Energy mix and climate change in Pakistan

Syed Murtaza Nadeem
IBA Karachi

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Author: Syed Murtaza Nadeem – IBA, Karachi
Introduction
Rational of the Study
Literature Review
Proposed Model
Data
Data Visualization
Findings
Conclusion and Recommendations
Drawback of the Study
Introduction

Table of Contents: Key Themes in this Research Paper

Chronological timeline of literature on energy and climate change

Carbon emission and the link with energy mix

Coal Consumption and carbon dioxide emission

Multiple stakeholders in the energy mix decision making

Long term sustainability of energy mix.

Steps to up-scale renewable energy

Limitations of study, renewable energy and optimal energy mix
This chronology shows timeline of environment theories and major events

**Environment summit and conferences**
- **1979**: First World Climate Conference
- **1988**: Earth Summit (Rio), the UN Framework Convention on Climate Change (UNFCCC)
- **1992**: Intergovernmental Panel on Climate Change (IPCC) is set up.
- **1997**: The Kyoto Protocol is formally adopted, legally binds developed countries to emission reduction targets.
- **2005**: The first Meeting of the Parties to the Kyoto Protocol
- **2009**: Copenhagen Accord drafted. Non-binding pledges
- **2012**: The Doha Amendment to the Kyoto Protocol
- **2016**: Paris Agreement: To strengthen global response to the threat of climate change.

**Major agreements and accords on environment**
- **1979**: Intergovernmental Panel on Climate Change (IPCC) is set up.
- **1997**: The Kyoto Protocol is formally adopted, legally binds developed countries to emission reduction targets.
- **2009**: Copenhagen Accord drafted. Non-binding pledges
- **2016**: Paris Agreement: To strengthen global response to the threat of climate change.

**Theory and Academic Literature**
- **1979**: Concept of “Environmental Kuznets Curve” initiated.
- **1988**: Academic literature on usage of fossil fuel and impact on climate.
- **1992**: Link of energy production to climate change empirically proved by data.
- **2016**: Energy mix and impact of coal consumption on the emissions. Renewable energy upscale.

Source: https://www.un.org/sustainabledevelopment/climate-negotiations-timeline/
Rational of the study

Increasing greenhouse gas emissions pose risk to environment.

Energy sector is a major cause of carbon dioxide emission.

Excess emissions accelerate the global warming issue.

Growing energy demand likely to accelerate global warming.

Energy generation mix plays a vital role in determining emissions.

Risk of energy mix and climate change circularity.

Global crisis of energy mix and implications for Pakistan

Source: EDGAR, Fossil CO2 emissions of all world countries - 2020 Report, EUR 30358 EN

