoral Private Investment to Innovation in Sectoral Public Investment



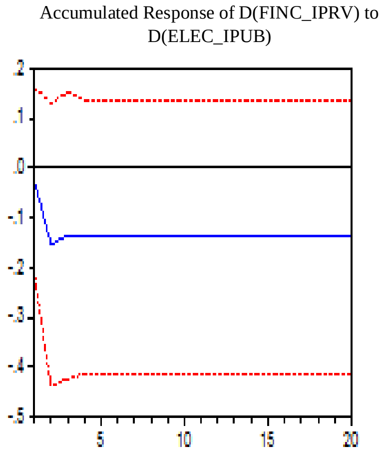
2E


Accumulated Response of D(ELEC_IPRV) to D(ELEC_IPUB)

2F


Accumulated Response of D(TRANP_IPRV) to D(ELEC_IPUB)

2G


Accumulated Response of D(FINC_IPRV) to D(ELEC_IPUB)

2H

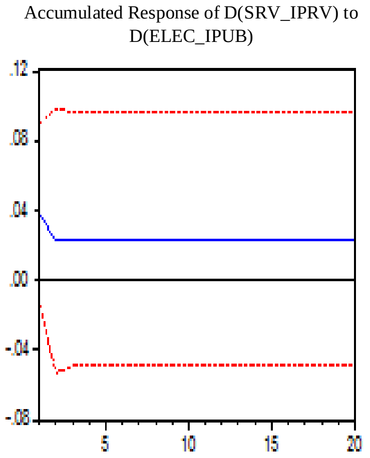
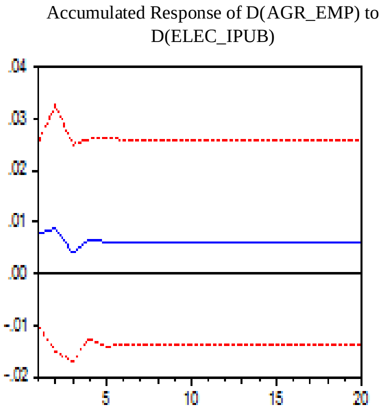
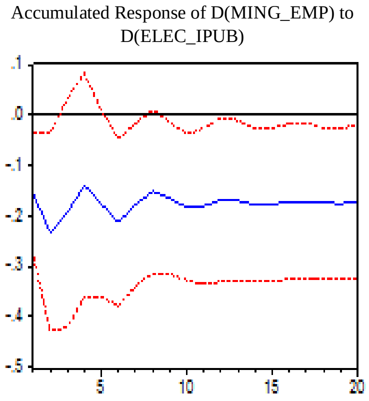

Accumulated Response of D(SRV_IPRV) to D(ELEC_IPUB)

Fig. 3. Accumulated Impulse Reponses of Sectoral Employment to Innovation in Sectoral Public Investment

3A

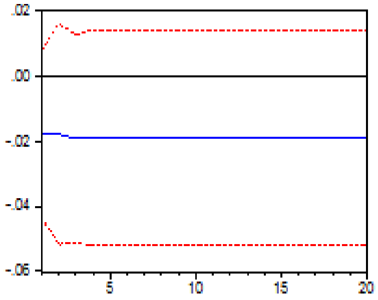

Accumulated Response of D(AGR_EMP) to D(ELEC_IPUB)

3B


Accumulated Response of D(MING_EMP) to D(ELEC_IPUB)

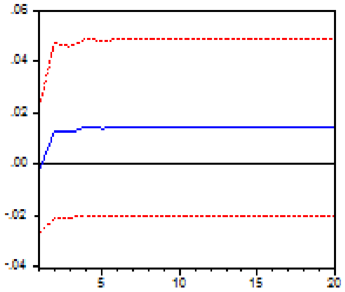
3C

Accumulated Response of D(MFG_EMP) to D(ELEC_IPUB)



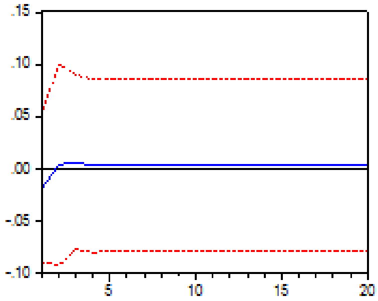
3D

Accumulated Response of D(CONST_EMP) to D(ELEC_IPUB)



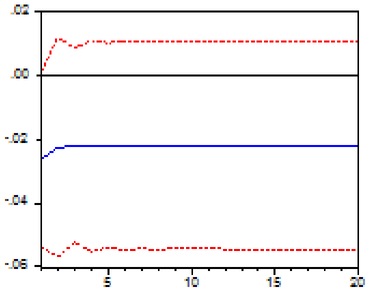
3E

Accumulated Response of D(ELEC_EMP) to D(ELEC_IPUB)



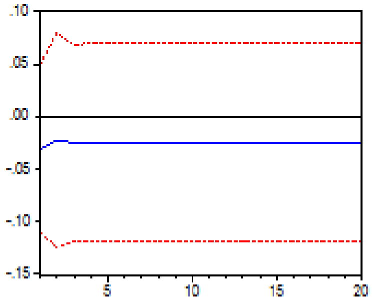
3F

Accumulated Response of D(TRANP_EMP) to D(ELEC_IPUB)



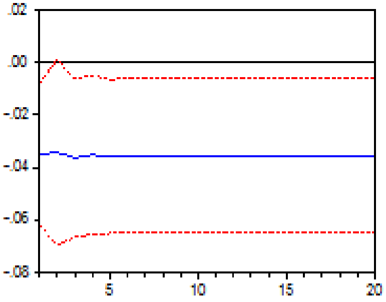
3G

Accumulated Response of D(FINC_EMP) to D(ELEC_IPUB)



3H

Accumulated Response of D(SRV_EMP) to D(ELEC_IPUB)



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Comments

It is an awesome topic to work on in the current scenario because the country is facing acute problem of energy which is among the major input in industrial as well as agriculture production. While reading the paper I felt that if authors can incorporate the following comments, it would enhance the quality of their paper.

Authors have used Growth model. Mankiw, Romer Weil (1991) already showed that human capital is extremely important in case of growth modeling, therefore, human capital is extremely important to include in the growth equation.

Since not all the sectors need energy such as finance and insurance thus all the sectors do not need to regress on energy. Therefore, I would recommend to exclude irrelevant variables from the analysis. Moreover, investment in public sector energy ventures are the investment in the manufacturing sector by the public sector, but rest of the investment is missing in the model. The variable is extremely important and should be included in the model to get correct partial association with the main variables.

Paper did not explain procedure adopted to fill the gaps in employment data. As a reader it is a useful information which is missing.

Cointegration in case of growth equation may not be a feasible technique because there are significant chances that labour, capital, human capital and growth are interlinked to each other and there is a problem of endogeneity. Therefore, proper technique should be applied to get the parameters.

The exercise done in Tale 4 is a very good exercise. However, the magnitude and signs of few variables seems to be incorrect. I believe that by including the human capital variables, inclusion and exclusion of relevant and irrelevant variables and adopting proper estimation technique may help in getting correct signs.

As much as I am not convinced with the estimation technique applied in the paper, I am also not convinced with the application of impulse response function on annual data. Impulse response function gives us the response of shock in any variable within the system. By using this technique we know the divergent or converging behavior of the variables. However, it also tells us the duration of period in which shock is either absorbed or tells. Using the technique on annual data, mostly, do not give meaningful results. Therefore, in my view either this technique is not used on annual data or the results should be interpret with caution because “variable will adjust after 8 periods implies 8 years”, which in most of the cases is not a meaningful result.

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Causality between Trade Openness and Energy Consumption: What Causes What in High, Middle and Low Income Countries

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INTRODUCTION

Trade liberalisation has affected the flow of trade (goods and services) between developed and developing countries. The Heckscher-Ohlin trade theory reveals that under free trade, developing countries would specialise in the production of those goods that are produced by relatively abundant factors of production such as labour and natural resources. Developed countries would specialise in the production of those goods that are produced by human capital and manufactured in capital-intensive activities. Trade openness entails movement of goods produced in one country for either consumption or further processing to other country. Production of those goods is not possible without the effective use of energy. Trade openness affects energy demand via scale effect, technique effect and composite effect. Other things being same, trade openness increases economic activities, thus stimulates domestic production and hence economic growth. A surge in domestic production increases energy demand , which is commonly referred as scale effect. Such scale effect is caused by trade openness. Economic condition of the country and extent of relationship between economic growth and trade openness determine the impact of trade openness on energy consumption [Shahbaz, *et al.* (2013); Cole (2006)]. Trade openness enables developing economies to import advanced technologies from developed economies. The adoption of advanced technology lowers energy intensity. The use of advanced technologies result in less energy consumption and more output that is usually referred to as technique effect [Arrow (1962)]. Composite effect reveals the shift of production structure from agriculture to industry with the use of energy intensive production techniques. In initial stages of economic development economy is based largely on agriculture sector, thus the use of energy is relatively less. As economy starts shifting from agriculture to industry, the energy consumption increases. Arrow (1962) calls it positive composite effect. Finally, at the later stage of economic development,

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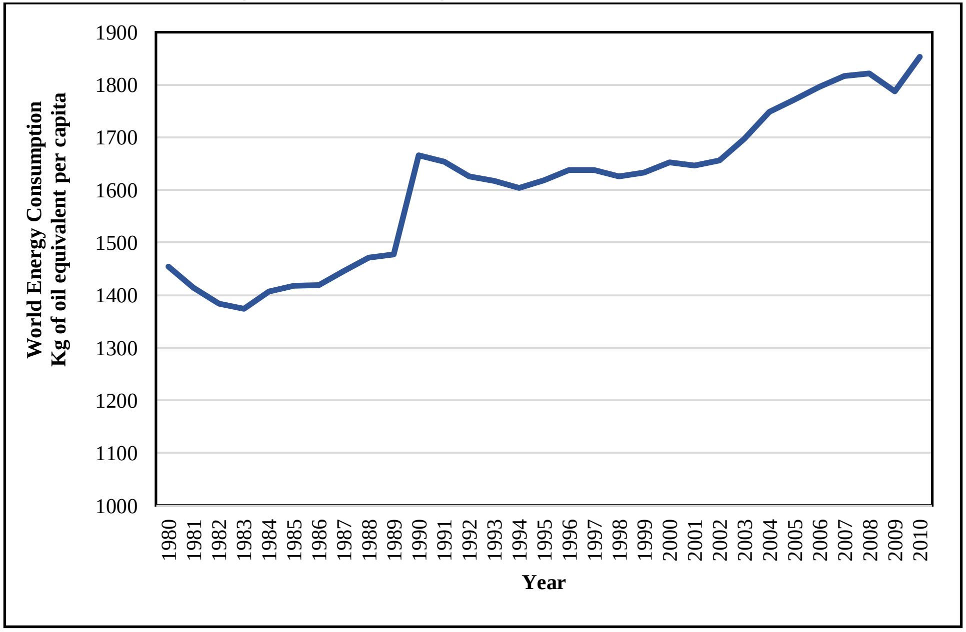
economic structure shifts from industry to services, there is less energy consumption, which implies that energy intensity is lowered because of composite effect.

Energy affects trade openness via various channels. First, energy is an important input of production because machinery and equipment in the process of production require energy. Second, export or import of manufactured goods or raw material require energy to fuel transportation. Without adequate energy supply, trade openness will be adversely affected. Consequently, energy is an important input in trade expansion and adequate consumption of energy is essential to expand trade via expanding exports and imports. The relationship between trade openness and energy consumption is important. Since energy plays a key role to promote exports or imports hence policies aiming at reduction of energy consumption such as energy conservation policies will negatively impact the flow of exports or imports and hence, reduce the benefit of trade openness. The bidirectional causal relationship between trade openness and energy consumption suggests that energy expansion policies should be adopted because energy consumption stimulates trade openness and trade openness affects energy consumption [Sadorsky (2011)]. The energy conservation policies will not have an adverse effect on trade openness if causality is running from trade openness to energy consumption or if neutral relationship exists between trade openness and energy consumption [Sadorsky (2011)].

Energy consumption in the world increases parallel to technological development, increase in trade and population growth. The world average energy consumption was 1454 Kg of oil equivalent per capita in 1980, which increased to 1852 Kg of oil equivalent per capita in 2010 (see Figure 1). According to American Energy Information Administration (EIA) and the International Energy Agency (IEA), the worldwide energy consumption will on average continue to increase by 2 percent per year.

Fig. 1. World Energy Consumption per Capita

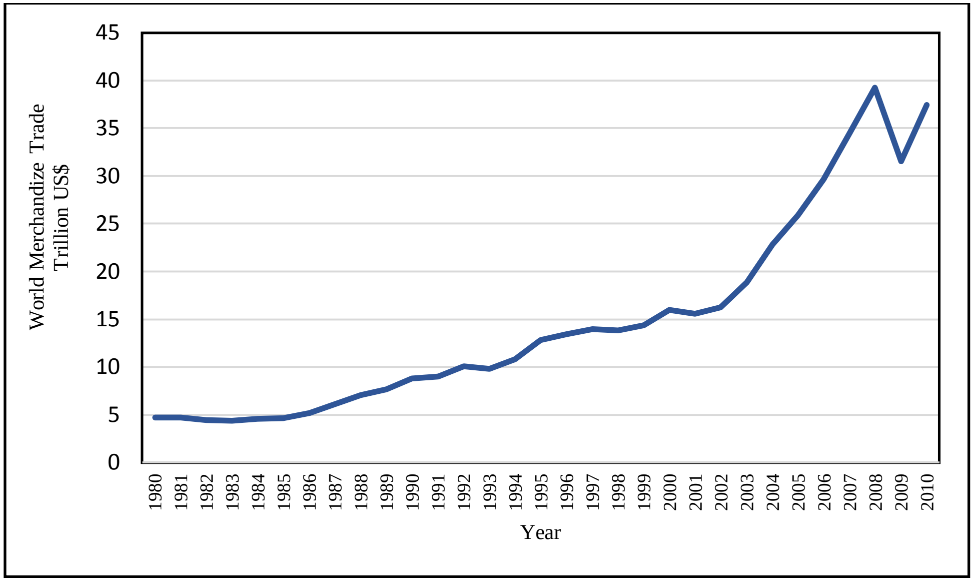


Source: World Development Indicators (CD-ROM, 2012).

Between 1980 and 2006, energy consumption has increased but fuel consumption structure varies by region. Coal has the largest share in fuel consumption of the world, accounting for 30.4 percent of total increase; Asia and Oceania contributed 97.7 percent of total coal increase between 1980 and 2006. During the same period, natural gas ranks second in total energy consumption, accounting for 28.7 percent, Asian and Oceania still contributed the largest part, 24 percent of total gas increase, Eurasia, Europe and Middle East contributed about 17 percent and 20 percent respectively. Oil ranked as the third fuel in total consumption, accounting for 21.5 percent. Asia and Oceania still were the biggest contributors; accounting for about 67.9 percent of increase in oil consumption. The nuclear power contributed about 10.7 percent to total increase, the increase was mainly contributed by Europe, North America and, Asia and Oceania where more new nuclear reactors have been started. Hydropower has developed in Asia and Oceania and Central and, South America, because of their abundant hydro resources. And these two regions contribute 80 percent to global hydropower increase. However, global industry sector has reduced the use of total energy from 33 percent in 1980 to 27 percent in 2006 because most developed countries used less energy in industry by improvement in energy efficiency, technology development and major production structure changes.

Growth in world energy consumption reached 5.6 percent in 2010, the highest growth rate since 1973. Energy consumption in OECD countries grew by 3.5 percent while in non-OECD countries by 7.5 percent in 2010. Chinese energy consumption grew by 11.2 percent and China surpassed the United States as the world’s largest energy consumer. Oil remained the world’s leading fuel in 2010, and accounted for 33.6 percent of global energy consumption. World natural gas consumption grew by 7.4 percent in 2010, the most rapid increase since 1984. The United States witnessed the world’s largest increase in consumption, which rose by about 5.6 percent in 2010. Asian countries also registered large increase of about 10.7 percent, led by a 21.5 percent increase in India. Coal consumption grew by 7.6 percent in 2010, the fastest global growth since 2003. The share of coal in world energy consumption is 29.6 percent, more than 25.6 percent of ten years ago. China consumed 48.2 percent of world coal and accounted for nearly two-third of global coal consumption. The use of modern renewable energy sources including wind, solar, geothermal, marine, modern biomass and hydro continued to grow rapidly and accounted for 1.8 percent of world energy consumption in 2010, up from 0.6 percent in 2000. Energy use in transport sector increased very rapidly during the recent years due to rapid economic development and population growth. Over the past 30 years, energy use in transport sector has doubled. Transport sector accounts for 25 percent of world energy consumption in 2010 [International Energy Agency (2012)].The volume of merchandise trade among countries has been rapidly increasing for last two decades due to globalisation. Global merchandise trade (exports plus imports of goods) was US$ 3.8 trillion in 1980 but it amounted to US$ 37 trillion in 2010 (see Figure 2).

Fig. 2. World Merchandise Trade



Source: World Development Indicators (CD-ROM, 2012).

In 2006, merchandise exports in volume terms increased among regions. Exports from North America and Asia grew faster than imports. The growth rate of Asian export was 13 percent while imports grew by 9 percent. Europe recorded balanced export and import growth of 7 percent. For South and Central America, the Commonwealth of Independent States, Africa and the Middle East, import growth was larger than exports. This pattern is attributed to more favourable terms of trade due to increases in commodity prices in the past few years. The global economies faced negative trade shock in 2009. This negative trade shock was mainly due to massive contraction of global demand that reduced commodity prices in all regions of the world. The trade shock was strongest in transition economies and the economies of Western Asia and Africa. However, the similar situation does not exist in 2010. All WTO regions experienced double-digit increase in the dollar value of both exports and imports in 2010 due to rise in prices of fuel and other commodities. The top merchandise exporters in 2010 were China (US$ 1.58 trillion) followed by United States (US$ 1.28 trillion), Germany (US$ 1.27 trillion), Japan (US$ 770 billion) and Netherlands (US$ 572 billion). The leading merchandise importers in 2010 were United States (US$ 1.97 trillion), China (US$ 1.40 trillion), Germany (US$ 1.07 trillion), Japan (US$ 693 billion) and France (US$ 606 billion) (*Source*: World Trade Report, 2011).

There are a few studies that examined the relationship between energy consumption and economic growth [Masih and Masih (1996); Yang (2000); Narayan, *et al*. (2008)], energy consumption and exports [Narayan and Smyth (2009); Lean and Smyth (2011); Halicioglu (2010); Shahbaz, *et al*. (2013a)]. However, the relationship between trade openness and energy consumption is still understudied. The objective of this study is to fill this gap by investigating the relationship between trade openness and energy consumption using global data of 91 high, middle and low-income countries for the period 1980-2010. The pooled mean group and mean group models are used to show non-linear relationship between trade openness and energy consumption. Test for establishing the long-run relationships between variables are carried out by using the panel cointegration approach developed by Larsson et al. (2001) while test for causality is conducted by using a modified version of Granger causality test developed by Hurlin and Venet (2001).

The rest of the paper is organised as follows: Section 2 gives a brief review of empirical studies, Section 3 presents the methodology and data source, Section 4 presents the results and discussion and Section 5 gives the conclusions and policy implications.

2. LITERATURE REVIEW

There is an extensive literature available on the relationship between economic growth and energy consumption. Energy consumption is an important factor of production like capital and labour and it affects economic growth. After the end of 1970s energy crisis, many studies [e.g. Kraft and Kraft (1978), Akarca and Long (1979 and 1980), Yu and Choi (1985)] exposed that energy consumption is positively correlated with economic growth. However, empirical evidence provided by Zahid (2008), Amirat and Bouri (2010), Noor and Siddiqi (2010), Apergis and Payne (2010) is conflicting about direction of causality. For instance, Nondo and Kahsai (2009) investigated the long-run relationship between total energy consumption and economic growth for a panel of 19 African countries. They applied Levine, *et al.* (2005), Im, *et al.* (2003) and Hadri (2005) panel unit root tests to test the integrating properties of real GDP and total energy consumption. Their analysis indicated that both the variables are cointegrated for long run relationship confirmed by Pedroni (1999) panel cointegration approach. Moreover, they noted that economic growth is cause of energy consumption in long run as well as in short run. Noor and Siddiqi (2010) investigated the causal relationship between per capita energy consumption and per capita GDP in five South Asian countries namely Bangladesh, India, Nepal, Pakistan and Sri Lanka. They applied panel unit root tests IPS, LLC and MW, and Pedroni cointegration as well as Kao residual cointegration approaches. They reported that energy consumption enhances economic growth. Their causality analysis reveals that economic growth Granger causes energy consumption in South Asian countries.[1]

There are a few studies investigating the relationship between trade openness and energy consumption. For instance, Cole (2006) examined the relationship between trade liberalisation and energy consumption. Cole (2006) used data of 32 countries and found that trade liberalisation promotes economic growth, which boosts energy demand. Moreover, trade liberalisation stimulates use of capital intensive techniques, which in turn affects energy consumption. Jena and Grote (2008) investigated the impact of trade openness on energy consumption. They noted that trade openness stimulates industrialisation via scale effect, technique effect, composite effect and comparative advantages effect, which affect energy consumption. Narayan and Smith (2009) examined the causal relationship between energy consumption and economic growth by incorporating exports as an indicator of trade openness in production function for a panel of six Middle Eastern countries namely Iran, Israel, Kuwait, Oman, Saudi Arabia and

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[1] Payne (2010) and Ozturk (2010) presented comprehensive survey studies on the relationship between economic growth and energy consumption.

Syria. They applied panel unit root test, panel cointegration and panel causality tests. Their analysis confirmed the presence of cointegration relationship between variables. Furthermore, they reported that that a short-run Granger causality exists running from energy consumption to real GDP and from economic growth to exports but neutral relationship is found between exports and energy consumption.

Later on, Sadorsky (2011) examined the causal relationship between total energy consumption and trade openness. The panel means group cointegration and panel Granger causality approaches were used for the panel of 8 Middle Eastern countries namely, Bahrain, Iran, Jordan, Oman, Qatar, Saudi Arabia, Syria and UAE. The empirical evidence reported that long run relationship exists between the variables. Sadorsky found that that 1 percentage increase in real per capita GDP increases per capita energy consumption by 0.62 percent. A 1 percent increase in real per capita exports increases per capita energy consumption by 0.11 percent while 1 percent increase in real per capita imports increases per capita energy consumption by 0.04 percent. Panel Granger causality analysis revealed that exports Granger cause energy consumption and the feedback is found between imports and energy consumption in short run. Similarly, the bidirectional causality exists between GDP and energy consumption in short run. Sadorsky (2012) used production function to investigate the relationship between trade openness and energy consumption in South American countries namely Argentina, Brazil, Chile, Ecuador, Paraguay, Peru, and Uruguay over the period of 1980-2007. The panel cointegration developed by Pedroni (2004), fully modified ordinary least squares (FMOLS) and the VECM Granger causality approaches were applied. The empirical evidence confirmed the presence of cointegration for long run relationship between the variables. The relationship between exports and energy consumption is bidirectional and imports Granger cause energy consumption in short run. Using data of 52 developed and developing economies, Ghani (2012) explored relationship between trade liberalisation and energy demand. The results indicated that trade liberalisation has insignificant impact on energy consumption but after a certain level of capital per labour, trade liberalisation affects energy consumption.

Hossain (2012) examined the relationship between electricity consumption and exports by adding foreign remittances and economic growth as additional determinants in SAARC countries namely Pakistan, India and Bangladesh. The author reported the no causality between exports and electricity demand. Dedeoğlu and Kaya (2013) investigated the relationship between exports, imports and energy consumption by incorporating economic growth as additional determinant of trade openness and energy consumption using data of the OECD countries. They applied the panel cointegration technique developed by Pedroni (2004) and used the Granger causality developed by Canning and Pedroni (2008). Their analysis showed the cointegration between the variables. They also noted that economic growth, exports and imports have positive impact on energy consumption. Their causality analysis revealed that the relationship between exports (imports) and energy consumption is bidirectional.

3. ESTIMATION STRATEGY

Panel Unit Roots

We apply Levine, *et al.* (2002) (LLC), Im, *et al.* (2003) (IPS), Maddala and Wu (1999) (MW, ADF) and Maddala and Wu (1999) (MW, PP) panel unit root tests to check the stationarity properties of the variables. These tests apply to a balanced panel but the LLC can be considered a pooled panel unit root test, IPS represents a heterogeneous panel test and MW panel unit root test is non-parametric test.

3.1. LLC Unit Root Test

Levin, *et al.* (2002) developed a number of pooled panel unit root tests with various specifications depending upon the treatment of the individual specific intercepts and time trends. This test imposes homogeneity on the autoregressive coefficient that indicates the presence or absence of unit root problem while the intercept and the trend can vary across individual series. LLC unit root test follows ADF regression for the investigation of unit root hypothesis as given below step by step:

(1) We use a separate ADF regression for each country:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{it-1} + \sum_{j=1}^{p_i} \alpha_{i,j} \Delta y_{i,t-j} + \varepsilon_{i,t} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

The lag order p_i is allowable across individual countries. The appropriate lag length is chosen by allowing the maximum lag order and then using the t-statistics for *ij b* to determine if a smaller lag order is preferred.

(2) We run two separate regressions and save the residuals $\tilde{\eta}_{it}, \tilde{\mu}_{i,t-1}$

$$\Delta y_{i,t} = \lambda_i + \sum_{j=1}^{p_i} \gamma_{i,t-j} \Delta y_{i,t-j} + \eta_{i,t} \Rightarrow \tilde{\eta}_{it} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

$$y_{i,t-1} = \partial_i + \sum_{j=1}^{p_i} \ell_{i,t-j} \Delta y_{i,t-j} + \mu_{i,t-1} \Rightarrow \tilde{\mu}_{i,t-1} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

LLC procedure suggests to standardise the errors $\tilde{\eta}_{it}, \tilde{\mu}_{i,t-1}$ by regressing the standard error through the ADF equation provided above:

$$\tilde{\eta}_{it} = \frac{\tilde{\eta}_{it}}{\hat{\sigma}_{\varepsilon i}}, \tilde{\eta}_{it-1} = \frac{\tilde{\eta}_{i,t-1}}{\hat{\sigma}_{\varepsilon i}} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

(3) Regression can be run to compute the panel test statistics following Equation 5:

$$\tilde{\eta}_{it} = \alpha \tilde{\eta}_{i,t-1} + \nu_{i,t} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

The null hypothesis is as follows: $H_\circ : \rho_1, .. = ...\rho_n = \rho = 0$ and alternate hypothesis is: $H_A : \rho = ...\rho_n = \rho < 0$.

3.2. IPS Unit Root Test

Im, Pesaran and Shin (IPS), (2003) introduced a panel unit root test in the context of a heterogeneous panel. This test basically applies the ADF test to individual series thus allowing each series to have its own short-run dynamics. But the overall t-test statistic is based on the arithmetic mean of all individual countries' ADF statistic. Suppose a series (TR_{ti}, EC_{ti}) can be represented by the ADF (without trend).

$$\Delta x_{i,t} = \varpi_j + \varpi_i x_{i,t-1} + \sum_{j=1}^{p_i} \phi_{i,j} \Delta x_{i,t-j} + \nu_{i,t} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

After the ADF regression has different augmentation lags for each country in finite samples, the term $E(t_T)$ and $\mathrm{var}(t_T)$ are replaced by the corresponding group averages of the tabulated values of $E(t_T, P_i)$ and $\mathrm{var}(t_T, P_i)$ respectively. The IPS test allows for the heterogeneity in the value ϖ_i under the alternative hypothesis. This is more efficient and powerful test than usual single time series test. The estimable equation of IPS unit root test is modeled as follows:

$$t_{NT} = \frac{I}{N} \sum_{i=1}^{N} t_{i,t}(P_i) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

where $t_{i,t}$ is the ADF t-statistics for the unit root tests of each country and P_i is the lag order in the ADF regression and test statistic can be calculated as follows:

$$\mathrm{A}_{\bar{t}} = \frac{\sqrt{N(T)}[\bar{t}_T - E(t_T)}{\sqrt{\mathrm{var}(t_T)}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

As t_{NT} is explained above and values for $E[t_{iT}(P_i, 0)]$ can be obtained from the results of Monte Carlo simulation carried out by IPS. They have calculated and tabulated them for various time periods and lags. When the ADF has different augmentation lags (P_i) the two terms $E(t_T)$ and $\mathrm{var}(t_T)$ in the equation above are replaced by corresponding group averages of the tabulated values of $E(t_T, P_i)$ and $\mathrm{var}(t_T, P_i)$ respectively.[2]

3.3. MW Unit Root Test

The Fisher-type test was developed by Maddala and Wu (1999), which pools the probability values obtained from unit root tests for every cross-section *i*. This is a non-

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[2] Karlsson and Lothgren (2000) demonstrate the power of panel unit root tests by Monte Carlo simulation. The null of all these tests is that each series contains a unit root and thus is difference stationary. However, the alternative hypothesis is not clearly specified. In LLC the alternative hypothesis is that all individual series in the panel are stationary. In IPS the alternative hypothesis is that at least one of the individual series in the panel is stationary. They conclude that the "presence or absence of power against the alternative hypothesis where a subset of the series is stationary has a serious implications for empirical work. If the tests have high power, a rejection of the unit root null can be driven by few stationary series and the whole panel may inaccurately be modelled as stationary. If, on the other hand, the tests have low power it may incorrectly concluded that the panel contains a common unit root even if a majority of the series is stationary'' (p. 254). The simulation results reveal that the power of the tests (LLC, IPS) increases monotonically with: (1) an increased number (N) of the series in the panel; (2) an increased time series dimension (T) in each individual series; (3) increased proportion of stationary series in the panel. Their Monte Carlo simulations for N=13 and T=80 reveal the power of the test is 0.7 for LLC tests and approaching unity for the IPS tests.

parametric test and has a chi-square distribution with 2nd degree of freedom where n is number of countries in a panel. The test statistic is given by:

$$\lambda = -2\sum_{i=1}^{n}\log_e(p_i) \sim \chi^2_{2n}(d.f.) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)$$

Where p_i is probability value from ADF unit root tests for unit i. The MW unit root test is superior to IPS unit root test because MW unit root test is sensitive to the lag length selection in individual ADF regressions. Maddala and Wu (1999) performed Monte Caro simulations to prove that their test is more advanced than the test developed by IPS (2003).

3.4. The Likelihood-based Panel Cointegration Test

The panel LLL trace test statistics is actually derived from the average of individual likelihood ratio cointegration rank trace test statistics of the panel individuals. The multivariate cointegration trace test of Johanson (1988, 1995) is applied to investigate each individual cross-section system autonomously, in that way, allowing heterogeneity in each cross-sectional unit root for said panel. The process of data generation for each of the groups is characterised by the following heterogeneous VAR (p_i) model:

$$Y_{i,t} = \sum_{j=1}^{p_i}\Lambda_{i,j}Y_{i,t-j} + \varepsilon_{i,t} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (10)$$

Where $i = 1,......,N; t = 1,......T$

For each one, the value of $Y_{i,-j+1},.....Y_{i,0}$ is considered fixed and $\varepsilon_{i,t}$ are independent and identically distributed (normally distributed): $\varepsilon \sim N_K(0,\Omega_i)$, where Ω_i is the cross-correlation matrix of the error terms: $\Omega_i = E(\varepsilon_{i,t},\varepsilon'_{i,t})$. The Equation 10 can be modified as vector error correction model (VECM) as given below:

$$\Delta Y_{i,t} = \Pi_i Y_{i,t-1} + \sum_{j=1}^{p_i-1}\Gamma_{i,j}\Delta Y_{i,t-j} + \varepsilon_{i,j} \quad \dots \quad \dots \quad \dots \quad \dots \quad (11)$$

Where $\Pi_i = \Lambda_{i,1} + ...+ \Lambda_{pi} - 1$ and $\Gamma_{i,j} = \Lambda_{i,j} - \Lambda_{i,j-1}, \Pi_i$ is of order $(k \times k)$. If Π_i is of reduced rank: rank $(\Pi_i) = r_i$, which can be de-composed into $\Pi_i = ab'$, where α_i and β_i are of order $(k \times r_i)$ and of full column rank that represents the error correction form. The null hypotheses of panel LLL (2001) rank test are:

$H_\circ = rank(\Pi_i) = r_i \leq r$ for all $i = 1,.....,N$ against
$H_a = rank(\Pi_i) = k$ for all $i = 1,.....,N$

The procedure is in sequences like individual trace test process for cointegration rank determination. First, we test for $H_\circ = rank(\Pi_i) = r_i \leq r, r = 0$, if null hypothesis of no cointegration is accepted, this shows that there is no cointegration relationship

$(rank(\Pi_i) = r_i = 0)$ in all cross-sectional groups for said panel. If null hypothesis is not accepted then null hypothesis *r* = 1 is tested. The sequence of procedure is not disconnected and continued until null hypothesis is accepted, *r* = *k* –1, or is rejected. Accepting the hypothesis of cointegration *r* = 0 along with null hypothesis of rank $(\Pi_i) = r \leq 0(0 < r < k)$ implies that there is at least one cross-sectional unit in panel, which has rank $(\Pi_i) = r > 0$. The likelihood ratio trace test statistic for group *i* is as following;

$$LR_{iT}\{H(r)/H(k) = -2\ln Q_{iT}(H(r)/H(k) = -T\sum_{l=r+1}^{p}\ln(1-\lambda'_{li}) \quad \ldots \quad \ldots \quad (12)$$

Where λ'_l is the l^{th} largest eigen value in the i^{th} cross-section unit. The LR-bar statistic is calculated as the average of individual trace statistics:

$$L\bar{R}_{iT}[H(r)/H(k)] = \frac{1}{N}\sum_{i=1}^{n} LR_{iT}[H(r)/H(k)] \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

Finally, modified version of above equation is defined as:

$$\lambda_{L\bar{R}}[H(r)/H(k) = \frac{\sqrt{N}(L\bar{R}_{NT}[H(r)/H(k)] - E(Z_k)}{\sqrt{VAR(Z_k)}} \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

Where $E(Z_k)$ and $Var(Z_k)$ are mean and variance of the asymptotic trace statistics, which can be obtained from simulation. The LLL (2001) proves the central limit theorem for the standard LR-bar statistic, according to which under the null hypothesis, $\lambda_{L\bar{R}} \Rightarrow N(0,1)$ as N and $T \to \infty$ in such a way that $\sqrt{NT}^{-1} \to 0$, under the assumption that there is no cross-correlation in the error terms, that is given below:

$$E(\varepsilon_{i,t}) = 0 \text{ and } E(\varepsilon_{i,t}, \varepsilon_{j,t}) = \begin{cases} \Omega_i \\ 0 \end{cases} \text{ for } i = j, i \neq j$$

LLL (2001) notes that $T \to \infty$ is needed for each of the individual test statistic to converge to its asymptotic distribution, while $N \to \infty$ is needed for the central limit theorem.

3.5. Panel Causality Test

Hurlin and Venet (2001) extended the Granger (1969) causality test for panel data models with fixed coefficients. The estimable equation for empirical estimation is modeled as following:

$$y_{i,t} = \sum_{K=1}^{P}\gamma^{(K)}y_{i,t-K} + \sum_{K=0}^{P}\beta_i^{(K)}x_{i,t-K} + v_{i,t} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (15)$$

With $P \in N^*$ and $\nu_{i,t} = \partial_i + \varepsilon_{i,t}$, where $\varepsilon_{i,t}$ are *i.i.d* (O,σ^2_ε). In contrast to Nair–Reichert and Weinhold (2001), we assume that the autoregressive coefficients $\gamma^{(k)}$ and the regression coefficients slopes $\beta_i^{(k)}$ are constant $\Omega k\varepsilon[1,p]$. We also assume that parameters $\gamma^{(k)}$ are identical for all individuals, whereas the regression coefficients slopes $\beta_i^{(K)}$ could have an individual dimension. Hurlin and Venet (2001), consider four principal cases following Equation 15.

3.6. Homogenous Non-Causality Test

Initially the homogenous non-causality (HNC) hypothesis has been discussed. Conditional to the specific error components of the model, this hypothesis assumes no prevalence of any individual causality association:

$$\forall i \in [1,N] \;\; E\left(y_{i,t} / \overline{y}_{i,t}, \alpha_i\right) = E\left(y_{i,t} / \overline{y}_{i,t}, \overline{x}_{i,t}, \alpha_i\right) \quad \dots \quad \dots \quad \dots \quad (16)$$

In Equation 15, the corresponding test[3] is defined by:

$$H_o : \beta_i^{(K)} = 0 \;\; \forall_i \in [1,N], \forall k \in (1,p) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$
$$H_a : \exists (i,k) / \beta_i^{(K)} \neq 0$$

In order to test these N_p linear restrictions Wald Statistic is employed:

$$F_{hnc} = \frac{(RSS_2 - RSS_1)/(Np)}{RSS_1 / [NT - N(1+p) - p]} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (18)$$

Where RSS_2 indicates the restricted sum of squared residuals. RSS_1 corresponds to the residual sum of squares of equation-15. If the realisation of this statistic is not significant, the homogeneous non-causality hypothesis is accepted. This result implies that the variable *X* is not causing *Y* in finite sample set in all countries. If the non-causality result is totally homogenous then further empirical exercise is stopped.

