

# 1. Introduction

---

*'We underline that climate change is one of the greatest challenges of our time. We emphasize our strong political will to urgently combat climate change in accordance with the principle of common but differentiated responsibilities and respective capabilities. To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2°C, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change.'*

Copenhagen Accord, 18 December 2009

## **Greenhouse Gases**

Climate change poses the greatest challenge for humankind today as its implications on a global level are as serious as the mitigation efforts required. During the periods with instrumental records extending from 1860 onwards, 1990s was the warmest decade on record and 1998, an El Niño<sup>1</sup> year has been the warmest year (Gautier et al., 2008). The IPCC Fourth Assessment Report (IPCC, 2007) referred to in the Copenhagen accord states: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean

---

<sup>1</sup> Sustained difference in Pacific Ocean average temperatures of at least  $\pm 0.5$  C lasting 9 months to 2 years at regular intervals of 2-7 years

temperatures, widespread melting of snow and ice, and rising global average sea level”.

Human activities have been interfering with the natural environment in diverse and ever-increasing ways (Rasool et al., 2008). The concentration of CO<sub>2</sub> has increased from<sup>2</sup> 280 ppm in 1748 to 310 ppm in 1958 and near 379<sup>3</sup> ppm in 2008 of which fossil fuels account for two-thirds of increase and the remaining by land use activities like deforestation, agriculture etc. These increases are projected to rise to 700-900 ppm before the end of the 21st century. Accounting for non-CO<sub>2</sub> greenhouse gases also, the current CO<sub>2</sub>-*equivalent* concentration is about 430 ppm (IPCC, 2007). It is known that carbon dioxide levels are substantially higher now than at any time in the last 800,000 years.

Global methane concentration has also increased from 750 ppb in 1750 to about 1775 ppb in 2006, most of which is of biospheric origin like wet lands, cattle, rice etc. other greenhouse gases like n<sub>2</sub>o, tropospheric ozone and aerosols from human activities have also been on the increase. Rasool et al. (2008) point out that increased concentration of greenhouse gases has led to  $2.6 \pm 0.25$  W/m<sup>2</sup> of additional radiative forcing<sup>4</sup> since preindustrial era, which is increasing. Not only that the ocean waters have experienced warming leading to a rise in sea level at the rate of  $3.1 \pm 0.8$  mm / year, the ocean waters are turning acidic due to increased concentration of CO<sub>2</sub>.

---

<sup>2</sup> 1 ppm CO<sub>2</sub> = 2.12 GtC

<sup>3</sup> Often the 1990 level of CO<sub>2</sub> concentration of 355ppm is taken as the base in view of the Kyoto mechanisms.

<sup>4</sup> Radiative forcing due to a perturbation is the change in net irradiance(Watts/square meter) at the tropopause with stratospheric temperatures at radiative equilibrium and surface temperatures at unperturbed levels.

## Global Warming and Climate Change

The surface temperature of the earth is 34°C higher than what it would have been without atmosphere. The planet has been rescued from the Siberian subzero chilliness by the greenhouse effect provided by CO<sub>2</sub>, O<sub>3</sub> and H<sub>2</sub>O in the atmosphere which is referred to as the primary greenhouse effect. However, post-1750 industrial era, the concentrations of these and new greenhouse gases<sup>5</sup> have been increasing at a fast rate leading to warming effects referred to as secondary greenhouse effect. Total CO<sub>2</sub>-equivalent concentration of greenhouse gases are projected to reach 550 ppm (about double pre-industrial levels) by around mid century corresponding to a mean temperature rise of 2.9°C over pre-industrial levels (Aldy et al. 2009). Annexure 1 gives the main GHGs with their sources, concentrations, and contribution to the greenhouse effect.

It is interesting to note that all the greenhouse gases are trace gases in the atmosphere. The fragility and chaotic nature of the climate system become evident from the impact these trace gases have on the macro level changes in the climate parameters. The key lies in the nature of infra-red spectroscopy of these gas molecules wherein the molecular vibrations are infra-red active<sup>6</sup> due to the generation of a dipole moment as the atoms vibrate (on account of their having more than two atoms per molecule).

