ASSESSMENT OF GLOBAL CARBON DIOXIDE EMISSION AND WARMING WITH A FOCUS ON PAKISTAN

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ABSTRACT

The global emission of Green House Gases (GHGs) is on the rise since the era of industrialization (ca. 1750s), with a current global monthly average of slightly more than 400 ppmv for CO_2[#]. This has resulted in rise in mean surface temperature of Earth, commonly referred to as Global Warming (GW). The need to reduce this accelerated global emission of GHGs developed the concepts, such as climate stabilization, and climate change engineering. The United Nations Framework Convention on Climate Change (UNFCCC) was thus proposed more than two decades ago to provide a global platform to negotiate protocols for reduction of GHG emissions. Under the assumption of GW being dominantly due to GHG emissions, Kyoto Protocol was proposed almost two decades ago. Since then several amendments to the Kyoto Protocol have been brought forward with a common goal of GHG emission reduction by committing nations. Because of asymmetric emission of GHGs globally, concept of Carbon trading was coined. Pakistan, being a ratifying party to Kyoto Protocol, has currently several options to implement Carbon trading. Twenty third conference of parties to UNFCCC (COP23), expected to be held in Germany, in November 2017, provides an excellent opportunity for Pakistan to reiterate its commitment and to exercise its options to shape its sustainable economy for coming decades by taking advantage of asymmetric GHG emissions.

Keywords: *Carbon Dioxide emissions, Global Warming, Statistical Analysis, UNFCCC, Kyoto Protocol, Pakistan.*

1. INTRODUCTION

The objective of this review article is to present some statistics related to Carbon Dioxide (CO_2) emissions and global warming in the context of Pakistan. This would provide a background scientific reading for the forthcoming 23rd international meeting of parties to United Nations Framework Convention on Climate Change (UNFCC)/Kyoto Protocol (COP23/CMP13) being held in November 2017. The increased CO_2 emissions and associated global warming are currently evolving discourses in climate change science studies (see, for instance, Weart, 2015).

The available discourses on global and regional Carbon emissions are too numerous to be summarized in such a short review article. Furthermore, they are expanding at a rapid pace. Therefore, only selected and subjective topics have been addressed in this review article.

2. DOMINANCE OF CARBON EMISSION IN GREEN HOUSE GASES

The concentration of emitted CO_2 is the highest among the other Green House Gases (GHGs) (CH_4, N_2O, HFCs, PFCs, and SF_6) as suggested in the Kyoto Protocol. In fact, in recent decades, global CO_2 emission is higher by several orders of magnitude than the rest of above listed GHGs. A main concern with CO_2 is its somewhat uncertain but long staying time in atmosphere, resulting in a significantly bigger contribution to global warming as compared to other GHGs, such as CH_4 (Stocker, et al., 2013). The alarming rate of rising concentration of GHGs, in particular, the CO_2, is of concern both for scientists and policy-makers.

Since 1958, the results of CO_2 emission observations reported from Manua Loa observatory, Hawaii, USA, are considered to be representative of global Carbon emissions (Keeling, 1960; Keeling, et al., 1976). The time series of CO_2 emission is now commonly known as Keeling curve. Manua Loa is a barren lava field of an active volcano situated at 19°32' N, 155°35' W, and 3397 m above mean sea level, in the state of Hawaii in the Pacific ocean in USA. Although now the Carbon emission is measured at more than 100 locations, globally (Gurk, et al., 2008; Matsueda, et al., 2015; Sweeney, et al., 2015; see also http://www.esrl.noaa.gov/gmd/), including recent attempts to map the atmospheric content of CO_2 using remotely sensed data (Watanabe, et al., 2015). The global monthly CO_2 emissions have both regional as well as seasonal variability (Guo, et al., 2015).

3. RELATION BEWTEEN CARBON DIOXIDE EMISSION AND GLOBAL WARMING: CALLENDAR EFFECT

It is worthwhile to briefly touch upon these two topics and the possible connection between the two. Apparently, Guy Stewart Callendar, an English steam engineer, building upon earlier works, was the (first)

[#] In this article, CO_2 emissions and Carbon emissions are used interchangeably.