3.7. Homogenous Causality Test

Secondly, homogenous causality (HC) hypothesis is proven, in which there exist *N* causality relationships:

$$\forall i \in [1,N] \;\; E\left(y_{i,t} / \overline{y}_{i,t}, \alpha_i\right) \neq E\left(y_{i,t} / \overline{y}_{i,t}, \overline{x}_{i,t}, \alpha_i\right) \quad \dots \quad \dots \quad \dots \quad (19)$$

In this case, suppose that the *N* individual predictors, obtained conditional to the fact that $\overline{Y}_{i,t}, \overline{X}_{i,t}$ and α_i, are the same:

$$\forall (i,j) \in [1,N] \;\; E\left(y_{i,t} / \overline{y}_{i,t}, \overline{x}_{i,t}, \alpha_i\right) = E\left(y_{i,t} / \overline{y}_{j,t}, \overline{x}_{j,t}, \alpha_j\right) \quad \dots \quad \dots \quad (20)$$

Two configurations could appear, if we reject hypothesis of non-homogenous causality. The first one corresponds to the overall causality hypothesis (homogenous causality hypothesis) and occurs if all the coefficients β_i^K are identical for all *k*. The

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[3] Here, we do not consider instantaneous non-causality hypothesis.

second one is more plausible, which is that some coefficients β_i^K are different for each individual. Thus, after the rejection of the null hypothesis of non-homogenous causality, the second step of the procedure consists of testing if the regression slope coefficients associated to $x_{i,t-k}$ are identical. This test corresponds to a standard homogeneity test. Formally, the homogenous causality hypothesis test is as following:

$$H_o : \forall k \in [1, p] \ / \beta_i^k = \beta^k \ \forall i \in [1, N] \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (21)$$

$$H_a : \exists k \in [1, p], \exists \, (i, j) \ \in [1, N] / \beta_i^k \neq \beta_j^k$$

The homogenous causality hypothesis implies that the coefficients of the lagged explanatory variables $x_{i,t-k}$ are identical for each lag k and different from zero. Indeed, if we have rejected, in the previous step, the non-homogenous causality hypothesis $\beta_i^K = 0 \ \forall (i, k)$, this standard specification test allows testing the homogenous causality hypothesis. In order to test the homogenous causality hypothesis, F-statistic is calculated by applying the given mechanism:

$$F_{hc} = \frac{(RSS_3 - RSS_1)/[p(N-1)}{RSS_1/\left[NT - N(1+p) - p\right]} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (22)$$

where, RSS_3 corresponds to the realisation of the residual sum of squares obtained in Equation 15 when one imposes the homogeneity for each lag k of the coefficients associated to the variable $x_{i,t-k}$. If the F_{hc} statistics with $P(N-1)$ and $NT - N(1 + P) - P$ degrees of freedom is not significant, the homogenous causality hypothesis is accepted. This result implies that the variable X is causing Y in the N countries of the samples, and that the autoregressive processes are completely homogenous.

3.8. Heterogeneous Causality Test

Third case is relevant to the heterogeneous causality hypothesis. Under HEC hypothesis, it is assumed there exists at least one individual causality relationship (and at the most N), and second that individual predictors, obtained conditional to the fact that $\bar{y}_{i,t}, \bar{x}_{i,t}, \bar{\lambda}_t$ and, α_i are heterogeneous.

$$\exists i \in [1, N] \ \ E(y_{i,t} / \bar{y}_{i,t}, \alpha_i) \neq E(y_{i,t} / \bar{y}_{i,t}, \bar{x}_{i,t}, \alpha_i) \qquad \ldots \quad \ldots \quad \ldots \qquad (23)$$

$$\exists (i, j) \ \in [1, N] \ E(y_{i,t} / \bar{y}_{i,t}, \bar{x}_{i,t}, \alpha_i) \neq E(y_{j,t} / \bar{y}_{j,t}, \bar{x}_{j,t}, \alpha_j) \qquad \ldots \quad \ldots \qquad (24)$$

3.9. Heterogeneous Non-causality Test

Finally, heterogeneous non-causality hypothesis assumes that there exists at least one and at the most N−1 equalities of the form:

$$\exists i \in [1, N] \ \ E(y_{i,t} / \bar{y}_{i,t}, \alpha_i) = E(y_{i,t} / \bar{y}_{i,t}, \bar{x}_{i,t}, \alpha_i) \qquad \ldots \quad \ldots \quad \ldots \qquad (25)$$

The third step of the procedure consists of testing the heterogeneous non-causality hypothesis (HENC). The following equation explains this mechanism:

$$H_o : \exists i \in [1, N] \,/\, \forall k \in [1, p]\; \beta_i^K = 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (26)$$

$$H_a : \forall i \,\varepsilon\, [1, N],\ \exists k \,\varepsilon\, [1, N] \,/\, \beta_i^K \neq 0$$

This test is proposed to test this last hypothesis with two nested tests. The first test is an individual test realised for each individual. For each individual $i = 1\dots N$, we test the nullity of all the coefficients of the lagged explanatory variables $x_{i,t-k}$. Then, for each i, we test the hypothesis $\beta_i^K = 0, \forall k \in [1, p]$. For that, we compute N statistics:

$$F_{hene}^{i} = \frac{(RSS_{2,i} - RSS_1)/p}{RSS_1/\left[NT - N(1+2p) + p\right]} \quad \dots \quad \dots \quad \dots \quad \dots \quad (27)$$

where, $RSS_{2,i}$ corresponds to the realisation of the residual sum of squares obtained in model (15), when one imposes the nullity of the k coefficients associated to the variable $x_{i,t-k}$ only for the individual i. A second test of the procedure consists of testing the joint hypothesis that there is no causality relationship for a sub-group of individuals. Let us respectively denote I_c and I_{nc} as the index sets corresponding to sub-groups for which there exists a causal relationship and there does not exist a causal relationship. In other words, we consider the following model $\forall t \in [1, T]$:

$$y_{i,t} = \sum_{k=1}^{p} \gamma_i^k y_{i,t-k} + \sum_{K=0}^{p} \beta_i^k x_{i,t-k} + v_{i,t} \quad \dots \quad \dots \quad \dots \quad \dots \quad (28)$$

with

$$\beta_i^K \neq 0 \ for\ i \in I_c$$
$$\beta_i^K = 0 \ for\ i \in I_{nc}$$

Let $n_c = \dim(I_c)$ and $n_{nc} = \dim(I_{nc})$. Suppose that $n_c/n_{nc} \rightarrow \theta < \infty$ as n_c and n_{nc} tend to infinity. One solution to test the HENC hypothesis is to compute the Wald statistic.

$$F_{henc} = \frac{(RSS_4 - RSS_1)/(n_{nc}p)}{RSS_1/\left[NT - N(1+p) - n_c p\right]} \quad \dots \quad \dots \quad \dots \quad \dots \quad (29)$$

where RSS_4 corresponds to realisation of the residual sum of squares obtained from equation-15 when one imposes the nullity of the k coefficients associated to the variable $x_{i,t-k}$ for the n_{nc} individuals of the I_{nc} sub-group. If the HENC hypothesis is accepted, it implies that there exists a sub-group of individuals for which the variable x does not cause the variable y. The dimension of this sub-group is then equal to n_{nc}. On the contrary, if the HENC hypothesis is rejected, it implies that there exists a causality between x and y for all individuals of the panel.

3.10. Data and Data Sources

The 91 countries are selected for the estimation of causality between energy consumption and trade openness on the basis of data availability.[4] The study covers the

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[4] The selection of countries is restricted to availability of data. The names of countries are listed in Appendix-A.

period 1980-2010. All necessary data for the sample period are obtained from World development Indicators (CD- ROM, 2012). Energy consumption in kg of oil equivalent per capita is used to measure energy consumption, real exports (US$) plus real imports (US$) divided by population are used to measure trade openness. Both variables are used in their natural logarithmic form.

4. EMPIRICAL RESULTS AND THEIR DISCUSSIONS

The results of ADF unit root test in the presence of intercept and, intercept and trend reported in Table 1 suggest that all the series are non-stationary at their level, but stationary at first difference. This implies that real trade per capita (TR_t) and energy consumption per capita (EC_t) are integrated at I(1) for each country in our sample.

The unit root test results set the stage for Johansen cointegration approach. The results are presented in Table 2. We find the acceptance of null hypothesis i.e. no cointegration in case of Angola, Brazil, Bulgaria, Cameroon, Congo Dem Rep, Congo Rep, Israel, Italy, Kenya, South Korea, Kuwait, Nicaragua, Pakistan, Panama, Philippines, Sudan, Tunisia, Turkey, Zambia and Zimbabwe. We find two cointegrating vectors in case of Benin, Saudi Arabia, Cyprus, Denmark, Ecuador, Ghana, Indonesia, Luxemburg and Paraguay and for the rest of countries, we find one cointegrating vector. The existence of one or two cointegrating vectors confirms the presence of cointegration between the variables. This shows that trade openness and energy consumption have long run relationship over selected period of time i.e., 1980–2010.

This ambiguity in the results based on single country study prompts us to apply panel cointegration approach.[5] For this purpose, we apply panel unit root tests to check for stationary properties of the series. The results based on the LLC, IPS, MW (ADF) and MW (PP) unit root tests with constant and, constant and trend are reported in Table 3. The tests show that all variables are found to be non-stationary at level. At first difference, all the series are integrated i.e. I(1). This unique order of integration of the variables helps us to apply Johansen panel cointegration approach to examine long run relationship between the variables for selected panel.

The results are reported in Table 4. We find that maximum likelihood ratio i.e. 5.9035 is greater than critical value at 1 percent level of significance. This leads us to reject the null hypothesis of no panel cointegration between the variables. We may conclude that the panel cointegration exists between trade openness and energy consumption in sampled countries. The Table 5 shows that trade openness affects energy consumption in high, middle and low-income countries. In high-income countries, we find that the relationship between trade openness and energy consumption is inverted U-shaped. This implies that initially trade openness is positively linked with energy consumption and after a threshold level, it declines energy demand due to adoption of energy efficient technology. This indicates that a 1 percent increase in trade openness raises energy demand by 0.860 percent and negative sign of nonlinear term of trade openness corroborates the delinking of energy consumption as trade openness is at optimal level. In case of middle and low

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[5] In some countries we could not find cointegration while in rest of the countries we found the existence of cointegration between the variables.

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Table-1

ADF Unit Root Test

	Level		1^{st} Difference			Level		1^{st} Difference	
Country/ Variable	Intercept	Trend & Intercept	Intercept	Trend & Intercept	Country/ Variable	Intercept	Trend & Intercept	Intercept	Trend & Intercept
Algeria					**Angola**				
TR_t	0.4189	–0.8701	–3.8052**	–5.1733*	TR_t	1.5123	–0.5634	–3.5182**	–4.5661*
EC_t	–0.6407	–1.4528	–5.8948*	–5.2814*	EC_t	–1.6214	–1.5625	–3.2417**	–5.9735*
Argentina					**Australia**				
TR_t	–1.0531	–3.0792	–5.2571*	–5.0271*	TR_t	0.3937	–2.6913	–4.3756*	–4.5020*
EC_t	–0.8932	–2.8109	–3.6245**	–3.6308**	EC_t	0.1996	–2.7783	–4.1198*	–4.2963**
Austria					**Albania**				
TR_t	–0.5524	–2.4505	–3.2985**	–3.5066***	TR_t	–0.7642	–1.6930	–4.4905*	–4.9971*
EC_t	–0.1863	–2.5139	–4.6619*	–4.4885*	EC_t	–1.5043	–1.2434	–3.0995**	–3.2659***
Bangladesh					**Belgium**				
TR_t	0.6132	–3.0994	–3.9199*	–3.9065**	TR_t	–0.5282	–2.2922	–3.0316**	–3.5863***
EC_t	1.0205	–2.3929	–4.6232*	–5.1651*	EC_t	–1.9601	–2.6871	–3.5797**	–3.5434***
Benin					**Bolivia**				
TR_t	–0.3299	–2.3450	–4.9286*	–5.0471*	TR_t	0.2859	–1.3079	–2.9710***	–4.3259**
EC_t	–1.9601	–2.6871	–3.5797**	–3.5434***	EC_t	–1.4582	–2.1065	–3.5069**	–3.4382***
Botswana					**Brazil**				
TR_t	–1.4420	–2.4192	–3.9853*	–4.0636**	TR_t	1.1870	–2.1045	–4.5757*	–4.8461*
EC_t	–1.0734	–1.3623	–3.0628**	–5.6302*	EC_t	–0.9027	–2.4494	–3.1364**	–3.7495**
Brunei Darussalam					**Bulgaria**				
TR_t	–0.3508	–1.4825	–3.6958**	–5.7109*	TR_t	–0.4585	–0.4585	–2.7263***	–4.3906**
EC_t	–1.9429	–3.1187	–3.7129**	–3.6122***	EC_t	–1.3805	–2.2254	–3.3030**	–3.9770**
Canada					**China**				
TR_t	–1.9408	–2.4400	–4.9088*	–5.2583*	TR_t	0.1074	–2.1102	–4.8452*	–4.8994*
EC_t	–2.0028	–3.1663	–3.7820*	–3.7348**	EC_t	0.6452	–2.0721	–2.9494**	–3.2235***
Chili					**Congo Dem Rep**				
TR_t	–0.7908	–2.4845	–5.5118*	–5.3639*	TR_t	–2.5579	–2.8169	–3.9579*	–3.8466**
EC_t	0.3533	–2.8041	–2.9216***	–4.6043*	EC_t	–0.6483	–1.9564	–4.2579*	–4.1745**

Continued—

Table 1—(*Continued*)

Colombia					**Costa Rica**				
TR_t	–0.0635	–2.6416	–3.1969**	–4.5686*	TR_t	–0.2737	–2.3264	–3.6127**	–3.5250***
EC_t	–1.1615	–1.4324	–4.8072*	–4.8553*	EC_t	–0.2865	–0.3390	–3.2568**	–3.8902**
Congo Rep					**Cameroon**				
TR_t	–1.5302	–2.7516	–3.9847*	–3.8813**	TR_t	–1.5618	–2.9541	–2.7506***	–5.6762*
EC_t	–1.2094	–0.5212	–3.2900**	–3.4620***	EC_t	–1.0496	–1.0088	–3.6118**	–4.1561**
Cote D'Ivoire					**Cyprus**				
TR_t	0.2225	–1.9929	–3.6169**	–3.8302**	TR_t	–0.4131	–1.6628	–3.3912**	–3.3175***
EC_t	–0.9567	–1.7444	–3.9964*	–4.8263*	EC_t	–1.5058	–0.5346	–3.3796**	–3.8715**
Cuba					**Dominican Rep**				
TR_t	–1.8938	–1.6057	–2.7562***	–3.9406**	TR_t	–0.5985	–2.1949	–5.3140*	–5.2511*
EC_t	–1.4306	–2.8859	–2.9979**	–2.9527***	EC_t	–0.9124	–1.6794	–3.9453*	–3.8494**
Denmark					**Egypt**				
TR_t	–0.0910	–2.3117	–3.2089**	–3.5203***	TR_t	0.5745	–2.7622	–2.7713***	–3.6586**
EC_t	–2.0518	–2.7916	–3.7190**	–3.6570**	EC_t	–1.0024	–2.4033	–3.5517**	–3.3564***
Ecuador					**Ethiopia**				
TR_t	0.7030	–2.0413	–3.4003**	–3.9494**	TR_t	–0.0839	–1.2336	–4.3298*	–4.6814*
EC_t	–0.1665	–1.1361	–3.3996**	–4.2587**	EC_t	–1.4764	–1.9549	–3.2659**	–3.8596**
El Salvador					**France**				
TR_t	–0.0745	–2.2870	–3.4843**	–3.3700***	TR_t	–0.4312	–2.3780	–3.2569**	–3.6901**
EC_t	–0.0416	–1.7824	–2.8539***	–3.7315**	EC_t	–1.3933	–1.7466	–4.2313*	–4.6509*
Finland					**Ghana**				
TR_t	–0.6923	–2.7347	–3.7078**	–3.5774***	TR_t	–1.7857	–1.5640	–5.0802*	–5.4612*
EC_t	–2.3395	–2.7686	–4.3644*	–4.1951**	EC_t	–1.0468	–1.0777	–4.1390*	–4.2675**
Gabon					**Guatemala**				
TR_t	–0.9361	–2.7341	–3.9640*	–4.2463**	TR_t	0.7712	–3.0441	–3.3703**	–3.6195**
EC_t	–2.2723	–1.0959	–3.5525**	–4.5870*	EC_t	–1.3829	–2.0519	–3.3144**	–3.4552***
Greece					**Honduras**				
TR_t	0.5889	–2.8057	–3.5020**	–3.6567**	TR_t	–2.0091	–3.1213	–3.8804*	–4.4064*
EC_t	–1.8250	–2.0913	–4.5134*	–5.0303*	EC_t	–1.0752	–2.0968	–4.1316*	–4.7148*

Continued—

Table 1—(*Continued*)

Hong Kong Sar China					**Hungary**				
TR_t	–1.1785	–1.3189	–2.6850***	–3.8314**	TR_t	1.7100	–1.6508	–3.2192**	–4.3836**
EC_t	–2.2905	–2.1313	–4.1514*	–4.6741*	EC_t	–1.5879	–1.6464	–4.2076*	–4.1344**
Iceland					**India**				
TR_t	–0.0669	–2.9149	–3.9574*	–3.6995**	TR_t	1.8877	–0.6580	–3.0276**	–3.8732**
EC_t	1.3877	–1.0638	–2.6858***	–4.4322*	EC_t	–0.0584	–2.1698	–3.4824**	–3.3593***
Indonesia					**Iran**				
TR_t	0.2339	–2.9163	–3.0756**	–3.2696***	TR_t	–1.8514	–3.1574	–3.9574*	–3.8381**
EC_t	–0.8880	–1.1027	–3.0141**	–5.4069*	EC_t	–1.7349	–2.6435	–4.8904*	–4.8000*
Ireland					**Israel**				
TR_t	–0.3663	–2.9986	–3.4761*	–4.3522**	TR_t	0.2725	–3.0813	–4.7457*	–4.6242*
EC_t	–0.7152	–1.7686	–2.8905***	–3.9752**	EC_t	–1.3830	–1.3627	–2.6706***	–3.9254**
Italy					**Jamaica**				
TR_t	–0.4589	–2.1827	–3.0526**	–3.6232**	TR_t	–0.9943	–1.0985	–3.0749**	–3.3349***
EC_t	–0.6640	–0.6640	–3.7542*	–3.5772***	EC_t	–0.5598	–2.9249	–2.9871***	–3.9866**
Japan					**Jordan**				
TR_t	–0.5783	–1.5631	–3.7380*	–3.7787**	TR_t	1.6131	–1.0977	–3.5064**	–4.1582**
EC_t	–1.5272	–0.7059	–2.9823***	–3.4728**	EC_t	–1.6982	–2.4034	–3.9477*	–3.7925**
Kenya					**South Korea**				
TR_t	0.9276	–2.3376	–3.6645**	–4.5061*	TR_t	–0.4298	–2.3466	–3.7693*	–3.7279**
EC_t	–1.8363	–3.0614	–3.3529**	–3.3313***	EC_t	–1.1716	–1.7710	–3.3229**	–3.2994***
Kuwait					**Morocco**				
TR_t	–0.9690	–2.0366	–4.6979*	–5.2502*	TR_t	–0.9696	–2.0819	–4.3410*	–4.1784**
EC_t	–2.3481	0.4619	–4.8638*	–5.8653*	EC_t	–0.9635	–2.1519	–5.0387*	–5.2066*
Luxembourg					**Nepal**				
TR_t	–0.2836	–2.2064	–4.9548*	–4.8930*	TR_t	–2.3691	–1.8741	–3.7489*	–4.3319*
EC_t	–2.3473	–2.3293	–4.0122*	–5.6876*	EC_t	0.4621	–1.3866	–3.7507*	–4.3404*
Mexico					**Mozambique**				
TR_t	0.2913	–2.4058	–3.8353*	–3.8029**	TR_t	0.3713	–0.5526	–3.1407**	–3.3170***
EC_t	0.2726	–1.6751	–4.5094*	–5.8401*	EC_t	–2.2439	–1.5365	–3.5940**	–3.7322**

Continued—

Table 1—(*Continued*)

Netherland The					**New Zealand**				
TR_t	–1.4168	–3.2000	–3.8649*	–3.9471**	TR_t	–1.0605	–2.9833	–5.2135*	–5.1376*
EC_t	–2.4361	–2.8255	–5.0101*	–4.9431*	EC_t	–1.7181	–0.4779	–3.0886**	–3.3346***
Nicaragua					**Nigeria 62**				
TR_t	–0.4710	–1.1263	–3.3732**	–3.3756***	TR_t	–0.1775	–2.4375	–3.5531**	–3.9467**
EC_t	–1.5720	–1.9819	–4.6927*	–4.9537*	EC_t	–1.7124	–2.4091	–4.8954*	–4.7717*
Norway					**Oman**				
TR_t	–1.1537	–2.6473	–4.9267*	–4.7619*	TR_t	0.5709	–1.9620	–4.7076*	–5.4118*
EC_t	–1.4857	–2.6535	–3.7932*	–3.6945**	EC_t	–1.6655	–1.1611	–3.2912**	–3.8308**
Pakistan					**Panama**				
TR_t	–0.8509	–1.5699	–3.6078**	–3.7826**	TR_t	–0.0274	–2.9196	–3.6502**	–3.7050**
EC_t	–0.7991	–1.2641	–3.6304**	–3.6256**	EC_t	–1.4526	–2.1700	–3.5667**	–3.5796***
Paraguay					**Peru**				
TR_t	–1.0733	–1.8795	–3.3666**	–3.2948***	TR_t	0.9379	–1.2987	–4.1376*	–4.8637*
EC_t	–1.9243	–1.5327	–3.4150**	–3.5757***	EC_t	–2.4168	–1.6216	–3.0831**	–3.8628**
Philippines					**Portugal**				
TR_t	0.0850	–2.4948	–2.9139***	–4.0941**	TR_t	–0.9716	–1.9043	–3.1984**	–3.7547**
EC_t	–1.0685	–0.8958	–2.7434***	–5.7293*	EC_t	–1.4205	–0.5693	–3.0971**	–3.4068***
Senegal					**Saudi Arabia**				
TR_t	0.3681	–1.9134	–3.9852*	–4.0835**	TR_t	–1.1196	–3.0603	–2.9303***	–3.8555**
EC_t	–2.0357	–1.7417	–3.7402*	–4.0870**	EC_t	–0.4166	–2.4292	–4.3369*	–4.4657*
Sweden					**South Africa**				
TR_t	–0.2027	–3.2173	–3.6094**	–3.5278***	TR_t	–0.1611	–2.2382	–3.3540**	–3.5337***
EC_t	–2.3509	–2.2029	–3.7852*	–4.1207**	EC_t	–2.4185	–2.7120	–3.9703*	–3.8643**
Spain					**Switzerland**				
TR_t	–2.6228	–2.9807	–2.9065***	–3.9750**	TR_t	–0.5370	–2.1945	–3.0437**	–3.6199**
EC_t	0.3351	–2.5762	–3.3364**	–3.6564**	EC_t	–2.1958	–2.3868	–3.8958*	–4.1728**
Sudan					**Thailand**				
TR_t	0.9521	–0.2051	–2.6364***	–3.7561**	TR_t	–0.6347	–1.8510	–2.9256***	–3.8709**
EC_t	0.0171	–1.6685	–4.6910*	–5.0355*	EC_t	–0.6523	–2.1115	–2.9460***	–3.2717***

Continued—

Table 1—(*Continued*)

Syrian Arab Rep					**Trinidad and Tobago**				
TR_t	0.7897	–2.2773	–3.2714**	–3.7719**	TR_t	1.0311	–0.9596	–2.8083**	–4.8930*
EC_t	–1.3196	–0.1094	–3.9862*	–4.2562**	EC_t	1.4450	–0.9133	–3.1422**	–3.4384***
Togo					**Turkey**				
TR_t	–1.6974	–2.0971	–3.2771**	–3.4455***	TR_t	–0.4813	–3.1314	–4.9825*	–4.7570*
EC_t	–0.6940	–2.2815	–3.7204**	–3.6245**	EC_t	–1.0464	–2.1727	–3.6186**	–3.5759***
Tunisia					**United Arab Emirates**				
TR_t	0.2968	–2.9650	–2.6946***	–3.8919**	TR_t	1.1937	–2.0504	–2.7599***	–3.7995**
EC_t	–0.0885	–2.2401	–3.8989*	–3.6826**	EC_t	–2.4012	–1.6495	–3.6501**	–4.0875**
United Kingdom					**United States**				
TR_t	0.2412	–3.2119	–2.7876***	–3.2986***	TR_t	–0.5591	–2.7876	–4.2063*	–3.9376**
EC_t	–1.7197	–0.5494	–3.4085**	–4.1409**	EC_t	–2.4541	–1.7094	–5.8708*	–5.6874*
Uruguay					**Vietnam**				
TR_t	–0.1814	–2.6080	–3.0855**	–3.7887**	TR_t	–1.2282	–2.2356	–5.6683*	–5.7772*
EC_t	–2.3534	–3.0691	–4.1359*	–4.1451**	EC_t	1.6287	–0.7176	–3.7120**	–4.7837*
Venezuela R.B.De					**Zimbabwe**				
TR_t	0.1327	–2.2907	–3.9118*	–4.8369*	TR_t	–1.6008	–1.6471	–3.1144**	–3.4239***
EC_t	–1.8629	–1.8146	–3.5727**	–3.4811***	EC_t	–1.1851	–2.0258	–4.1822*	–4.2352**
Zambia									
TR_t	0.7516	0.3288	–3.4925**	–4.2436**					
EC_t	–1.5577	–0.5170	–3.8687*	–4.4820*					

Note: *, ** and *** denote significant at 1 percent, 5 percent and 10 percent levels respectively.

Table 2

Johansen Cointegration Test

Country	Likelihood Ratio	5% critical Value	P-value	Country	Likelihood Ratio	5% Critical Value	P-value
Algeria				**Angola**			
$R = 0$	34.8179*	25.8721	0.0030	$R = 0$	18.4636	25.8721	0.3136
$R \leq 0$	5.09129	12.5179	0.5833	$R \leq 0$	7.45470	12.5179	0.2995
Argentina				**Australia**			
$R = 0$	27.1434**	25.8721	0.0346	$R = 0$	29.8304**	25.8721	0.0152
$R \leq 0$	6.42493	12.5179	0.4083	$R \leq 0$	8.00144	12.5179	0.2516
Austria				**Albania**			
$R = 0$	27.04634*	25.8721	0.0094	$R = 0$	33.7549*	25.8721	0.0042
$R \leq 0$	4.400725	12.5179	0.1968	$R \leq 0$	7.23212	12.5179	0.3209
Bangladesh				**Belgium**			
$R = 0$	28.7918*	25.8721	0.0210	$R = 0$	26.6517**	25.8721	0.0400
$R \leq 0$	4.95061	12.5179	0.6035	$R \leq 0$	7.11880	12.5179	0.3323
Benin				**Bolivia**			
$R = 0$	41.7722*	25.8721	0.0003	$R = 0$	66.8464*	25.8721	0.0000
$R \leq 0$	15.0975*	12.5179	0.0181	$R \leq 0$	13.1493	12.5179	0.0392
Botswana				**Brazil**			
$R = 0$	27.4591**	25.8721	0.0315	$R = 0$	13.7969	25.8721	0.6743
$R \leq 0$	6.463937	12.5179	0.4038	$R \leq 0$	3.11117	12.5179	0.8631
Brunei Darrulsalm				**Bulgaria**			
$R = 0$	29.4351**	25.8721	0.0172	$R = 0$	21.5356	25.8721	0.1578
$R \leq 0$	9.58154	12.5179	0.1474	$R \leq 0$	3.88762	12.5179	0.7583
Cameroon				**Canada**			
$R = 0$	24.3665	25.8721	0.0761	$R = 0$	26.8541**	25.8721	0.0377
$R \leq 0$	9.47495	12.5179	0.1531	$R \leq 0$	12.1440	12.5179	0.0577
Chili				**China**			
$R = 0$	31.5805*	25.8721	0.0087	$R = 0$	25.9354**	25.8721	0.0491
$R \leq 0$	8.96315	12.5179	0.1826	$R \leq 0$	8.62820	12.5179	0.2045

Continued—

Table 2—(*Continued*)

Colombia				**Congo Dem Rep**			
$R = 0$	26.9458**	25.8721	0.0367	$R = 0$	11.5926	25.8721	0.8392
$R \leq 0$	7.87041	12.5179	0.2624	$R \leq 0$	3.06221	12.5179	0.8691
Congo Rep				**Saudi Arabia**			
$R = 0$	13.0347	25.8721	0.7355	$R = 0$	35.8987*	25.8721	0.0020
$R \leq 0$	2.38065	12.5179	0.9406	$R \leq 0$	17.0467*	12.5179	0.0082
Costa Rica				**Cote D Ivories**			
$R = 0$	26.6582**	25.8721	0.0399	$R = 0$	27.6100**	25.8721	0.0301
$R \leq 0$	5.27551	12.5179	0.5573	$R \leq 0$	4.79881	12.5179	0.6254
Cuba				**Cyprus**			
$R = 0$	35.5558*	25.8721	0.0023	$R = 0$	29.5951**	25.8721	0.0164
$R \leq 0$	8.0965	12.5179	0.2439	$R \leq 0$	12.9237**	12.5179	0.0427
Denmark				**Dominican Rep**			
$R = 0$	36.5301*	25.8721	0.0016	$R = 0$	41.7294*	25.8721	0.0003
$R \leq 0$	13.6372**	12.5179	0.0324	$R \leq 0$	9.29973	12.5179	0.1627
Ecuador				**Egypt**			
$R = 0$	49.3521*	25.8721	0.0000	$R = 0$	35.8685*	25.8721	0.0021
$R \leq 0$	13.7689**	12.5179	0.0307	$R \leq 0$	6.10382	12.5179	0.4472
El Salvador				**Ethiopia**			
$R = 0$	35.1654*	25.8721	0.0026	$R = 0$	30.3543**	25.8721	0.0129
$R \leq 0$	12.2436	12.5179	0.0555	$R \leq 0$	5.16437	12.5179	0.5729
Finland				**France**			
$R = 0$	26.9650**	25.8721	0.0365	$R = 0$	34.3356*	25.8721	0.0035
$R \leq 0$	6.82323	12.5179	0.3633	$R \leq 0$	6.76451	12.5179	0.3697
Gabon				**Ghana**			
$R = 0$	30.0153*	25.8721	0.0144	$R = 0$	35.1224*	25.8721	0.0027
$R \leq 0$	11.7234	12.5179	0.0676	$R \leq 0$	14.1094**	12.5179	0.0268
Greece				**Guatemala**			
$R = 0$	28.2878**	25.8721	0.0245	$R = 0$	29.5195**	25.8721	0.0168
$R \leq 0$	8.29920	12.5179	0.2282	$R \leq 0$	10.5420	12.5179	0.1046

Continued—

Table 2—(*Continued*)

Honduras				**Hong Kong**			
$R = 0$	26.0812**	25.8721	0.0471	$R = 0$	37.9506*	25.8721	0.0010
$R \leq 0$	10.9387	12.5179	0.0905	$R \leq 0$	7.72672	12.5179	0.2748
Hungary				**Iceland**			
$R = 0$	44.9969*	25.8721	0.0001	$R = 0$	38.8020*	25.8721	0.0007
$R \leq 0$	8.98506	12.5179	0.1813	$R \leq 0$	5.81125	12.5179	0.4847
India				**Indonesia**			
$R = 0$	26.1574**	25.8721	0.0461	$R = 0$	31.2241*	25.8721	0.0098
$R \leq 0$	4.72569	12.5179	0.6361	$R \leq 0$	12.2892**	12.5179	0.0546
Iran				**Ireland**			
$R = 0$	37.4250*	25.8721	0.0012	$R = 0$	34.3030*	25.8721	0.0035
$R \leq 0$	9.92483	12.5179	0.1306	$R \leq 0$	7.14944	12.5179	0.3292
Israel				**Italy**			
$R = 0$	24.6479	25.8721	0.0704	$R = 0$	17.09164	25.8721	0.4081
$R \leq 0$	4.03627	12.5179	0.7368	$R \leq 0$	4.836427	12.5179	0.6200
Jamaica				**Japan**			
$R = 0$	29.4438**	25.8721	0.0172	$R = 0$	39.5565*	25.8721	0.0006
$R \leq 0$	7.55742	12.5179	0.2900	$R \leq 0$	10.5050	12.5179	0.1060
Jordan				**Kenya**			
$R = 0$	33.1366*	25.8721	0.0052	$R = 0$	17.3930	25.8721	0.3862
$R \leq 0$	3.17938	12.5179	0.8545	$R \leq 0$	6.66917	12.5179	0.3803
South Korea				**Kuwait**			
$R = 0$	27.3817**	25.8721	0.0322	$R = 0$	28.2335**	25.8721	0.0250
$R \leq 0$	8.74030	12.5179	0.1970	$R \leq 0$	9.24276	12.5179	0.1659
Luxemburg				**Mexico**			
$R = 0$	40.8911*	25.8721	0.0003	$R = 0$	48.3444*	25.8721	0.0000
$R \leq 0$	19.2744*	12.5179	0.0032	$R \leq 0$	6.1009	12.5179	0.4476
Morocco				**Mozambique**			
$R = 0$	29.1988**	25.8721	0.0186	$R = 0$	31.0356**	25.8721	0.0104
$R \leq 0$	6.63904	12.5179	0.3837	$R \leq 0$	10.8260	12.5179	0.0943

Continued—

Table 2—(*Continued*)

Nepal				**Netherland The 62**			
$R = 0$	27.6112**	25.8721	0.0301	$R = 0$	26.4791**	25.8721	0.0420
$R \leq 0$	2.17146	12.5179	0.9572	$R \leq 0$	11.6056	12.5179	0.0707
New Zealand				**Nicaragua**			
$R = 0$	28.1404**	25.8721	0.0257	$R = 0$	11.8624	25.8721	0.8214
$R \leq 0$	8.54960	12.5179	0.2100	$R \leq 0$	2.8651	12.5179	0.8922
Nigeria				**Norway**			
$R = 0$	31.4737*	25.8721	0.0090	$R = 0$	28.8942**	25.8721	0.0204
$R \leq 0$	8.19985	12.5179	0.2358	$R \leq 0$	10.5826	12.5179	0.1031
Oman				**Pakistan**			
$R = 0$	26.4988**	25.8721	0.0418	$R = 0$	18.0948	25.8721	0.3376
$R \leq 0$	8.58027	12.5179	0.2078	$R \leq 0$	3.5568	12.5179	0.8048
Panama				**Paraguay**			
$R = 0$	21.1596	25.8721	0.1728	$R = 0$	35.5854*	25.8721	0.0023
$R \leq 0$	8.20377	12.5179	0.2355	$R \leq 0$	14.3679*	12.5179	0.0242
Peru				**Philippines**			
$R = 0$	26.0875**	25.8721	0.0470	$R = 0$	10.9235	25.8721	0.8795
$R \leq 0$	8.41322	12.5179	0.2198	$R \leq 0$	1.93863	12.5179	0.9723
Portugal				**South Africa**			
$R = 0$	12.4912	25.8721	0.7769	$R = 0$	31.1438**	25.8721	0.0100
$R \leq 0$	3.69726	12.5179	0.7854	$R \leq 0$	4.3126	12.5179	0.6965
Spain				**Sudan**			
$R = 0$	35.3192*	25.8721	0.0025	$R = 0$	20.9619	25.8721	0.1811
$R \leq 0$	10.2042	12.5179	0.1182	$R \leq 0$	7.2129	12.5179	0.3228
Sweden				**Switzerland**			
$R = 0$	31.8140*	25.8721	0.0081	$R = 0$	27.5750**	25.8721	0.0304
$R \leq 0$	6.4377	12.5179	0.4068	$R \leq 0$	7.2930	12.5179	0.3149
Syrian Arab Rep				**Thailand**			
$R = 0$	29.8728**	25.8721	0.0150	$R = 0$	39.8339*	25.8721	0.0005
$R \leq 0$	11.4533	12.5179	0.0748	$R \leq 0$	6.4373	12.5179	0.4069

Continued—

Table 2—(*Continued*)

Togo				**Trinidad and Tobago**			
$R = 0$	48.6538*	25.8721	0.0000	$R = 0$	27.7872**	25.8721	0.0286
$R \leq 0$	5.0368	12.5179	0.5911	$R \leq 0$	9.6121	12.5179	0.1459
Tunisia				**Turkey**			
$R = 0$	44.0057*	25.8721	0.0001	$R = 0$	30.0648**	25.8721	0.0141
$R \leq 0$	16.1203**	12.5179	0.0120	$R \leq 0$	6.6956	12.5179	0.3773
United Kingdom				**United Arab Emirates**			
$R = 0$	44.3407*	25.8721	0.0001	$R = 0$	33.2987*	25.8721	0.0049
$R \leq 0$	7.7262	12.5179	0.2748	$R \leq 0$	6.3311	12.5179	0.4194
Uruguay				**United States**			
$R = 0$	35.8733*	25.8721	0.0020	$R = 0$	31.4441*	25.8721	0.0091
$R \leq 0$	5.38711	12.5179	0.5418	$R \leq 0$	1.6455	12.5179	0.9861
Venezuela R.B.De				**Vietnam**			
$R = 0$	30.9671**	25.8721	0.0106	$R = 0$	26.1699**	25.8721	0.0459
$R \leq 0$	12.8779**	12.5179	0.0435	$R \leq 0$	8.0407	12.5179	0.2484
Zambia				**Zimbabwe**			
$R = 0$	30.39876**	25.8721	0.0127	$R = 0$	24.9006	25.8721	0.0657
$R \leq 0$	2.449747	12.5179	0.9345	$R \leq 0$	10.0065	12.5179	0.1269
Senegal							
$R = 0$	31.1438**	25.8721	0.0100				
$R \leq 0$	4.3126	12.5179	0.6965				

Note: * and ** denote rejection of null hypothesis at 1 percent and 5 percent levels of significance respectively.