Power Industry Includes power and heat generation plants (public and auto-producers).
Other Industrial Combustion includes combustion for industrial manufacturing and fuel production.
<table>
<thead>
<tr>
<th>Author Name &amp; Year</th>
<th>Title</th>
<th>Country and/or Region</th>
<th>Methodology &amp; Econometric Tests</th>
<th>Key Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>V.G.R. Chandran Govindaraju, Chor Foon Tang 2012-2013</td>
<td>The dynamic links between CO2 emissions, economic growth and coal consumption in China and India</td>
<td>China and India</td>
<td>Method of cointegration &amp; Granger causality test is used to evaluate link of CO2 emissions, economic growth and coal consumption in China and India.</td>
<td>Results indicate variables are cointegrated in the case of China but not India. Granger causality test for China reveal a strong evidence of unidirectional causality running from economic growth to CO2 emissions.</td>
</tr>
<tr>
<td>Suhail Zaki, Farooqui 2013</td>
<td>Prospects of renewables penetration in the energy mix of Pakistan</td>
<td>Pakistan</td>
<td>A survey of the availability of various renewable energy sources, and their penetration prospects in energy mix.</td>
<td>It is estimated that Pakistan has the feasible potential of 30 GW of installed power capacity from hydel and 50GW of installed capacity from wind by 2030.</td>
</tr>
<tr>
<td>Helen Cabalu, Paul Koshy, Erwin Corong, U-Primo E. Rodriguez, Benjamin A. Endriga. 2015</td>
<td>Modelling the impact of energy policies on the Philippine economy: Carbon tax, energy efficiency, and changes in the energy mix.</td>
<td>Philippine</td>
<td>This paper develops a computable general equilibrium (CGE) model of the Philippine economy to analyze the effects of such climate change policy options in the period to 2020.</td>
<td>The modelling results indicate that given the current level of development in the Philippine electricity generation and transport sectors, even relatively modest measures have marked impacts one emissions with marginal economic impacts.</td>
</tr>
<tr>
<td>Syed Anees Haider Zaidi &amp; Danish, Fujun Hou &amp; Faisal Mehmood Mirza 2018</td>
<td>The role of renewable and non-renewable energy consumption in CO2 emissions: a disaggregate analysis of Pakistan</td>
<td>Pakistan</td>
<td>This paper develops empirical evidence from auto-regressive distributive lag (ARDL) model of data from 1970 to 2016.</td>
<td>Renewable energy consumption has an insignificant impact on CO2 emission in Pakistan while natural gas and coal are the main contributors to the level of pollution in Pakistan.</td>
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<td>Boqiang Lin, Muhammad Yousaf Raza 2019</td>
<td>Analysis of energy related CO2 emissions in Pakistan</td>
<td>Pakistan</td>
<td>Logarithmic Mean Divisia Index technique using data from (1978 – 2017) and scenario analysis.</td>
<td>Shift in population, activity effects and gross domestic product are important factors causing increase in CO2 emissions.</td>
</tr>
<tr>
<td>Daniel Balsalobre-Lorente, Muhammad Shahbaz, David Roubaud, Sahbi Farhani 2018</td>
<td>How economic growth, renewable electricity and natural resources contribute to CO2 emissions?</td>
<td>Europe (EU-5) (Germany, France, Italy, Spain, and the United Kingdom)</td>
<td>Carbon emission function to investigate the environmental Kuznets curve for 1985–2016 period.</td>
<td>The empirical results confirm the existence of an N-shaped relationship between economic growth and CO2 emissions in the EU-5 countries.</td>
</tr>
<tr>
<td>Muhammad Zeshan Akber, Muhammad Jamaluddin Thaheem, Husnain Arshad 2017</td>
<td>Life cycle sustainability assessment of electricity generation in Pakistan: Policy regime for a sustainable energy mix</td>
<td>Pakistan</td>
<td>In total, 20 sustainability indicators have been assessed covering life cycle of seven electricity generation sources, currently in use.</td>
<td>Hydropower is found as the most sustainable option having lowest environmental and economic impacts. While due to worst economic and social impacts, oil is found to be the least sustainable option for the country.</td>
</tr>
<tr>
<td>Selahattin Murat Sirin, Irem Sevindik 2021</td>
<td>An analysis of Turkey’s solar PV auction scheme: What can Turkey learn from Brazil and South Africa?</td>
<td>Turkey</td>
<td>LCOE analysis to demonstrate that the project is vulnerable to macroeconomic shocks and financial risks.</td>
<td>Model results show that the capacity factor is the most prominent factor in costs, and 10% change in the capacity factor affects the LCOE about the same rate.</td>
</tr>
</tbody>
</table>
Analysis & Proposed Model

The ARIMA model is denoted by ARIMA \((p,d,q)\) where “p” represents order of the auto regressive process, “d” is the order of the data stationary and “q” is the order of the moving average process.

ARIMA model can be written as:

\[
\Delta^d y_t = \delta + \theta_1 \Delta^d y_{t-1} + \theta_2 \Delta^d y_{t-2} + \cdots + \theta_p \Delta^d y_{t-p} + e_{t-1} - \alpha e_{t-2} - \alpha_2 e_{t-2} - \cdots - \alpha_q e_{t-2}
\]

where, \(\Delta^d\) denotes differencing of order \(d\), i.e., \(\Delta y_t = y_t - y_{t-1}\), \(1, \Delta^2 y_t = \Delta y_t - \Delta y_{t-1}\), and so forth, and \(y_{t-1}, \cdots, y_{t-p}\), are past observations (lags), and \(\delta, \theta_1, \cdots, \theta_p\) are parameters (constant and coefficient)

\(y_t\) represents \(\ln(\text{carbon dioxide emissions in Pakistan at time } t)\)

The steps which are followed in order to define an ARIMA model as stated by Box & Jenkins:

a) Identifying a model;
b) Estimating the parameters of the model;
c) Diagnostic checking.