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one to systematically study the connection between Carbon emissions in the atmosphere, the absorption and emissions spectra of CO_2 in the atmosphere, and the global temperature rise (Callendar, 1938). A modern description of all of his works including a complete biography is available in Fleming (2007). Callendar i) showed that the anthropogenic contribution is higher than the natural CO_2 in the atmosphere and ii) included the impact of vertical thermal structure of earth, pressure broadening of line widths, the information that was not available to his previous research workers, while studying the absorptive properties of CO_2, and showed that the increase in the atmospheric CO_2 concentration of the atmosphere alters the altitude and thus raises the effective radiating temperature of the sky radiation reaching the ground. This is referred to as Callendar effect or the theory of GHGs.

Figure-1 displays the frequency distributions of emitted CO_2 (ppmv) concentrations and the northern hemisphere surface temperature anomaly, T (°C), and their scatter plot with a regressed fit indicating that a linear relationship between CO_2 and T accounts for 76% of proportion of variability, during the recent 50-year period (1961–2010). That is, more than half of the northern hemisphere warming may be attributed to the rise in emitted CO_2 concentrations. An exponentially regressed fit is found to explain somewhat less proportion of variability. The annual CO_2 emission data plotted in Figure-1 were obtained from Carbon Dioxide Information Analysis Center (CDIAC), Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, USA (http://cdiac.ornl.gov/). The anomaly based annual surface temperature dataset was obtained from Climate Research Unit at University of East Anglia, UK (http://www.cru.uea.ac.uk/). The presence of a linear trend and an oscillatory residual in the time series of emitted global concentration of CO_2 and surface temperature anomaly was also noticed for the same period. This is a statistical relationship only without taking into account any dynamics of mechanisms involved. More detailed statistical analysis of the relationship between the emitted concentration of CO_2 and T that takes into account the time ordering of the CO_2 data is also available (Sun and Wang, 1996).

In contrast to simple modeled instantaneous relationship between anomaly-based surface temperature and the CO_2 emissions, briefly mentioned above, it has already been noticed that the change in absolute surface temperature has a logarithmic response to CO_2 emissions, relative to a predefined baseline period (Callendar, 1938). The logarithmic response ensures saturation in change in absolute temperature as a result of increasing CO_2 emissions. Anderson, et al., (2016) provides a detailed historical description of Arrhenius' and Callendar's works including an analytic formula for the logarithmic response to CO_2 emissions following Callendar's earlier calculation. Considerable and wide ranging interest in the climate science community exists over this topic[*].

In addition to statistical relationships between the emitted concentration of CO_2 and T, the climate model based relationships between the two are also extensively studied for the twenty first century (see, for instance, Wigley and Schlesinger, 1985; Friedlingstein, et al., 2006; Allen, et al., 2009; Matthews, et al., 2009; Raupach, et al., 2011; Stocker et al., 2013; MacDougall and Friedlingstein, 2015). The climate model based limits of CO_2 emissions to remain below the climate stabilization target of 2°C rise in surface temperature (Meinshausen, et al. (2009)).

4. CLIMATE STABILIZATION TARGETS

Climate stabilization is currently considered in terms of amount of atmospheric concentration of CO_2 to be limited or reduced. For instance, for a 2°C equilibrium global average warming, the Carbon emission needs to be between 370 and 540 ppmv, with the best suggested value of 430 ppmv (National Research Council, 2011). As of July 2015/July 2016, the monthly average CO_2 at Mauna Loa was 401.30/406.81 ppmv (for update see, http://www.esrl.noaa.gov/gmd/ccgg/trends/). A considerable change in a range of socio-economic factors occurs as a result of per degree rise in equilibrium global average temperature (Edenhofer, et al., 2014). These include, but are not limited to, crop yield decease, sea level rise, recurrent occurrence of severe floods and droughts, and hence change in climate, both at regional and at global levels. Because of the time lags among interacting components in the Earth's climate, as well as because of the longevity of CO_2 lifetime in atmosphere of Earth (30–95 years, according to one estimate), a time scale

[*] For a physical description of this logarithmic dependence, the reader is referred to a blog site maintained by Mrs. Clive Best (http://clivebest.com/blog/?p=2241), whereas for an analytic description, the reader is referred to an unpublished article by Harvey Lam (http://www.princeton.edu/~lam/documents/LamAug07bs.pdf).