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Table 3

Panel Unit Root Test

IPS TEST				
	Level		1st Difference	
Variables	Intercept	Trend and Intercept	Intercept	Trend and Intercept
TR_t	10.5763	–1.1019	–19.8147*	–16.6784*
EC_t	2.5184	0.6182	–21.5562*	–17.8725*
LLC TEST				
	Level		1st Difference	
Variables	Intercept	Trend and Intercept	Intercept	Trend and Intercept
TR_t	5.6390	–0.4516	–19.1851*	–16.5538*
EC_t	1.7180	3.4397	–16.4287*	–13.5677*
MW(ADF) TEST				
	Level		1st Difference	
Variables	Intercept	Trend and Intercept	Intercept	Trend and Intercept
TR_t	30.9469	182.3521	366.570*	296.0253*
EC_t	164.2160	200.3711	563.351*	445.5541*
MW(PP) TEST				
	Level		1st Difference	
Variables	Intercept	Trend and Intercept	Intercept	Trend and Intercept
TR_t	32.2558	178.6561	1064.9488*	895.8082
EC_t	169.0261	196.1862	1471.0689*	1282.0323*

Note: * Denotes rejection of null hypothesis at 1 percent significance level.

Table 4

Panel Cointegration Test

Hypotheses	Likelihood Ratio	1% Critical Value
$R = 0$	5.9035*	2.45
$R \leq 0$	0.9523	

Note: *Denotes rejection of null hypothesis at 1 percent significance level.

Table 5

Panel Cointegration Estimates

Variables	Pooled Mean Group (PMG)	Mean Group(MG)	Hausman Test[6]
	High Income Panel[7]		
TR_t	0.860*	1.315**	3.31
	(0.000)	(0.041)	(0.191)
TR^2_t	–0.015*	–1.688**	
	(0.000)	(0.054)	
	Middle Income Panel		
TR_t	–0.023**	–0.191***	1.45
	(0.014)	(0.063)	(0.484)
TR^2_t	0.003*	0.116**	
	(0.000)	(0.043)	
	Low Income Panel		
TR_t	–1.493*	–2.827**	1.68
	(0.000)	(0.023)	(0.321)
TR^2_t	0.0387*	0.114**	
	(0.000)	(0.030)	

Note: *, ** and *** show significance at 1 percent, 5 percent and 10 percent levels respectively.

Table 6

Non-Homogenous and Homogenous Causality

	Non-homogenous Causality		Homogenous Causality	
Dependent Variables	ln TR_t	ln EC_t	TR_t	EC_t
ln TR_t	–	Causality Exists*	–	No Causality
ln EC_t	Causality Exists*	–	Causality Exists*	–

Note: *Represents significance at 1 percent level.

income countries, relationship between trade openness and energy consumption is U-shaped which reveals that trade openness decreases energy consumption initially but energy consumption is increased with continuous process of trade openness. In middle-income countries, trade openness stimulates industrialisation, which raises energy demand [Cole (2006)]. It is argued by Ghani (2006) that low-income countries are unable to reap optimal fruits of trade liberalisation because these economies are lacking in utilisation of energy efficient technology to enhance domestic production.

The presence of cointegration between the series leads us to investigate the direction of causality. In doing so, we have applied homogeneous and non-homogenous panel causality and results are reported in Table 6. The results of non-homogenous causality reveal the feedback hypothesis between trade openness and energy consumption as bidirectional causal relationship is confirmed between both the series. We find that trade openness Granger causes energy consumption confirmed by homogeneous causality (see Table 6).

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[6] Hausman test indicates that PMG model is preferred over PG model.

[7] A graph is provided in Appendix for high income countries.

Our results of non-homogenous causality validated the presence of *feedback effect*, as trade openness and energy consumption are interdependent. The unidirectional causality is found running from trade openness to energy consumption. This validates the presence of *trade-led-energy hypothesis* confirmed by homogenous causality approach. This ambiguity in results would not be helpful in policy-making and leads us to apply homogenous and non-homogenous causality approach using data of low, middle and high-income countries. This will not only help us in obtaining results region-wise but also enable us to design a comprehensive trade and energy policy for sustained economic growth and better living standards. In doing so, we have investigated the homogenous and non-homogenous causal relationship separately for high, middle and low-income countries. The results are reports in Table 7. In high income countries, non-homogenous causality confirms the unidirectional causality running from trade openness to energy consumption but feedback effect is confirmed by homogenous causality between both variables. The relationship between trade openness and energy consumption is bidirectional for middle and low-income countries confirmed by homogenous and non-homogenous causality approaches.

Table 7

Homogenous and Non-homogenous Causality

	Homogenous Causality		Non-homogenous Causality	
	High Income Countries			
Variables	ln TR_t	ln EC_t	TR_t	EC_t
TR_t	_	Causality Exists*	–	No Causality
EC_t	Causality Exists*	_	Causality Exists*	
Variables	Middle Income Countries			
	ln TR_t	ln EC_t	TR_t	EC_t
TR_t	_	Causality Exists*		Causality Exists*
EC_t	Causality Exists*	_	Causality Exists*	
Variables	Low Income Countries			
	ln TR_t	ln EC_t	TR_t	EC_t
TR_t	_	Causality Exists*		Causality Exists*
EC_t	Causality Exists*	_	Causality Exists*	

Note: *Represents the significance at 1 percent level.

Table 8

Heterogeneous Causality

Country	Variables	TR_t	EC_t
Algeria	TR_t	–	No Causality
	EC_t	Causality exists*	–
Angola	TR_t	–	No Causality
	EC_t	Causality exists*	–
Argentina	TR_t	–	No Causality
	EC_t	Causality exists*	–
Australia	TR_t	–	No Causality
	EC_t	Causality exists*	–
Austria	TR_t	–	No Causality
	EC_t	No Causality	–
Albania	TR_t	–	Causality exists*
	EC_t	Causality exists***	–
Bangladesh	TR_t	–	Causality exist***
	EC_t	No Causality	–
Belgium	TR_t	–	No Causality
	EC_t	No Causality	–
Benin	TR_t	–	Causality exist**
	EC_t	No Causality	–
Bolivia	TR_t	–	No Causality
	EC_t	No Causality	–
Botswana	TR_t	–	No Causality
	EC_t	Causality exists*	–
Brazil	TR_t	–	No Causality
	EC_t	Causality exists*	–
Brunei Darussalam	TR_t	–	No Causality
	EC_t	No Causality	–
Bulgaria	TR_t	–	No Causality
	EC_t	No Causality	–
Cameroon	TR_t	–	No Causality
	EC_t	No Causality	–
Canada	TR_t	–	No Causality
	EC_t	No Causality	–
Chile	TR_t	–	No Causality
	EC_t	Causality exist*	–
China	TR_t	–	Causality exist*
	EC_t	No Causality	–
Colombia	TR_t	–	No Causality
	EC_t	No Causality	–
Congo Dem Rep	TR_t	–	No Causality
	EC_t	No Causality	–
Congo Rep	TR_t	–	No Causality
	EC_t	No Causality	–
Costa Rica	TR_t	–	No Causality
	EC_t	Causality exist*	–
Cote D'Ivoire	TR_t	–	Causality exist***
	EC_t	Causality exist*	–
Cuba	TR_t	–	Causality exist*
	EC_t	No Causality	–
Cyprus	TR_t	–	Causality exist**
	EC_t	Causality exist*	–
Denmark	TR_t	–	No Causality
	EC_t	No Causality	–

Continued—

Table 8—(*Continued*)

Dominican Rep	TR_t	–	No Causality
	EC_t	No Causality	–
Ecuador	TR_t	–	Causality exist*
	EC_t	No Causality	–
Egypt	TR_t	–	Causality exist***
	EC_t	Causality exist*	–
El Salvador	TR_t	–	No Causality
	EC_t	Causality exist*	–
Ethiopia	TR_t	–	Causality exist*
	EC_t	No Causality	–
Finland	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
France	TR_t	–	Causality exist*
	EC_t	No Causality	–
Gabon	TR_t	–	Causality exist***
	EC_t	Causality exist*	–
Ghana	TR_t	–	No Causality
	EC_t	Causality exist*	–
Greece	TR_t	–	Causality exist*
	EC_t	No Causality	–
Guatemala	TR_t	–	Causality exist*
	EC_t	No Causality	–
Honduras	TR_t	–	Causality exist**
	EC_t	Causality exist*	–
Hong Kong	TR_t	–	Causality exist*
	EC_t	Causality exist***	–
Hungary	TR_t	–	No Causality
	EC_t	No Causality	–
Iceland	TR_t	–	No Causality
	EC_t	No Causality	–
India	TR_t	–	No Causality
	EC_t	Causality exist*	–
Indonesia	TR_t	–	Causality exist*
	EC_t	No Causality	–
Iran	TR_t	–	No Causality
	EC_t	No Causality	–
Ireland	TR_t	–	No Causality
	EC_t	No Causality	–
Israel	TR_t	–	No Causality
	EC_t	No Causality	–
Italy	TR_t	–	No Causality
	EC_t	Causality exist*	–
Jamaica	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
Japan	TR_t	–	No Causality
	EC_t	Causality exist*	–
Jordan	TR_t	–	No Causality
	EC_t	Causality exist*	–
Kenya	TR_t	–	No Causality
	EC_t	No Causality	–
South Korea	TR_t	–	No Causality
	EC_t	No Causality	–
Kuwait	TR_t	–	Causality exist*
	EC_t	Causality exist*	–

Continued—

Table 8—(*Continued*)

Luxemburg	TR_t	–	No Causality
	EC_t	No Causality	–
Mexico	TR_t	–	No Causality
	EC_t	Causality exist*	–
Morocco	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
Mozambique	TR_t	–	Causality exist*
	EC_t	No Causality	–
Nepal	TR_t	–	No Causality
	EC_t	Causality exist**	–
The Netherlands	TR_t	–	Causality exist*
	EC_t	No Causality	–
New Zealand	TR_t	–	No Causality
	EC_t	No Causality	–
Nicaragua	TR_t	–	Causality exist*
	EC_t	No Causality	–
Nigeria	TR_t	–	No Causality
	EC_t	No Causality	–
Norway	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
Oman	TR_t	–	No Causality
	EC_t	Causality exist*	–
Pakistan	TR_t	–	No Causality
	EC_t	Causality exist*	–
Panama	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
Paraguay	TR_t	–	Causality exist***
	EC_t	No Causality	–
Peru	TR_t	–	Causality exist***
	EC_t	No Causality	–
Philippines	TR_t	–	Causality exist***
	EC_t	No Causality	–
Portugal	TR_t	–	No Causality
	EC_t	Causality exist**	–
Saudi Arabia	TR_t	–	Causality exist**
	EC_t	Causality exist*	–
Senegal	TR_t	–	No Causality
	EC_t	No Causality	–
South Africa	TR_t	–	No Causality
	EC_t	No Causality	–
Spain	TR_t	–	No Causality
	EC_t	No Causality	–
Sudan	TR_t	–	No Causality
	EC_t	Causality exist*	–
Sweden	TR_t	–	Causality exist***
	EC_t	No Causality	–
Switzerland	TR_t	–	Causality exist*
	EC_t	No Causality	–
Syria	TR_t	–	No Causality
	EC_t	No Causality	–
Thailand	TR_t	–	No Causality
	EC_t	Causality exist*	–
Togo	TR_t	–	Causality exist***
	EC_t	Causality exist***	–

Continued—

Table 8—(*Continued*)

Trinidad and Tobago	TR_t	–	Causality exist*
	EC_t	No Causality	–
Tunisia	TR_t	–	No Causality
	EC_t	No Causality	–
Turkey	TR_t	–	No Causality
	EC_t	Causality exist*	–
United Kingdom	TR_t	–	No Causality
	EC_t	No Causality	–
United Arab Emirates	TR_t	–	Causality exist*
	EC_t	No Causality	–
Uruguay	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
Unites States	TR_t	–	Causality exist*
	EC_t	Causality exist*	–
Venezuela	TR_t	–	Causality exist*
	EC_t	No Causality	–
Vietnam	TR_t	–	No Causality
	EC_t	No Causality	–
Zambia	TR_t	–	Causality exist*
	EC_t	No Causality	–
Zimbabwe	TR_t	–	No Causality
	EC_t	No Causality	–

Note: *, ** and *** represent significance at 1 percent, 5 percent and 10 percent levels respectively.

The results of heterogeneous causality reported in Table 7 suggest the feedback relationship between trade openness and energy consumption i.e. bidirectional causality exists in case of Albania, Cote D'Ivoire, Cyprus, Egypt, Finland, Gabon, Honduras, Hong Kong, Kuwait, Morocco, Norway, Panama, Saudi Arabia, Togo, Uruguay and Unites States. Energy consumption Granger causes trade openness in case of Bangladesh, Benin, China, Cuba, Ecuador, Ethiopia, France, Greece, Guatemala, Indonesia, Mozambique, The Netherlands, Nicaragua, Paraguay, Philippines, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, Venezuela and Zambia.

The unidirectional causality is found running from trade openness to energy consumption. This validates the trade-led-energy hypothesis in case of Algeria, Angola, Argentina, Australia, Botswana, Brazil, Chili, Costa Rica, El Salvador, Ghana, India, Italy, Japan, Jordan, Mexico, Nepal, Oman, Pakistan, Portugal, Sudan, Thailand and Turkey. The neutral relationship between trade openness and energy consumption i.e. no causality exists between both the variables for Austria, Belgium, Bolivia, Brunei Darussalam, Bulgaria, Cameroon, Canada, Colombia, Congo Democratic Republic, Congo Republic, Denmark, Dominican Republic, Hungary, Iceland, Iran, Ireland, Israel, Kenya, South Korea, Luxemburg, New Zealand, Nigeria, Senegal, South Africa, Spain, Syria, Tunisia, United Kingdom, Vietnam and Zimbabwe.

5. CONCLUDING REMARKS AND FUTURE DIRECTIONS

This paper explores the relationship between trade openness and energy consumption using data of 91 heterogeneous (high, middle and low income) countries over the period of 1980-2010. In doing so, we have applied time series as well as panel unit root tests to examine the integrating properties of the variables. Similarly, to examine cointegration between the variables, we have applied single country as well as panel cointegration approaches. The homogenous and non-homogenous causality approaches are applied to examine the direction of causality between the variables in high, middle and low-income countries. Heterogeneous causality approach has also been applied to examine relationship between trade openness and energy consumption at country level analysis.

Our results indicated that our variables are integrated at I(1) confirmed by time series and panel unit root tests and same is inference is drawn about cointegration between trade openness and energy consumption. The pooled mean group estimation analysis reveals an inverted U-shaped relationship in high income countries and vice versa in middle and low income countries. The causality analysis confirms the existence of feedback effect between trade openness and energy consumption in middle and low income countries but bidirectional causality is confirmed by homogenous causality approach in high income countries, however non-homogenous causality approach indicates unidirectional causality running form trade openness to energy consumption. Heterogeneous causality exposes that in 18 percent of sampled countries, the feedback effect exists while 24 percent show that trade openness causes energy consumption and rest of sample countries confirm the presence of neutral relationship between trade openness and energy consumption.

Overall, our results demonstrate that the feedback effect exists between trade openness and energy consumption, which suggests in exploring new and alternative sources of energy to reap optimal fruits of trade. Trade openness stimulates industrialisation that in turn affects economic growth. This channel of trade affects energy demand via economic growth. Similarly, insufficient energy supply impedes economic growth, which affects exports as well as imports, and as a result energy consumption decreases. Trade openness also is a source of transferring advanced technologies i.e. energy efficient technology from developed countries to developing economies. Our findings confirm that the relationship between trade openness and energy consumption is U-shaped. This suggests that middle and low-income countries should import energy efficient technologies from developed economies to lower energy intensity. This will not be possible if developed countries do not promote those technologies and lower prices for countries, which do not have access to required amounts of capital. Further, it will have a positive impact on the world economy as it will save natural resources for future generations and it will reduce environmental pollution.

This paper can be augmented for future research by incorporating financial development, industrialisation, urbanisation in energy demand function following Shahbaz and Lean (2012) in case of low, middle and high-income countries. The semi-parametric panel approach proposed by Baltagi and Lu (2002) could be applied to investigate the impact of financial development, industrialisation, trade openness and urbanisation on energy consumption using global level data. Using global level data, trade openness, financial development, industrialisation, urbanisation and CO_2 emissions nexus could be investigated by applying heterogamous panel under cross-sectional dependence framework.

APPENDIX A

List of World Countries

High Income Countries	Middle Income Countries	Low Income Countries
Angola	Algeria	Bangladesh
Australia	Argentina	Benin
Austria	Bolivia	Congo Dem Rep
Albania	Botswana	Ethiopia
Belgium	Brazil	Kenya
Brunei Darussalam	Bulgaria	Mozambique
Canada	Cameroon	Nepal
Cyprus	Chile	Togo
Denmark	China	Zimbabwe
Finland	Colombia	
France	Congo Rep	
Greece	Costa Rica	
Hong Kong	Cote D’Ivoire	
Hungary	Cuba	
Iceland	Dominican Rep	
Israel	Ecuador	
Italy	Egypt	
South Korea	El Salvador	
Kuwait	Gabon	
Luxemburg	Ghana	
The Netherlands	Guatemala	
New Zealand	Honduras	
Norway	India	
Oman	Indonesia	
Portugal	Iran	
Saudi Arabia	Ireland	
Spain	Jamaica	
Sweden	Japan	
Switzerland	Jordan	
Trinidad and Tobago	Mexico	
United Kingdom	Morocco	
United Arab Emirates	Nicaragua	
Unites States	Nigeria	
	Pakistan	
	Panama	
	Paraguay	
	Peru	
	Philippines	
	Senegal	
	South Africa	
	Sudan	
	Syria	
	Thailand	
	Tunisia	
	Turkey	
	Uruguay	
	Venezuela	
	Vietnam	
	Zambia	

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Comments

Paper gives a good comparison among the high, middle and low income countries in terms of energy usage. Few comments which can improve the paper are; inclusion of the role of mediating/moderating variable which is production through which energy has causal relationship between trade openness. Baron and Kenny (1986)[8] gives a good technique of using moderating/mediating variable. Battery of tests is estimations are done in the paper but authors are very miser to explain the results. Since the panel data estimation is done to obtain the estimates therefore there is no need for single country regression or if authors have different objective in their mind then they did not explain it in the text. The paper says that 25 percent of the sample countries have positive association between energy and trade openness, what would author infer from this result. Since the data is from 1980-2010, thus I would recommend to apply a structural break test on the variables.

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Energy Consumption, Trade and GDP: A Case Study of South Asian Countries

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1. INTRODUCTION

Acute shortage of energy sources in developing countries in general and South Asian countries in particular has shown that energy has become a binding input for any production process. Nowadays operation of heavy machinery and electrical equipment, and transportation of raw material and final products from their place of origination to their destination require heavy consumption of energy in one form or the other. Therefore, energy consumption that was previously ignored in the production function of a firm and an economy is now considered a vital input in production process. It affects GDP directly as by increasing energy consumption; more output can be produced with given stock of capital and labor force in a country. Also uninterrupted availability of energy at reasonable cost improves competiveness of home products in international markets and thus increases exports of home country a great deal. Resulting increase in net exports further adds to the GDP through multiplier effect.

To acknowledge due importance of energy in production process, Energy Economics has been recognised as a new sub-discipline of Economics in the literature. Energy Economics mainly studies the relationship between energy consumption and output [e.g. Lee (2005); Khan and Qayyum (2006); Noor and Siddiqi (2010)]. Most of the studies have concluded a positive relationship between energy consumption and GDP. Some studies have shown unidirectional relationship running form energy consumption to GDP, some others from GDP to energy consumption and yet some others have proven bidirectional relationship between the two variables. Currently energy consumption is counted even more binding input than capital and labor in determination of GDP of developing counties in particular.

The relationship of trade and GDP has been widely discussed in classical theories from the era of Adam Smith to date. Trade enhances economic growth by increasing local market size, by allocating resources efficiently, by improving economies of scale and by increasing capacity utilisation. Blassa (1978) documented that besides traditional inputs of capital and labor of an aggregate production function, export orientation is another important factor in explaining inter-country differences in GDP growth rates.

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Moreover, exports of manufactured goods in a given year and their growth rate over time depend upon the level of energy consumption in the industrial sector of a country [Sadrosky (2011a)]. It means that energy consumption and trade have a long run relationship. It further implies that energy consumption also adds to GDP of a country indirectly through multiplier effect. However, there are few empirical investigations of this indirect effect.

The long run relationship among energy consumption, trade and GDP is relatively less studied area of economics particularly for South Asian countries. The understanding of the dynamics among these variables has important implications for energy and trade policies. For example, if unidirectional Granger causality running from GDP to exports is observed, then shortage of energy supply in a country may not have detrimental impact. However, if arrow of causality runs from exports to GDP, then uninterrupted supply of energy at reasonable cost becomes crucial for economic growth of the country. Consequently energy conservation policies to reduce energy wastage can offset the positive effects and benefits of trade promoting policies and thus may impede the economic growth of the country.

This study is different from previous ones in the following three respects: First, most of the previous studies have focused either on energy-GDP relationship or on export-GDP relationship, whereas this study explores the simultaneous relationship between energy consumption, exports and GDP. Second, in this study panel co-integration approach is used to identify the long run causality relationship among the variables. This approach is generally considered more advantageous than a single equation approach. Third, this study investigates impact of energy consumption along with exports on GDP for South Asian region,

The roadmap for the remainder of this study is as follows. Section 2 reviews the literature related to the topic. Section 3 describes theoretical framework of the study and presents descriptive analysis of its variables. Section 4 explains econometric methodology of the study and sheds light on data construction and data sources. Section 5 reports empirical results of this research and explains their economic relevance. The final section contains conclusion and policy implications.

2. LITERATURE REVIEW

This section is further divided into three parts: (1) review of energy consumption and GDP relationship, (2) review of trade/exports and GDP relationship, and (3) review of energy consumption, trade/exports and GDP relationship.

2.1. Energy Consumption and GDP

A number of studies have explored the nature of relationship between energy consumption and GDP. Production function in microeconomics and macroeconomics textbooks and neo-classical growth theories consider only labor and capital as important factors of production and ignore energy consumption. However, following the two oil crises in 1970s, energy consumption has gained considerable importance in explaining GDP growth rate of a country. Initially, Kraft and Kraft (1978) studied the casual relationship between energy consumption and GNP. Since then there is a plethora of studies on this topic. The results are, however, mixed about the relationship between these two variables. There are four basic hypotheses for the causality relationship between energy consumption and GDP: First is the neutrality hypothesis, which suggests that there is no significant causal relationship between energy consumption and GDP. Second is the conservation hypothesis, which suggests that there is one-way causality running from GDP to energy consumption. Third is the feedback hypothesis, which suggests that there is two-way causality between energy consumption and GDP. Fourth is the growth hypothesis, which suggests that there is one-way causality running from energy consumption to GDP.

Using ARDL approach and annual data for the period 1972-2004 for Pakistan, India, Sri-Lanka and Bangladesh, Khan and Qayyum (2006) found a positive relationship between energy consumption and GDP. Therefore, they concluded that energy consumption played a vital role in generating and accelerating economic activity in these countries. Noor and Siddiqi (2010) used panel co-integration and fully modified OLS technique to investigate relationship between energy consumption and GDP in five South Asian countries (Pakistan, Bangladesh, Nepal, Sri-Lanka and India). They found a negative long run relationship between energy consumption and GDP but they found short run unidirectional causality running from GDP to energy consumption.

Using a sample of 18 developing countries, Lee (2005) used panel co-integration technique and panel VECM to check the relationship between energy consumption and GDP for the period 1975-2001. The results supported growth hypothesis. He also found long run relationship between these two variables after allowing for individual county effects. Therefore, he suggested that any policy of energy conservation in these countries might be harmful for their economic growth. Lee and Chang(2008) confirmed long run relationship between energy consumption, GDP, capital stock and labor using panel co-integration technique for 16 Asian countries over the period 1971-2002. Their results were in support of growth hypothesis that indicated one-way causality running from energy consumption to GDP.

Using panel data of ten newly industrialised Asian countries for the period 1971-2001 and applying co-integration technique, Chen, *et al.* (2007) investigated the relationship between electricity consumption and GDP. They found long run feedback relationship between them. For the short run, there was one-way causality running from GDP to electricity consumption. Therefore, they recommended conservation policies to avoid wastage of energy in the short run and to ensure its sufficient supply in the long run to enhance economic growth.

Dahmardeh, *et al.* (2012) found a feedback relationship between energy consumption and GDP growth rate for 10 Asian developing countries. They used panel data of the variables concerned for the period 1980-2008. The panel VECM was used to investigate the causality relationship between the two variables. Their results indicated unidirectional causality running from energy consumption to GDP in the short run while a bidirectional causality between the two variables in the long run. Ghali and El-sakka (2004) used co-integration technique and VECM to study the long run relationship and causality direction between the two variables for Canada. The results of their estimation showed bidirectional causality between them. Therefore, they suggested energy consumption as the limiting factor for GDP growth rate in Canada.

Asufu-Adjaye (2000) found unidirectional causality running from energy consumption to GDP for India and Indonesia and bidirectional causality between the two variables for Philippines and Thailand. Their findings were based on co-integration and VECM approach by using ML method of estimation. Their results did not reject the neutrality hypothesis for India and Indonesia in the short run. Their results supported the notion that developing countries, which lacked natural sources of energy like oil and gas were more vulnerable to energy shocks than developed countries, which had access at least to renewable energy sources.

2.2. Trade and GDP

The relationship between trade and GDP growth has been discussed at length in various theories of international trade since the inception of Economics as a separate discipline of knowledge. Export promotion increases economic welfare and GDP growth rate of home country. Kemal, *et al.* (2002) investigated the export-led growth hypothesis for five South Asian countries (Pakistan, Bangladesh, India, Nepal and Sri Lanka) by using co-integration technique in a restricted VAR model. They found a one-way causality running from exports to GDP growth for Pakistan and India and two-way long run causality for the remaining three countries. Overall their findings were in support of export-led growth hypothesis. Therefore, they recommended export promotion policies for these countries to achieve sizable growth rates.

Din (2004) also investigated the export-led growth hypothesis for five South Asian economies by incorporating the role of imports as well. Results of the study suggested long run unidirectional causality running from GDP to exports and imports for the economies of Pakistan and Bangladesh and short run bidirectional causality for the economies of Bangladesh, Sri Lanka and India. However, no long run relationship was found between the two variables for Nepal, India and Sri Lanka.

Awokuse (2008) investigated the prevalence of export-led and import-led growth hypothesis in three Latin American countries (Peru, Colombia, Argentina) using a neoclassical production function and estimating it by multivariate co-integrating VAR. The findings were in support of import-led growth hypothesis as he found bidirectional and unidirectional causality running from imports to GDP growth for all three countries. However, impulse-response function provided support for export-led growth hypothesis for Argentina and Peru.

Bahmani-Oskee, *et al.* (1993) used panel data of 62 developing countries for the period 1960-1999. Their estimated results indicated co-integrating relationship between exports and GDP growth when GDP was taken as the dependent variable but the converse was not true. So their findings supported the export-led growth hypothesis. Giles and Williams (2000a, 2000b) tested export-led growth hypothesis with standard causality techniques. They discovered that Granger causality test was sensitive to the degree of deterministic component and to the method used to check non-stationarity.

Shirazi and Manap (2005) analysed imports, exports and GDP data of Pakistan for the period 1960-2003. They used Johansen co-integration technique and Toda and Yamamoto causality test for their analysis. They concluded that there existed long urn bidirectional relationship between imports and GDP, and unidirectional long run causality running from exports to GDP for the country.

2.3 Energy Consumption, Trade and GDP

There are few studies that simultaneously considered both energy consumption and trade as determinants of GDP and thus tried to highlight direct and indirect impacts of energy consumption on GDP. One such study was by Narayan and Smyth (2009) in which energy consumption was approximated by electricity used. Its results suggested a statistically significant long run feedback relationship or two-way causality between GDP, electricity used and exports for a panel of Middle Eastern countries. For the short run, they found unidirectional causality running from electricity used to GDP and from GDP to exports.

Another similar study by Lean and Smyth (2010a) identified capital, labor, electricity consumption and exports as the determinants of GDP and used annual data from 1970 to 2008 for Malaysia. The empirical results indicated unidirectional causality running from electricity consumption to exports. Therefore, the authors supported export-led growth hypothesis for the country. Yet another study by the same authors, Lean and Smyth (2010b), noted unidirectional causality running from GDP growth to electricity generation but found no causal relationship between exports and electricity generation. Thus, the latter study supported neither export-led growth hypothesis nor growth-led exports hypothesis for Malaysia.

Sadorsky (2011a) noted unidirectional short run Granger causality running from exports to energy consumption while a bidirectional Granger causality between energy consumption and imports and between energy consumption and GDP for a panel of eight Middle Eastern countries. In his subsequent research, Sadrosky (2011b) analysed corresponding data for seven South American countries and found a long run relationship between GDP, labor, capital and trade while short run results showed a feedback relationship for export and energy consumption and unidirectional causality running from energy to imports.

It is clear from all these studies that energy consumption has either unidirectional or bidirectional relationship with GDP and with trade/exports showing vital importance of energy consumption for formulation of trade and energy policies of any country. Therefore, the present study contributes to the literature by investigating both direct and indirect impacts of energy consumption on GDP of South Asian economies because there is little or no empirical research on this topic for this region.

3. ANALYTICAL FRAMEWORK AND DESCRIPTIVE ANALYSIS

This section is divided into two parts; analytical framework and descriptive analysis.

3.1. Analytical Framework

Sadorsky (2011b) modeled capital, labor, energy consumption and trade as the main determinants of GDP. He analysed the data of seven South American economies. The present study uses the same model and same variables for five South Asian economies. There is one exception that trade has been replaced with exports. The countries included in this study are Pakistan (PAK), Bangladesh (BAN), Sri Lanka (SRI), India (IND) and Nepal (NEP). Initially the objective was to include all the seven countries, which are currently members of SAARC in our study but due to data limitations for Bhutan and Maldives, these two countries were dropped. The data set is for the period of thirty years from 1980 to 2009.

$$Y = f(K, L, E, T) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.1)$$

Y denotes GDP at 2000 prices in US dollars; K denotes capital that has been represented by gross fixed capital formation at 2000 prices in US dollars; L represents labor force that includes both employed workers and unemployed ones looking for jobs, E represents energy that has been measured by energy consumption in kilo tons of oil equivalents and T is used for exports at 2000 prices in US dollars. Data on the first four variables have been taken from the World Bank CD-ROM 2012, which is also available in the World Development Indicators 2012, whereas data on exports was available in nominal terms only from the same source. Therefore, to convert data on exports at 2000 prices in US dollars, we used consumer price index of respective countries given in the Penn World Table version 7.1.

Assuming that the functional form is non-linear like the one of Cobb-Douglas type production functions, we have taken natural logarithms to convert the function into its linear form. For its estimation, we have added an error term with usual property of being independently and identically equal to zero on the average and a constant term (s_i) to represent the fixed country effect as given below:

$$y_{it} = \alpha_1 k_{it} + \alpha_2 l_{it} + \alpha_3 e_{it} + \alpha_4 t_{it} + s_i + \varepsilon_{it} \quad \dots \quad \dots \quad \dots \quad (3.2)$$

3.2. Descriptive Analysis

To see the average trend of all variables in the model, we have calculated average annual growth rates of the variables over the period of 1980-2009 and presented them in Table 1.

Table 1

Average Annual Growth Rates of Variables in the Model Over 1980-2009

Country	Energy Consumption	Real GDP	Real Fixed Capital Formation	Labour	Real Exports
Bangladesh	4.47	4.74	7.78	2.73	13.21
India	4.21	6.09	8.55	2.63	14.36
Pakistan	4.38	4.99	4.33	3.25	8.87
Sri Lanka	2.57	4.77	4.40	1.18	7.67
Nepal	2.74	4.56	0.85	2.90	9.28

All the variables have positive growth rates over this period. Average annual growth rate of energy consumption ranges from the lowest value of 2.57 percent for Sri Lanka to the highest value of 4.47 percent for Bangladesh. It is more than 4 percent for Bangladesh, India and Pakistan and more than 2.5 percent for Sri Lanka and Nepal. For Pakistan and Bangladesh average annual growth rates of energy consumption are almost equal to their average annual growth rates of real GDP, while for the remaining countries, average annual growth rates of energy consumption are significantly less than their corresponding growth rates of real GDP. India stands out for having the highest average annual growth rate of real GDP while all remaining countries have almost same rate that is 4 percent. Bangladesh and India are the countries having double-digit average annual growth rates in their exports. To have an idea of the sign and magnitude of estimated coefficients of independent variables, we have prepared the correlations matrix for their first differences as given in Table 2.

Table 2

Correlation Matrix for Variables in the Model

Variable	ΔGDP	ΔK	ΔL	ΔE	ΔT
ΔGDP	1				
ΔK	0.399*	1			
ΔL	–0.019	0.027	1		
ΔE	0.264*	0.184*	0.106	1	
ΔT	0.261*	0.120	–0.002	0.203*	1

The asterisk (*) shows that correlation coefficient between two variables is significant at 5 percent.

The correlation coefficients between GDP and energy consumption, between GDP and exports, and between exports and energy consumption are all positive and significant. This suggests that energy is closely linked with GDP and exports. As exports are significantly correlated with GDP too; it points out to indirect impact of energy consumption on GDP. The correlation coefficient between GDP and capital is also significant that shows that capital is a crucial factor to explain GDP of a country. However, the correlation coefficient between capital and exports is though positive, yet it is insignificant. It means that capital has little indirect multiplier effect on GDP of a country through exports. The correlation coefficient between GDP and labor is positive but insignificant and between exports and labor is negative and insignificant statistically. This suggests that labor is no more a binding input for GDP and exports of a country. The reason could be relatively high rate of unemployment in these countries.

4. METHODOLOGY AND DATA CONSTRUCTION

This section is divided in four parts. The first part explains three alternative unit root tests to check the stationarity of data. The second part discusses co-integration test. The third part gives details of Granger causality test. The last part explains dynamic OLS estimation technique.

4.1. Alternative Unit Root Tests

The first step is to check co-integration among the variables of a model in order to ensure that the order of integration of the variables is same. So for this purpose, following two types of panel unit root tests have been used.

Im, Pesaran, and Shin (IPS) (2003), modified Levin, *et al.* (2002) (LL) test by allowing the coefficient of the lagged dependent variable to be heterogeneous. They proposed a test based on the average of single unit root test statistics. IPS test is different from LL test with respect to the alternative hypothesis as LL test assumes common unit root process while IPS assumes individual unit root process.

Maddala and Wu (1999) (MW) proposed a model, which can be estimated with an unbalanced panel and they also preferred heterogeneous alternative. MW type test performs well as compared to LL or IPS test when errors of different cross section units are cross correlated. Furthermore, MW has a small size distortion when T (time period) is large and N (cross section) is small.

In all of the tests, if the results do not reject the null hypothesis at standard significance levels in level form for any variable but reject the null hypothesis for the same variable in the difference form then this variable would be declared as non-stationary or integrated of order one i.e., I(1).

4.2. Panel Co-integration Test

According to the definition of Engle and Granger (1987), if any two variables x or y are integrated of same order (one or more) and if we estimate them by OLS and their residuals u_t are found to be stationary (or their order of integration is one less than those of the estimated variables) then they are said to be co-integrated and have a long run equilibrium relationship. Using the same approach of testing the non-stationarity properties of the residual from ordinary regression of the variables, Pedroni (1999, 2004) extended the above approach to panel data. For time series data, panel co-integration approach leads to more precise and reliable estimates. Panel framework is particularly preferable when sample size of each cross sectional unit is short because we can increase sample size and degrees of freedom by combining different cross sectional units.

Following panel co-integration approach adopted first by Pedroni, Equation (3.2) is estimated by OLS for each of the five countries. Then their residuals are worked out to estimate the following equation:

$$\mu_{it} = \rho_i \mu_{it-1} + \varepsilon_{it} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (4.1)$$

In this equation, ρ_i refers to the autoregressive parameter and ε_{it} are the stationary error terms. The null hypothesis of co-integration test is:

H_0: $\rho_i = 1$, where I = 1,…..,6

The acceptance of the above hypothesis means that there is no co-integration among the cross sections of the panel. Pedroni has provided seven statistics to test null hypothesis of no co-integration.

The test is divided into two categories with respect to the alternative hypothesis. The first category is called within-dimension (panel test) in which the AR coefficient across the cross sectional units of the panel are pooled to apply unit root test on the residuals obtained by the procedure described above. There are four tests with respect to within-dimension category and these tests involve calculating the average test statistics for each country in the panel. These four tests called panel-v, panel-PP-ρ panel-PP-t and panel-ADF-t give us four statistics and the alternative hypothesis for all these statistics is as follows:

H_1: $(\rho_i = \rho) < 1$, where i=1,…..,N

The second category is called between-dimension (group-means approach) in which autoregressive coefficients are averaged for each country of the panel to apply unit root test on the residuals obtained by estimating Equation (3.2) by OLS method. For the between-dimension approach, averaging is done in pieces and it includes group-PP-ρ statistic, the group-PP-t statistic and group-ADF-t statistic. The alternative hypothesis for these 3 tests is as follows:

H$_1$: $\rho_i =< 1$, where i=1,…..,N

So the null hypothesis is same for both categories but the alternative hypothesis is different for within-dimension and between-dimension categories. The group-means or between-dimension test is considered less restrictive as it does not put a condition on the value of ρ to be common for all cross sections in the alternative hypothesis so this allows more heterogeneity of the parameters across the countries of the panel.