Analysis of INDC Forecast

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<tr>
<td>Energy</td>
<td>85.8</td>
<td>168.47</td>
<td>171.44</td>
<td>185.97</td>
<td>898</td>
<td>11.1%</td>
</tr>
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<td>Agriculture</td>
<td>71.63</td>
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<td>174.56</td>
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<td>7.1%</td>
</tr>
<tr>
<td>Waste</td>
<td>4.45</td>
<td>7.24</td>
<td>10.55</td>
<td>12.29</td>
<td>89</td>
<td>14.1%</td>
</tr>
<tr>
<td>Total</td>
<td>182</td>
<td>330</td>
<td>374</td>
<td>405</td>
<td>1603</td>
<td>9.6%</td>
</tr>
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</table>

Source: Pakistan’s Intended Nationally Determined Contribution (PAK-INDC) Document

- As part of an international policy climate regime, governments are required to submit Intended Nationally Determined Contributions to achieve stabilization of GHG.
- Pakistan’s submission shows alarming levels of emissions increase from energy sector.
- This is primarily due to capacity additions in non-renewable projects specifically coal power projects.

ARIMA Model For Carbon dioxide forecasting

Inventory of GHG Emissions (in MT CO2-equivalent) and projected emissions for 2030

<table>
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</table>

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### Carbon dioxide emission
- **Type:** Time Series Data
- **Unit:** Mt of Co2/ year
- **Periodicity:** Annual
- **Series – Years:** 1991 – 2019
- **Source:** EDGAR, Fossil CO2 emissions of all world countries - 2020 Report

### Coal Consumption
- **Type:** Time Series Data
- **Unit:** Tonnes
- **Periodicity:** Annual
- **Series – Years:** 1991 – 2019
- **Source:** Energy Yearbook Pakistan (Various Editions)

<table>
<thead>
<tr>
<th>Summary Statistic</th>
<th>Co2 Emission (Mt)</th>
<th>Total Coal Consumption (tonnes)</th>
<th>Coal Consumption in power sector (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>135</td>
<td>6,786,380</td>
<td>544,554</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>42.70</td>
<td>4,421,858.34</td>
<td>1,306,545.19</td>
</tr>
<tr>
<td>Variance</td>
<td>1,823</td>
<td>19,552,831,210,221</td>
<td>1,707,060,344,141</td>
</tr>
<tr>
<td>Coefficient of Variation=sd/x</td>
<td>0.32</td>
<td>0.65</td>
<td>2.40</td>
</tr>
<tr>
<td>Min</td>
<td>67</td>
<td>3,042,839</td>
<td>24,603</td>
</tr>
<tr>
<td>Maximum</td>
<td>224</td>
<td>21,527,068</td>
<td>5,901,536</td>
</tr>
<tr>
<td>Range</td>
<td>157</td>
<td>18,484,229</td>
<td>5,876,933</td>
</tr>
<tr>
<td>Quartile 1 - 25th percentile</td>
<td>99</td>
<td>3,461,444</td>
<td>104,604</td>
</tr>
<tr>
<td>Quartile 2 - 50th percentile</td>
<td>132</td>
<td>6,557,452</td>
<td>164,397</td>
</tr>
<tr>
<td>Quartile 3 - 75th percentile</td>
<td>158</td>
<td>8,138,503</td>
<td>346,549</td>
</tr>
<tr>
<td>Quartile 4 - Max Value</td>
<td>224</td>
<td>21,527,068</td>
<td>5,901,536</td>
</tr>
<tr>
<td>Interquartile Range = Q3-Q1</td>
<td>59</td>
<td>4,677,059</td>
<td>241,945</td>
</tr>
</tbody>
</table>

Published by iRepository, 2021
Data Visualization

Pakistan Co2 emission and coal consumption

Co2 Emission forecast using R

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ARIMA Model

Model Selection Criteria

• Checked model fitting by using various combinations as well.