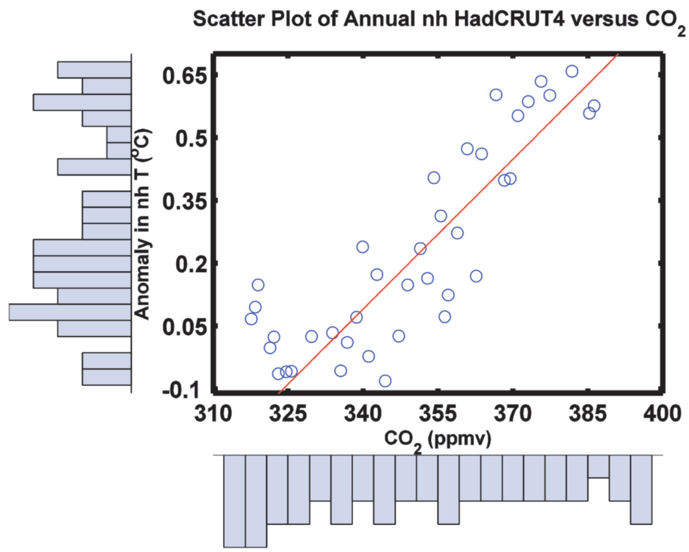

Figure-1: Bivariate Distributions of CO_2 Emissions (ppmv) and Northern Hemisphere Anomaly in T (°C), including their Scatter Plot During the Recent 50-year Period (1961–2010). The Continuous Straight Line is a Linearly Regressed Fit for the Paired Open Circles Values.

of centuries is involved to obtain climate stabilization and reversibility (see, for instance, Inman, 2008). This longevity estimate is based on the current understanding of Carbon cycle. This lag has led to the concept of transient and equilibrium warming. A consequence of this mechanism is that irrespective of when the concentration of CO_2 is reduced, global warming will continue for decades to centuries. This is not the case for other GHGs, for which the warming effect lasts for few decades only. In fact, a reduction of more than 80% in atmospheric concentration of CO_2 is required to stabilize the CO_2 concentration at century scale, at any time. The increase in global surface temperature also leads to change in extreme climate events, such as extreme precipitation events (Athar, 2014; Hegrel, et al., 2015).

5. UNFCCC AND KYOTO PROTOCOL

Given the above mentioned growing evidence in favor of rise in mean surface temperature, international concerns started shaping in the form of international discussion groups, especially at UN Headquarters in New York, USA, to address the causes of it. A multi government organization panel was thus formed, now known as IPCC in 1988 (Agrawala, 1998).

Kyoto Protocol was initiated in 1995 to address the issues related to global warming that were not covered by Montreal Protocol (UNFCCC, 2015). Montreal Protocol mainly addresses the concerns related to ozone layer depletion in the upper atmosphere. There are two key assumptions, upon which Kyoto Protocol is based upon. It is assumed that i) global warming is occurring, and that ii) Carbon emission is a dominant cause of it. Kyoto Protocol is a comprehensive 28 article document linked to UNFCCC, which commits its parties (as listed in its Annex-I) by setting internationally binding emission reduction targets. The main goal of the Kyoto Protocol is to constrain emissions of the main GHGs in ways that reflect underlying national differences in GHG emissions, wealth, and capacity to make the reductions. It is a legally binding document to its Annex I party countries. The Kyoto Protocol was presented and adopted in Kyoto, Japan, on 11 December 1997. The detailed rules of implementation of the Kyoto Protocol were adopted in Marrakesh; they are referred to as Marrakesh accord. After the condition that at least 55 members rectify it, which was met in 2005, its first commitment period started in 2008, and ended in 2012. Its second commitment period started in 2013 and will end in 2020. During the first commitment period, parties committed themselves to reduce GHG emissions to an average of 5% below 1990 levels (which was 354 ppmv). During the second commitment period, parties committed themselves to reduce GHG emissions by at least 18% below 1990 levels. Several amendments to Kyoto Protocol were made. These include adoption of Doha Amendment on 8 December 2012.