4.3. Panel Granger Causality Test

If there is found evidence in support of the co-integration relationship among the variables, then there exists an error correction mechanism by which a variable is adjusted towards its long run equilibrium. Following the approach of Engle and Granger (1987), we can estimate the error correction model (ECM) for the panel. With this approach, a change in the dependent variable is estimated with the level of the disequilibrium in the co-integration relationship and other independent variables. The estimation is done with independent variables in difference form with appropriate lag lengths. Further, there exists Granger causality in at least one direction, if a co-integration relationship is found between a set of variables. The panel VECM for Equation (3.2) is written as follows:

$$\Delta y_{it} = \propto_{1i} + \sum_{j=1}^{p} \beta_{11ij}\,\Delta y_{it-j} + \sum_{j=1}^{p} \beta_{12ij}\,\Delta k_{it-j} + \sum_{j=1}^{p} \beta_{13}\,\Delta l_{it-j}$$

$$+\sum_{j=1}^{p} \beta_{14}\,\Delta e_{it-j} + \sum_{j=1}^{p} \beta_{15}\,\Delta t_{it-j} + \beta_{16i}\mu_{it-1} + \omega_{1it} \quad \ldots \quad \ldots \text{(4.2a)}$$

$$\Delta k_{it} = \propto_{2i} + \sum_{j=1}^{p} \beta_{21ij}\,\Delta y_{it-j} + \sum_{j=1}^{p} \beta_{22ij}\,\Delta k_{it-j} + \sum_{j=1}^{p} \beta_{23}\,\Delta l_{it-j}$$

$$+\sum_{j=1}^{p} \beta_{24}\,\Delta e_{it-j} + \sum_{j=1}^{p} \beta_{25}\,\Delta t_{it-j} + \beta_{26i}\mu_{it-1} + \omega_{2it} \quad \ldots \quad \ldots \text{(4.2b)}$$

$$\Delta l_{it} = \propto_{3i} + \sum_{j=1}^{p} \beta_{31ij}\,\Delta y_{it-j} + \sum_{j=1}^{p} \beta_{32ij}\,\Delta k_{it-j} + \sum_{j=1}^{p} \beta_{33}\,\Delta l_{it-j}$$

$$+\sum_{j=1}^{p} \beta_{34}\,\Delta e_{it-j} + \sum_{j=1}^{p} \beta_{35}\,\Delta t_{it-j} + \beta_{36i}\mu_{it-1} + \omega_{3it} \quad \ldots \quad \ldots \text{(4.2c)}$$

$$\Delta e_{it} = \propto_{4i} + \sum_{j=1}^{p} \beta_{41ij}\,\Delta y_{it-j} + \sum_{j=1}^{p} \beta_{42ij}\,\Delta k_{it-j} + \sum_{j=1}^{p} \beta_{43}\,\Delta l_{it-j}$$

$$+\sum_{j=1}^{p} \beta_{44}\,\Delta e_{it-j} + \sum_{j=1}^{p} \beta_{45}\,\Delta t_{it-j} + \beta_{46i}\mu_{it-1} + \omega_{4it} \quad \ldots \quad \ldots \text{(4.2d)}$$

$$\Delta t_{it} = \propto_{5i} + \sum_{j=1}^{p} \beta_{51ij}\,\Delta y_{it-j} + \sum_{j=1}^{p} \beta_{52ij}\,\Delta k_{it-j} + \sum_{j=1}^{p} \beta_{53}\,\Delta l_{it-j}$$

$$+\sum_{j=1}^{p} \beta_{54}\,\Delta e_{it-j} + \sum_{j=1}^{p} \beta_{55}\,\Delta t_{it-j} + \beta_{56i}\mu_{it-1} + \omega_{5it} \quad \ldots \quad \ldots \text{(4.2e)}$$

In all of the above Equations from (4.2a) to (4.2e), the Δ is used to show the first difference operator, p is the appropriate lag length, y is the real output, k is the real fixed capital formation, l is the labor force, e is the real energy consumption, t is the trade variable (measured by real exports) and all of the above variables are in natural logarithm form, μ is the lagged error correction term and it is obtained by the residual estimated from Equation (3.2) for each country and ω shows the random disturbance terms. The panel VECM is obtained by using OLS with panel corrected standard errors. The coefficients of the lagged difference explanatory variables show the short run dynamics and they are used to interpret the short run Granger causality relationship among the variables while for the long run Granger causality interpretation, adjustment coefficients of the lagged error correction terms are used.

4.4. Dynamic OLS (DOLS)

In case of the above panel co-integration test, if there is an indication for a significant co-integrating relationship, then estimation of Equation (3.2) is also recommended and its estimates show long run elasticities. However, estimation of panel data by OLS method gives asymptomatically biased estimators and their distribution depends on the nuisance parameters. Pedroni (2000, 2001) documented that nuisance parameters are the regressors that could generate unwanted endogeneity and serial correlation although they are not part of the true data generating process. So to address the problem of endogeneity and serial correlation, Pedroni (2000) proposed dynamic OLS (DOLS) method. Pedroni (2001) further modified DOLS method to handle panel data in the presence of nuisance parameters and called it fully modified dynamic OLS (FMOLS) method.

FMOLS employs a non-parametric correction to deal with endogeneity and serial correlation problem, whereas DOLS employs a parametric correction by adding leads and lags dynamics of the right hand side variables. FMOLS is preferred over DOLS in small samples as DOLS consumes more degrees of freedom than FMOLS but in large samples both methods are equally good. Since sample size of this research is sufficiently large, therefore only DOLS method has been used. The DOLS equation is written as:

$$y_{it} = \alpha_{ki}k_{it} + \alpha_{li}l_{it} + \alpha_{ei}e_{it} + \alpha_{ti}t_{it} + \sum_{j=1}^{p}\beta_{k1ij}\,\Delta k_{it-j} + \sum_{j=1}^{p}\beta_{l1ij}\,\Delta l_{it-j} + \sum_{j=1}^{p}\beta_{e1ij}\,\Delta e_{it-j} + \sum_{j=1}^{p}\beta_{t1ij}\,\Delta t_{it-j} + s_i + \varepsilon_{it} \quad \dots \quad \dots \quad \dots \quad (4.3)$$

Here p shows the lag length, s_i is the country specific fixed effect and ε_{it} is the random error term.

5. EMPIRICAL RESULTS AND DISCUSSION

This section is divided in four parts. The first part presents and interprets the results of panel unit root tests; the second part discusses the results of co-integration test, the third part gives details of Granger causality test and the last section reports results of DOLS or elasticities of variables.

5.1. Results of Panel Unit Root (Stationarity) Tests

The results of all the panel unit root tests on the variables in level form and in first difference form are reported side by side in Table 3.

Table 3

Results of Panel Unit Root Tests

Method	Y	Δy	k	Δk	L	Δl	e	Δe	x	Δe
Im, Pesaran and Shin	6.33	–4.73	3.08	–4.48	3.52	–3.55	3.12	–5.60	1.95	–4.16
W-stat	(1.00)	(0.00)	(0.99)	(0.00)	(0.99)	(0.00)	(0.99)	(0.00)	(0.97)	(0.00)
ADF - Fisher Chi-square	1.378	42.99	3.15	38.5	5.17	32.92	4.38	50.69	4.77	37.00
	(0.99)	(0.00)	(0.97)	(0.00)	(0.87)	(0.00)	(0.92)	(0.00)	(0.90)	(0.00)
PP - Fisher Chi-square	7.62	67.77	3.117	76.16	24.11	73.37	13.45	92.47	7.21	101.4
	(0.66)	(0.00)	(0.97)	(0.00)	(0.00)	(0.00)	(0.19)	(0.00)	(0.70)	(0.00)

Probability value for each test is given in parentheses below its test-statistic. Im, Pesaran and Shin test assumes an asymptotic normal distribution while the other two tests assume an asymptotic Chi-square distribution.

The results of all three tests run for level form accept the null hypothesis of unit root as p-values of their test-statistics are greater than 0.05 except for labour as indicated by PP-Fisher Chi-square test, while results based on difference form reject the null hypothesis of unit roots as p-values of their test-statistics are less than 0.05. It means that at level, all the variables are integrated of order one and at their first difference, they are integrated of order zero. It implies that these variables have a long run equilibrium relationship or they are co-integrated.

5.2. Results of Panel Co-integration Test

The results of panel co-integration test both for within-dimension and between-dimension categories are shown in Table 4.

Table 4

Panel Co-integration Test Result

Test	Test-statistic	Probability	Test	Test-statistic	Probability
Panel v-statistic	–0.688822	0.7545	Group rho-statistic	0.700439	0.7582
Panel rho-statistic	–0.912894	0.1806	Group PP-statistic	–1.694875	0.0450
Panel PP-statistic	–3.382694	0.0004	Group ADF-statistic	–0.528387	0.2986
Panel ADF-statistic	–1.483608	0.0690			

Note: The null hypothesis for all these seven tests-statistics is that there is no co-integration among the variables.

To test co-integration among the variables, first Equation 3.2 was estimated and then seven test-statistics; four for within-dimension or panel test-statistics and three for between-dimension or group test-statistics as suggested by Pedroni were calculated. The probabilities for panel PP, panel ADF and group PP test-statistics are less than 0.1; therefore these tests reject the null hypothesis of no co-integration at 10 percent level of significance, whereas panel-v and panel rho, and group rho and group ADF accept the null hypothesis. Since four tests accept the hypothesis and three reject if, therefore, it may be concluded that there is a co-integration relationship between real GDP, real fixed capital formation, labor, energy consumption and exports or the residuals from Equation (3.2) are stationary.

5.3. Results of Granger Causality Test

To determine the direction of Granger causality between GDP, energy consumption, labor, capital and exports, first we estimated Equation (3.2) for each country separately. Then we worked out their residuals and saved them. Finally using the saved residuals, we estimated Equations (4.2a) to (4.2e) outlined in Section 4.3. The results are reported in Table 5.

Table 5

Results of Granger Causality

	From				
To	Δy	Δk	Δl	Δe	Δx
Δy		4.49	–0.94	3.06	2.37
		(0.00)	(0.34)	(0.00)	(0.01)
Δk	4.82		0.61	0.85	–0.10
	(0.00)		(0.54)	(0.39)	(0.92)
Δl	–0.95	0.60		1.30	–0.20
	(0.34)	(0.54)		(0.19)	(0.84)
Δe	3.18	0.85	1.31		1.65
	(0.00)	(0.39)	(0.19)		(0.10)
Δx	2.47	–0.20	–0.10	1.64	
	(0.01)	(0.92)	(0.84)	(0.10)	
μ_{t-1}	–4.43	1.50	–0.91	2.26	0.15
	(0.00)	(0.13)	(0.36)	(0.02)	(0.87)
Speed of Adjustment	–.445133	.803		–.075	.326

Probability value for each test is given in parentheses below its test-statistic.

All rows in this table except the last one show t-statistics of respective variables, whereas the last row contains coefficients of lagged error correction terms, which show speed of adjustment towards long run equilibrium after any shock.

The results of short run Granger causality test show that there exist feedback relationships between energy consumption and GDP, between trade and GDP, between capital and GDP, and between energy consumption and exports. The first three relationships are significant at 1 percent and the last one is significant at 10 percent level of significance. For other variables, the results are not significant statistically implying no Granger causality relationships.

For the long run Granger causality relationship to exist, coefficients of lagged error correction term need to be significant. For Equation (4.2a) with GDP as dependent variable, the coefficient of the lagged error term has a value of –0.44 that is significant at 1 percent level of significance. It means that 44 percent of a given variation due to any shock is driven back to long run equilibrium in the first year and 44 percent of the remaining error is corrected in the next year and so on. So there is evidence of long run Granger causality running from capital, labor, energy consumption and exports to GDP.

Similarly Equation (4.2d) with energy consumption as dependent variable shows that the coefficient of the lagged error term has a value of 0.32 that is significant at 1 percent level of significance. So there is evidence of long run Granger causality running from capital, labour, exports and GDP to energy consumption. Equations (4.2b), (4.2c) and (4.2e) indicate that the coefficients of lagged error correction terms are not significant implying no long run causality between respective variables on the left-hand side and the ones on the right-hand side.

The results confirm feedback relationship between exports and GDP in the short run and unidirectional relationship running from exports to GDP in the long run. This supports export-led growth hypothesis both in short and long runs and growth-led exports hypothesis only in the short run for the South Asian region. This finding is similar to that of Kemal, *et al.* (2002). The feedback relationship between capital and GDP suggests that capital formation is also an important determinant of GDP in the short run and vice versa. Moreover, evidence of feedback relationship between energy consumption and GDP suggests that energy is a limiting factor to GDP growth and GDP is an important factor in explaining changes in energy consumption both in short and long runs. This finding is similar to the one derived from Noor and Siddiqi (2010). It suggests that energy shortfall adversely affects GDP growth in the South Asian region.

5.4. Results of DOLS or Long Run Elasticities

Table 6 contains the results of DOLS estimation of Equation (4.3). Since the equation is in log linear form, therefore its estimated coefficients show elasticities of dependent variable with respect to corresponding independent variables.

Table 6

DOLS Results

Dependent Variable = y Coefficient		t	P - value
k	0.113	2.31	0.021
l	0.514	2.04	0.041
e	0.328	1.30	0.202
x	0.270	5.57	0.000

The sign of all coefficients is positive as expected. However, coefficients of capital, labour and exports are 0.11, 0.51 and 0.27 that are statistically significant at 5 percent level while coefficient of energy is 0.32 that is insignificant even at the 10 percent level of significance. This means that one percent increase in capital increases GDP by 0.11 percent; one percent increase in labor increases GDP by 0.51 percent and one percent increase in exports increases GDP by 0.27 percent.

The results of DOLS suggest that energy is insignificant in explaining GDP in the long run. It is in contradiction with positive correlation coefficient between energy consumption and GDP that is statistically significant as reported in descriptive analysis in section 3.2. It is however less peculiar than the findings of Noor and Siddiqi (2010) who reported a negative relationship between energy and GDP for the South Asian countries. A possible reason could be that energy consumption has gained importance in explaining GDP only recently. That is, in earlier years of panel data, energy might not have been so crucial input.

6. CONCLUSION AND POLICY IMPLICATIONS

The purpose of present study was to investigate the dual role of energy consumption for economic activity of a country; its direct impact on GDP as a crucial input for every production process and its indirect impact as an important input in the industry of exportable goods which, if increased, affect the GDP through multiplier effect in subsequent periods. For this purpose, we used panel data of five South Asian economies (Bangladesh, India, Pakistan, Sri Lanka and Nepal) for the period 1980–2009. In addition to energy consumption and exports, we used capital stock and labor force as other explanatory variables of GDP. We used panel co-integration approach with Granger causality test.

The results of our estimation support the feedback relationship or two-way causality between energy consumption and GDP, between trade and GDP, and between energy consumption and exports for the short run. However, in the long run, the feedback relationship between energy consumption and GDP is confirmed but for other variables, it is unidirectional such that arrow of causality runs from exports to energy consumption and exports to GDP. It means that any shortage of energy supplies or any energy conservation policy that decreases energy consumption in the current period adversely affects GDP and exports. Any reduction in exports, in turn, hampers competitiveness of the country in international markets that may take years to get back at the par. It means that benefits of export promotion and trade liberalisation policies may be offset if there is shortage of energy supply in a country.

One of the policy implications of the causal linkages among crucial variables of this research is that policies to ensure uninterrupted supply of energy should be given priority over export promotion and trade liberalisation policies. Otherwise if trade liberalisation policies are implemented before formulating suitable energy policies, then competitiveness of the country in the international market will deteriorate and benefits of trade policies may be reversed. Another implication is that protectionist policies for trade are not advisable if sufficient supply of energy is ensured. To sum up, trade liberalisation policies are beneficial for South Asian countries provided that they develop new resources of energy production such as construction of dams, solar panels, and wind power plants to fulfill energy demand.

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Energy Sources and Gross Domestic Product: International Evidence

WASEEM AHMAD and TANVIR AHMED

INTRODUCTION

The relationship between energy consumption and economic growth received a significant amount of attention in energy economics literature [Al-Iraiani (2006)]. Rufael (2006) stated that different energy sources are a necessary requirement for economic and social development and no country in the world has progressed from subsistence economy without the use of energy. In this regard, four views have emerged over time about the relationship between energy consumption and output growth. One point of view is that energy is the prime source of value and other factors like labor and capital cannot do without energy. Many studies argue that the impact of energy use on growth depends on the structure of the economy and the stage of economic growth of the country concerned [Ghali and Sakka (2004)]. The bulk of the literature reports a uni-directional causality from energy consumption to economic growth. When the causality runs from energy consumption to economic growth, it is also called 'growth hypothesis'. Table 1 provides a list of the studies, which show such results. It implies that an increase in energy consumption has a significant impact on economic growth and if it is positive, then energy conservation policies have a detrimental impact on economic growth. Alternatively, if an increase in energy consumption has significant negative impact on GDP, it implies that growing economy needs a less amount of energy consumption, may be due to shift towards less energy intensive sectors [Payne (2010)]. Second point of view is that economic growth has a positive influence on energy consumption. There may be uni–directional causality from economic growth to energy consumption. Table 1 displays a list of studies showing such results. When the causality runs from economic growth to energy consumption, it is often referred to as 'conservation hypothesis'. It implies that energy conservation policies formulated to reduce energy consumption may not adversely affect economic growth. Third point of view is that the cost of energy use is very small compared to GDP and consequently its impact on economic growth is non-significant. There may be no causality between energy consumption and GDP; it is often referred to as 'neutrality hypothesis". A list of studies showing such results is given in Table 1. It implies that energy consumption has not a significant influence on economic

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Table 1

Studies Showing Various Types of Causality from Energy Consumption to Economic Growth

Country	Authors	Period	Methodology
Causality from Energy Consumption to Economic Growth			
USA	Stern (2000)	1948-1994	Co-integration, Granger causality
Turkey	Soytas, *et al.* (2001)	1960-1995	Co-integration, Granger causality
Taiwan	Lee and Chang (2007a)	1955-2003	Granger causality, co-integration, VECM
Hong Kong	Ho and Siu (2007)	1966-2002	Co-integration , VEC model
Causality from Economic Growth to Energy Consumption			
USA	Kraft and Kraft (1978)	1947-1974	Granger causality
India	Cheng (1999)	1992-1995	Co-integration, ECM, Granger causality
Pakistan	Aqeel and Butt (2001)	1955-1996	Hsiao's version of Granger causality Method, Co-integration
Iran	Zamani (2007)	1967-2003	Granger causality, Co-integration, VECM
Turkey	Karanfil (2008)	1970-2005	Granger Causality Test, Co-integration test
China	Zhang and Cheng (2009)	1960-2007	Granger causality
No Causality between Economic Growth and Energy Consumption			
New Zealand	Fatai, *et al.* (2002)	1960-1999	Granger causality, ARDL, Toda and Tamamoto test
Turkey	Halicioglu (2009)	1960-2005	Granger causality, ARDL, co-integration
USA	Payne (2009)	1949-2006	Toda-Yamamoto causality test
Turkey	Belloumi (2009)	1960-2000	Toda-Yamamoto causality test
Bi-directional Causality between Economic Growth and Energy Consumption			
Korea	Glasure (2002)	1961-1990	Co-integration, error correction, variance decomposition
Canada	Ghali and El-Sakka (2004)	1961-1997	Co-integration,, VEC, Granger causality
India	Paul and Bhattacharya (2004)	1950-1996	Co-integration and Granger causality
Turkey	Erdal, *et al.* (2008)	1970-2006	Pair-wise Granger causality, Johansen co-integration

growth, which means that neither conservation nor expansive policies pertaining to energy consumption have any effect on economic growth [Ozturk (2010)]. Fourth point of view is that when output and energy consumption are moving together towards a long-run equilibrium, and energy consumption and GDP are interdependent, and affect each other at the same time, there may be bi-directional causality [Payne (2010); Ozturk (2010)]. It implies that an increase (decrease) in GDP causes an increase (decrease) in energy consumption and similarly an increase (decrease) in GDP results in an increase (decrease) in energy consumption. It is also called 'feedback' hypothesis. A list of studies reporting such results is given in Table 1.

Different forms of causality between energy consumption and the economic growth have been reported by many studies in different countries (Table 2). Further multi-country studies also show similar results (Table 3). Thus empirical studies conducted on the energy consumption and economic growth yielded mixed results in terms of the above hypotheses; that is, some studies show causality running from energy consumption to economic growth, others report causality running from economic growth to energy consumption, while some studies find no causality or bi-directional causality. There is absence of consensus on the relationship between energy consumption and growth.

Table 2

Studies Showing Different Energy Consumption and Economic Growth Causality for the Selected Countries

Countries	Causality Relationship			
	GDP→EC	EC→GDP	EC←→GDP	GDP-----EC
India	Cheng (1999)	Masih (1996)	Paul and Bhattacharya (2004)	Soytas and Sari (2003)
Japan	Cheng (1998), Lee (2006)	Soytas and Sari (2003)	Erol and Yu (1987)	–
Korea	Yu and Choi (1985), Soytas and Sari (2003)	Oh and Lee (2004)	Glasure (2002)	–
Malaysia	Ang (2008)	Chiou-Wei, *et al.* (2008)	–	Masih (1996)
Turkey	Lise and Van Montfort (2007), Karanfil (2008)	Murray and Nan (1996), Soytas, *et al.* (2001), Soytas and Sari (2003)	Erdal, *et al.* (2008)	Altinay and Karagol (2004), Altinay and Karagol (2007), Karanfil (2008), Soytas and Sari (2009), Halicioglu (2009)
USA	Kraft (1978), Abosedra and Baghestani (1989)	Stern (2000), Soytas and Sari (2006), Bowden and Payne (2009)	Lee (2006)	Akarca and Long (1980), Yu and Hwang (1984), Yu and Choi (1985), Yu and Jin (1992), Cheng (1995), Soytas and Sari (2003), Chiou-Wei, *et al.* (2008), Payne (2009)

Table 3

Causal Relationships between Energy Consumption and Economic Growth for Multi-Country Studies

Authors	Period	Countries	Methodology	Causality Relationship
Soytas and Sari (2003)	1950–1992	G-7 Countries	Co-integration and Granger causality	EC←→ GDP (Argentina) GDP→EC (Italy, Korea) EC→GDP (Turkey, France, Japan, Germany)
Lee (2005)	1975–2001	18 Developing Countries	Panel VECM	EC→GDP
Lee (2006)	1960–2001	11 Developed Countries	Granger causality test	GDP- ---EC(Germany, UK) EC←→ GDP (Sweeden, USA) EC→GDP (Belgium, Netherlands, Canada, Switzerland)
Soytas and Sari(2006)	1960–2004	G-7 Countries	Multivariate co-integration, ECM, generalised variance decompositions	GDP→EC (Germany) EC→GDP (France, USA) EC←→GDP (Canada, Italy, Japan, UK)
Lee and Chang(2007b)	1965–2002 1971–2002	22 Developed Countries,18 Developing Countries	Panel VARs and GMM	GDP→EC (developing countries) EC←→GDP (developed countries)
Chiou-Wei, *et al.*(2008)	1954–2006	Asian Countries and USA	Granger causality	GDP- ---EC(USA, Thailand, South Korea) GDP→EC (Philippines, Singapore) EC→GDP (Taiwan, Hong Kong, Malaysia, Indonesia)
Chang, *et al.* (2013)	1970-2010	12 Asian Countries	Panel causality analysis	EC----GDP (China, Indonesia, Japan, Malaysia, Pakistan, Philippines, Singapore, South Korea, Taiwan) EC→GDP (Philippines) GDP→EC (India) EC←→GDP (Thailand and Vietnam)

Karanfil (2009) has suggested that any future research using the same methods, variables and changing study period have no more potential to make a contribution to the existing energy consumption—economic growth literature. In order to avoid conflicting and unreliable results, Ozturk (2010) has suggested the use of new approaches, including panel data approach. Further, a majority of studies (Tables 1 to 3) estimate the causal relationship between aggregate energy consumption and economic growth. Use of aggregate energy consumption may mask the differential impact associated with various forms of energy consumption like gas, oil, electricity and coal [Payne (2010)]. The aim of this paper is to empirically investigate the relationship between output and energy use of various forms. We use a framework of neoclassical production economics where labour, capital and various forms of energy (i.e. gas, oil, electricity and coal) are treated as separate inputs. Within this framework, we use cross country panel data over the period 1990–2011. The results of the translog production function show that labor, capital, gas, oil and electricity have positive and significant impact on the GDP, while the coal has negative significant impact. This paper contributes in the following ways, first we use panel data approach to estimate the impact of energy consumption on economic growth. Second, we use the cross country data of countries having different levels of income to estimate the relation, which has not been done so far. Third, we estimate the relationship between energy consumption of various forms along with labor and capital on output.

The remainder of the paper is organised as follows. Section 2 is concerned with the data and variables, and reports methodology along with the description of the model. Section 3 presents the empirical results and Section 4 deals with the conclusion and policy implications.

DATA AND VARIABLES

In this study, cross country data have been used to estimate the production function by using real GDP as dependent variable and factors like total labour force, gross capital formation, and consumption of gas, oil, electricity and coal as independent variables. Besides these variables, dummy variables have been included in the model to capture the region specific, income level and climate effects. Data for real GDP are measured in constant 2005 US dollar and are obtained from the *World Development Indicators* [WDI, The World Bank (2011)]. Labour is a conventional input and is measured in millions, capital is measured in terms of gross capital formation in million US$ and is considered as a reliable proxy for capital stock [Jin and Yu (1996) and Shan and Sun (1998)]. The data for total labor force and gross capital formation are obtained from World Development Indicators [WDI, The World Bank (2011)]. Natural gas consumption is measured in billion cubic meters. Oil products include all liquid hydrocarbons obtained by refining of crude oil and NGL and by the treatment of natural gas, in particular LPG (liquid petroleum gas) production; it is measured in million tons. Electricity is measured in terawatt hours; it includes electricity consumption of private, public and industrial sectors. Coal is measured in million tons. The data for gas, oil, electricity and coal are obtained from *Global Statistical Yearbook* (http://yearbook.enerdata.net/). Regional dummy variables are included to capture the regional specific effects. These regions are Europe, Commonwealth of Independent States, North America, Latin America, Asia, Pacific, Africa and Middle East. All World Bank countries have been divided into three groups on the basis of gross national income per capita i.e. low income ($1035 or less), middle income ($1036 to $12615) and high income ($12616 or more) (http://data.worldbank.org/about/country-classifications/country-and-lending-groups). Dataset are available from 1990 to 2011 about the above variables only for 40 countries. These countries are either in the middle income or in high income group. Therefore only one dummy variable is used in the analysis. A list of countries included in this study is given in Appendix. The Koppen climate classification system divides the world's climate into 5 types on the basis of annual and monthly averages of temperature and precipitation. For the purpose of this study, last two types of climate i.e. Moist Continental Mid-latitude climate - E category (where the winter is cold and average temperature of the coldest month is less than –3 C^0) and Polar Climates - D category (where the soil is permanently frozen to depths of hundreds of meters or where the soil surface is permanently covered with snow and ice) have been grouped into one category. A dummy variable assumes a value of one if the country is mainly located in either of the above two climate zones, otherwise zero.

The descriptive statistics show that the average GDP of countries included in the sample is 833139 million US $. It may be noted that the countries included in the sample belong to the high income or middle income categories. The average value of dummy variable for middle income group shows about 48 percent countries included in the sample belong to the middle income category and 52 percent countries in the sample belong to the high income category. Due to non-availability of data about the low income countries, we could not include them in the analysis. The average value of electricity is 243.83 terawatt hour and the mean value of gas and oil are 45.30 million cubic meter and 58.60 million tons respectively (as shown in Table 4). The regional dummies show that about 35 percent countries included in the analysis are from European region and 15 percent countries included in the analysis are each from Latin America and Asian region. Dummy for climatic region shows that about 20 percent countries included in the analysis belong to D or E region.

Table 4

Descriptive Statistics of Variables Used in the Analysis

Variable[a]	Mean	Standard Deviation
GDP	833139	1844001.00
G	45.30	96.74
O	58.62	126.67
E	243.83	548.80
C	72.58	164.07
L	34.14	67.79
K	164277.70	348603.40
Deu	0.35	0.48
Dcis	0.08	0.26
Dnamerica	0.05	0.22
Dlamerica	0.15	0.36
Dasia	0.15	0.36
Dpacific	0.05	0.22
Dmiddle	0.48	0.50
Dcold	0.20	0.40

[a] Definitions of variables are given in Table 5.

The Model

The present study examines the relationship between gross domestic product (GDP) and various factors in production function framework such as total labor, gross capital formation and energy; energy is further divided into different forms such as oil, gas, electricity and coal. Mathematically it can be written as:

$$GDP = f(L, K, G, O, E, C) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where *GDP r*epresents the gross domestic product (GDP), *L* denotes total labor, *K* shows the capital, *G* represents gas, *O* denotes oil, *E* shows electricity and *C* indicates the coal consumption.

In this study a Translog function has been used; this function can be approximated by second order Taylor series. The Translog functional form imposes fewer restrictions on the production technology. It does not impose any a priori restriction on returns to scale and elasticity of substitution. Because of above mentioned reasons, it is widely used in the production economics literature [Kim (1992)]. We also used dummies for different regions, income levels and climatic zone. The detailed functional form can be written as follows:

$$\begin{aligned}
LnGDP_{jt} &= \beta_0 + \beta_1 LnL_{jt} + \beta_2 LnK_{jt} + \beta_3 LnG_{jt} + \beta_4 LnO_{jt} + \beta_5 LnE_{jt} + \beta_6 LnC_{jt} \\
&+ \frac{1}{2}(\beta_{11} LnL_{jt} LnL_{jt} + \beta_{22} LnK_{jt} LnK_{jt} + \beta_{33} LnG_{jt} LnG_{jt} + \beta_{44} LnO_{jt} LnO_{jt} + \beta_{55} LnE_{jt} LnE_{jt} \\
&+ \beta_{66} LnC_{jt} LnC_{jt}) + \beta_{12} LnL_{jt} LnK_{jt} + \beta_{13} LnL_{jt} LnG_{jt} + \beta_{14} LnL_{jt} LnO_{jt} + \beta_{15} LnL_{jt} LnE_{jt} + \beta_{16} LnL_{jt} LnC_{jt} \\
&+ \beta_{23} LnK_{jt} LnG_{jt} + \beta_{24} LnK_{jt} LnO_{jt} + \beta_{25} LnK_{jt} LnE_{jt} + \beta_{26} LnK_{jt} LnC_{jt} + \beta_{34} LnG_{jt} LnO_{jt} \\
&+ \beta_{35} LnG_{jt} LnE_{jt} + \beta_{36} LnG_{jt} LnC_{jt} + \beta_{45} LnO_{jt} LnE_{jt} + \beta_{46} LnO_{jt} LnC_{jt} + \beta_{56} LnE_{jt} LnC_{jt} + \gamma_1 Deu \\
&+ \gamma_2 Dcis + \gamma_3 Dnamerica + \gamma_4 Dlamerica + \gamma_5 Dasia + \gamma_6 Dpacific + \gamma_7 Dmiddle + \gamma_8 Dcold + \mu_{jt}
\end{aligned}$$

Where GDP_{jt} is gross domestic product of *j*th country in year *t*, L_{jt} is total labor of *j*th country at *t* year, K_{jt} is gross capital formation of jth country at *t* year, G_{jt} is total gas consumption of *j*th country at *t* year, O_{jt} is total consumption of oil products in *j*th country at *t* year, E_{jt} is total domestic consumption of electricity in jth country at *t* year, C_{jt} is total consumption of coal in *j*th country at *t* year, Deu, Dcis, Dnamerica, Dlamerica, Dasia, Dpacific are different regional dummies, Dmiddle shows the dummy for middle income countries, Dcold denotes the dummy for cold climatic zone and μ_{jt} is the random error term.

The elasticity of GDP with respect to each input i.e. labor, capital, gas, oil, electricity and coal would be calculated by using:

$\varepsilon_i = \dfrac{\partial LnGDP}{\partial LnX_i}$ where X_i represents labour, capital, gas, oil, electricity and coal. So the elasticity of each input can be written as:

$$\begin{aligned}
\varepsilon_L &= \beta_1 + \beta_{11}\overline{LnL} + \beta_{12}\overline{LnK} + \beta_{13}\overline{LnG} + \beta_{14}\overline{LnO} + \beta_{15}\overline{LnE} + \beta_{16}\overline{LnC} \\
\varepsilon_K &= \beta_2 + \beta_{22}\overline{LnK} + \beta_{12}\overline{LnL} + \beta_{23}\overline{LnG} + \beta_{24}\overline{LnO} + \beta_{25}\overline{LnE} + \beta_{26}\overline{LnC} \\
\varepsilon_G &= \beta_3 + \beta_{33}\overline{LnG} + \beta_{13}\overline{LnL} + \beta_{23}\overline{LnK} + \beta_{34}\overline{LnO} + \beta_{35}\overline{LnE} + \beta_{36}\overline{LnC} \\
\varepsilon_O &= \beta_4 + \beta_{44}\overline{LnO} + \beta_{14}\overline{LnL} + \beta_{24}\overline{LnK} + \beta_{34}\overline{LnG} + \beta_{45}\overline{LnE} + \beta_{46}\overline{LnC} \\
\varepsilon_E &= \beta_5 + \beta_{55}\overline{LnE} + \beta_{15}\overline{LnL} + \beta_{25}\overline{LnK} + \beta_{35}\overline{LnG} + \beta_{45}\overline{LnO} + \beta_{56}\overline{LnC} \\
\varepsilon_C &= \beta_6 + \beta_{66}\overline{LnC} + \beta_{16}\overline{LnL} + \beta_{26}\overline{LnK} + \beta_{36}\overline{LnG} + \beta_{46}\overline{LnO} + \beta_{56}\overline{LnE}
\end{aligned}$$

Where $\overline{LnL}, \overline{LnK}, \overline{LnG}, \overline{LnO}, \overline{LnE}$ and $\overline{LnC}$ represent the average values.

The definition of variables and their expected signs are presented in Table 5.

Table 5

Variable Definitions and Expected Signs

Variables	Variable Description	Expected Sign
GDP	Gross domestic product (million US $)	
L	Total labor force (millions)	+ve
K	Gross capital formation (million US $)	+ve
G	Gas domestic consumption (million cubic meters)	+ve
O	Oil products domestic consumption (million tons)	+ve
E	Electricity domestic consumption (terawatt hour)	+ve
C	Coal and lignite domestic consumption (million tons)	+ve
Deu	Deu=1 if the observation belongs to European region, otherwise 0	
Dcis	Dcis=1 if the observation belongs to Commonwealth of Independent States region, otherwise 0	
Dnamerica	Dnamerica=1 if the observation belongs to North American region, otherwise 0	
Dlamerica	Dlamerica=1 if the observation belongs to Latin American region, otherwise 0	
Dasia	Dasia=1 if the observation belongs to Asian region, otherwise 0	
Dpacific	Dpacific=1 if the observation belongs to Pacific region, otherwise 0	
Dmiddle	Dmiddle=1 if the observation belongs to middle income country, otherwise 0	
Dcold	Dcold=1 if the observation belongs to a country which is located in D and/or E Koppen climate classification system, otherwise 0	

Results

For estimation purpose, Translog model has been used on panel data of 40 countries from 1990 to 2011. In this regard likelihood ratio, heteroscedasticity and auto correlation tests were used for diagnostic purposes.

Likelihood ratio test is used to test the nested hypothesis of the model, in this regard; we compare the restricted (Cobb Douglas) and unrestricted (Translog) model. LR test helps us to identify whether the imposition of restriction holds or not. The LR test statistic is 535.09 and this value is significant at 1 percent level of significance. It indicates that the unrestricted model (Translog) performs better than Cobb Douglas.

In the presence of heteroscedasticity the estimates are unbiased but inefficient [Gujarati (2007)]. We use likelihood ratio test for testing existence of heteroscedasticity in the panel data [Ahmad and Anders (2012)]. The χ^2 value is 1063.15, which is significant at 1 percent level of significance. It shows that there is a problem of heteroscedasticity in the data.

Serial correlation in panel data model biases the standard error and makes the results inefficient. In the present study, we use Wooldridge test to test for serial correlation in the model. This test is easy to implement and requires relatively less assumptions [Drukker (2003)]. The result of the Wooldridge test statistic is 260.51, which is significant at 1 percent level of significance. The result of the test shows that there is a problem of autocorrelation in the data.

To fix the problem of heteroskedasticity and autocorrelation, we applied feasible generalized least square approach. It gives us unbiased and consistent results.

In the present study, we also applied Wald test to see the joint significance of different regions. The value of Wald test is 891.36 and it is significant at 1 percent level of significance. Thus on the basis of results of the model, the null hypothesis that there are no regional differences is strongly rejected as a composite hypothesis. Thus different regions have jointly significant impact on the GDP of the country.

The results of the estimated model are presented in Table 6. It presents the estimated coefficients and their standard errors. Overall results of model show that most of the coefficients are statistically significant. Based on the Translog production function estimates shown in Table 6, we derive the returns to scale and output elasticities with respect to the inputs. By taking sum of six output elasticities, we can get the value of return to scale. This value comes out to be 1.084 showing almost constant returns to scale.