• Checked for the lowest AIC, and BIC for the best parameters.

• R Code for the model for checking fitting of Seasonal ARIMA model
  `sarima(lnco2emission.ts, 1, 1, 2)`

• R code for the plot of ARIMA forecast on the next page
  `sarima.for(Co2emissionpakistan.ts, n.ahead = 31, 1, 1, 2)`

Source: Data: EDGAR Co2 emissions JCR Report.
Chart: R – R studio for calculations and forecast using ARIMA
Conclusion and Findings

- As per academic research, emissions are linked to energy production and GDP.

- A CAGR of 9.6% depicts overestimation in emissions, as past statistics show gradual increase in emissions as a percentage of GDP.

- While conducting cointegration tests between coal consumption and carbon dioxide emission in Pakistan, existence of a long run relationship can be seen.

- Causality test reveal uni-directional causality from coal consumption towards carbon emission.

- Although the causality of coal consumption in power sector and carbon dioxide emission does not show significant causality at this stage, but the incoming coal power projects under CPEC are expected to hike the coal consumption in power sector.

- In the above scenario, power sector coal consumption is expected to cause a surge in carbon dioxide emissions in the future years.

In the above scenario, power sector coal consumption is expected to cause a surge in carbon dioxide emissions in the future years.

INDC forecasts depict overestimation but increasing coal consumption trajectory can act as catalyst.

Forecasts carbon dioxide emissions of Pakistan in 2050 using ARIMA

- Based on the forecast results, the carbon dioxide emissions are expected to reach ~350 Mt which is a drastic increase of more than 100 Mt.

- Therefore, the government should rethink the policy about how to reduce the emissions to prevent further climate change disasters.

- The forecast result also shows the grey boundary around the red forecast line. It basically indicates the standard error from the forecast result. Emission forecasting is difficult so it has greater intervals.
Conclusion and Discussion

Emissions & INDC forecast indicate upcoming energy policy and environmental issues

- **Targets**
  - The government should set targets for renewable energy to develop a diversified energy mix.

- **PPA**
  - Just like power purchase agreements are decided to be renegotiated with the IPPS, similarly the government should consider the same with CPEC based coal power projects.

- **Energy Dynamics**
  - While NEPRA may argue that these power projects were approved at a time when there was power shortage, the current situation has changed, and the country has an energy surplus.

- **Steps**
  - Various steps can be taken to upscale the renewable energy in Pakistan which we discuss in next few slides.

- **Downsides**
  - Renewable energy also has limitations which are considerable in case of Pakistan.

- **Stakeholders**
  - Multiple stakeholders such as federal government, provincial government, lobbies, public, pressure groups make decision making even more difficult in energy business.
**Conclusion & Recommendations**

**Findings & Implications**

**Energy Policy**
- Worsening indicators depict that government should reconsider CPEC coal power projects and at least renegotiate PPA’s.
- Government should focus on a diversified energy mix and incorporate climate factors in energy policy.

**Environment Policy**
- While governments discuss climate change, they fail to show any understanding of energy and environment link.
- Environmental policy should consider energy mix and production as well.

**Optimal Energy Mix**
- Optimal energy mix is the diversified energy mix that meets the energy needs of the country with a limited surplus and is both economically & environmentally sustainable for the current & future generations.

**Policy Implications**
- Government should aim to target optimal energy mix by decreasing coal usage in power sector and increasing renewable energy for diversification in energy mix.

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**Limitations of Study**

**Limitations of ARIMA**
- ARIMA as well because it forecasts linearly and assumes that there is no change in government policy. It only uses past data of emissions to forecast.

**Limitations of Causality**
- Granger causality is not a true causality test. It may produce misleading results when the true relationship involves three or more variables.