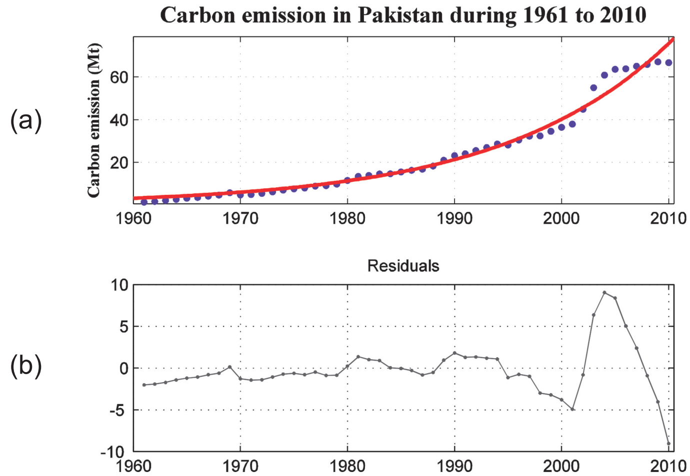

Figure-2: (a) The Gaseous Fuel Based Carbon Emission (Mt) in Pakistan during 1961-2010, the Solid Continuous Line Represents a Regression Fit. (b) the Residuals of the Regression Fit, Displaying an aperiodicity of Varying and Progressively Increasing Amplitude.

Considerable discussions are available on the definition and mechanisms of technology transfer in the context of Carbon trading, given the institutional capacity of the developing countries to capitalize on the technology transfer (Haselip, et al, 2015). Briefly, Kyoto Protocol offers the following three mechanisms to reduce CO_2 emissions:

i) International Emissions Trading (IET or EIT),
ii) Joint Implementation (JI), and
iii) Clean Development Mechanism (CDM).

The IET is meant for Annex II parties to Kyoto Protocol, those who have accepted targets for limiting or reducing the CO_2. The EIT, as set out in article 17 of the Kyoto Protocol, allows countries that have emission units to spare - emissions permitted them but not used - to sell this excess capacity to countries that are over their targets. The JI, as set out in article 16 of the Kyoto Protocol, is for those parties to Kyoto Protocol who have their own standards of reduction in CO_2, whereas the CDM, as set out in article 12 of Kyoto Protocol, is meant for developing countries, who have not yet set standards for reduction of CO_2. These mechanisms are based on the principle that no matter where the gases come from, the impact on environment is the same, and the reduction in emissions should come from the places where it will cost the least. Pakistan is a non-annex I party to Kyoto Protocol and has implemented the CDM mechanism (http://www.cdmpakistan.gov.pk).

6. CARBON EMISSION AND WARMING IN PAKISTAN: PAST, PRESENT AND FUTURE

Figure-2 indicates that the rise in Carbon emission (Mt) due to gaseous fuel consumption is almost exponential in Pakistan during 1961 to 2010. The annual CO_2 emission data for Figure-2 was obtained from CDIAC. A low amplitude oscillatory component can be seen in the residuals, with a gradual increase in amplitude after 1990. In this dataset, slight increase in 2003 and 2004 occurs and then a leveling off occurs. The data fits with an exponential function with 97% proportion of variance of data accounted for, and with an increasing rate of 6%/year.

According to Carbon emission inventory of Pakistan for 2008, the Carbon emission of Pakistan accounts for less than 1% of global Carbon emission. The 2008 inventory indicates that the dominant contribution in this Carbon emission by Pakistan is from CO_2, which is 54%, followed by CH_4, which is 36%. The energy sector is the largest single contributor to GHG emissions in Pakistan, which is nearly 51%, followed by the Agriculture sector, which is nearly 39%.