Table 6

Estimates of the Inter Country Translog Production Function

Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
Constant	9.522* (0.581)	lngcapital^2	0.089* (0.006)	Lnelectgcapital	–0.123* (0.038)
Lngas	–1.503* (0.125)	Lngasoil	–0.267* (0.029)	Lncoaltlabor	0.008 (0.006)
Lnoil	1.596* (0.342)	Lngaselec	–0.009 (0.020)	Lncoalgcapital	–0.058* (0.009)
Lnelectric	0.564** (0.305)	Lngascoal	–0.031* (0.008)	Lntlaborgcapital	–0.063 (0.026)
Lncoal	0.198* (0.070)	Lngastlabor	0.057* (0.019)	Dcold	0.026 (0.032)
Lntlabor	0.901* (0.204)	Lngasgcapital	0.211* (0.016)	Deu	0.638* (0.041)
Lngcapital	–0.762* (0.088)	Lnoilelec	0.003 (0.076)	Dcis	–0.312* (0.065)
Lngas^2	0.003 (0.006)	Lnoilcoal	0.091* (0.016)	Dnamerica	–0.030 (0.077)
Lnoil^2	0.106** (0.057)	Lnoiltlabor	0.075 (0.048)	Dlamerica	0.468* (0.037)
Lnelec^2	0.142* (0.044)	Lnoilgcapital	–0.159* (0.041)	Dasia	0.165* (0.039)
Lncoal^2	–0.006* (0.002)	Lneleccoal	0.047* (0.021)	Dpacific	0.681* (0.062)
Lntlabor^2	–0.051* (0.013)	Lnelectlabor	–0.071* (0.034)	Dmiddle	–0.130* (0.032)

Estimates obtained by using FGLS procedure.

Standard error of the Coefficient is given in the parenthesis.

* and ** represent statistical significance at 5 percent and 10 percent level of significance respectively.

The estimated elasticities of different inputs are given in Table 7. The elasticity estimates show that the coefficients of conventional inputs labor and capital are 0.04 and 0.43 respectively. These coefficients show that if there is 1 percent increase in labor, it will increase the GDP by 0.04 percent while 1 percent increase in the capital will result in an increase of 0.43 percent. A number of studies show that economic growth is influenced by the amount of energy as well as primary inputs i.e. labor and capital [Beaureau (2005)]. Lie and Liu (2011) reported the mean GDP elasticity with respect to labor and capital over the 10 years study period to be 0.302 and 0.614 respectively. Thus the study results show that capital intensive technology will be more beneficial for countries. The GDP elasticity estimates of gas, oil and electricity are positive; these results show that these energy inputs have positive impact on the GDP.

The GDP elasticity of gas, oil and electricity are 0.001, 0.19 and 0.45 respectively. These results show that among the various forms of energy, electricity is the most important factor in influencing the GDP. It is important to ensure its supply for sustainable economic development. These results indicate that electricity increase has the largest effect on the GDP while gas increase has the lowest positive impact on the GDP. The GDP elasticity of electricity shows that an increase of electricity by 1 percent will increase the GDP by 0.45 percent.

Table 7

Elasticities Estimates of Different Inputs

Input	Elasticity Estimate
G	0.0018*
O	0.1914*
E	0.4521*
C	–0.0328*
L	0.0438*
K	0.4280*

*Represents statistical significance at 5 percent level of significance.

The GDP elasticity with respect to coal is negative. It shows that an increase in consumption of coal by 1 percent will decrease GDP by 0.03 percent. This results due to the fact that the average domestic consumption of coal showed either decreasing or stagnant behavior during the first thirteen years of study period. However, there was an increasing trend in the use of coal during the last nine year. Many countries showed substantial reduction in the domestic consumption of coal. For example, coal domestic consumption decrease from 448.81 million tons (MT) to 238.0 MT in Germany, 106.68 MT to 51.22 MT in United Kingdom, and 149.85 MT to 72.85 MT in Ukraine over the period 1990 to 2011. There was also reduction in coal consumption in Belgium, France, Romania, Spain, Kazakhstan, Uzbekistan and Columbia. However, there was an increase in the domestic consumption of coal in India from 220.86 MT to 703.28 MT, Indonesia from 8.27 MT to 71.25 MT and Turkey from 54.42 MT to 102.06 MT. Japan, Chile, Mexico, Malaysia, Thailand, South Africa also experienced an increase in coal consumption. Other countries like Italy, Netherlands, Portugal, Sweden, Egypt, Argentina, Nigeria, Algeria, Pakistan, Kuwait, Norway etc. either experience stagnant behavior or negligible use of coal.

CONCLUSION AND POLICY IMPLICATIONS

The paper determines the relationship between energy consumption in different forms and conventional inputs i.e. labour and capital with real gross domestic product in a production function framework. A Translog production function model is used on panel data of forty countries from 1990 to 2011. Feasible generalised least squares approach is applied in order to fix the problem of heteroskedasticity and autocorrelation. The results of the study show that all the independent variables included in the analysis have positive and significant impact on GDP except the coal variable. The study reveals that different regions, income level and climatic zones have significant impact on the GDP. Energy consumption in the form of electricity has the strongest impact on GDP than any other variable. The GDP elasticity estimate of electricity is 0.45, which shows that 1 percent increase in the electricity increases GDP by 0.45 percent. The GDP elasticity of electricity is substantially higher than any other form of energy. This suggests that policy maker should ensure sustainable electricity supply and place more emphasis on this form of energy. Any shocks to electricity supply will adversely affect the real GDP growth. In order to avoid the adverse effects of electricity supply, it is necessary for countries, especially developing countries facing its shortage, to plan and develop generation capacity to meet the electricity demand of their countries.

APPENDIX

Belgium, Finland, France, Germany, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden, United Kingdom, Norway, Turkey, Kazakhstan, Ukraine, Uzbekistan, Canada, United States, Argentina, Brazil, Chile, Columbia, Mexico, Venezuela, India, Pakistan, Indonesia, Japan, Malaysia, Thailand, Australia, New Zealand, Algeria, Egypt, Nigeria, South Africa, Kuwait, Saudi Arabia, United Arab Emirates.

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Determinants of Energy Inflation in Pakistan: An Empirical Analysis

ADNAN HAIDER, QAZI MASOOD AHMED, and ZOHAIB JAWED

1. INTRODUCTION

Energy inflation has remained a significant topic in macroeconomic policy for the past few decades. This is due to several reasons pertaining to both demand and supply sides. In addition, the history of energy prices has also been characterised by extreme volatilities, Hamilton (2008). This makes forecasting and modelling of energy prices difficult, nevertheless it is important to model and forecast energy prices in all economies. In this paper we have tried to identify the determinants of energy inflation in Pakistan.

Energy products are a critical component in any economy, serving as a core input, particularly in manufacturing industries. Moreover, the demand for energy and fuel comes from households fuelling cars and kitchens for which other alternatives are not easily available. This renders the demand inelastic compared to any other good [Edelstein and Kilian (2009)], making economies vulnerable to supply and price shocks. The energy price inflation therefore through cost push inflation and demand-pull inflation has a major impact on core inflation itself, thereby playing a significant role in macroeconomic health of a country. As predicted by Ben Bernanke for the US in 2006, "*in the long run energy prices can reduce the productive capacity of US economy if high energy costs make businesses less willing to invest new capital*". The nature of the energy market itself creates a major gap between the oil consumers and oil producers. Whilst demand is inelastic everywhere, supply is limited and is difficult to increase, and confined to certain regions on Earth. This is true particularly for two of the most common energy types: oil and gasoline. The supply of oil is controlled by a few countries, and supply shocks therefore lead to an immediate surge in prices. The oil shock of 1970s created by OPEC

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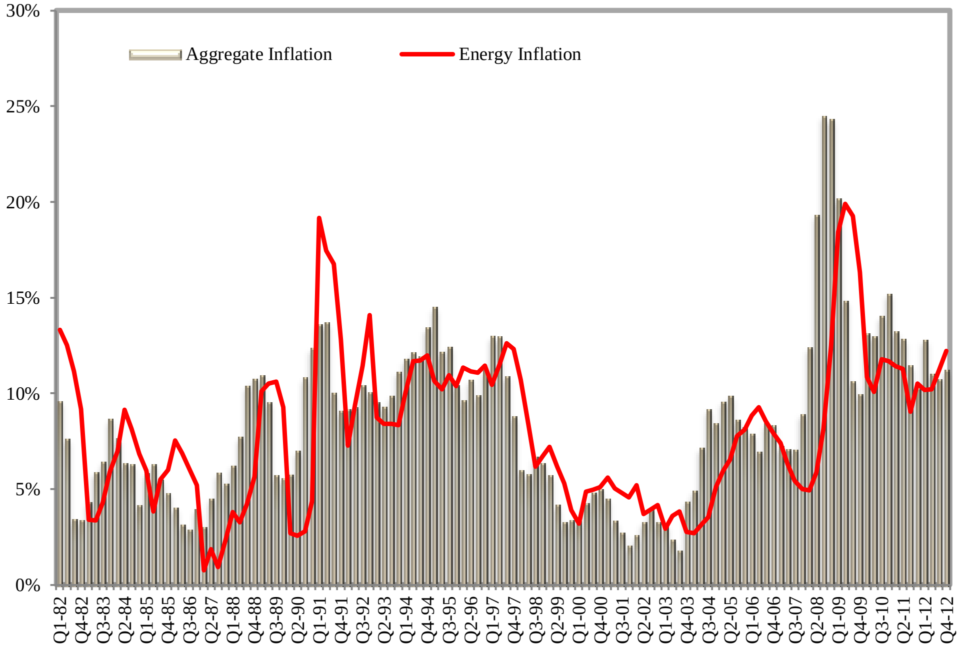
caused a major setback for all oil importing countries of the world, resulting in a global recession. Energy prices shot up, creating huge demand supply gaps. This is the case particularly for energy importing countries, which were helpless in the face of a strong demand and supply gaps. Energy policy now aims to bridge this gap so that such recessions do not occur again [Kolev and Riess (2007)].

In an emerging economy like Pakistan, the issue is of prime concern. With growing industrialisation and high population growth rates, the demand for energy in Pakistan is set to increase in the coming years. Pakistan is a net importer of oil, which makes it vulnerable to oil supply shocks putting subsequent pressure on its import bills. It has become of critical importance to address the main causes underlying energy price inflation, and take policy measures to mitigate such concerns in a timely manner. Energy inflation in Pakistan is no different than the normal inflation. As we can see in Figure 1, the trend of energy inflation moves in accordance with the aggregate inflation. In the past there have been several studies identifying determinants of the aggregate inflation and more specifically, those studies were focused on food inflation. Our attempt in this paper is targeted specifically to study energy inflation.

Fig.1. A Comparison of Energy Inflation with Overall Consumer Price Inflation in Pakistan



Source: Pakistan Bureau of Statistics (PBS, Price Survey datasets).

In the next section, we will be talking about some stylised facts about energy. Section 3 will cover the literature review. Section 4 will discuss the methodology and data. Section 5 will talk about the results and the last section will conclude the paper along with policy recommendations.

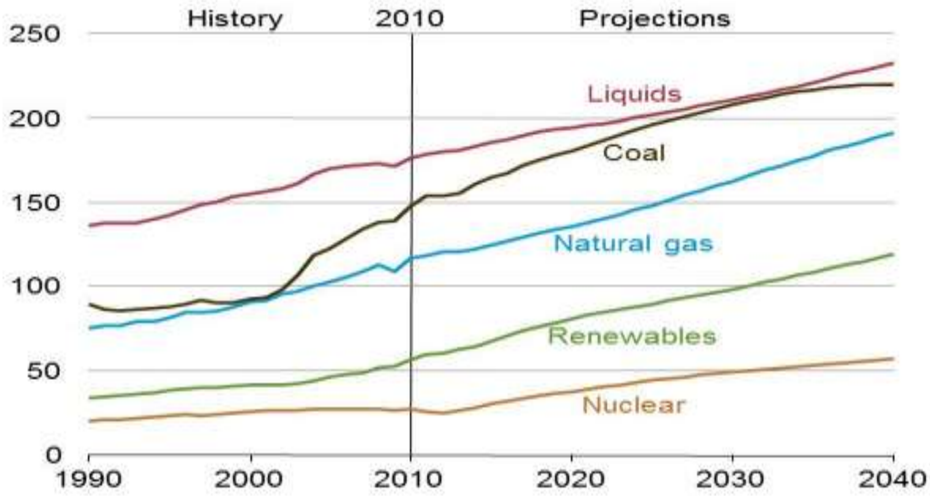
2. SOME STYLISED FACTS

This section provides some stylised-facts and an overview about energy outlook both globally and domestically.

2.1. International Energy Outlook

Before analysing domestic energy scenario, some highlights are obtained from Global Energy Outlook 2012. International energy consumption pattern is changing globally over the years. According to International Energy Outlook (IEO) 2012, liquids supply the largest share of world energy consumption over the projection period, but their share falls from 34 percent in 2010 to 28 percent in 2040, largely in response to a reference case scenario in which world oil prices are expected to remain relatively high. Due to this surge in international oil prices, use of gas and coal has been gaining importance. Natural gas, and coal are expected to continue supplying much of the energy used worldwide, meanwhile, the share of nuclear energy has remained stagnant (see, Figure 2). Although growth in the energy consumption was 11 percent in 2010, the annual increase of only 1.6 percent would lead to a 15 percent growth in consumption by 2040.

Fig. 2. World Energy Consumption by Fuel Type (1990-2040)

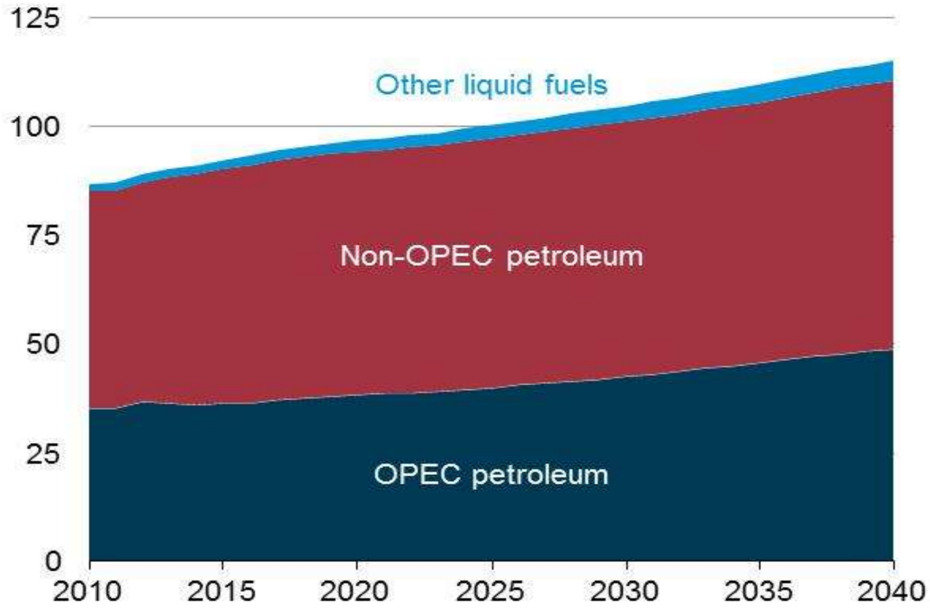


Source: International Energy Outlook, 2012.

The IEO 2012 has also projected a steady rise in the demand for oil in Asia by 2040. This rise in demand is due to higher economic growth and it is expected that oil consumption of the Asian region will exceed the North America by 2010; and by 2020 its demand will become nearly half of the world's total demand for oil. The use of liquids and other petroleum grows from 87 million barrels oil equivalent per day in 2010 to 97 million barrels per day in 2020 and 115 million barrels per day in 2040. The liquids share of world energy consumption declines through 2030, however, as other fuels replace liquids where possible. In most regions of the world, the role of liquid fuels outside the transportation sector continues to be eroded.

Liquids remain the most important fuels for transportation, because there are a few alternatives that can compete widely with liquid fuels. On a global basis, the transportation sector accounts for 63 percent of the total projected increase in liquids use from 2010 to 2040, with the industrial sector accounting for virtually all of the remainder.

Fig. 3. World Liquid Production (2010–2040)



Source: International Energy Outlook, 2012.

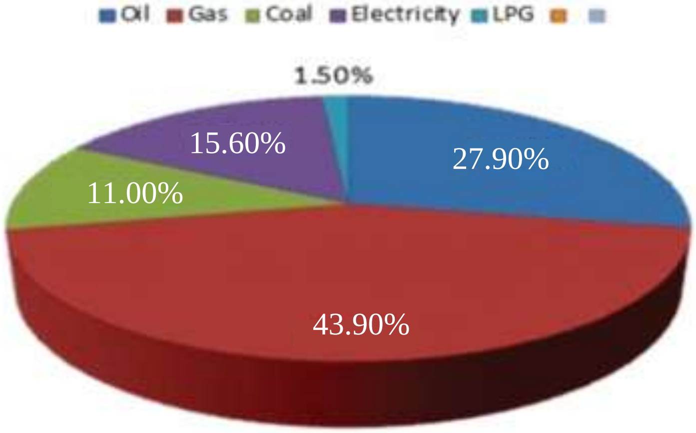
The rising demand for oil and its limited supply has created deep concern throughout the world as it is believed that nearly all the largest oil fields have already been discovered and are being exploited. To meet this demand pressure, total supply in 2040 is projected to be 28.3 million barrels per day higher than the 2005 level of 84.3 million barrels per day. It is also assumed that OPEC producers will choose to maintain their market share of world liquids supply, and that OPEC member countries will invest in incremental production capacity so that their conventional oil production represents approximately 40 percent of total global liquids production throughout the projection period. Increasing volumes of conventional liquids (crude oil and lease condensates, natural gas plant liquids, and refinery gain) from OPEC members contribute 13.8 million barrels per day to the total increase in world liquids production, and conventional liquids supplies from non-OPEC countries add another 11.5 million barrels per day (see, Figure 3).

2.2. Pakistan's Energy Outlook

Pakistan with a population of more than 180 million has been on the path of rising GDP growth for the last four years, however a decline in output growth is observed in FY12 but its growth is still on the higher side as compared with other developing countries. Real GDP growth reached 3.4 percent in FY11, after a recovery in FY12, real output growth reached 7 percent. However, after a moderate decline it dropped to 5.8

percent in FY08. Since energy sector has a direct link with the economic development of a country. So energy consumption has also grown rapidly consistent with the high growth rate of real GDP.

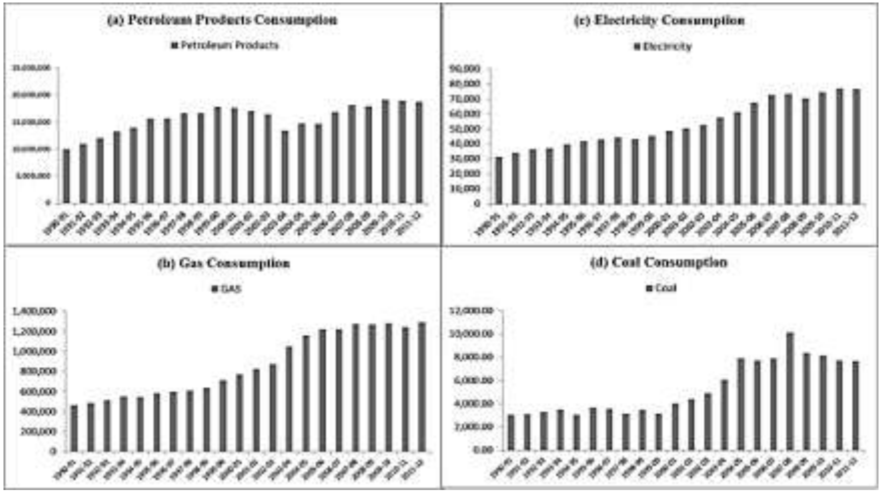
Fig. 4. Energy Consumption in Pakistan (2011-12)



Source: Pakistan Energy Year Book, 2011-12.

There has been a consistent energy consumption mix pattern in Pakistan since FY91. Per capita energy consumption of the country is estimated at 14 million btn. The energy consumption has grown at an annual average rate of 4.5 percent from 1990-91 to 2011-12. The major change in energy mix has taken place in the share of oil and gas consumption. The share of oil in energy consumption mix has dropped from 48 percent in FY97 to 32 percent in FY11. Figure 4 demonstrates the energy mix in 2011-12, where oil accounts for 29 percent of the total energy used.

Fig. 5. Sources of Energy Consumption in Pakistan

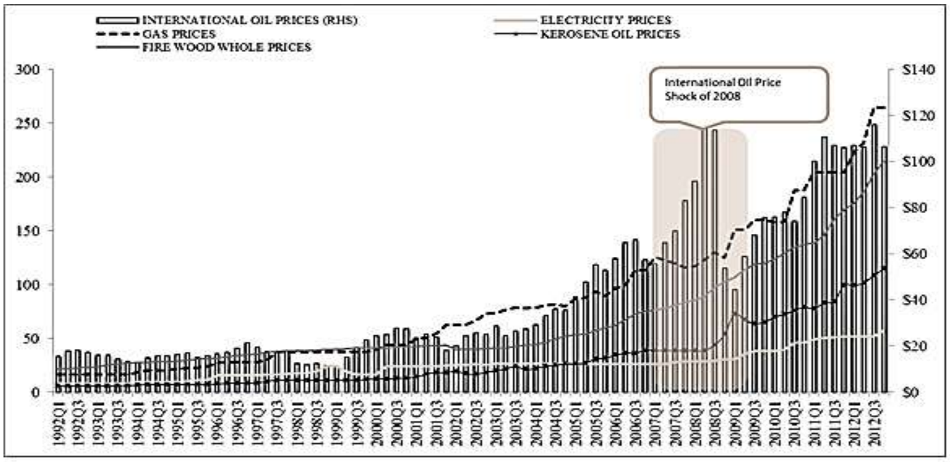


Source: Pakistan Energy Year Book, 2011-12.

Figure 5 (a to d) shows the trend in the use of different sources of energy in the last ten years. Oil consumption although has declined in the last few years but still accounts for 29 percent of the total energy consumed. Consumption of other energy sources shows rising trend with a moderate decline in last fiscal year. When we talk about energy inflation, the first variable, which comes to our mind is international oil price. What affect does oil price have on energy inflation? An increase in oil price is expected to have a reduction in standard of living by 20 percent for the oil importing countries and vice versa for the oil exporting countries [Thoresen (1982)]. If the direct impact does not reflect itself in wage reduction, it will be evident through high inflation. Although in some countries, the inflationary effect of oil price is limited despite the fact that fluctuations in crude oil price is a key element in inflation variation [Alvarez, *et al*. (2011)]. In Pakistan, we experience an indirect effect of Oil price. Figure 6 shows the overall trend of energy inflation in Pakistan and oil prices for the period of 1991–2012.

The fact that inflationary effect of oil price is weak can be witnessed from Figure 6. During FY08, a spike in oil prices was witnessed due to the global financial crises but on the other hand energy inflation in Pakistan has been consistent and showed a smooth behaviour. Nevertheless, we have been experiencing a rise in fuel and electricity charges over the years. This graph also shows the prices of crude oil, gas, firewood, electricity and kerosene-oil for the period 1991-2012. We can see that prices of different commodities have been growing at different exponential rates with different volatilities over time.

Fig. 6. Energy Prices in Pakistan at Disaggregate Level



International Oil Price Shock of 2008

Source: Pakistan Bureau of Statistics (PBS, Price Survey datasets).

The crude oil prices have increased significantly over time, showing high volatility. There have been cyclical rises and falls, with prices peaking during the International Oil Shock during mid-2008. After facing a huge downfall right after the price shock, the prices soon rose to high levels in 2012. The rise in gas prices is relatively less sharp than crude oil, showing little volatility in the earlier periods, and increasing volatility in the later periods. It is also notable that the crude oil prices have been rising and falling about the steady trend of gas prices, such that the average prices of both commodities appear to be fairly similar. Only in the 2008 Oil Shock, the crude oil prices drastically differed from the gas prices. The firewood prices too have been rising steadily with no volatility. The prices of kerosene oil rose very slowly in the earlier periods but began to show higher growth rates after 2008. The electricity prices were fairly stable and experienced a slow growth in comparison to the prices of other commodities. It is evident however, that over time there has been a rise in all types of commodity prices, contributing to overall energy price inflation. However, these sudden increments in prices lead us to investigate the determinants of energy inflation in the case of Pakistan.

3. SELECTED LITERATURE REVIEW

A low and stable level of inflation is one the major goals of any economy. The question then arises that how to achieve a low level of inflation or how to maintain inflation at the current level. To understand this, one needs to look at the causes of inflation. Inflation can be caused in two broad situations. One is where “too much money is chasing too few goods” i.e., demand pull inflation. The other is when increase in prices of raw materials drive up costs of production, which feed into the prices of finished goods. This is referred to as cost push inflation. Inflation has a twofold effect on the economy. It can be bad as well as good. There is a threshold level beyond, which inflation can be harmful to the economy [Bruno and Easterly (1998); Khan and Senhadji (2001); David, *et al*. (2005)]. In the case of Pakistan that threshold happens to be 9 percent [Mubarik (2005)]. However, Hussain (2005) suggests a 3 percent - 6 percent inflation rate to have positive effects on Pakistan’s economy. It provides incentives to production, investment and growth in wages. Friedman (1970) presented the theoretical foundations on the quantity theory of money, which is the part of classical economic theory. He argued that “*inflation is always and everywhere a monetary phenomenon*”. Friedman and Schwartz (1970) tested it empirically. The classical are of the views that increase in the money supply results in proportionate increase in prices, assuming economics agents are rational and output and real money balances are constant.

In the context of Pakistan, the history for analysing the determinants of inflation started 30 years ago when [Khan (1982)] concluded that demand for money improves the variation in the rate of inflation. Till 1989, inflation has been seen as a monetary phenomenon. Saleem (2008) also suggested the same. Her argument was inflation, interest rate and money supply move in the same direction.

A look at recent inflation trends in Pakistan helps give a snapshot of inflation as well as factors affecting inflation as a whole. [Khan, *et al*. (2007)] endorse a dynamic approach to determining causes of recent inflation in Pakistan in 2005-06. High growth rates were also accompanied with sharp rises in inflation. Keeping in context the volatile economies of developing countries they apply a structuralist approach, which includes both demand and supply side factors. They find that adaptive expectations have been one of the key determinants of inflation in Pakistan over the decades as well as in the period of 2005-06. This is through the channel of food prices as more than half of the budget of the poor comprises of food expenditure. Overall for the year 2005-06, the adaptive expectations contributed 3.66 percentage points to the inflation rate of 8 percent, explaining 45.73 percent of headline inflation rate. Non-government sector borrowing was the second largest contributor (which explained 35 percent of headline inflation or contributed 2.8 percentage points to the inflation rate of 8 percent).

Knowing inflation trends in general is not enough [Khan and Schimmelpfennig (2006)] rightly point out that determining what causes inflation will determine which policy makers are to tackle it. If inflation is a monetary phenomenon then it is appropriate for the Central Bank to control it. However if inflation is affected by supply side factors, and here they look at support prices of wheat, then it becomes more appropriate for the Ministry of Agriculture to devise a course of action to deal with inflation. Focusing on headline inflation and using monthly data, they find that wheat support prices affect inflation only in the short run, whereas monetary variables of broad money and private sector credit affect inflation in the long run and by a lag of 12 months.

Refining the argument further, determining which factors affect which type of inflation will also determine which policy makers are most appropriate to deal with the situation. Not much work has been done to identify the determinants of energy inflation in Pakistan. From the international perspective, a recent study in Finland [Irz, *et al.* (2011)] about determinants of food inflation with its linkages with energy inflation was conducted. A long run relation was evident between food inflation and energy prices as well as some other agriculture products. Similarly, energy inflation is itself a determinant of various other factors e.g. house prices etc. The correlation was found in a study conducted for Euro Area. In U.S, it was also evident that energy prices are a key determinant of inflation [Dhakal, *et al. (*1994)].

4. DATA AND EMPIRICAL METHODOLOGY

We have used data from 1973–2012 on an annual frequency basis. It is taken from multiple sources including State Bank of Pakistan, World Development Indicators, Pakistan Bureau of Statistics. Table 1 provides list of sources along with descriptive statistics of selected variables.

Table 1

List of Variables with Descriptive Statistics

Variables	Energy Inflation	Growth in MS	Exchange Rate	Oil Prices	Energy Import-Gap Ratio	Tax Revenue of Manufacture Sector
Data Sources	PBS	SBP	SBP	SBP	WDI	PES
Mean	9.25	15.68	36.01	32.35	9.72	0.82
Median	8.06	14.85	26.21	23.66	9.65	0.87
Maximum	27.40	26.19	94.42	108.88	12.17	1.04
Minimum	3.28	6.15	9.90	3.27	8.06	0.54
Std. Dev.	5.20	5.15	25.85	25.58	0.98	0.15
Skewness	1.97	0.37	0.67	1.58	0.52	–0.60
Kurtosis	7.46	2.58	2.19	4.58	2.81	2.09
Jarque-Bera	57.45	1.18	4.08	20.77	1.87	3.82
Probability	–	0.55	0.13	0.00	0.39	0.15
Sum	360.78	611.44	1440.48	1293.92	388.84	32.75
Sum Sq. Dev.	1028.19	1006.65	26054.73	25519.71	37.12	0.85
Observations	39.00	39.00	40.00	40.00	40.00	40.00

Note: *PBS = Pakistan Bureaus of Statistics.
*SBP = State Bank of Pakistan.
*WDI = World Development Indicators.
*PES = Pakistan Economic Survey.

Given the dynamics of our country and past literature, we have estimated the following equation:

$$P_t^{Energy} = \boldsymbol{f}\begin{pmatrix} P_t^{Oil}, M_{2,t}^{S}, Exch.Rate_t, EnergyImportGapRatio_t, \\ Tax.\frac{Revenue}{ValueaddedManufc}_t, Dum_{2008}, P_{t-1}^{Energy} \end{pmatrix} + \varepsilon_t$$

In this functional form, P_t^{Energy} is energy price inflation. Other variables, Oil Prices, Money Supply, Nominal Exchange Rate, Energy Import-Gap Ratio (EIMPR), Govt. Tax Revenue as a ratio of Value Added to Manufacturing Sector and Adaptive Expectation are used to determine the energy inflation. $\varepsilon_t$represents residual term. All the variables except Energy Imports-Gap ratio and Tax Revenue as ratio of Manufacturing Sector are taken in logarithmic form. To estimate the model, we have used Ordinary Least Square (OLS), Generalised Least Square (GLS) and Generalised Method of Movement (GMM) methods. EIMPR is the ratio of energy imports and energy gap that is prevailing in our country. The rationale behind this key variable is that it will reflect the significance of energy shortages on prices. Given the ground realities of our country we expect it to have a positive sign. Tax revenue as the ratio of the manufacturing sector value added has also been included as one of the independent variables. The main rationale behind this variable is that most of the industries get affected due to the rising electricity prices. Due to energy shortages, government tends to raise taxes and thus it ought to affect the energy prices. Any surge in International Oil prices or any depreciation in the domestic Exchange Rate affect the Import Bill significantly, which ultimately put pressure on energy inflation. The temporal relationships of these variables with energy inflation are shown in Scatter plots available in Appendix. Constantly increasing prices can create expectations for future inflation. The role of expectations is critical in analysing future prices. With the increase in prices, individual expects higher salaries, speculation in asset prices increases, credit diverts to real estate and stock markets etc. and rent seekers become active in expecting a higher price in future. A similar pattern of expectations goes for energy inflation therefore to incorporate all of these elements we have used a variable of lag of energy inflation. We expect it to show a positive sign as well.

5. RESULTS AND DISCUSSIONS

This section discusses the results based on our estimation. The first task was to diagnose the stationary properties of individual variable. For this purpose we have tested the variables for unit root using Augmented Dicky-Fuller and Philips-Perron tests. As shown in Table 2, all the variables appear to have an integration of order 1.

After diagnosing the stationarity properties we have estimated the model using three estimation approaches, OLS, GLS and GMM. Our prime task is to analyse the long run relationship. For this purpose we have carried out the co-integration tests. Both Engle-Granger and Johansen-Juselius show the existence of co-integration vector. Considering the co-integration results, we estimated our model at level. The estimation results in Table 3 are promising and show theoretically correct signs of the coefficients. Broad money, Oil prices, Exchange rate, Tax Revenue as ratio of Value Added of Manufacturing Sector and dummy for 2008, are statistically significant. Since the variables are in log form, the estimated coefficients can be termed as elasticities. For example, a 10 percent change in Tax Revenue as ratio of Value Added to Manufacturing Sector can in turn affect the energy inflation by 2.6 percent. Oil prices have an indirect effect on the energy inflation in our country. It is significant with a lag of one year. The coefficient of 0.082 does not show a large impact but the t-stats of 4.52 make it quite a significant variable. We have discussed immense literature that talks about inflation being a monetary phenomenon and therefore Broad Money has always been a significant variable in determining the inflation. In our results, it is highly significant with t-stats of 9.8. The coefficient of 0.34 can be interpreted as when there is a 10 percent increase in money supply, it will affect energy prices by 3.4 percent. Energy Import-Gap ratio shows a positive sign but it is insignificant. Primarily because it is a ratio and the quantum of energy imports is low. Exchange Rate is another highly significant variable with t-stats of 5.74 and with coefficient of 0.38. In Pakistan, exchange rate plays a vital role in affecting inflation. It has the pass through effect through currency depreciation, which is quite evident from our results. After adaptive expectations, exchange rate is the most critical variable that affects energy prices given its elasticity.

Table 2

Stationarity Diagnostics: Tests of Unit Roots

	Augmented Dicky-Fuller Test			Phillips-Perron Test		
Variables	Level	Difference	Order of Integration	Level	Difference	Order of Integration
Energy Inflation	0.974	0.002	I(1)	0.463	0.002	I(1)
Money Supply	0.560	0.002	I(1)	0.632	0.002	I(1)
Exchange Rate	0.991	0.000	I(1)	0.986	0.000	I(1)
Oil Prices	0.984	0.000	I(1)	0.997	0.000	I(1)
Energy Import-Gap ratio	0.761	0.001	I(1)	0.124	0.000	I(1)
Tax Revenue as Ratio of Manf Sector	0.846	0.032	I(1)	0.819	0.000	I(1)

Note: Authors' Calculations.

Table 3

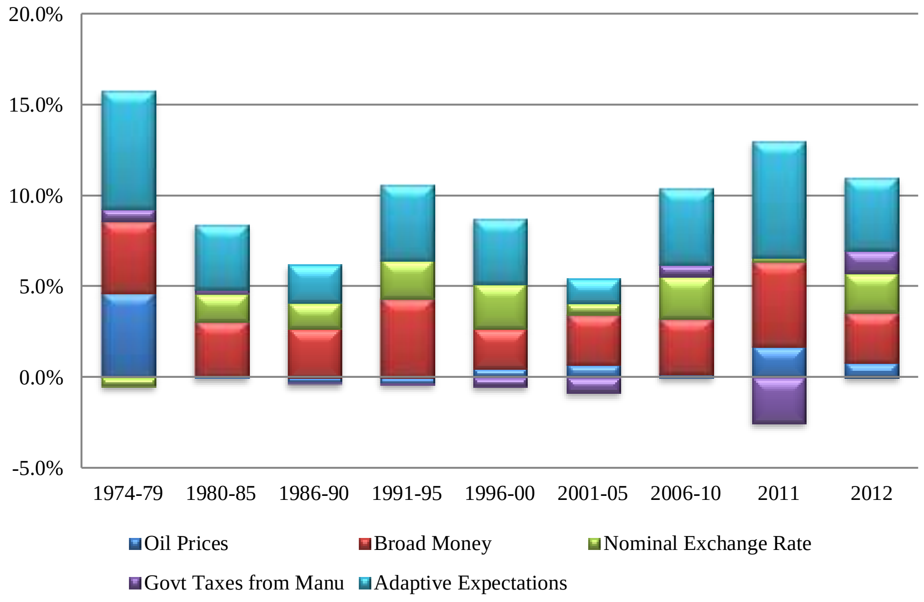
Estimation Results (Dependent Variable CPI-Energy Inflation)

Sample (Adjusted): 1973-2012	OLS		GLS		GMM	
Variables	Coefficients	t-Stats	Coefficients	t-Stats	Coefficients	t-Stats
Constant	–2.333	–7.75	–0.961	–3.236	–0.961	–2.885
Lagged Oil Price	0.082	4.568	0.051	3.005	0.051	2.680
Broad Money	0.341	9.817	0.128	3.348	0.128	2.985
Govt. Taxes as a Ratio of Manufacturing Sector	0.260	2.580	0.149	2.117	0.149	1.887
Exchange Rate	0.387	5.741	0.274	4.755	0.274	4.239
Energy Import-Gap Ratio	0.005	0.687	0.011	1.790	0.011	1.595
Dummy Variable for 2008	–0.057	–2.284	–0.015	–2.316	–0.015	–2.117
Adaptive Expectations	0.668	4.880	0.497	5.473	0.497	4.879
R-squared	0.999		0.999		0.999	
Adjusted R-squared	0.999		0.999		0.998	
Durbin-Watson Stat	1.425		1.592		1.618	
J-Statistic*	–		–		0.037	
Cointegration (Engle-Granger)	Yes		Yes		Yes	
Cointegration (Johansen and Juselius)	Yes		Yes		Yes	

*Instruments list:= lag terms and lag difference terms.