Earth's surface radiation is mainly in the infra-red with a peak at 10.1 μm due to the surface temperature of 288°K whereas solar radiation spectrum is of shorter wavelength peaking at 0.5 μm. The

---

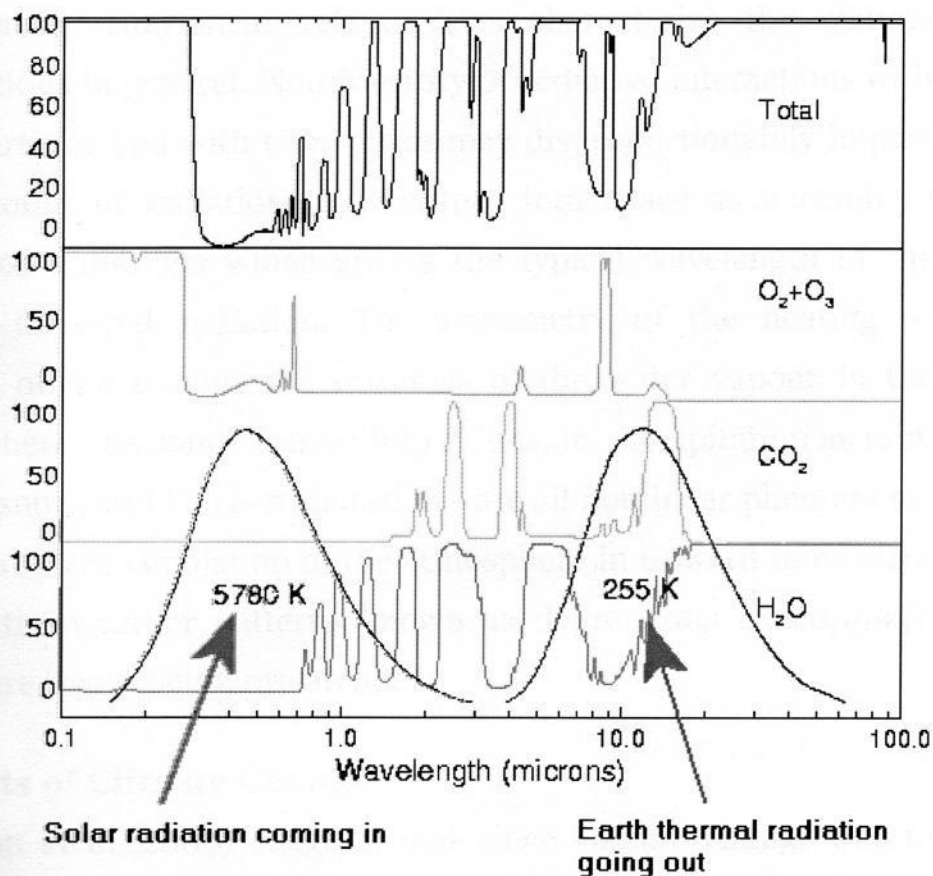
<sup>5</sup> Kyoto Protocol mentions 6 greenhouse gases, namely, Carbon dioxide(CO<sub>2</sub>), Methane(CH<sub>4</sub>), Nitrous Oxide(N<sub>2</sub>O), Hydrofluorocarbons(HFC), Perfluorocarbons(PFC) and Sulphur HexaFluoride(SF<sub>6</sub>)

<sup>6</sup> See Tuckett, Richard P. in Letcher, Trevor M. (Editor) (2009) for details

infra-red activity of greenhouse gases leads to absorption of radiation emitted by the relatively warmer surface which is emitted to space at the colder atmospheric temperatures, leading to a net trapping of energy within the atmosphere which is called the greenhouse effect. At radiative equilibrium, there is a balance between the incoming solar radiation, the reflected solar radiation and the emitted infra-red radiation. Increased concentration of gases increases the quantum of stored energy in the atmospheric reservoir to drive the climate system (Figure 1).

*Figure 1: Infrared Absorption Spectrum for CO<sub>2</sub> and other greenhouse gases*

(Source: [http://www.te-software.co.nz/blog/augie\\_auer.htm](http://www.te-software.co.nz/blog/augie_auer.htm))



Though overwhelming evidence points to the contrary, there are sceptics who believe that anthropogenic impact on climate is

negligible or at least exaggerated in the literature. However, it is obvious that evidence from diverse phenomena are so overwhelming as to conclude the anthropogenic nature of global warming, even if part of the conclusion admittedly stems from the principle of parsimony or Ockham's Razor. In view of the controversies in this regard (like the controversy relating to Himalayan glaciers), it is necessary to have a comprehensive climate observation system as well as increase the accuracy of the predictive models.