Figure-3 displays the interannual variability of surface temperature over Pakistan using observed as well as multi (climate) model-based datasets, both from AR4 and AR5 groups, for 1961–2010, following Asmat and Athar (2015). The observed (re-analysis based) gridded temperature dataset was obtained from a USA-based website (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html), and is abbreviated as NCR. In the AR4 group of models, the

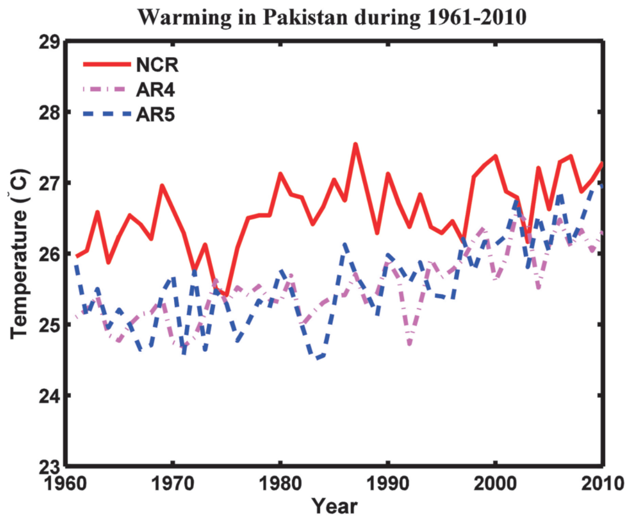

Figure-3: Inter-annual Variability of Surface Temperature (°C), Over Pakistan Using the Observed Gridded Dataset (NCR), and Using Two of the State-of-Art Atmospheric Ocean Coupled Climate Models (from AR4 and AR5). All Three Datasets Display an Increasing Linear Warming Trend

following coupled atmospheric ocean general circulation models were used: 20C3M and A1B versions of GFDL-CM2.0 and GFDL-CM2.1, whereas in the AR5 group of models, GFDL based models with representative concentration path way suggesting a CO_2 emission of 4.5 watt/m^2 by the end of twenty first century (RCP4.5) are employed. For validation details of GDFL based models over Pakistan, see Asmat and Athar (2015). All three temperature datasets were re-gridded to a common 2°x2° grid prior to analysis. The NCR data displayed more interannual variability relative to mean of climate models, both in AR4 and AR5 groups, with a linear warming trend of 0.17°C/decade with proportion of variation accounted for, R2=26.50%, whereas AR4 (AR5) based models displayed a linear warming trend of 0.25°C/decade (0.29°C/decade) with R2 = 56.10% (48.80%), respectively. Comparatively, this warming rate is less than half of that in Saudi Arabia, which is 0.60°C/decade with R2 = 65.00%, in recent decades (Almazroui, et al., 2012).

Figure-4 displays the spatial distribution of Carbon emission in the neighboring countries of Pakistan as of 2010, taken from CDIAC. The darker the color of a country on the map, the higher its Carbon emission. The highest Carbon emitters in the neighboring countries include Russian Federation (877 Kt), Iran (294 Kt), and China (197 Kt).

The Government of Pakistan presented its plans to reduce the Carbon emissions via a seven-point Intended Nationally Distributed Contribution (INDC) to COP 21, which was held in Paris in December 2015. This INDC is available from Ministry of Climate Change website cited in further reading, late in this review article. However, this 300-word INDC by Pakistan reflects more the need for preparation of a reliable national Carbon inventory so that quantitative estimates for Carbon reduction can be communicated by Pakistan in future. In contrast, among developed countries, USA suggested to achieve 26% to 28% reduction in CO_2 emission from all of its energy sectors by 2025 relative to 2005 levels, based on its national Carbon inventory.

An aim of COP21 was to propose a universal binding agenda on reduction of Carbon emissions. By now, 162 countries out of 196, have already submitted their INDCs to COP21/Paris 2015 conference secretariat. More than 180 countries producing more than 90% of global emissions had submitted their INDCs to COP21. Additionally, the commitments by non-governmental players, such as cities and regions were surprisingly quite numerous.

In general, the COP21 findings emphasized the requirements that all parties report regularly on their emissions and implementation efforts, and undergo international reviews. This includes the communication of new INDCs every five years, containing information necessary to track progress made in implementing and achieving their INDCs. Although, operational details of the new framework were left to be decided by future COPs.

Figure-4: Spatial Distribution of Carbon Emissions (Kt) in Asia Neighboring Pakistan as of 2010 (CDIAC-2015). Timor-Leste, Mongolia and Nepal are Among the Least Carbon Emitting Countries. Pakistan's Contribution is 66.7 Kt as Compared to India's 98.5 Kt. The Darker the Blue Shade, the Higher the Carbon Emission.