The effect of inertia cannot be ignored when we analyse inflation, especially in Pakistan. Based upon the estimation results, we have calculated the contribution of the explanatory variables in explaining energy inflation. In Pakistan, Adaptive Expectations have always been a major contributory factor in explaining inflation, food as well as energy. People in Pakistan, expect prices to grow rather than decline. As expected, the significance of Adaptive expectations is quite evident. Over the last 30 years, it has contributed almost 42 percent on an average to the total energy inflation. The second contributing factor is the broad money with an average contribution of 37 percent over the same period. During the early 70s, energy inflation was 15.3 percent, highest ever in the past 30 years. It was mainly because of the 70s oil price shock, which created an expectation of high inflation. This can be seen since adaptive expectations are contributing almost 42 percent with a value of 6.5 percent in the overall inflation of 15.3 percent.

Fig. 7. Temporal Contribution to Energy Inflation



Note: Authors' Calculations.

Early 80s and 90s are the era of low inflation. Private sector borrowing, broad money and adaptive expectations were the main factors contributing to this energy price growth. Contribution during the 80s and 90s remained consistent to 40 percent as far as inertia is concerned. As for exchange rate, its contribution surged from 18 percent in early 80s to 29 percent in the late 90s. Such an increase was probably due to the frequent change in governments and inconsistency of policies, nuclear explosion and other political uncertainities. During this time period, energy inflation was around 8.2 percent. In early 2000, energy inflation declined to 4.5 percent and broad money was the major contributor to it, explaining almost 60 percent of energy inflation. During 2006, inflation shot up again to 10.4 percent, adaptive expectations alone explained almost 40 percent of it. It was considered to be the highest compared to the average inflation of 4.5 percent during the millennium decade. The major hike in inflation during this time was probably due to the surge in house rents. In 2008-09 energy inflation took a sudden bump to 18 percent due to the oil price shock. However the impact was not significant enough to last for a longer period. This may be probably because our economy is not directly affected by international oil prices. By 2011-12, energy inflation came back to 11 percent with adaptive expectation contributing 6.4 percent (60 percent of energy inflation). It was because of the oil price shock that people were expecting that the effects of the shock will last for coming years or so. But in 2012 this expectation dropped by 4 percent explaining 36 percent of energy inflation. Other factors such as Nominal Exchange rate and broad money were other major contributors with 2.2 percent (explaining 20 percent of energy inflation) and 2.7 percent (25 percent of energy inflation) respectively.

The second most important factor was broad money. Broad money over the period of last three decade has contributed around 3 percent (38 percent of energy inflation) on an average to the energy inflation according to our finding. In 80s and 90s broad money contributed around 3.1 percent (37 percent if energy inflation) on an average. It was the second major contributor after adaptive expectations. During the first half decade of 2001-05 its contribution shot up to 2.8 percent (60 percent of energy inflation) when energy inflation was 4.6 percent and growing. From 2006-2012, energy inflation has been growing and reached 11 percent and contribution of broad money has declined to 2.7 percent (25 percent of energy inflation). It was mainly because other factors such has house prices, oil prices came into play that resulted in high energy inflation. Nominal Exchange rate contributed 1.6 percent (16.5 percent of energy inflation) over the last 3 decades. Its highest contribution was witnessed in late 90s when it rose to 2.5 percent (30 percent of energy inflation) after adaptive expectations. This may have occured due to the uncertain changes in governments and frequent changes in policies, nuclear explosion and other political situation that was prevailing during that era.

The above mentioned factors were not the sole contributors to energy inflation. By 2008-09 the issue of circular debt came into play, which raised the electricity prices to a great extent. The period of 2008-12 was a period of power sector inefficiencies, which have cost the country significantly directly in the form of budget costs in the last five years.

6. CONCLUSION

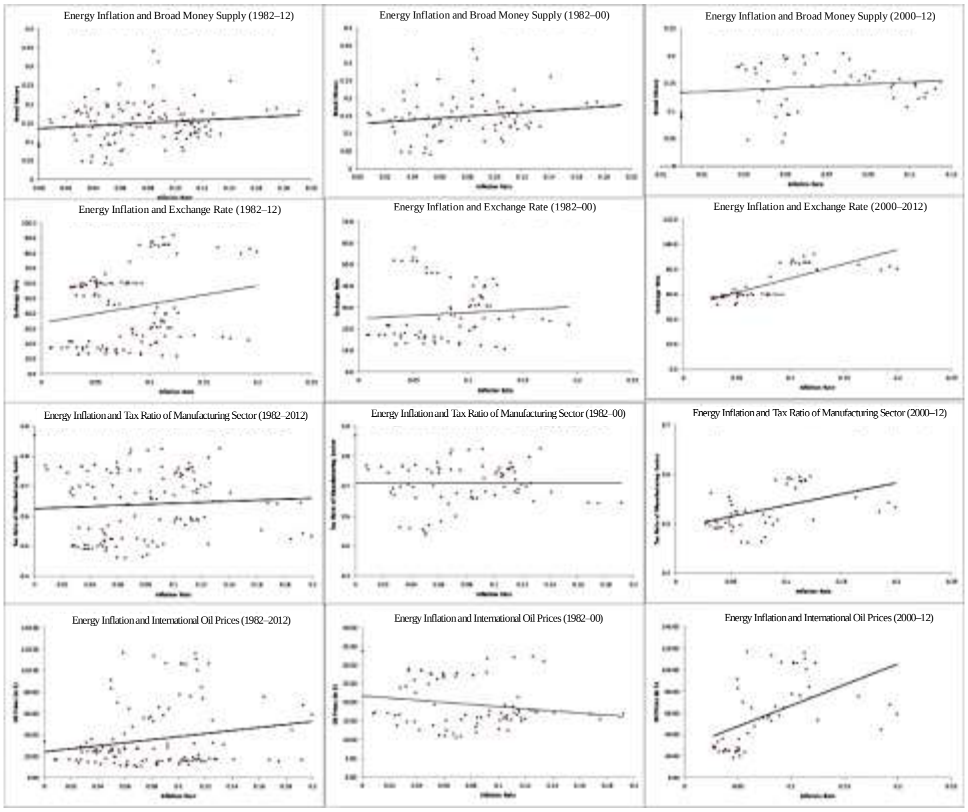
This paper talks about the determinants of energy inflation in Pakistan. It evaluates the role of various factors in explaining energy inflation, which include broad money, exchange rate, international oil prices and adaptive expectations. These are the most prominent factors in explaining energy inflation. Others includes tax revenue as a ratio of the manufacturing sector value added and energy import-gap ratio. Our results conclude that the behaviour of monetary (State Bank of Pakistan) and fiscal (Ministry of Finance) authorities seems to be pro-cyclical in response to energy supply side bottlenecks. This pro-cyclical behaviour along with any international oil price shock and exchange rate depreciation put upward pressure on energy inflation. The heavy reliance of government on indirect taxation of energy items strongly hits the poor segment of the society.

Supreme-court of Pakistan has also observed this behaviour of the government, which reduces the overall welfare. As expected approximately 60 percent of the energy inflation is explained by adaptive expectations. Given such issues including that of circular debt, it is only logical to expect the prices to go up.

Also, there are certain shortcomings in the infrastructure that need to be taken care of. There is a complete disconnect among all the stake holders involved at the policy level. The Ministry of Water and Power being the critical stakeholder does not have a roadmap for itself. It is more reactive than proactive to the power sector reforms, which is perceptibly due to lack of political will to improve the system. There is lack of professional attitude at the regulatory level. The regulator fails to address the problems of the power sector and is working in isolation. Furthermore there is no governance at the entities level. Despite the fact that they are being micro-managed by policy makers and regulators, they themselves have no attitude of moving forward and are satisfied in maintaining a status quo. Until and unless there is a serious accountability for the above mentioned issues, inflation expectations will always play a significant role. There must be proper structural reforms that require effort from all. There should be a roadmap outlined and roles defined for all the entities so that there is no ambiguity in achieving the ultimate objective.

APPENDIX

Relationships of Energy Inflation with Key Determinants



Source: Author's calculations.

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Structure and Regulation of the Electricity Networks in Pakistan

AMIR JAHAN KHAN

1. INTRODUCTION

This paper studies the electricity industry network in Pakistan, particularly in the context of structural and regulatory reforms started in the 1990s. Published reports by the regulator show that the reforms process is not going anywhere even after two decades and the industry is performing poorly [NEPRA[1] (2010)]. The market is not clearing as load demand is higher than total system supply, particularly during the summer season.[2] There is no electricity, due to load shedding, for long hours in major parts of country served by the distribution networks during the hot and long summer period. An effort is made here to document the basic facts of industry in an orderly manner and to draw major lessons from the failure of the reforms process and poor functioning of the electricity market. The focus will be on the electricity supply chain networks and issues in the regulation of the electricity industry. The restructuring of the natural monopoly components of industry will be discussed in detail.

The electricity industry in Pakistan is quite under researched [Pakistan (2013)], the main source of industry knowledge is based on government publications. According to available research [NEPRA (2011), Malik (2007)], the rich information provided in policy documents and regulatory reports has not been analysed in detail. Therefore, documenting basic industry facts and related issues in this paper is a contribution to the existing literature and will be useful for future policy reforms.

The electricity industry in Pakistan has been functioning as a state monopoly for a long time. The state monopoly includes two vertically integrated electric utilities in the country; the Water and Power Development Authority (WAPDA) with a customer base of 20.3 million and the Karachi Electric Supply Corporation (KESC) serving 2.1 million

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[1] List of abbreviations and acronyms is provided in the Appendix Table 3A.

[2] There are no official figures available on load shedding hours. The summer season runs from April to October in most parts of the country.

customers.[3] In the last two decades, two major changes have occurred in the electricity industry of Pakistan. First, the two state owned utilities went through structural reforms and unbundling in 2002. Second, regulation of the electricity industry started in 1998 and an authority was put in place to regulate electricity prices, allow entry into the industry and set standards for the electricity supply. The reforms were motivated by the intuition that state owned monopolies were less efficient than private enterprises and there was a need to either privatise or restructure state entities. The unbundling process included separation of the potentially competitive segment (i.e. power generation) from the network based natural monopoly of the electricity industry (i.e. transmission, and distribution of power), and division of the natural monopoly part of industry into transmission and distribution networks. The network components of industry are subject to regulation, and distribution utilities also perform as retail electricity suppliers.

The restructuring plan for the state-owned power sector was approved by the government of Pakistan in 1992, however the first substantial change in the industry was the commissioning of independent power producers (IPPs) in 1994. The IPPs started supplying electricity to the system in the late 1990s, and this was followed by privatisation of a public power plant in 1996. These early initiatives created political debate and legal disputes between government and IPPs due to the lack of transparency in contractual arrangements and no obvious change in the competitive structure of the generation segment.

The regulation of the industry started in 1998 when the National Electric Power Regulatory Authority (NEPRA) was put in place to regulate price, quality, and entry in the industry. NEPRA issued licences to 9 distribution companies (DISCOs) in 2002, including 8 companies in the WAPDA system. A licence was also issued to the National Transmission and Dispatch Company (NTDC)[4] for the transmission business in the WAPDA system. The 8 distribution companies and the NTDC are working as government owned monopolies in the distribution and transmission network of WAPDA served areas, structure of the industry is presented in Figure 1.

The electricity industry in Pakistan is plagued by financial and operational issues which are affecting the economic efficiency and growth of the industry [Pakistan (2013)]. The distribution companies and the transmission company rely on large and recurrent public subsidy[5], 1,290 billion Rupees[6] have been transferred as subsidies to DISCOs from 2007 to 2012 [Pakistan (2013)]. The regulator decides the electricity price for each utility (i.e. a DISCO) after taking into account the consumer mix, transmission losses and operational cost of the DISCOs in accordance with the tariff standards and procedure rules [NEPR (2011)]. The government determines the final electricity price, which is lower than the price determined by regulators for most utilities. Therefore central government does not pass all of the electricity supply costs to consumers by charging less

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[3] In the year 2011, 90 percent power generation (91,663 GW h) was done by WAPDA system while 10 percent (10,036GW h) in KESC system [NEPRA (2011)].

[4] This paper covers transmission and distribution networks of WAPDA system, KESC is a vertically integrated company operational in the greater Karachi region (with no effective separate cost centres) and issues related to KESC might need a different framework for discussion. However, possible experiment can be done to compare performance of KESC with government owned distribution companies.

[5] The issues related to network part of the industry are discussed here in detail, as the focus is on the distribution and transmission segments of the industry in WAPDA/NTDC system.

[6] about 18 billion US dollars.

than the tariffs determined by the regulator to promote economic development[7]. The government introduced price differential subsidies in order to pursue the policy of uniform electricity prices in the country. In this way the performance incentives for firms in power networks can be partially determined by the subsidy allocation mechanism and regulatory tariff structure.

The main objective of this paper is to present an account of the network of the electricity industry and analyse the transition from state monopoly to a regulated state monopoly. An effort is made to highlight the factors which are potentially slowing growth of the industry and resulting in poor allocation of resources. The documentation of technical, economic, and institutional factors related to transmission and distribution segments is an integral part of understanding market functioning and incentive structure in the electricity industry [Joskow and Schmalensee (1983)]. The economic efficiency in the electricity industry also depends on the contractual nature and consequent incentives in network economy, and the tariff incentive structure applicable to utilities (DISCOs) and system operator (NTDC). The current tariff structure and evolution to its current state is discussed here, with respect to corresponding implications for incentives for firms in the business of electricity networks.

The electricity networks are an important component of the electricity industry, efficient functioning of transmission and distribution companies and timely capital investment in distribution networks is required for the growth of other segments of the industry. For instance, the power generation segment performance will depend on the reliability and structure of the transmission and distribution networks. The missing interconnection of transmission networks or inadequate capacity in the networks affects the operation of existing power plants and has delayed the commissioning of new power generation plants [NEPRA (2010)].

The analysis of incentive mechanism for the electricity networks assumes the separation of network segments into clearly defined distribution and transmission networks [Joskow (2008)]. Although the unbundling of electric power in WAPDA system occurred in 2002 with the establishment of distribution companies DISCOs and transmission company NTDC, however formal contractual relationships between DISCOs and NTDC are not in place and they were under “de facto” common management until recently [NEPRA (2011)]. The role of key public institutions[8] during transition needs to be discussed in order to understand the incentive structure and resulting behaviour of DISCOs and NTDC (see Figure 1 for structure of the Industry). The electricity networks in the main system are government owned regulated monopolies where the authority (i.e. NEPRA) oversees the regulation and determines tariffs for the electricity generation, transmission, and distribution. The knowledge about regulatory effectiveness and incentives creation by tariff structure or regulator lag is quite limited for Pakistan [Malik (2007)]. The documentation of all the institutional details with potential economic consequences for the electricity industry will be useful for the future reforms of the electricity industry in Pakistan.

[7] Government documents show that electricity sale price for all utilities is equal to the lowest determined price for any utility (among all utilities) for a given year [Pakistan (2013)].

[8] One example, Pakistan Electric Power Company (PEPCO), PEPCO’s main responsibilities included to oversee WAPDA’s unbundling, and to restructure and to corporatise distribution and generation public firms [NEPRA (2010)].

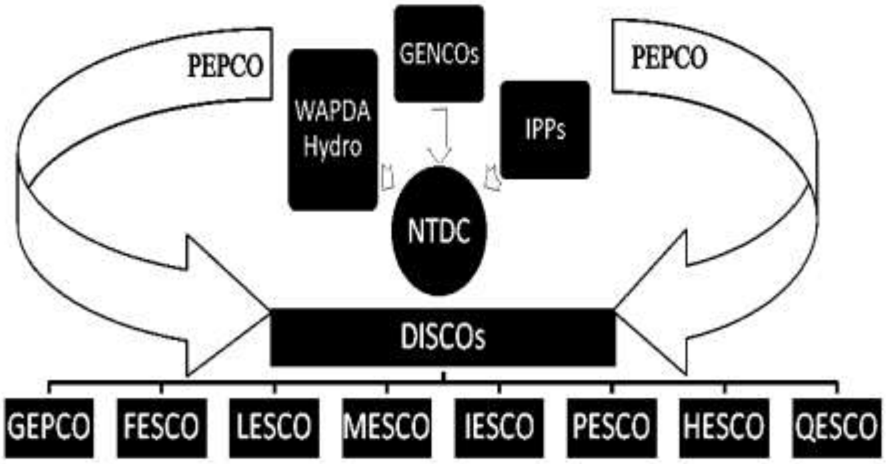
The following discussion in this paper is divided into four sections, the next section discusses issues related to the structure and management of electricity distribution networks, the natural monopoly role of electricity networks and its implications for economic efficiency are also analysed in this part. The Section 3 documents incentive regulation particularly relevant to electricity networks and compares it with current practice in Pakistan. The Section 4 expands discussion to the public sector role in the power industry particularly in electricity networks and incentive mechanisms for market based reforms. Some policy recommendations based on analysis and concluding remarks are documented in the last section. Additional tables and list of abbreviations are given in the appendices.

2. STRUCTURE OF ELECTRICITY NETWORKS

In this section we will discuss the implications of "electricity network" structure for economic efficiency of the electricity systems in the context of theoretical considerations and general practice in the electricity industry. The distribution networks operator also plays the role of retail business in Pakistan, the issues related to the quality of electricity supply are also documented in this section. The structure of electricity networks is considered as a regulated natural monopoly like gas or water supply networks, where duplication cost can be avoided by serving a geographical market with a single transmission or distribution company, instead of more than one firm doing the same job [Joskow and Schmalensee (1983)]. Transmission networks carry high voltage power and connect a generator to other generators and the load centres in the system, while the distribution networks supply electricity on low voltage to consumers and are connected to high voltage transmission networks through boundary grid stations.

In Pakistan, government owned distribution companies DISCOs and system operator NTDC are functioning as distribution and transmission monopolies respectively, while government owned generation companies (GENCOs) are competing with private power producers to supply electricity in the system (Figure 1 below). This structure of industry shown in Figure 1 requires explanation of the past institutional context.

Fig. 1. The Unbundled Structure of the Vertically Integrated State Monopoly



Historically, utilities in Pakistan were vertically integrated in their generation, transmission and distribution[9] businesses. Incentives for vertical integration of distribution with generation-transmission arise due to some basic complementarities. The distribution networks are load centres and they provide reliable load forecast to generation and transmission firms for the efficient functioning of the electricity system. The accurate load forecasts are also necessary for short term planning and long term investments in a generation-transmission system [Joskow and Schmalensee (1983)].

The distribution and transmission networks were part of vertically integrated state-monopoly Water and Power Development Authority (WAPDA). As a result of WAPDA's restructuring in 2002, the regulator issued licences to distribution companies DISCOs and transmission company NTDC to work as unbundled natural monopolies. Further, Pakistan Electric Power Company (PEPCO) was formed to manage the unbundling process and to make sure that electricity networks make a successful transition. However, centralisation incentive persisted with central government in guise of NTDC/PEPCO as the current system is without any effective contractual arrangements between distribution firms and other parts of the industry, until recently distribution companies (DISCOs) were under the management of NTDC and PEPCO (NEPRA 2010). However, DISCOs are functioning as unbundled units and are also performing as retail businesses in monopoly controlled areas.

There is theoretical justification along with international practice for the natural monopoly status of distribution networks and the efforts to "unbundle" electric utility in Pakistan. The electricity unbundling initiative started in the US in 1980s and a number of countries, including the UK have "unbundled" electricity supply. According to the basic model, the network part of industry became a natural monopoly while power generation firms became part of the competitive market. The intuition for cost saving by one distributor sounds plausible, the unit cost is likely to go down as the number of customers or load increases on a system in a limited geographical location. But there could be limits to economies of scale because grid stations, distribution lines, and interconnectors become overstressed as load increases in a given location. Similarly, diseconomies in equipment maintenance and overheads along with other x-inefficiencies can emerge as distribution network area expands unboundedly.[10]

2.1. Distribution Networks

The distribution networks supply electricity from the transmission system to lines below 220 kilo volt, the network infrastructure includes distribution lines and 132 kilo volt and lower capacity grid stations. As shown in Table 1 below, the electricity industry suffers from high system losses (including theft) and high revenue losses. The non-theft system losses can be attributed to the current state of technology and to the size of the distribution network. The resistance loss increases as the size of a distribution network

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[9] In Pakistan distribution companies also perform the role of electricity supplier or retailing. In principle, a government or a private firm can run retail business by procuring electricity and paying to intermediary firms in power supply chain. The words distribution companies, DISCOs, and utilities are used interchangeably in this paper for electricity suppliers.

[10] As demand for new connections increases or power is supplied to household not already connected to the system.

increases and the system loss can also increase as demand increases. The regulator reports that *"distribution system in urban centres is over stressed and needs to be upgraded, augmented, and expanded"* [NEPRA (2010)]. Therefore technical line losses can arise both in large networks (due to resistance) and in small congested distribution networks due to resistance and high demand.

On the other hand, system losses caused by theft and revenue losses can arise from managerial inefficiency and corrupt governance in the network segment. Even technical losses resulting from poor engineering design and system operation can be a result of bad governance and lack of planning. The influence of managerial effort and pure technical losses cannot be disentangled, as disaggregate data for the required analysis is not available, however conjecture can be made where decentralised system loss data is available for a distribution network. Similarly, the potential of theft can be assessed from the number of customers and total number of households not connected to national grid in a given distribution network.

The average area of a government owned distribution system is 98 thousand square kilometres with average density of 67 customers per square kilometre, as shown in Table 1. There is considerable variation in peak load demand and composition of urban towns among networks. There is significant negative correlation (–0.65) between a network density and the system losses (including theft) or recovery (billing) losses.[11] Technical, structural and managerial diseconomies exist in large distribution companies. For instance, Hyderabad Supply Company HESCO is losing more than one-third electricity from the system and on the top of it recovering money for less than 60 per cent of final electricity sold.[12] The trends in Table 1 persist over time (see Table 2, and Table 3).

The genuine system losses are not disentangled from theft losses, but three companies QESCO, HESCO, PESCO are susceptible to huge theft losses due to political instability and lawlessness in the region.[13] The high losses also suggest that basic infrastructure is getting overstressed and requires maintenance and replacements, while investment in substations, distribution lines, and human capital will depend on the financial health of the firm which in turn depends on system losses and billing losses.

Table 1

Electricity Prices, Density, and Losses for Distribution Companies, 2010

Distribution Company	Total Consumers	Peak demand (MW)	Density (consumer/area)	System[1] Losses (%)	Billing Losses (%)	Power Purchase Price (rupee/kWh)
IESCO	2,059,207	1457	88.9	9.8	4.1	7.6
LESCO	3,182,292	3916	166.9	13.7	8.2	8.2
GEPCO	2,454,254	1813	142.6	11.0	4.0	8.1
FESCO	2,879,188	2298	65.0	10.9	3.0	8.2
MEPCO	4,057,491	3006	38.5	18.9	4.2	8.7
PESCO	2,947,108	3685	29.0	37.0	14.6	11.4
HESCO	1,511,878	1797	11.2	34.8	40.2	11.0
QESCO	490,805	1316	1.4	20.7	42.3	9.0
KESC	2,051,964	2562	315.7	34.9		

Source: NEPRA, State of Industry Report 2010-11, 1 distribution network losses.

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[11] Except privatised KESC distributing electricity in Karachi, high line losses in KESC are probably caused by theft and lawlessness in a city of 12.9 million.

[12] The regulation authority appears to be concerned about the inefficiencies in large distribution networks; HESCO was divided into two distribution companies in 2011 (HESCO and SEPCO).

[13] This is validated by published regulator reports and unstructured interviews with officials.

Table 2

Distribution Network, Total System Losses[1], (%)

Distribution Company	2006	2007	2008	2009	2010	2011	2012
Peshawar	31.8	32.2	32.4	35.2	34.7	35.2	34.9
Islamabad	13.3	12.2	10.3	10.8	9.8	9.7	9.5
Lahore	10.2	11.7	11.2	10.7	11.0	12.0	11.2
Gujranwala	13.1	12.8	12.5	13.3	13.8	13.3	13.5
Faisalabad	11.6	11.5	11.1	10.6	10.8	11.2	10.8
Multan	20.5	18.7	18.5	18.4	18.9	18.2	19.3
Hyderabad	39.2	37.0	35.9	35.1	34.8	28.6	27.7
Sukkur						49.4	49.4
Quetta	20.7	21.4	20.8	20.1	20.7	20.4	20.8
Karachi	37.5	34.2	33.8	38.5	37.3	34.8	32.6

Source: NEPRA, State of Industry Report 2010, 2011, 1 percentage gap between units purchased and sold/billed by the firm.

Table 3

Distribution Network, Revenue Losses for Domestic Consumers[1], (%)

Distribution Company	2008	2009	2010	2011	2012
Peshawar	23.0	48.3		28.0	48.8
Islamabad	2.0	–3.0	0.4	4.0	–1.1
Lahore	1.0	3.8	3.1	0.8	-1.5
Gujranwala	2.0	3.1	4.1	2.0	3.4
Faisalabad	1.0	1.8	1.7	0.8	0.2
Multan	1.0	2.2	3.6	1.7	1.2
Hyderabad	26.0	42.1	51.1	54.1	36.7
Sukkur[2]					62.8
Quetta	10.0		28.2	31.0	26.5
Karachi	100.0	0.0	0.0	17.1	16.2

Source: NEPRA, State of Industry Report 2010, 2011. 1 percentage gap between amount billed and amount recovered, 2 Sukkur was part of Hyderabad before 2012. The negative numbers show additional recovery on account of deferred payments for previous years.

Despite area-losses correlation, the other factors in poorly performing distribution regions cannot be ignored, these include lack of good governance, law and order, and economic development.[14] High system losses of distribution companies manifest in the power purchase price for distribution companies, in 2010 price ranged from 7.6 rupees per kilowatt hour to 11.4 rupees per kilowatt hour.[15] The high revenue losses in technically inefficient distribution companies suggest that incentives for improvements in management are low. New investment is not taking place due to poor financial

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[14] Particularly poor state of law and order and weak political administrative structure in Quetta QESCO, Hyderabad HESCO, and Peshawar PESCO regions

[15] The variation in regional power purchase price is not in contradiction with uniform tariff policy as average tariffs are affected by consumer mix and other tariff adjustment by the regulator as shown in Table 9.

performance, which restricts the capability of firms to improve system losses, turning into a vicious circle.

Tables 2, 3, and 4 show the time trend for system losses, revenue losses and potential consumers without electricity respectively. In theory, housing units without formal electricity connections are not connected to the system, but in practice they might be informally connected to the system without any billing meter[16], particularly in congested areas and remote areas where monitoring of the system is poor or the employees submit to bribes. A major fraction of household consumers are not connected to the system in distribution networks operating in Peshawar (PESCO), Hyderabad (HESCO), Karachi (KESC), and Multan, coincidently the distribution system losses are also high in these firms (Table 2). This supports the hypothesis that households not connected to the system in the congested systems, such as KESC, enjoy stolen electricity from the system. However, it is difficult to attribute system losses to theft in low density networks, such as HESCO, because the system is losing at low voltage lines while supplying electricity to a dispersed population, for instance a high feeder is supplying electricity on long low voltage lines to a few scattered houses with low demand.

On the other hand, all is not well with medium density low distribution loss networks as high technical inefficiency and system losses prevail in parts of these networks as well. Again this can be a result of poor engineering design, other technical losses, and managerial inefficiency. For instance Gujranwala Electricity Company (GEPCO) is considered to be among the better performing utilities according to regulator reports, however in more than 40 percent of GEPCO sub-divisions system losses are higher than 12 percent.

Table 4

Domestic Consumers without Electricity, (%)

Distribution Company	Potential Consumers 2012	2006	2007	2008	2009	2010	2011	2012
Peshawar	2,761,232	45.2	42.7	41.5	41.2	37.4	36.6	36.0
Islamabad	1,882,619			0.0	0.0	0.0	0.0	0.0
Lahore	2,258,940	14.1	11.5	8.6	7.3	4.9	2.6	0.6
Gujranwala	2,808,748	20.6	17.1	14.6	12.5	10.0	7.7	5.7
Faisalabad	2,712,234	30.4	25.7	21.2	18.1	15.8	13.4	11.3
Multan	3,888,629	45.4	40.2	35.8	33.8	31.2	29.5	27.3
Hyderabad	718,422	71.2	70.5	70.3	70.2	70.1	70.1	67.5
Sukkur	552,110							72.8
Quetta	394,843	71.9	71.2	70.6	70.0	69.7	69.6	69.4
Karachi	1,659,766	22.2	21.3	21.6	22.5	21.5	20.6	20.8

Source: NEPRA, State of Industry Report 2010, 2011, estimates suffer substantial downward bias due to lower estimated total potential consumer data in the distribution network, particularly in later years, the last Population Census was conducted in 1998 and the available projections are much lower than actual figures based on partial housing census of 2012.

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[16] An illegal connection to system without a meter is called "kunda" (the hook on the wire) in local jargon

Overall issues with system losses, engineering design, and managerial practices will affect cost of electricity supply. The system losses result in higher average unit cost of electricity with negative welfare consequences for consumers. The shortage of bulk supply coupled with system losses result in long periods of load shedding and low system reliability. The system reliability in industry is measured by utilities reporting System Average Interruption Index (SAIFI) and System Average Interruption Duration Index (SAIDI). The long durations of power outage due to lack of power supply in the system render SAIFI and SAIDI meaningless as it becomes hard to disentangle the interruptions when there was no power supply and the interruptions when power supply was there, but utility network collapsed due to poor technology. SAIFI and SAIDI are reported in Table 5 below.

Table 5

Distribution System Performances, 2008-09

Distribution Company	Consumers	SAIFI[1]	SAIDI[2]
Islamabad	2,059,207	0.5	22.8
Lahore	3,182,292	100.2	6847.7
Gujranwala	2,454,254	17.3	19.4
Faisalabad	2,879,188	64.9	114731.9
Multan	4,057,491	0.03	2.01
Peshawar	2,947,108	193.97	15787.43
Hyderabad	1,511,878	918.53	83969.3
Quetta	490,805	155.4	12757.3
Karachi	2,051,964	0.1	1074.6

Source: NEPRA, State of Industry Report 2010.

1 SAIFI= (Frequency of Interruption/Total Connected Customers).

2 SAIDI= (Hours of Interruption/Total Connected Customers).

2.2. Transmission Network

The transmission network plays a fundamental role in coordination and achieving system economies, and enables the reliable, stable, and efficient supply of electricity for final use in homes, markets and industries. The importance of the transmission network in electricity industry depends on its critical function and not just operational cost, as the smaller cost[17] component of the transmission network in total cost of electricity can be misleading [Joskow and Schmalensee (1988)]. Generation and transmission operations of electricity are simultaneous decisions, transmission lines link power plants to load centres, and installing new generation capacity depends on interconnectors and lines facilities provided by transmission companies. The long run, low cost supply of electricity depends on investment and new technology adoption in transmission, and on a high level of coordination between generation and load centres. Lack of coordination and investment in transmission systems can make generation investments ineffective or can

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[17] The cost components of generation, distribution, and transmission in Pakistan are 90 percent, 8 percent, and 2 percent respectively. However when system losses are included effective cost of network components increase substantially.

delay the supply of electricity due to dysfunctional interconnectors,[18] this institutional context of electricity industry has favoured vertical integration of generation-transmission and distribution. The existence of economies of scale in the use of high voltage lines and transmission links make transmission networks work efficiently as a natural monopoly. While the natural monopoly structure of transmission exists in the electricity industry, however for efficiency reasons high level coordination between transmission and other components of industry is required for an efficient and stable system.

Sunk costs in investments, formal and informal contracts, and system externalities are main features of any transmission network. The investment decisions by transmission operators require high level coordination between load centres and generators, as post investment reallocation of transmission infrastructure and resources becomes costly. It is not clear that decentralisation (unbundling) in industry structure will increase or reduce the electricity supply cost in the system. This aspect is important in Pakistan where policy making authority appears to pursue more decentralisation and structural disintegration in the system with independent distribution and transmission networks. The successful unbundling of electric power will require mechanisms for the enforcement of formal contracts and regulatory set up to resolve contingencies uncovered in formal contracts.

National Transmission and Dispatch Company (NTDC) works as a licensed monopoly, sole service provider covering a large area. Although there is no optimal scale for system coordination, some past studies (Joskow and Schmalensee, 1988) mention 10,000 MW of peak demand for efficient scale of transmission network. The area coverage and peak load demand suggest problems in NTDC system, constraints in extra high voltage transmission lines resulted in increased forced outage of the power system [NEPRA (2010)]. The overall transmission losses in recent years are comparable with international standards [World Bank (2011)], see Table 6.

The inexorable electricity demand in Pakistan, particularly the air-conditioning during summer months, has pushed the peak demand to 16,000 MW in the system[19] [NEPRA (2011)]. In an electricity system, supply needs to meet demand in real time, the system becomes unstable if demand is higher than supply.[20] On the other hand, the system should be able to hold supply to match rising demand. System operators need to check the reliability of transmission systems to sustain peak demand, as policy makers are keen to increase supply to meet unfulfilled demand in the future. It appears that over the years, large gaps between demand and supply of electricity during long summer season has weakened the coordination system between transmission and distribution networks. The load centres (i.e. DISCOs) are unable to determine potential demand in the summer season, as full demand is not met in all parts of the network at any given time. There are even reported incidents stating that when some DISCOs tried to meet peak demand, the distribution network was unable to sustain the load.

[18] For instance, recently a number of new power plants failed to supply electricity because of inadequate capacity of interconnectors and transmission system (NEPRA 2011).

[19] The minister for power affairs recently mentioned in an interview that during hot summer months demand keeps on exceeding supply despite system adding electricity from more production or new plants. In summer, rolling blackouts have been observed since 2008 that imply system operator might not even know exact peak demand during summer.

[20] Constraints in transmission or distribution networks can make power system unstable; the load shedding is required to keep the system stable. Since 2008 load shedding is prevalent in country particularly in summer months.

Table 6

Energy Generation, Units Sold, and Losses in NTDC System, 2002-2010

Year	Net Generation(GWh)	Units Sold Billed (GWh)	Transmission Losses (%)	Distribution Losses (%)
2002	59545	45204	7.6	16
2003	62694	47421	7.7	16.2
2004	67697	51492	7.3	16.1
2005	71670	55342	7.4	14.9
2006	80404	62405	7.1	14.8
2007	85987	67480	3.7	17.3
2008	84584	66539	3.4	17.5
2009	82705	65286	3.5	17.1
2010	87072	68878	3.1	17.4

Source: GOP, Electricity Demand Forecast, NTDC.

3. TARIFF STRUCTURE AND INCENTIVE REGULATION

3.1. Cost of Service and Incentive Regulation: Theoretical Aspects

According to the regulator, the electricity industry in Pakistan is subject to price, entry and quality of service regulation [NEPRA (2010)], the regulator, NEPRA, determines tariffs for transmission, distribution, and generation business of electricity. This section examines the theory of incentive regulation in the context of unbundled distribution and transmission electricity networks. The basic idea is to review the issues that arise when the regulator is imperfectly informed and faces asymmetric information about costs and managerial efficiency, and is unable to document the optimal price mechanism in specific scenarios. The prevalent tariff structure in Pakistan is reviewed later to check the conformity with theoretical knowledge and also to see if the electricity industry satisfies basic assumptions for exposure to incentive regulation for unbundled electricity networks [Joskow (2008)].

The knowledge about effectiveness of electricity network regulation in Pakistan is limited, Malik (2007) documented the overview of electricity regulation in Pakistan, and highlighted issues including, the ineffectiveness of the regulator, the lack of autonomy and weak governance of NEPRA, although it is not quite clear what incentives there are for network operators in the current setup to cut cost and enhance efficiency. There are multiple factors affecting the current state of the electricity industry in Pakistan, but regulation framework and related incentives appear to be an important constraint in the growth of the electricity industry.[21]

The proper incentives for firms, operating regulated networks, are important for the efficiency of networks and the generation segment, because well performing networks will lead to better decisions and operations by generation firms. The network service cost contributes to final electricity supply cost, better incentives manifested in lower networks

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[21] The comparison of electricity industry between a state monopoly (till 2002), and regulated industry since 2002 requires deeper understanding of issues in both periods, and is not feasible due to limited information available.

cost can improve welfare for society. While documenting the regulatory discussion Kahn (1971) noted that "......*the central institutional questions have to do with the nature and adequacy of the incentives and pressures that influence private management in making the critical economic decisions*". Ideally networks should be operated at minimum cost and the regulator should specify the efficient network price. However, the economic incentives in lowering production costs are more important than enforcing the efficient pricing mechanism. This point is well documented in the literature, as the efficiency loss of high cost is of "first order" (impact all infra marginal units) while tariff or price inefficiency loss is second order (Harberger triangle). These earlier notions and the latter theoretical advances provide the foundation for incentive regulation in electricity and other networks.

In a typical situation *ex-ante,* a regulator is not perfectly informed about managerial efforts, technical processes and other factors to lower networks cost, but can get more information through ex post regulatory hearings and mandatory audits. However, the distribution and transmission companies are better informed about the cost of production and managerial practices adopted to improve efficiency. In this situation two extreme tariff regimes can be followed according to Laffont and Tirole (1993).

The first regime is a fixed price regime, where network fees will be charged to consumers by distribution companies going forward. The fixed network charge will evolve by incorporating exogenous price changes in factor inputs; this is referred to as a price cap mechanism [Joskow (2008)]. As a price mechanism is responsive to only exogenous price changes, the firm's increased effort to lower cost will result in an equal amount added to the profit of the firm. Therefore the effective price cap mechanism provides greater incentives for the network operator to increase managerial efforts to reduce cost, improve system efficiency, and lower system losses. But given that the regulator wants to make sure that the firm meets budget constraints, uncertainty arises about the level of price cap. Too high a price cap can still generate incentives to lower cost but may leave large profits for firms, so the mechanism will not be good from "rent extraction" point of view.