**Data Limitations**
- Carbon dioxide emissions can be attributed to concentration of industries and coal power plants in certain cities and also includes spillover effects of pollution from neighboring countries especially India and China.
- Specific formulae is used for Co2 emissions which varies.
- Pakistan energy yearbook mentions that sectoral data consumption of coal is mostly not available, except for power sector and has therefore been estimated to calculate the total coal consumption in Pakistan.

**Limitations of Renewable Energy**

**Variable Output Nature**
- Renewable energy generation is variable in nature due to weather and climate.

**Storage Cost and Technology**
- With the improvement in technology in solar panel photo-voltaic (PV) is now cheaper however battery storage technology is still expensive.

**Peaking Season Issues**
- Limited benefit in peaking season in comparison to fossil fuels

**Argument of Unemployment**
- Renewable energy is not labour intensive, therefore transition may lead to unemployment.

Therefore, a diversified sustainable energy mix is optimal.
Thank You
The share of oil and gas has dominated Pakistan’s energy generation mix over the past decade.

Share of coal has recently increased in 2019 to 12.3% from 0.2% in 2013. As per NEPRA, Coal’s share in power generation surged to 25% in October 2019.

China, India and USA are major consumers of coal, contributing to about half of the world's carbon dioxide emissions. In its recent report IMF, (World Economic Outlook Oct 2020) mentions that many countries are taking steps to reduce their dependence on fossil fuels, especially coal, as they seek to pursue a more sustainable future. Due to high carbon intensity, coal accounts for just under half of global CO2 emissions and nearly three-quarters of all power sector CO2 emissions. In the absence of pollution mitigation systems, it contributes to local air pollution, with potentially severe damaging effects on human health (Smith et al., 2004).
Granger Causality Model

\[ Y_t = \sum_{k=1}^{p} \alpha_k X_{t-k} + \sum_{l=1}^{q} \beta_k Y_{t-l} + \epsilon_t \]

\[ X_t = \sum_{i=1}^{m} \alpha_i X_{t-i} + \sum_{j=1}^{n} \beta_j X_{t-j} + \epsilon_t \]

\( Y_t = \log \text{carbon dioxide emission in Pakistan} \)
\( X_t = \log \text{coal consumption in Pakistan} \)

within which \( \epsilon_t \sim N(0, \delta_{\epsilon}^2) \) and \( \epsilon_t \sim N(0, \delta_{\epsilon}^2) \)

Null Hypothesis Ho: \( \beta_1 = \beta_2 = \ldots = \beta_j = 0 \)
Alternate Hypothesis Ha: At least one parameter of \( \beta_j \neq 0 \)

If there are at least a parameter value of \( \beta_j \) not zero, which indicates that the equation of null hypothesis does not hold, it proves that \( X_t \) (Coal Consumption) does strictly Granger cause \( Y_t \) (Carbon dioxide emission).

ARIMA Model For Carbon dioxide forecasting

The ARIMA model is denoted by ARIMA \((p,d,q)\) where “p” represents order of the auto regressive process, “d” is the order of the data stationary and “q” is the order of the moving average process.

ARIMA model can be written as:

\[ \Delta^d y_t = \delta + \theta_1 \Delta^d y_{t-1} + \theta_2 \Delta^d y_{t-2} + \ldots + \theta_p \Delta^d y_{t-p} + e_{t-1} \alpha e_{t-1} - \alpha_2 e_{t-2} \alpha_q e_{t-2} \]

where, \( \Delta^d \) denotes differencing of order \( d \), i.e., \( \Delta y_t = y_t - y_{t-1} \), \( 1 \), \( \Delta^2 y_t = \Delta y_t - \Delta y_{t-1} \), and so forth, and \( y_{t-1}, \ldots, y_{t-p} \), are past observations (lags), and \( \delta, \theta_1, \ldots, \theta_p \) are parameters (constant and coefficient)

\( y_t \) represents \( \ln(\text{carbon dioxide emissions in Pakistan at time } t) \)

The steps which are followed in order to define an ARIMA model as stated by Box & Jenkins:

a) Identifying a model;
b) Estimating the parameters of the model;
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