The COP22 was held in Morocco in November 2016. The aim being to enter into agreement for parties to start implementing the Paris Agreement reached during COP21. In general, COP22 reaffirmed the commitments laid out in COP21 as declared in Marrakech action proclamation, including the reaffirmation of USD$ 100 billion mobilization goal by Developed Country Parties, as well as a call for common vision for accelerating climate action. Other highlights include the development of progress tracker based on the goals set out in COP21.

7. ROAD AHEAD: COP23 AND BEYOND

The COP23 is expected to be held in November 2017 in Bonn, Germany, with the aim to assess the progress in achieving the targets for global CO_2-emission reduction agreed upon in Paris during COP21.

Based on the mitigation strategies proposed in INDCs submitted to COP21, Sanderson et al. (2016) have presented details of several idealized RCPs to achieve the 1.5° and 2.0° C warming targets by the end of 21st century, as a function of annual CO_2 emissions, relative to unmitigated baseline RCP8.5 (high emission scenario), and as a function of mitigation starting year. An ensemble of perturbed versions of the Integrated Science Assessment Model (ISAM) was used to assess the uncertainty in the idealized RCPs, under the assumption that intermediate complexity ISAM mimics well the RCP2.6 (low emission mitigation) scenario in the Coupled Carbon Cycle Climate Model Intercomparison Project (C4MIP) models. It was concluded that a 10% cut in GHG emissions by 2030 (relative to 2015) could likely achieve 2°C target with RCP2.6 level like negative subemissions (-1.5 Gt CO_2/yr)*. For a further discussion on these estimates, see Crane (2016).

The road ahead is not free from challenges for Pakistan. It has been brought to notice through several studies that considerable political will is required to overcome several culture based societal hurdles (Sher, et al., 2011). For instance, in the energy sector, the electricity generation is a selected societal sector where mitigation has to be implemented, as tentatively selected by Pakistan. Within this sector, challenges for environmental-friendly and low Carbon electricity generation include awareness barrier, economic barrier, financing barrier, institutional barrier, and policy and regulatory barriers.

8. CONCLUSIONS AND RECOMMENDATIONS

More awareness at grass-root levels is needed around the world about the adverse consequences of accelerated rates of emission and then accumulation of Carbon in the atmosphere so that more systematic and coherent efforts can be made and sustained at policy-making levels. Specifically, for Pakistan, it is imperative to:

- Get propriety rights for Green technology;
- Eradicate poverty and establish Green industries

* For details of RCPs, see http://www.pik-potsdam.de/~mmalte/rcps/.

that are low on Carbon emissions;
- Develop and maintain more comprehensive national GHG inventory.

These must start with a strong political will towards sustainable environment. More efficient Green technologies are being created along with changing political dynamics both locally and regionally. This calls for a constant dialogue among various national stakes holders to come up with more comprehensive and feasible Carbon reduction plans at short, medium and long-term time scales.

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FURTHER READING

Excellent sources of updated information on science (Stocker, et al., 2013), and policy aspects (Edenhofer, et al., 2014; Field, et al., 2014; Barros, et al., 2014), of global as well as regional CO_2 emissions and likely associated warming are presented in fifth annual report (AR5) of Intergovernmental Panel on Climate Change (IPCC). For a more detailed description of the topics covered here, the reader is referred to the above excellent sources. For updated information on global Carbon measurements, see www.esrl.noaa.gov/research/themes/carbon/. Furthermore, for Pakistan specific information, several sources are available; these include but not limited to websites by Government of Pakistan, such as Ministry of Climate Change website (www.mocc.gov.pk). In particular, a vast amount of analyzed information on various aspects of climate change issues is continuously provided by governments and semi-government organizations globally, including World Bank, non-profit organizations, as well as electronic media based community sites (see, for instance, http://www.rmets.org/paris_climate_communique). The interested reader is referred to these mainly online sources of updated information: the level of discussions vary considerably in these updated sources of information, ranging from expert opinions in internationally refereed journals to amateur discussions and from subject specialists' deliberations to beginner level illustrative conversations. All cited references and sources of information in this brief review article thus can only be considered as representative ones rather than exhaustive ones.

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