Second regime is standard "cost of service regulation", under this mechanism the network operator will be compensated for all of the production or service costs incurred to run a network. This tariff plan makes sure that firms earn normal profit, so the "rent extraction" issue discussed above can be fixed, but on the other hand there are no incentives for firms to reduce costs as there is no economic rent left by the regulator. Therefore managers will not get a reward for any cost savings in the "cost of service" regulatory plan, or they will overspend in capital expenses in line with Averch-Johnson effects. The fixed price (price cap) regime performs poorly on "rent extraction" while "cost of service" regimes will provide no space for being cost efficient. In an ideal situation a mixture of two regimes can perform better than the adoption of a single regime when the regulator is imperfectly informed about networks [Joskow (2008)], so in effect the price will be contingent on variation in realised cost, while a portion of cost will be fixed ex ante [Schmalensee (1989), Lyon (1996)].

As noted by Joskow (2008) the theoretical literature provides partial guidance for incentive regulation in electricity networks, and other circumstance based factors are also incorporated in the practical regulation mechanism adopted by regulatory authorities. In practice, a mix of "price cap" and "cost of service" mechanism is adopted by utilities. An initial price level P_o is set by using cost based or "return to capital employed" yardstick and adjusted for the rate of input price increase (RPI) and productivity factor z of firms in latter time periods, which gives equation,

$$P_1 = P_0(1 + \text{RPI} - Z) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

The tariffs are initially imposed for usually five years and at the end of the period P_o and Z are readjusted after post regulation audit and for the firm's realised costs. In practice, incentive regulation requires an established cost of the service based regulation system. In Pakistan the cost of service or rate base regulation started effectively in 2004, and from then on the regulator conducts "pricing reviews" to determine tariffs, this mechanism is evolving and recent regulatory reports mention methodological process of tariff determination.[22] In the next subsection the tariff or distribution margin determination process for distribution networks is analysed, this will serve two purposes. First, the regulator's information sources for distribution companies costs are highlighted, and the effectiveness of cost reporting protocols are assessed. Second, we check the potential of the regulator's current cost information for credible benchmarking of incentive regulation.

3.2. Cost of Service and Incentive Regulation: Practical Issues

The analysis of incentive regulation for electricity networks usually assumes that the electricity supply is unbundled with a clearly defined distribution and transmission network, and the industry is regulated by an independent regulator staffed with adequate strength and skills to monitor the industry and implement regulation activities (Joskow, 2008), both of these assumptions are subject to caveats in Pakistan. Although the electricity delivery is unbundled, contractual relationships between network utilities, i.e. DISCOs and transmission monopoly, i.e. NTDC are not well established, at least on transparency grounds [NEPRA (2010)]. The appointment of the board of directors for DISCOs and interference of NTDC in DISCOs highlights the lack of independence of utilities to run their managerial affairs. The regulator faces constraints to implement the procedures and monitor generation and transmission activities, and standard procedures to supply basic industry data have not yet been adopted by distribution networks, from regulator reports it appears that although uniform system of accounts for DISCOs were proposed, such systems have not been operational till recently.

The cost of electricity supply includes generation cost, transmission cost, and distribution margins (DM), these tariff components are fixed by the regulator NEPRA. In 2011 the distribution margin including line losses contributed to approximately 25 percent of the average electricity cost, while network fees were less than 2 percent of average electricity cost.[23] The tariff structure is based on cost of service or rate of return regulation, the electricity networks recover costs through distribution margin and transmission cost. The cost is collected from consumers by DISCOs, and then DISCOs transfer power purchase price[24] including transmission fees to the central

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[22] NEPRA tariff determination 2012-13.

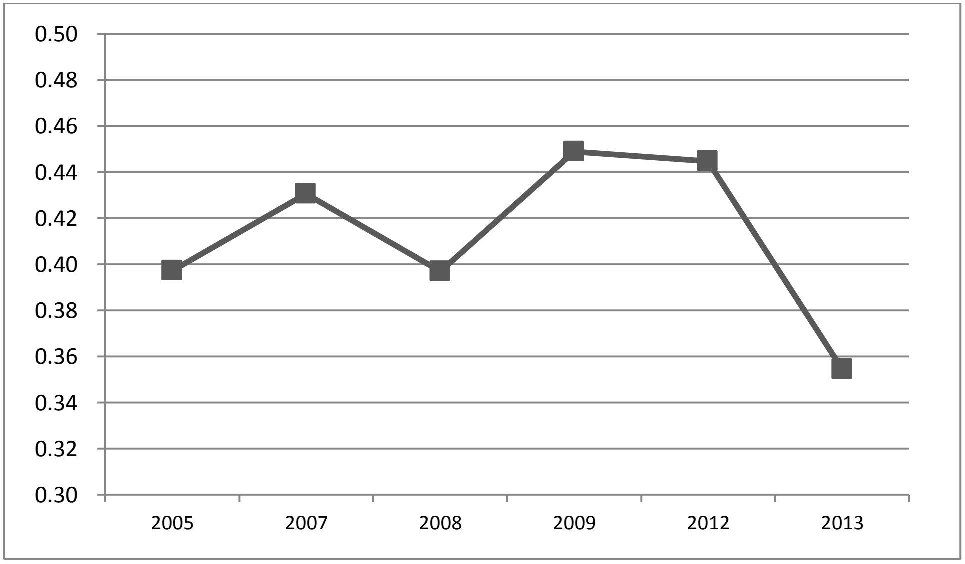
[23] Estimates based on public data (NEPRA 2011).

[24] Power Purchase Price PPP is a pass through cost item.

transmission/dispatch company NTDC.[25] In a single buyer model, NTDC procures electricity from all generators at the prices agreed in Power Purchase Agreements (PPA) and transmits bulk power to DISCOs on high voltage lines. The regulator enforces the tariff mechanism under the principle that network operators (transmission and distribution firms) recover sufficient return on capital to cover all operation costs and reasonable funds for capacity expansion for future needs (NEPRA 2010). The tariff is imposed for a period, and intermediate requests for fuel adjustment charges are entertained by the regulator. The frequency of pricing reviews and average cost for a selected distribution company are shown in Appendix Table 1A and Figure 2.

The regulatory tariff standards listed in the Appendix (see Table 2A) and the discussion above imply that the current practice of price regulation in the electricity industry is set in a "cost of service" or rate of return framework. There is no "price cap" mechanism enforced and tariff petitions are settled on a case-to-case basis. The distribution networks are publicly owned monopolies facing no incentives to cut operation costs or line losses as ultimately government through subsidy have to finance the cost of the distribution companies to meet their budget constraints. Earlier, some of the distribution companies proposed multi-year tariffs for five year periods, but the regulator declared an incentive based price cap regime unsuitable for the government owned distribution companies, until the companies are partly divested or privatised [NEPRA (2004)]. All of the distribution networks in the main system are government owned; therefore the chances of incentive based regulation are minimal until distribution firms are privatised.

Fig. 2. Real Distribution Cost, GEPCO (Rupees per kWh)



Source: NEPRA, Tariff Determination Reports Various Issues, 200-01 constant prices.

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[25] NTDC is given transmission license for a term of thirty years in 2002 by the regulator. *"The Company is entrusted to act as System Operator (SO), Transmission Network Operator (TNO), Central Power Purchase Authority (CPPA) and Contract Registrar and Power Exchange Administrator (CRPEA)"* [NEPRA (2011)].

3.3 Case Study of a Distribution Network

The analysis based on a sample distribution company, Gujranwala Electric Power Company (GEPCO) shows that the regulator determines a firm's distribution margin on the basis of reported costs for operation and maintenance, depreciation, and Return On Rate Base (RORB) (e.g. cost of capital). The frequency of pricing reviews for GEPCO is given in Table 1A. The distribution margin[26] is the economic rent, which the firm gets for operating the distribution network. The margin consists of operation and maintenance expenses, depreciation charges, and return on rate base, further adjustments are made for any income earned by the firm. The detail of the distribution margin components is given in Table 7.

Operation and maintenance expenses, including wage and salaries, are the largest component of a distribution network's cost (about 90 percent) excluding transfer prices for generation and transmission companies. Distribution networks are public owned companies and jobs are sanctioned for various pay scales historically with employees entitled to post retirement benefits. The regulator allows costs for salaries and wages based on past audited figures with the adjustment of annual pay increases of public employees and the impact of hiring on vacant positions, with very little allowance for new staff hiring, particularly for non-technical contract employees.[27] But pricing reviews reveal information asymmetry with the regulator, for instance, in 2012 the regulator allowed Rs 3,563 million for wages and salary, while audited account puts the figure at Rs 5,040 million. Apparently, the company spends money through public exchequer and put in prior year adjustments in the next year "pricing review". This shows a lack of consistent accounts data availability for current expenses of workers' wages and post-retirement benefits. The regulator matches the GEPCO request for new staff hiring with the justification for "prudent utility practices", while neither of the firms supply matching information on any potential "efficient utility practices" gained by new hiring, nor does the regulator specify any yardstick for new appointments.

Table 7

Distribution Margin GEPCO, Selected Years (Million Rupees)

	2006-7	2007-8	2008-9	2011-12	2012-13
Operation and Maintenance	3,298	3,254	3,739	6,318	5,454
Depreciation	510	556	829	971	1,098
Other Income	–970	–970	–1,116	–1,505	–1,960
Return on Assets	893	799	1,522	1,313	1,583
Income Tax		195			
Net Distribution Margin	3,732	3,833	4,979	7,097	6,175

Source: NEPRA, Tariff Determination Reports Various Issues, data is missing for some years.

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[26] Although revenue requirements of a distribution network include power purchase price including transmission network user fee but that requirement is part of transfer fees so is not directly related to incentive items for a distribution company.

[27] GEPCO is a 100 percent Public Sector Company, since unbundling the employees are hired on contractual basis and regularised to permanent posts after sometime.

This is quite similar to the situation when new investment requirements by the firm are matched with potential system improvement gains to justify new investment. The lack of information coordination between the regulator and the distribution company underlines the gap in current cost-based regulation regime. This information gap needs to be filled in order to set the platform for incentive based regulation and continual human capital investment in the distribution firm.[28]

Table 8

Rate Base GEPCO, Selected Years (Million Rupees)

	2011-12*	2012-13**
Opening Fixed Assets in Operation	27,681	31,379
Assets Transferred During the Year	3,698	2,914
Gross Fixed Assets in Operation	31,379	34,239
Less: Accumulated Depreciation	9,387	10,485
Net Average Fixed Assets in Operation(Rate Base)	21,992	23,754
Plus: Capital Work In Progress (closing)	2,811	4,371
Total Fixed Assets	24,803	28,125
Less: Deferred Credit	11,516	13,324
Total Regulatory Base	13,287	14,801

Source: NEPRA, Tariff Determination Reports Various Issues, data is missing for some years,* actual, ** projected.

Since regulation started in 2004, it is important that in this early stage, standards in cost-based reporting are set and benchmarks are established in order to enforce cost-based regulation effectively. To some extent goals were set at the same time as the “rate base” was set in 2004, and updated accordingly in pricing reviews (Table 8). However, the basic accounting information is coming from the distribution company through internal audit reports. The regulator requests for the required information from firms, but has not commissioned any study to determine the standards for various cost components, listed in Table 7 and Table 8.

According to regulation rules, sufficient tariffs should be allowed to generate a reasonable investment in technology to maintain the system and improve the reliability of the electricity supply [NEPRA (2012-13)]. In practice the regulator examines the effect of a firm’s capital investment on rate base, so that chances of overinvestment can be reduced. However there is no mechanism available to ascertain a reasonable amount of investment in infrastructure that will ensure a reliable electricity supply. In regulatory pricing reviews, GEPCO has not provided evidence of any perceived benefits of proposed investment to the regulator, but the regulator allowed investment on the basis of past trends. That shows a gap of information in the regulatory system which can result in overinvestment or under investment in infrastructure for distribution companies. Since a reliable electricity supply depends on continued investment in infrastructure, the regulator should develop a detailed knowledge base for the investment needs of distribution firms after taking into account future demand growth and system reliability.

[28] The current annual total investment in the government owned network segments is US $ 885 million while the Ministry of Water and Power (MWP) reports that US $ 6 billion is required to revamp the national grid.

4. PUBLIC SECTOR OWNERSHIP, SUBSIDY, AND REFORMS INCENTIVE

The electricity supply network including distribution companies DISCOs and the transmission company NTDC are publicly owned monopolies,[29] this is in line with industry practice in most countries where the natural monopoly part of a power supply chain is treated as a regulated monopoly.[30] The power sector reforms started in the 1990s to unbundle electricity industry and thereby establish distribution networks as independent organisations with their own command and management structure. However corporatisation of DISCOs has not been worked out fully and no formal contractual relationship exists among transmission, distribution and generation (government owned) segments of the industry [NEPRA (2010)]. A new government-owned establishment, Pakistan Electric Power Company (PEPCO), was formed in 1998, to corporatise generation, distribution and transmission units of the vertically integrated state monopoly WAPDA, and make these entities administratively and financially independent.

Published reports by the regulator suggest that PEPCO continues to interfere in matters of government-owned generation and distribution firms, posing problems for independent and optimal decision making and resource allocation of these firms. The distribution networks claim that noncompliance with efficiency and quality regulation targets results because of centralised management of routine decision making through PEPCO [NEPRA (2011)]. This gives an impression that the power industry has not completed the transition from state monopoly to unbundled electric supply. On the one hand, the efficiency gains from vertical integration and central planning have decreased, while on the other hand, scant benefits have emerged from unbundling. The actual situation regarding overall management practices in industry might be even worse, as in the past all of the firms were part of a vertically integrated monopoly with coherent managerial hierarchy, while in the post-reforms period there is an increase in an interventionist role of other ministries and corporatisation departments.[31]

In the following discussion, two questions are raised. First, what is the role of public institutions in allocating resources among distribution firms and how efficient are these transfer mechanisms? Second, what is the motivation for changing ownership from public to private enterprise in the electricity industry and is there any evidence within the industry to support this?

The government of Pakistan has adopted a uniform electricity price policy across the distribution networks in the country, although prices vary across different customer categories within each distribution network. The regulator determines the retail price of electricity for a distribution network after taking into account revenue requirements of the firm including distribution margin, while the government only allows a uniform end user price according to the lowest determined price for each customer category among all distribution firms [Pakistan (2013)]. The government does not allow the full passing on of the electricity supply cost to customers, the gap between the cost of electricity and

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[29] There are also some generation plants owned by public generation companies GENCOs.

[30] Although electricity networks can potentially save resources as regulated natural monopolies, but they are not necessarily government owned in practice.

[31] A complete study of history of reforms requires detailed information and is beyond the scope of the present study.

government set tariff results in a subsidy referred to as tariff differential subsidy (TDS), Table 8 highlights this gap for few periods. The failure of the government to settle tariff differential subsidy, regularly results in the accumulation of Circular Debt[32] in the electricity industry. The other major contribution to this resource gap emerges from the inability of distribution firms to collect revenue (either in the shape of no recovery of bills or high system losses, see Table 1).

Table 9

Average Cost of Electricity Supply and Price charged in Rupees

Period	Cost Per[1] KWh	Price Per[2] KWh	Gap Per KWh
24 February 2007	5.14	4.25	0.89
01 March 2008	5.6	4.78	0.82
05 September 2008	8.42	5.58	2.84
25 February 2009	8.42	5.63	2.79
01 October 2009	8.42	5.96	2.46
01 January 2010	10.09	6.67	3.39

Source: NEPRA, State of Industry Report 2011, 1 Cost based Tariff determined by regulator 2 Consumer-end Tariff determined by Pakistani Government.

The tariff differential subsidy is transferred by the central government to the central power purchasing company NTDC, and the NTDC allocates the subsidy among distribution firms. During 2007 to 2012 Rs1.29 trillion worth of price subsidies for distribution networks was transferred to the central transmission company. There is no transparent information available for the transfer of these payments [Pakistan (2013)]. Assuming transfers are made according to the actual difference between regulator price (cost of electricity supply) and the consumer end price (government allowed), the resulting subsidy allocation mechanism lacks any incentive for an efficient distribution firm. On the contrary, subsidy payment compensates for inefficiency caused by a distribution firm.

For instance, Peshawar Electric Supply Corporation (PESCO) experiences the highest operation cost including line losses, but it charges the end consumer the price of the lowest cost supply firm according to the government policy. As a result, PESCO recovers substantial business cost through tariff differential subsidy, while an efficient supply firm collects most resources through consumers. Since fulfilling budget balance constraints and subsidy internalisation mechanisms are not transparent, therefore, the exact welfare consequences for each firm are not clear. However, in the current regulation and subsidy transfer system there are virtually no incentives for unbundled electricity networks to increase efficiency and reduce system losses.

4.1. Privatisation Reforms

The basic idea of the 1990s strategic reforms for state monopoly was to make unbundled firms in the electricity industry administratively and financially viable and

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[32] Circular Debt is common terminology in Electricity Industry of Pakistan, the debt is caused by accumulation of deficit which results when payments flow in supply chain of power is disrupted. The distribution companies do not pay to the transmission company (power purchasing agency) that does not pay to power generators who do not pay to oil/gas supply companies for fuel.

then sell these firms to the private sector. However, current financial chaos partially caused by the political pricing regulation regime (uniform end user electricity price), lack of financial transparency in unbundled firms, and the Circular Debt, probably provide few incentives to private buyers to invest in the electricity network business.[33] For instance, for some time now, publicly owned distribution firms with high line and revenue losses have been potentially available for privatisation,[34], but so far, have not been privatised despite government efforts.

In theory, if electricity is considered as a basic infrastructure facility and the government wants to continue the supply of electricity to consumers at an "affordable" price, then the government can transmit and distribute electricity in-house or procure through a private supplier. The private owner has an incentive to lower costs while facing a given output price, but the private supplier might lower product quality. The private supplier might lower quality of the product, as quality is non-contractible component of the contract [Hart, *et al*. (1997)]. In the case of the electricity supply specifying the quality of product is relatively easier than another public good such as schooling or hospital as electricity is a homogenous product. The private distribution firms can be monitored by a quality regulation regime with specific parameters including average interruption indices. The efficiency gains and asset ownership incentives also go in favour of the private supplier, as private firms can offer a more flexible contract to employees depending on their human capital and experience.

However, it is not clear what the economic gains of privatising a state monopoly (say a distribution network) will be, if the current regulation with asymmetric information along with government's subsidy policy continues. Keeping the regulatory regime unchanged will result in an inefficient private monopoly instead of an inefficient public monopoly. The opinion on privatising state owned firms is divided among policy makers and politicians [World Bank (1997)], overstaffing, non-performance based worker salaries, and lack of transparent procurement are associated with public owned electricity networks [Pakistan (2013)]. However, in the absence of a fully informed regulator and without an incentive based regulation regime there is a chance that private firms will not function very differently from public firms.

The pace of privatisation and market based reforms in the electricity industry are slow, so far one distribution firm, Karachi Electricity Supply Corporation (KESC), has been sold to private firms. KESC was privatised in 2005; the comparison between KESC and other distribution companies can give some idea about potential gains by privatisations in some selected indicators. As the government implements the same tariff policy in the whole country, so KESC also receives a public subsidy to cover the difference between cost of electricity supply and average tariff charged to costumers. However KESC's policy is to cut power for longer hours in the locations where revenue recovery is low and theft or system loss is higher. Although KESC earned profit for the first time in 2012, the system losses are still high, Table 2. There is a modest reduction in KESC losses, again it is not clear if that shows improvement in infrastructure or the

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[33] PEPCO was formed in 1998 to monitor unbundling and corporatisation for two years, the slow pace of reforms can be judged from the fact that PEPCO dissolution occurred in 2012.

[34] Some of electricity firms including PESCO, QESCO, HESCO, and FESCO are listed on privatisation priority list, not clear about the timing of the inclusion or any future selling date. Privatisation Commission Pakistan http://www.privatisation.gov.pk/power/power.htm (Accessed 13 September 2012).

effectiveness of a better load shedding management plan. In comparison, no incentives are available to government owned distribution companies (DISCOs) to lower cost and improve quality of the electricity supply. The government recently reconstituted boards of directors for DISCOs and increased the number of private board members in these public companies, but still the utilities are far from privatisation.

5. CONCLUDING REMARKS

The cost of supplying electricity and the price charged to consumers are two basic parameters that can be employed to evaluate the performance of power sector reforms and the future of the industry. The production incentives generated by current ownership structure and the regulatory regime, along with other residual factors, are affecting price and cost of the electricity supply. The price charged for electricity produced is not covering the cost of production giving incentives for consumers to overuse electricity. The inefficiencies in distribution networks including high line losses and low recovery are making the electricity supply costly.

The technical losses in the system cannot be disentangled from non-technical losses (including theft), continuous investment in physical capital and system maintenance is required to improve the reliability of the electricity supply and reduce technical losses. The experience of privatisation of one utility does not support that non-technical losses can be reduced in short run with a change of management or ownership structure. The multiproduct nature of the electricity supply requires a reliable demand forecast, as the cost of the electricity supply in high-demand summer hours will be different from the low-demand winter season. The cost of the high-demand season supplies has to incorporate future investment in infrastructure in order to ensure reliability. In the current practice, the regulator and the firms lack sufficient knowledge about the required investment and potential costs of a multiproduct electricity supply.

In the current practice, investment rules of utilities that would affect system loss reduction efforts and timely investment for reliable supply of electricity are not being implemented. The distribution firms lack information about the investment gap or at least they cannot justify the required investment to the regulator, while the regulator has not set any tangible yardstick for better utility practices. This information asymmetry between the regulator and utilities is slowing down the growth of the electricity industry and is not reflecting the actual cost of a reliable electricity supply, which might be substantially higher than that determined by the regulator. The revenue losses and system losses create a real challenge to generate the investments required for revamping the basic network infrastructure, let alone moving to new technologies such as real-time monitoring and smart meters.

Further research should focus on the economic model of electricity supply in Pakistan to address the fundamental question, is electricity a public good, a private good or a marketable public good? The historical experience in Pakistani context puts electricity closer to being a marketable good supplied by the government. In the current situation, privatisation will make electricity a privately provided public good as has happened in the case of Karachi Electricity Corporation (KESC), because KESC has supplied heavily subsidised electricity in private ownership since 2005. The politically motivated village electrification plan falls in line with the "cheap affordable electricity" model where the supply of electricity to a scattered housing unit could result in substantial system loss. The future industry reforms should be undertaken in light of further research and clarity on the business model for the electricity supply in Pakistan.

APPENDIX

Table 1A

Tariff Determination, Gujranwala Electric Power Company (GEPCO)

27-03-2013	Determination of the Authority in the matter of Petition filed by Gujranwala Electric Power Company Ltd. for Determination of its Consumer end Tariff Pertaining to the FY 2012-13.
24-02-2012	Decision of the Authority in the Matter of Reconsideration Request filed by Ministry of Water & Power against Authority's Determination for GEPCO for the FY 2011-12.
13-12-2011	Determination of the Authority in the matter of Petition filed by GEPCO for determination of its Consumer end Tariff Pertaining to the FY 2011-12.
27-04-2011	Determination of the Authority in the matter of Petition filed by GEPCO for Determination of its Consumer end Tariff pertaining to the 2nd, 3rd and 4th Quarters (October - June 2011) of the FY 2010-11.
09-12-2010	Decision of the Authority with respect to Motion for Leave for Review filed under Rule 16(6) of NEPRA (Tariff Standards and Procedure) Rules, 1998 by GEPCO against the Authority's Determination.
08-09-2010	Determination of the Authority in the Matter of Petition filed by GEPCO for Determination of Consumer-End Tariff for 4th Quarter (April - June 2010) of FY 2009-10.
19-04-2010	Determination of the Authority in matter of Petition filed by GEPCO for Determination of Consumer-end Tariff for 2nd Quarter (October-December) of Fy 2009-10.
09-12- 2009	1st Quarterly Determination Based on the FY 2009-10 Determined under NEPRA (Tariff Standards and Procedure) Rules, 1998 for GEPCO.
14-09-2009	Determination of the Authority in the Matter of Petition by GEPCO for Determination of Consumer-end Tariff for the Year 2008-2009 under NEPRA (Tariff Standards and Procedure) Rules, 1998.
15-01-2009	Modified Decision of the Authority on Federal Government's Request for the Reconsideration of Gujranwala Electric Power Company Ltd (GEPCO) Decision dated 1st January, 2009 [Case No. NEPRA/TRF-102/GEPCO-2008 (3)].
09-09-2008	Determination of Tariff in respect of Petition filed by (GEPCO) [(Case No. NEPRA/TRF-102/GEPCO-2008 (3)].
30-05-2008	Decision of the Authority on Federal Government's Request for the Reconsideration of GEPCO decision dated January 10, 2008 (Case No. NEPRA/TRF-36/GEPCO-2005).
01-02-2008	Biannual Adjustment in the Consumer-end Tariff on Account of Charge in Power Purchase Price.
10-01-2008	NEPRA/TRF-36/GEPCO-2005 (Revised).
28-06-2004	NEPRA/TRF-23/GEPCO-2003.

Notes: In between more than 35 “fuel price reviews” were conducted by NEPRA to adjust fuel prices in electricity supply prices.

Table 2A

Regulation Standards for Tariff

1. Tariffs should allow licensees the recovery of any and all costs prudently incurred to meet the demonstrated needs of their customers, provided that assessments of licensees' prudence may not be required where tariffs are set on other than cost-of-service basis, such as formula-based tariffs that are designed to be in place for more than one year
2. Tariffs should generally be calculated by including a depreciation charge and a rate of return on the capital investment of each licensee commensurate to the rate earned by other investments of comparable risk.
3. Tariffs should allow licensees a rate of return which promotes continued reasonable investment in equipment and facilities for improved and efficient service
4. Tariffs should include a mechanism to allow licensees a benefit from, and penalties for failure to achieve the efficiencies in the cost of providing the service and the quality of service.
5. Tariffs should reflect marginal cost principles to the extent feasible, in view of the financial stability of the sector.
6. The Authority shall have a preference for competition rather than regulation and shall adopt policies and establish tariffs towards that end.
7. The tariff regime should clearly identify interclass and inter-region subsides and shall provide such subsides transparently if found essential, with a view to minimising if not eliminating them in view of the need for an adequate transition period.
8. Tariffs may be set below the level of cost of providing the service to consumers consuming electric power below the consumption levels determined for the purpose from time to time by the Authority, as long as such tariffs are financially sustainable.
9. Tariffs should, to the extent feasible, reflect the full cost of service to consumer groups with similar service requirements.
10. Tariff should take into account Government subsidies or the need for adjustment to finance rural electrification in accordance with the policies of the Government.
11. The application of the tariffs should allow reasonable transition periods for the adjustments of tariffs to meet the standards and other requirements pursuant to the Act including the performance standards, industry standards and the uniform codes of conduct.
12. Tariffs should seek to provide stability and predict ability of customers; and
13. Tariffs should be comprehensible, free of misinterpretation and shall state explicitly each component thereof.

Source: NEPRA (2010).

Table 3A

Abbreviations and Acronyms

CPPA	Central Power Purchase Company
DM	Distribution Margins
DISCOs	Distribution Companies
FESCO	Faisalabad Electric Supply Company
GEPCO	Gujranwala Electric Power Company
GENCOs	Generation Companies
GOP	Government of Pakistan
GWh	Giga-watt Hours
HESCO	Hyderabad Electric Supply Company
IESCO	Islamabad Electric Supply Company
IPP	Independent Power Producers
KESC	Karachi Electricity Supply Company
KWh	Kilo-watt hours
MEPCO	Multan Electric Supply Company
MMCF	Million Cubic Feet
MWP	Ministry of Water and Power
MW	Mega Watt
NEPRA	National Electric Power Regulatory Authority
NTDC	National Transmission and Dispatch Company
PEPCO	Pakistan Electric Power Company
PESCO	Peshawar Electric Supply Company
PPA	Power Purchase Agreement
QESCO	Quetta Electric Supply Company
SAIFI	System Average Interruption Index
SAIDI	System Average Interruption Duration Index
SEPCO	Sukkur Electric Supply Company
SO	System Operator
WAPDA	Water and Power Development Authority

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Comments

This paper is a valuable collection of information relating to the electricity network of Pakistan (especially in the light of theoretical justification); despite the fact that some (of courses not all) of the details documented here in this paper have repeatedly been discussed in the previous studies on the electricity sector of Pakistan. Overall it's a well-written paper. The author has done a useful analysis on the distribution system in Section 2.

It is true that economic incentives in lowering production costs are more important than enforcing the efficient pricing mechanism and can help in improving welfare for the society. This point is well documented in the literature and has been proved empirically. As efficiency has become a main concern in electricity networks, benchmarking analysis of company's inefficiency levels is more frequently used as an instrument to monitor the companies and induce cost-saving incentives. Benchmarking can be used in many forms in regulatory arrangements. For instance, the efficiency estimates of different firms can be used to adjust their X-factor in price cap regulation to differentiate maximum prices across companies. At the same time benchmarking can also be used to reduce the information disadvantage of the regulator about companies' expenditures. For instance, parametric frontier methods can be used to predict costs in order to assess if the reported company's costs used in rate of return regulation are reasonable.[35]

In Pakistan, despite the availability of empirical research on the benchmarking and regulation for the electricity distribution sector, regulator, unfortunately has not been able to set benchmarks for efficiency and performance of the distribution sector. It may be because either they don't have the expertise or the authority to implement those decisions.

As far as privatisation is concerned it is not the only solution to bring market efficiency and improve competition. As author has also pointed out that keeping the regulatory regime unchanged will result in an inefficient private monopoly instead of an inefficient public monopoly. It is also obvious from the case of KESC. There are countries like Norway with very efficient and competitive electricity markets without privatisation where better public participation through a corporate sector was a strong alternative. Therefore, complete corporate structure for all DISCOs; and tariffs for each DISCO based on its efficiency, is must for progress in the sector.

The power system (though unbundled to a certain level) as an outcome of first generation reforms in the power sector has again become centralised under PEPCO which continues to hold influence (in financial management, power purchase and sales and in the appointment of senior management) over the operating companies (GENCOs and DISCOs). Further, these companies lack technical and managerial skills to operate independently. For instance, DISCOs besides having inferior operational performance,

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[35] For details, see Farsi, *et al*. (2007) "Benchmarking and Regulation in the Electricity Distribution Sector". CEPE Working Paper No. 54, ETH Zürich, Zurich, Switzerland.

are not aware about their role and need of good governance as a corporate entity. Despite being a corporate entity their attitude is still that of a public sector organisation. Unless all distribution companies in Pakistan are made accountable for all their decisions and finances, it would not be possible to bring in efficiency in the system. At present inefficient DISCOs like Quetta, Hyderabad, and Peshawar are being indirectly subsidised by some profit making DISCOs like Lahore, Islamabad, and Faisalabad.

Lack of expertise in the form of financial and commercial skills is a serious impediment in the way of accountability, quick decision-making and commercial orientation, and it is applicable to not only the network operators but also to the regulator. All the issues can only be addressed if the management of energy sector becomes more professional and competitive. With improvement in managerial capacities they would be able to identify required investments and potential costs.

Generally speaking, vested interests in the successive governments have stalled the due level of competence and commitment that are prerequisite for progress in the electricity sector. They not only lacked the capacity to foresee the emerging challenges but were also not able to respond in an efficient manner. As a result of these problems tariffs, investment and appointment of senior management and staff have largely been politicised. Therefore, improvement in the processes of decision making and implementation could be an important ingredient in working towards a fair and sustainable electricity sector.

Professor Mohen Munasinghe in Allama Iqbal Lecture (in this Conference) very rightly pointed out that ownership does not matter whether its public or private what really matters is the government interference. The least the intervention the better it is.

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Energy Intensity: A Decomposition Exercise for Pakistan

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1. INTRODUCTION

Since the recent energy crises, the research in this strand has increased considerably. A variety of its dimensions have been examined in the literature. For instance, higher energy prices; instability in the supplies of its various components; its rapid depletion and global warming are some of its dimensions, which have been the focus of discourse among both researchers and policy-makers. Equally, energy intensity measuring the energy consumption to GDP ratio has been an important component of energy policies [Ang (2004); Liu and Ang (2007); Jimenez and Mercado (2013)]. In particular, there is a special focus on sorting out the contribution of energy efficiency—ratio of sectoral specific energy consumption to sectoral GDP—to alienate the impact of efficiency on energy intensity from other relevant factors. This is because energy efficiency is recognised as one of the most cost-effective strategies to address crosscutting issues of energy security, climate change and competitiveness [IDB (2012)]. Consequently, the information regarding energy intensity, its efficiency or activity aspects are useful tools for policy decisions and evaluation and are regularly in practice in most of the advanced countries.

Pakistan is currently faced with severe energy crisis. In particular, it is facing formidable challenges in meeting its energy requirements and providing adequate energy to users at affordable costs. Electricity shortage is continuously widening since 2006-07. For instance, the gap between demand and supply of electricity increased to the level of 5000 MW in 2011.[1] Such shortages have adverse consequences for the economy of Pakistan. According to Abbasi (2011), energy shortages have cost the county up to 2 percent of GDP per annum. Similarly, Siddiqui, *et al.* (2011) proclaim that the loss in industrial output due to power shortages is estimated to be from 12 percent to 37 percent. They have also forced the closure of hundreds of factories, paralysing production and exacerbating unemployment. Additionally, they imperil much-needed investments in development and infrastructure. Despite these facts, Pakistan's energy intensity per unit of GDP is higher

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[1] During the month of May in 2011, the shortfall had surpassed 7000 MW. See for the details Malik (2012).

relative to Countries like India, USA, Germany, Japan and China [Allcott and Greenstone (2012); IEA (2012c)]. Also, in case of Pakistan, it has taken a rising trend over time. For instance, the consumption of oil in 1972 was 12 percent of its consumption level in 2011. Similarly, it was 9 percent in case of gas and 7 percent in case of electricity. At the same time, gross value added in 1972 was 14 percent of its 2011 level. These trends show that we are now using more energy per each unit of economic activity.

However, to overcome energy crisis and achieve energy security, we must have to bring efficiency in the usage of energy. But before any successful policy formulation, our academia and policy makers must be aware of the past trends and current status of the energy intensity. So far, commendable research has been done on energy issues in Pakistan but most of the studies have been conducted in the context of changes in energy prices and their relation to economic growth, inflation and other macroeconomic indicators [Malik (2007, 2008, 2012); Kiani (2009); Jamil and Ahmed (2010); Syed (2010); Khan and Ahmad (2011); Siddiqui, *et al.* (2011)]. To our knowledge, the only study conducted on energy intensity in Pakistan is done by Alam and Butt (2001) which uses Sun (1998) 'complete decomposition method'. The Sun (1998) method of decomposition, based on jointly created and equally distributed principle, is weaker as compared to recently developed decomposition techniques. Second, the current energy crises have intensified since 2005, so the study by Alam and Butt (2001) has been a little bit older now. In this paper, we make an endeavor to address these two issues. The study provides an empirical decomposition of energy intensity into its constituent factors, efficiency and economic activity for Pakistan. We apply Fisher Ideal Index Decomposition Approach (IDA) and cover a period from 1972 to 2011. In our analysis, we show the effects of change in efficiency and changes in activities on the change in energy intensity. This study contributes to the literature in three main aspects. First, the time of the study is of particular importance. It covers the period that includes all the three major oil price shocks as well as the recent energy crisis in Pakistan. Second, instead of considering the overall energy consumption, we first construct the indices at component level and then aggregate the individual indices to understand the overall trends. This has allowed us to see the intensities pattern of oil, gas and electricity separately. Finally, we have used the most suitable decomposition tools recommended in most recent literature.

Rest of the paper is organised in four sections. Section 2 reviews the decomposition methodologies and their empirical implications. Detailed methodology and the construction of variables are discussed in Section 3. In Section 4, we provide the details of our empirical analysis. Section 5 concludes the paper.

2. REVIEW OF DECOMPOSITION LITERATURE

In order to decompose aggregates into their component parts, different decomposition methodologies have been developed and applied in empirics. These different methodologies can be broadly divided into four groups: Shift Share Analysis (SSA), Growth Accounting Analysis (GAA), Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) [Fengling (2004)]. SSA is mainly observed in regional studies and GAA is used in decomposing identity [Fengling (2004); Szép (2013)]. In the same manner, the Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) are widely used in energy and emission studies [Ang and Zhang (2000)]. However, the choice between these two methodologies largely depends on their ease of application and data requirements. SDA uses information from input-output Tables while IDA uses aggregate data at the sector-level. The advantage of IDA is its lowest data requirement along with its strong theoretical foundation [Hoekstra and Bergh (2003); Fengling (2004); Liu and Ang (2007)]. In contrast, SDA can distinguish between a range of technological effects and final demand effects that are not possible in the IDA. However, Hoekstra and Bergh (2003) have formally shown that IDA techniques can be transferred to SDA. Similarly Boer (2009) proved that the generalised Fisher approach, introduced in IDA is equivalent to SDA. Because of this equivalence and its lower data requirements, IDA remains a popular tool of decomposition.

In the energy decomposition, IDA is extensively used since 1980s. The earlier literature in which the energy intensity is decomposed into contributions from structural and efficiency effects left an unexplained residual term [Bossanyi (1983); Boyd, *et al.* (1988); Li, *et al.* (1990); Howarth, *et al.* (1991); and Park (1992)]. The long-mean Divisia index, proposed by Ang and Choi (1997), was an improvement to these earlier techniques because it leaves no residual term. Since then several other perfect methods have been developed by different authors.[2] For instance, Sun (1998) introduced Refined Laspeyres Index (RLI), which is based on the principle of jointly created and equally distributed principle. Similarly, Mean Rate of Change Index (MRCI) by Chung and Rhee (2001) leaves no residue. Further, the decomposition technique of Albrecht, *et al.* (2002), which is based on Shapley Value and the Log Mean Divisia Method and Modified Fisher Ideal Index method by Fengling (2004) are yet other approaches that are perfect in decomposition.

All of these methods have been extensively used in empirical studies.[3] In case of energy intensity, different approaches have come up with different results on the relative roles of the efficiency and structural effects. For instance, Kander and Lindmark (2004) found that efficiency was a major factor in the improvement of energy intensity in case of Sweden. Similarly, a number of other case studies have been conducted and have come up with similar results [Liao, Fan, and Wei (2007) for China between 1997-2002; Metcalf (2008) for U.S. between 1970-2001; Sahu and Narayanan (2010) for Indian manufacturing between 1990-2000; Shahiduzzaman and Alam (2012) for Australia between 1978-2009; Song and Zheng (2012) for China between 1995-2009; Szép (2013) for Czech Republic, Slovakia, Slovenia, Poland and Hungary between (1990-2009)]. In most of the studies, at disaggregate level analysis, the share of structural changes increases even when the same methods of decomposition were used [Karen, *et al.* (2004) for China; and Huntington (2010) for U.S. The possible justification is that aggregations cause the overstatement of the contribution of sub-sector energy productivity improvements while assigning insufficient weight to the role of sectoral shift. Despite this disadvantage, the aggregate level studies are preferred due to their relatively comprehensive coverage. Likewise, the literature places emphasis on the efficiency

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[2] A method is regarded as perfect if it leaves no residual term.

[3] Boyd and Roop (2004) and Metcalf (2008) used Fisher ideal index for U.S, Hatzigeorgiou, *et al.* (2008) used arithmetic mean Divisia method for Greece, Mairet and Decellas (2009) used log mean Divisia method for France, Sahu and Narayanan (2010) used the Laspeyres index approach and the Divisia index approach for Indian manufacturing industries for 1990-2008, Zhao, *et al.* (2010) used log mean Divisia method while Song and Zheng (2012) used Fisher ideal index for China, Szép (2013) examined energy intensity for Czech Republic, Slovakia, Slovenia, Poland and Hungary between 1990 and 2009 using eight different decomposition methods (results were almost same for all of the methods).

effects in reducing energy intensity, especially in the advanced countries [Ang (2004); Fengling (2004); Liu and Ang (2007); Ang, *et al*. (2009)].

However, the selection of suitable index decomposition method is very important for getting accurate results. Generally, a method, which leaves no residual is regarded as the most desirable. Such methods are referred to as perfect decomposition methods. Other desirable properties that IDA must satisfy to become a good decomposition method are adaptability, ease of use and interpretation, consistency in aggregation and robustness to zero and negative values [Liu and Ang (2007)]. The two methods that satisfy most of these properties are Log Mean Divisia techniques and Fisher Ideal Index [Ang (2004); Fengling (2004); Liu and Ang (2007); Ang, *et al*. (2009)]. Given its suitability, we use Fisher Ideal Index in our study like Metcalf (2008) and Song and Zheng (2012). Besides the perfect decomposition and its robustness to zero-negative values, the Fisher Ideal Index satisfies time-reversal test, factor reversal test and proportionality test as well.

3. METHODOLOGY FOR DECOMPOSITION OF ENERGY INTENSITY AND DATA

In this section, we provide the detailed methodology of the study. Also, we give a description of the construction of our variables.

3.1. The Decomposition Methodology

As is stated earlier, decomposition analysis is used to break down the aggregate series into understandable and meaningful components. In this study, our purpose is to use these techniques to decompose the change in aggregate energy intensity into changes in economic activity and changes in efficiency. Also, we decompose change in total consumption. For our analysis, the aggregate energy intensity is defined as the ratio of total energy consumption to aggregate output of the economy:

$$e_t = {}^{E_t}\!/_{Y_t} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.1)$$

$$e_t = {}^{E_t}\!/_{Y_t} = \sum_i {}^{E_{it}}\!/_{Y_{it}} \; {}^{Y_{it}}\!/_{Y_t} = \sum e_{it} s_{it} \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.2)$$

Where, E_t is aggregate energy consumption, Y_t is gross domestic product, Y_{it} is sectoral output and E_{it} sector specific intensity. We want to choose suitable analytical tools to decompose the aggregate changes in energy, Δe_t, into changes in economic activity and changes in efficiency, that is, into Δs_{it} and Δe_{it} respectively. For this purpose, we use Fisher Ideal Index. Fisher Ideal Index has many advantages over most of the other methods as are mentioned in the previous section.

Using e_0 to denote aggregate energy intensity in the base year, we construct energy intensity index and then derive its decomposition.[4]

$${}^{e_t}\!/_{e_0} \cong I_t = I_t^{act} I_t^{eff} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.3)$$

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[4] We are broadly following Boyd and Roop (2004).

Where, I_t^{act} is the corresponding activity index and I_t^{eff} is the efficiency index. As the equation indicates, the aggregate energy index is decomposed into activity and efficiency indexes with no residual term and this is guaranteed only by Fisher ideal index.[5] Once we have these indices, we can easily determine the amount of change in energy consumption, which is caused by changes in efficiency and the part that is due to change in activity. Using E_0 to denote energy consumption that would have prevailed had energy intensity not changed since the base year. Following Metcalf (2008), this is done below:

$$\Delta E_t = E_t - E_0 = \Delta E_t \left[\frac{\ln I_t^{act}}{\ln I_t} \right] + \Delta E_t \left[\frac{\ln I_t^{eff}}{\ln I_t} \right] = \Delta E_t^{act} + \Delta E_t^{eff} \qquad \ldots \qquad \ldots \quad (3.4)$$

The term ΔE_t indicates change in energy consumption, which is the difference between actual consumption in a given year and the consumption, which would have occurred had energy intensity remained at 1972 level, that is, $E_t - E_0$. As is shown in the equation, this has enabled us to decompose a given change in energy consumption, relative to a base year, into changes in efficiency and changes in activities.

3.2. The Construction of Variables

We carry out the decomposition analysis for various components of energy, *i.e.* oil, gas and electricity. Together, these three comprise about 90 percent of the total energy consumption in Pakistan. Here, we present the details of the data of all the three components. The energy year book reports the oil consumption data under six headings: household consumption; industrial consumption; agricultural consumption; transport consumption; power consumption; and other government consumption. In order to construct the indices, we need the contribution of each of these sectors to the national gross valued added. For this purpose, we make certain matching operations. For instance, for the share of household sector in gross value added, we use household final consumption expenditure.[6] Similarly, for the share of industrial sector, we take into account the industrial value added net of the electricity and gas distribution. This is because electricity and gas distribution is considered to compute the share of power sector in the total gross value added. The gross value added accruing from transport, storage, and communication is taken as the share of transport sector. For agricultural sector, its share in gross valued added is considered for the analysis.

The data on the consumption of gas is reported for seven sectors, i.e., household, commercial, industrial, cement, fertiliser, power, and transport sectors. To make it congruent to the national accounts data, we merge the data of cement and fertilisers with the industrial consumption of gas. In the same manner, the data of transport consumption is merged into the data of commercial sector. In the overall contribution of commercial sector to gross value added, we include the value additions of transport, storage and communications, wholesale and retail trade, and finance and insurance. The shares of the remaining sectors are constructed in a similar way to those, which are constructed in the case of oil sector.

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[5] For instance, see the appendix for details.

[6] We are following Metcalf (2008) in this calculation.

In the case of electricity, the consumption of traction, street light and other government sector are eliminated from the total electricity consumption. This is not going to make any difference because collectively the share of these sectors in the total consumption of electricity is less than 7 percent. Consequently, for our analysis of the electricity sector, we consider four sectors, i.e. household, commercial, industrial, and agriculture.

Finally, the gross value addition of each of the mentioned sectors is in constant prices of 2000. The data is taken from four sources: Energy Year Books; Statistical Supplements; Hand Book of Statistics; and the World Development Indicators of the World Bank. The descriptive statistics of the various sectors is summarised in the appendix.

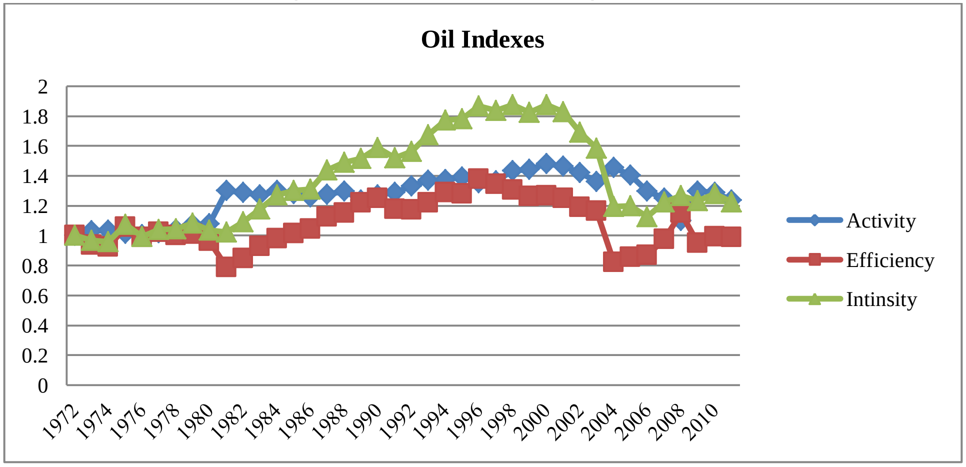
4. RESULTS OF THE DECOMPOSITION ANALYSIS

In order to carry out the detailed analysis of the changes in intensity, we have done separate analysis for each of the three major energy components. In this section, we provide the details of our empirical results one by one.

4.1. Oil Energy

The decomposition of oil intensity between 1972 and 2011 is presented in Figure 4.1. Overall, the oil intensity is 22 percent higher in 2011 as compared to that of 1972. The highest intensity is in the year 2000, which is 88 percent higher as compared to that of 1972. On average per annum, intensity is 37 percent higher than that of 1972. However, the indices of activity and efficiency are giving divergent patterns. For instance, the activity index is 24 percent higher in 2011 as compared to 1972 while the efficiency index is 1 percent lower in 2011 as compared to its base value. The highest value of activity index is 1.48, which is in the year 2000 while the highest value of efficiency index is 1.38 in 1996. Besides, the activity index remains above its 1972 level for whole time period covered in this study. Since 1980, the indices show rising trends for the onward two decades with the activity index dominating the efficiency index. This means that during this period the share of oil using sectors increased in relative terms. However, after 2000 we have experienced sharp reduction in oil intensity with efficiency as a dominant factor in this change.

Fig. 4.1. Trends in Oil Energy Indices



The data of oil consumption indicate that total oil consumption in 2011 would have been 3387509 tonnes lower had the energy intensity remained at its 1772 level.[7] Equation 3.4. can be used to decompose this change into the changes in activities and a change in efficiency. According to our analysis, change in economic activities cause oil consumption to increase by 3596498 tonnes in 2011 as compared to 1972. In contrast, the change in efficiency causes oil consumption to drop by 217989 tonnes in 2011. The year wise details of this analysis are given in the appendix.

As we compare the trends in our indices with the changes in oil prices, some interesting results emerge. The global economy has experienced three big shocks in oil prices. The first was in 1973 when the Organisation of Petroleum Exporting Countries (OPEC countries) imposed embargo on oil exports in response to Arab-Israel war. The second shock occurred in 1979, which was mainly caused by the Islamic Revolution in Iran. From 1983 to 1998, oil prices remained stable both in domestic as well as international markets. However, since 1999 the world is experiencing a third big oil price shock in the global history. In their meeting in March 1999, the OPEC countries agreed to cut the oil production with a view to increasing the prices of crude oil to around $20 per barrel. As a consequence, the oil prices very quickly surpassed the $20 per barrel with a dramatic increase in the new century. For instance, in 2003-04 oil prices were 11 percent higher than those of 2002-03 and around 41 percent higher in the following year compared to those of 2003-04. In the same manner, in 2007-08 oil prices were 53 percent higher as compared to those in the preceding year. Continuing with the rising pattern, the prices reached to a record level of about $150 per barrel in 2008-09.

The comparison of oil price history with Figure 4.1, in particular with the efficiency index, shows that the indices remained almost stable during the whole 1970s. In 1980, efficiency started improving, which continued until 1984. During this period, the efficiency was better than that of 1972. Onwards, the indices have steadily increased and this increasing trend continues up to 1998. After 2000, the aggregate intensity strongly falls and the dominant factor for this fall can be seen as the efficiency index. For instance, the efficiency index falls from 1.16 in 2003 to 0.82 in 2004 and during the same period, oil prices increased by 41 percent as compared to preceding year. This trend holds not only for the international prices but also for the domestic variation in the prices of furnace oil, HOBC, HSD etc. If the relation holds true, it implies that whenever oil prices increase, we increase efficiency in its use. This is an important implication and requires in-depth analysis. After the year 2000, the activity index also shows declining trend; however, it is not as pronounced as the efficiency index.

4.2. Gas Energy

In this sub-section, we extend our analysis to the case of gas. The decomposition analysis of gas intensity, shown in Figure 4.2, indicates that gas intensity in 2011 is 58 percent higher as compared to that of 1972. The intensity is the highest in 2005, which is 87 percent higher than that of 1972. On average, the gas intensity is 43 percent higher than 1972 for the onward period. The index of activity is dominated by the index of efficiency. For instance, the activity index in 2011 is 06 percent higher as we compare it

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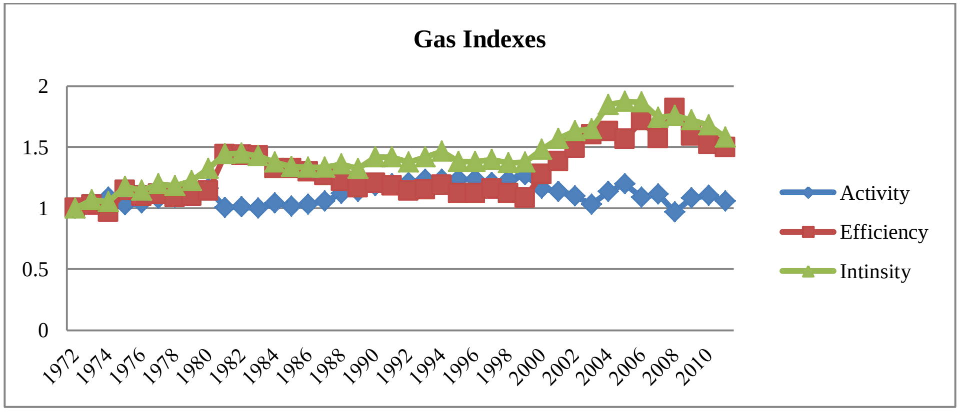
[7] Note that it does not include the consumption under the other government heading.

with that of the 1972. In contrast, the efficiency index is 50 percent higher in 2011. The highest value of activity index is 1.27 in 1999 while the highest value of efficiency index is 1.81 in 2008. In the same way, the lowest value of the efficiency index is estimated at 0.97 in 1974. In general, the efficiency index remains above its 1972 level for most of the period covered in this study. As is evident from the figure below, the aggregate intensity index is strongly driven by the efficiency index in case of gas consumption.

Moreover, the intensity index goes through two notable upward spikes, one in around 1981; and the second is the most prolonged one beginning in 2000 and lasts up to 2008. 2008 onwards, we have experienced a declining trend in gas intensity with efficiency as the dominant factor in this change. One factor for the higher intensity in the beginning of 21st century can be the policies of the Musharraf administration, which converted most of electricity or oil run industries to gas. For instance, one critical sector in this regard is transport sector. In 1998, transport sector was using 490 (mm cft) of gas, which increased to 113055 (mm cft) in 2011. Again, a striking feature is that the increase is mainly dominated by the efficiency changes rather than the activity changes.

Fig. 4.2. Gas Energy Indexes Trends

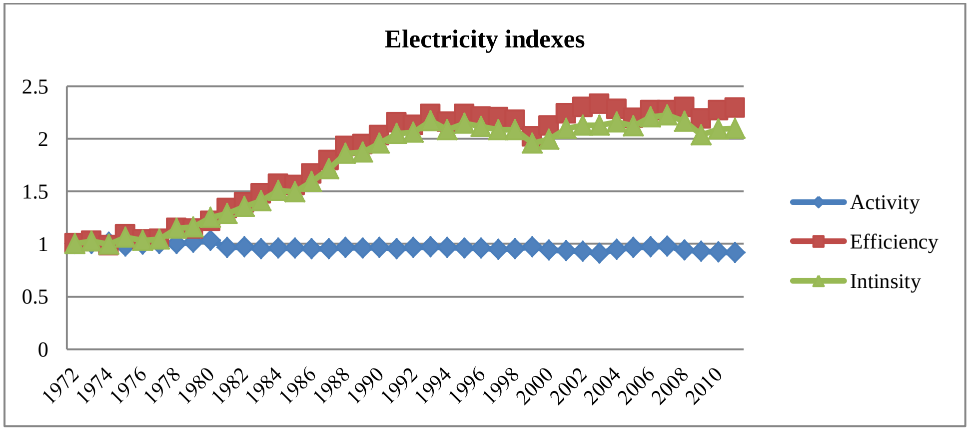


The gas consumption data indicate that total gas consumption of 1240672(mm cft) in 2011 would have been 784286.2 (mm cft) had energy intensity remained at its 1772 level. The increase is jointly shared by the activity and efficiency factors. For instance, the increase in gas consumption caused by the change in economic activity is estimated to 55458.55 (mm cft) in 2011 as we compared it to the level of 1972. Similarly, the change in efficiency causes gas consumption to increase by 400927.3 (mm cft) in 2011 compared to the level of 1972. The year wise details of the changes in indices are given in the appendix.

4.3. Electricity Energy

This section provides the blueprints of the intensity of electricity. The details of the decomposition analysis are shown in figure 4.3. Overall, the intensity of the electricity is 110 percent higher in 2011 as compared to that of 1972. This difference is highest in the year 2007 where the index is 122 percent higher than that of the base year. For all the periods onwards the base year, the index is on average 75 percent higher than that of the base year. So far the decomposition is concerned; the activity index is 08 percent lower whereas the efficiency index is 129 percent higher compared to their corresponding values in 1972. The efficiency effect is dominating the activity effect for almost the whole period covered in this study. The highest value that the activity index takes is 1.03 in 1980 while the highest value that efficiency index takes is 2.33 in 2003. The efficiency index remains above its base year value for almost the whole period covered. As a consequence, the aggregate intensity index is perfectly guided by the efficiency index in case of electricity consumption. As is shown in the figure, both the aggregate index and the efficiency index are increasing over time while the activity index remains static and sometimes is slightly below its 1972 level. The analysis shows that each unit of output produced in Pakistan uses more and more electricity with each passing year.

Fig. 4.3. Electricity Energy Indexes Trends



Given our analysis, the total electricity consumption of 71845 (GWH) in 2011 would have been 34215.9 (GWH) had the energy intensity remained at its base year level. This translates that our electricity consumption is 110 percent higher than would have been had the energy intensity remained at the level of the base year. We have shown above that most of the increase in the consumption of electricity is mainly driven by the inefficiency in the use of electricity. For instance, the change in economic activity causes the consumption of electricity to decrease by 4386.27 (GWH) in 2011 as compared to 1972. In contrast, the change in efficiency causes electricity consumption to increase by 42015.37(GWH) in 2011 as compared to 1972. The year-wise details for the whole period of the analysis are given in the appendix.

4.4. Discussion

We have shown above that the changes in efficiency guide the changes in intensity in case of gas and electricity while change in activities is a dominant factor in case of oil. There are definitely some cases where an increase in efficiency index in one sector was accompanied by a corresponding decrease in other sector.[8] In order to truly understand the dynamics of efficiency indices, we aggregate the indices and check whether the change in

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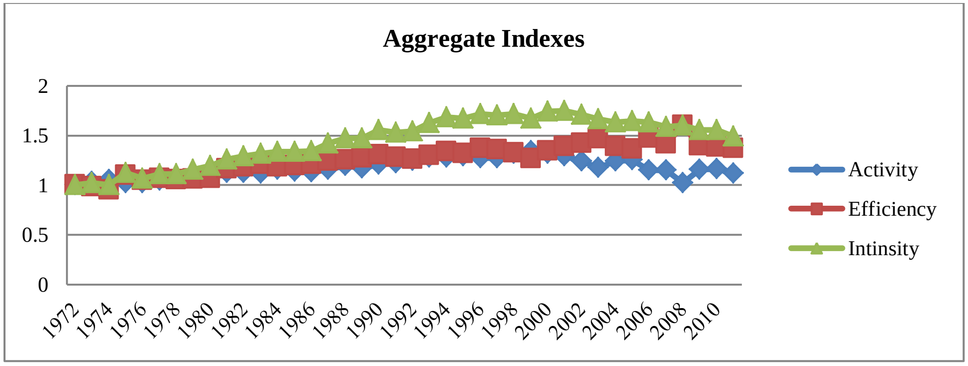
[8] For instance see the oil and gas efficiency indices after 2000.

efficiency is mere a transfer of activity from one component to another or is just a real wastage of energy. In this regard, we have taken the weighted average of the respective individual indices of each component. Weights are given according to the contribution of each energy component in the total energy consumption. This analysis is shown in Figure 4.4. The resulting aggregate activity index smoothly increases and reaches its maximum value 1.4 in 1999. This trend is mostly explained by the oil energy. However, after 2000, the index is falling, which may be due to the severe shocks to the gas supply and oil prices, which are evident throughout the first decade of this century. This demonstrates that the share of sectors using energy in the total gross value added is falling after 2000. The main justification is that in the initial decades of independence, our economy was moving away from less energy intensive agricultural sector to more intensive industrial sector. But in recent decades, the trend is completely different: both the agriculture and industry are losing their shares to another less energy intensive services sector. Given the sectoral transformation of the economy, this result is not surprising.

Fig. 4.4. Combined Indexes Trends



The aggregate efficiency index shows that increasing energy use per each unit of output is the dominant factor of the increase in intensity during the study period. The index is smoothly increasing for most of the period with the highest value of 1.6 for the year 2008. Ultimately, this has guided the change in energy intensity in Pakistan since 1972. It is clearly evident that after 1998, the fluctuations in this index are caused by the indices of gas and oil.

In conclusion, it is stated that energy intensity in Pakistan increases by 45 percent on average between 1972 and 2011. A critical feature of the increase is that 52 percent of the increase is caused by the inefficiency associated with the use of energy. Alternatively, for the same unit of output, we are using more energy now as compared to the per unit use of 1972. Most of the inefficiencies arise in the consumption of electricity, followed by gas sector. This translates into that oil sector is relatively efficient as we compare it with gas and electricity. In particular, the oil price hikes have beneficial effects on improving the efficiency in oil sector.

5. CONCLUSION

The study is motivated by the recent energy crises in Pakistan. Most of the existing literature in case of Pakistan deals with the energy prices and their impact on other macroeconomic variables like economic growth, inflation, employment etc. To our knowledge, there is no commendable work on the energy intensity side. We are filling this gap by providing a complete analysis of the energy intensity. Our analysis of energy is components-wise to see the trends in different components like oil, gas and electricity. The study, covering the period from 1972 to 2011, uses the decomposition method of Fisher Ideal Index. We disaggregate the change in aggregate energy intensity into changes in the efficiency and changes in the activities. Our analysis shows that aggregate energy intensity has steadily increased over time until the recent years. The consumption of electricity in 1972 was 7 percent of its consumption in 2011. At the same time, the gross value added in 1972 was 14 percent of its level in 2011. This implies that growth in the consumption of electricity is greater than the growth rate of gross value added.

According to our results, energy intensity in Pakistan increased by 45 percent on average between 1972 and 2011 and 52 percent of the increase is due to the worsening efficiency in its use. In other words, the use of energy per unit of output has increased significantly since 1972. The inefficiencies in the consumption of electricity are dominating, followed by the inefficiencies in gas sector. For instance, in case of electricity, the average index of efficiency is 1.82, which implies that a given amount of output is now produced with 1.82 (GWH) of electricity on average whereas the same amount of output required only 1 (GWH) in 1972. In comparison, the average value of activity index is 0.97, again in case of electricity, which is showing that the share of electricity intensive sectors in total gross value added is declining. In case of the consumption of gas, the average value of efficiency index is 1.29 and the average value of activity index is 1.11. It implies that the level of efficiency also has declined in case of the consumption of gas. Unlike electricity and gas sectors, the oil sector is relatively efficient. For instance, the average value of efficiency index in case of oil is 1.08 while the average value of activity index is 1.26.

In summary, the change in aggregate intensity is mainly caused by the inefficiencies. The main deriver of the change in aggregate energy intensity is electricity with its average intensity index of 1.75. The aggregate intensity of oil and gas is falling following the recent prices and supply crisis. Countries like China, USA, and India have experienced significant gains in the aggregate energy intensity over the past years. In these countries, improvements in efficiency are regarded as the catalyst behind the changes in energy intensity. In contrast, in Pakistan efficiency has worsened over time instead of improving. In general, the change in efficiency index in Pakistan seems to be somehow related to the price changes. For instance, whenever the price hikes have taken place, oil efficiency index has improved. Additionally, our analysis shows that energy sources with relatively low prices are more prone to increased inefficiencies. This is an important area for future research; in particular with relevance to policy formulation.

APPENDIX

The Construction of Fisher Ideal Index is given below

First we construct Laspeyres and Paasche activity and efficiency indexes. The Laspeyres activity and efficiency indexes are

$$L_t^{act} = \frac{\sum_i e_{i0} s_{it}}{\sum_i e_{i0} s_{i0}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \text{(A1)}$$

$$L_t^{ef} = \frac{\sum_i e_{it} s_{i0}}{\sum_i e_{i0} s_{i0}} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(A2)}$$

The Paasche activity and efficiency indexes are

$$P_t^{act} = \frac{\sum_i e_{it} s_{it}}{\sum_i e_{it} s_{i0}} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(A3)}$$

$$P_t^{ef} = \frac{\sum_i e_{it} s_{it}}{\sum_i e_{i0} s_{it}} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(A4)}$$

Now the Fisher ideal indexes for activity and efficiency are given as

$$I_t^{act} = \sqrt{L_t^{act} P_t^{act}} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(A5)}$$

$$I_t^{ef} = \sqrt{L_t^{ef} P_t^{ef}} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(A6)}$$

Using this we can construct the aggregate energy index (2.3) as below

$$e_t / e_0 \cong I_t = I_t^{act} I_t^{eff} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \text{(A7)}$$

Table A1

Descriptive Statistics of Sectors Included in the Analysis

		Economic Activity		Intensity	
Sector	Components	Mean	SD	Mean	SD
Household	Oil	2209813	1074383	0.3242	0.2077
	Gas	–	–	0.0317	0.0171
	Electricity	–	–	0.005	0.0027
Commercial	Oil	830726	526754	--	--
	Gas	–	–	0.0262	0.0171
	Electricity			0.0027	0.0004
Transport	Oil	274094	168383	20.4162	2.9852
	Gas	–	–	–	–
	Electricity	–	–	–	–
Agriculture	Oil	686997	293882	0.4062	0.2536
	Gas	–	–	–	–
	Electricity	–	–	0.0065	0.0016
Industry	Oil	698696	410210	–	–
	Gas	–	–	–	–
	Electricity	–	–	0.0152	0.0017
Industry Net of Electricity	Oil	617727	373753	1.8379	0.8543
	Gas	–	–	0.4281	0.0531
	Electricity	–	–	–	–
Electricity	Oil	80969	45366	29.98	20.7199
	Gas	–	–	2.3744	0.8548
	Electricity	–	–	–	–

Source: SPB, WB, Ministry of Finance, Hydrocarbon Development Institute of Pakistan.

Table A2

Oil Consumption Decomposition

Year	E-E^ (tonnes)	Activity Index	Change Due to Activity	Efficiency Index	Change Due to Efficiency
1972	0	1.00	0	1.00	0
1973	–71123.5	1.03	72154.99	0.94	–143278
1974	–99043.7	1.04	85272.88	0.93	–184317
1975	194409.1	1.02	41235.18	1.06	153173.9
1976	–15271.2	1.01	14929.45	0.99	–30200.7
1977	115246.5	1.02	51754.2	1.02	63492.28
1978	125501.8	1.04	120104.4	1.00	5397.38
1979	260575	1.07	226153.2	1.01	34421.72
1980	124849.2	1.08	254885.2	0.96	–130036
1981	85207.14	1.30	941485.5	0.79	–856278
1982	355269.5	1.29	1007013	0.85	–651744
1983	729035	1.27	1055317	0.93	–326282
1984	1150859	1.30	1251281	0.98	–100422
1985	1375348	1.28	1296462	1.02	78886.04
1986	1519733	1.26	1284095	1.04	235637.8
1987	2265023	1.28	1524955	1.13	740067.9
1988	2699635	1.30	1754870	1.15	944764.6
1989	2966072	1.24	1532993	1.22	1433079
1990	3544186	1.27	1833546	1.25	1710640
1991	3294799	1.29	1995895	1.18	1298904
1992	3842105	1.33	2464075	1.17	1378030
1993	4694140	1.37	2870828	1.22	1823312
1994	5603384	1.37	3106205	1.29	2497180
1995	5972654	1.39	3417268	1.28	2555386
1996	7047755	1.35	3425000	1.38	3622754
1997	6927567	1.37	3549863	1.35	3377704
1998	7679937	1.43	4397130	1.31	3282807
1999	7349618	1.44	4500968	1.26	2848649
2000	8151257	1.48	5075029	1.27	3076228
2001	7822836	1.46	4947586	1.25	2875250
2002	6749384	1.42	4499642	1.19	2249742
2003	5977893	1.36	4021050	1.16	1956843
2004	2140302	1.45	4494238	0.82	–2353936
2005	2400226	1.40	4444422	0.86	–2044195
2006	1617995	1.30	3494033	0.87	–1876038
2007	3009863	1.25	3347383	0.98	–337520
2008	3760082	1.10	1500483	1.15	2259600
2009	3292826	1.30	4108234	0.95	–815408
2010	4120181	1.29	4237332	0.99	–117152
2011	3378509	1.24	3596498	0.99	–217989

See text for Construction.

Table A3

Gas Consumption Decomposition

Year	E-E^(mm cft)	Activity Index	Change Due to activity	Efficiency Index	Change Due to Efficiency
1972	0	1.00	0	1.00	0
1973	8213.916	1.04	5362.295	1.02	2851.621
1974	–11474.9	1.09	–19557.6	0.97	8082.723
1975	23808.13	1.03	3889.607	1.15	19918.52
1976	19652.4	1.04	5600.364	1.10	14052.04
1977	27860.49	1.08	11433.79	1.11	16426.71
1978	27389.14	1.09	13890.4	1.09	13498.74
1979	36083.72	1.11	19236.49	1.10	16847.23
1980	55737.73	1.16	30087.99	1.14	25649.74
1981	81504.18	1.00	1036.355	1.44	80467.82
1982	88396.04	1.01	2743.793	1.43	85652.24
1983	90009.15	1.00	–208.002	1.43	90217.15
1984	82220.45	1.04	9948.178	1.32	72272.27
1985	81194.71	1.02	4156.875	1.32	77037.83
1986	84537.01	1.03	8233.405	1.30	76303.6
1987	89890.42	1.06	17273.95	1.26	72616.48
1988	102317.7	1.12	36863.71	1.22	65454.03
1989	96523.41	1.13	43193.57	1.17	53329.84
1990	130896.1	1.18	62182.63	1.20	68713.52
1991	136895.7	1.20	71403	1.18	65492.68
1992	133301.8	1.21	79328.93	1.14	53972.92
1993	150814.6	1.24	91252.58	1.15	59562
1994	174298.7	1.23	95780.51	1.19	78518.17
1995	151260.9	1.23	98560.72	1.12	52700.18
1996	161239.7	1.23	105035.9	1.12	56203.77
1997	168991.7	1.21	95931.31	1.15	73060.35
1998	164100.5	1.23	106536.4	1.12	57564.07
1999	173455.2	1.27	131420.5	1.08	42034.72
2000	234326.5	1.16	89841.59	1.27	144485
2001	278199.6	1.14	79586.36	1.38	198613.3
2002	319491.4	1.10	59631.08	1.49	259860.4
2003	343280.9	1.03	19946.36	1.60	323334.6
2004	482849.4	1.14	101100.6	1.63	381748.8
2005	541543.6	1.20	156607.3	1.56	384936.4
2006	567841.6	1.09	76096.43	1.72	491745.1
2007	520711.4	1.11	98938.83	1.57	421772.6
2008	549193	0.97	–31969.9	1.81	581162.8
2009	530910.8	1.08	77380.62	1.59	453530.1
2010	516655.6	1.10	96539.04	1.52	420116.5
2011	456385.8	1.06	55458.55	1.50	400927.3

See text for Construction.

Table A4

Electricity Consumption Decomposition

Year	E-E^(Gwh)	Activity Index	Due to Activity	Efficiency Index	Due to Efficiency
1972	0	1.00	0	1.00	0
1973	147.1306	1.00	14.25343	1.03	132.8772
1974	–20.094	1.01	76.58612	0.98	–96.6802
1975	271.3448	0.98	–92.2112	1.09	363.556
1976	210.6708	0.99	–34.184	1.04	244.8548
1977	263.4431	1.00	1.67046	1.04	261.7726
1978	967.3281	1.00	–1.69634	1.15	969.0245
1979	1142.583	1.02	127.4104	1.14	1015.173
1980	1899.576	1.03	272.4253	1.21	1627.15
1981	2314.522	0.97	–309.645	1.33	2624.167
1982	3040.936	0.97	–300.997	1.39	3341.933
1983	3748.127	0.96	–503.867	1.47	4251.994
1984	4830.246	0.96	–482.532	1.57	5312.778
1985	5155.73	0.96	–488.386	1.55	5644.115
1986	6518.233	0.95	–670.08	1.67	7188.312
1987	8319.675	0.96	–697.942	1.79	9017.617
1988	10721.78	0.97	–576.98	1.93	11298.76
1989	11343.9	0.96	–729.227	1.95	12073.13
1990	13043.9	0.96	–703.4	2.03	13747.3
1991	15001.11	0.95	–1043.28	2.15	16044.38
1992	16013.47	0.97	–706.488	2.13	16719.95
1993	18444.27	0.97	–650.369	2.23	19094.64
1994	17850.8	0.97	–840.403	2.16	18691.2
1995	19730.41	0.96	–1070.89	2.23	20801.31
1996	20562.7	0.96	–1156.37	2.21	21719.07
1997	20358.5	0.95	–1475.6	2.20	21834.11
1998	20956.88	0.96	–1298.36	2.18	22255.24
1999	19312.85	0.97	–893.759	2.02	20206.61
2000	20781.92	0.94	–1908.99	2.12	22690.91
2001	23440.61	0.94	–2022.77	2.24	25463.38
2002	24872.55	0.93	–2499.79	2.30	27372.35
2003	25961.16	0.91	–3157.89	2.33	29119.05
2004	28765.17	0.95	–2030.25	2.28	30795.41
2005	30233.22	0.97	–1383.39	2.19	31616.61
2006	34602.73	0.97	–1169.79	2.27	35772.53
2007	37391.74	0.98	–905.152	2.27	38296.89
2008	36803.11	0.94	–2926.09	2.30	39729.19
2009	33439.63	0.93	–3361.8	2.19	36801.43
2010	36181.78	0.92	–3992.01	2.27	40173.79
2011	37629.1	0.92	–4386.27	2.29	42015.37

See text for Construction.

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Comments

Energy intensity in Pakistan is more than double to that of the world average and more than five times to that of Japan and the UK. For resource constrained economies like Pakistan it is more cost effective to increase its energy security and ease supply constraints through efficiency in its use and conservation compared to exploiting/ building new sources of energy.

Energy efficiency is regarded as an important component in national energy strategy but so far it is the most neglected area in Pakistan's energy strategies and plans. In this context, this study is a significant attempt in terms of examining the change in energy intensity over the years and decomposing this change in terms of activity and efficiency. I have few suggestions:

Besides correcting some typo's and editorial mistakes which made it difficult for the reader to understand, some in-depth analysis on changes in energy intensity for the main economic sectors would make this study even more interesting and useful. Because when analysing energy intensity for Pakistan it is important as well as useful from policy perspective to identify those economic activities that are crucial to reduce energy consumption. Similarly, there is a need to highlight potential strategies and measures for improving the efficiency of final energy use with reference to particular economic activities. Since you have already collected energy consumption details at the sector level which might help you in some sort of discussion on efficiency of energy end uses for sub-activities. Moreover, while discussing and analysing energy intensities some discussion on electrification over the years would make the discussion more valuable. Likewise, when you are discussing positive changes in oil intensity it may be because of negative changes in other sources of energy.

Similarly, in the analysis of your results you can make some comparison with the studies for other countries. For instance, China has decreased its energy intensity significantly through improvement of energy efficiency; whereas structural-mix changes played a low, but positive role in decreasing the energy intensity. But in Pakistan as your results show it's the opposite. Similarly in India, energy efficiency also played a positive role, but, the industrial structure has become more energy-intensive because of the increasing share of energy-intensive sub-sectors, which offsets the impact of energy efficiency on energy intensity. So you need to discuss on how other countries have enhanced efficiency in the use of energy.

Even, you can compare your results with the previous study on Pakistan by Alam and Butt (2001) (you mentioned in your paper) to highlight the significance of your study and your results.

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