There is the natural and sometimes chaotic variability of the climate system and there are challenges involving uncertainties in the global carbon cycle as well as atmospheric and ocean phenomena. Non-linear relationships characterize the climate interactions in general. Non-linearity of radiative interactions with dust particles and with trace gases may disproportionately impact the amount of radiation that escapes into space as a result of increased emissions which affects the typical wavelength of the earth's infra-red radiation. The asymmetry of the heating or cooling of the oceans, the workings of the water vapour in the atmosphere - its condensation into clouds, its precipitation as rain, hail or snow, and its re-evaporation - are all nonlinear phenomena, as is turbulent circulation of the atmosphere in upward movement within the weather patterns known as depressions (Read,1994). These are issues being researched.

### **Impacts of Climate Change**

Solomon et al.(2009) suggests that since climate change due to increase in carbon dioxide concentration is largely irreversible for about 1,000 years after emissions stop, it is *incorrect* to assume

that slow processes such as climate change pose small risks on account of the presumption that choices could always be made to quickly reduce emissions and thereby reverse any harm within a few years or decades. Though the removal of atmospheric carbon dioxide decreases radiative forcing, atmospheric temperatures do not drop significantly for at least 1,000 years due to the slower loss of heat to the ocean. Sea level rise, increased acidification of the ocean and irreversible dry-season rainfall reduction in several regions are the other illustrative impacts of emissions.

Various scenarios predict a rise of carbon dioxide concentrations from the current levels of about 385 parts per million by volume (ppmv) to a peak of 450–600 ppmv over the present century. There has been anthropogenic global warming of 0.5°C over the past century, mostly after 1980 and a rise of 1.4–5.8°C has been predicted over the present century (IPCC, 2001). Due to the thermal expansion of the warming ocean alone, global average sea level may irreversibly rise at least 0.4–1.0 m, if concentrations exceed 600 ppmv and 0.6–1.9 m if it exceeds 1,000 ppmv.

Human-induced climate change has already had many other impacts<sup>7</sup>:

- Decreases in the duration of ice cover on rivers and lakes in the mid- and high latitudes of the Northern Hemisphere over the 20th century;
- Decreases by 10 percent in the area of snow cover since satellite images became available in the 1960s;
- Thinning of Arctic sea ice;

---

<sup>7</sup> See <http://www.learner.org/courses/envsci/unit/text.php?unit=12&secNum=7> for a detailed summary

- Retreat of non-polar glaciers;
- Increases by about 1 to 4 days per decade in growing seasons in the Northern Hemisphere, especially at higher latitudes, during the last 40 years; and
- Thawing, warming, and degrading of permafrost in some regions

Letcher (1999) provides a detailed analysis of indications based on scientific evidence regarding the impacts of global temperature rise. The following are some of the findings:

- i. Evidence indicates that key elements of the atmospheric circulation have been moving poleward during the past few decades. Even small changes in the atmospheric general circulation have important implications for regional climates by modifying patterns of storminess, temperature and precipitation.
- ii. The warming will not be spatially homogeneous, with impact on polar regions more than the tropical belt. An enhanced hydrological cycle with more evaporation and precipitation at the global scale coupled with changes in frequency of El Nino and Tropical cyclones and changes in the Monsoon systems may raise the probability of extremes (floods and droughts).
- iii. Currently observed and future warming have and are likely to continue altering the geographical distribution of primary and secondary planktonic production, affecting marine ecosystem services such as oxygen production, carbon sequestration and biogeochemical cycling and placing additional stress on already depleted fish and mammal populations

- iv. Climate change is affecting coral reef systems with mass coral bleaching due to rising temperatures with impacts on coral survival and the associated systems
- v. Inter-tidal invertebrates and algae are already responding to global warming with shifts in bio-geographic distributions away from warmer low latitude regions towards cooler poles.
- vi. There is clear evidence that plants are responding to climate change through changing phenology and distribution patterns with species tending to disperse towards cooler areas.
- vii. Extremes in temperature are dangerous to crop production. More northerly zones become wetter and warmer which could benefit crop production in the short term but the tropics and subtropics become hotter and drier. Arid areas may expand in developing countries. Africa is thought to be the region most vulnerable to negative impacts of climate change on crop production.
- viii. Anthropogenic forcing by greenhouse gases has become a dominant cause for recent sea level rise. Modern rates of sea level rise started about 100 years ago and the rate of 20<sup>th</sup> century sea level rise appears to be faster than rates reconstructed for the warm intervals of the Medieval Climatic Optimum and the middle Holocene. Evidence compiled over recent years strongly demonstrates a human-induced warming signal in the ocean temperature record also. Since pre-industrial times ocean pH has decreased by a global average of 0.1 and it has been estimated that unmitigated CO<sub>2</sub> emissions will cause ocean pH to decrease by as much as 0.4 by the year 2100 and 0.77 by 2300. These changes are a

threat to the survival of many marine organisms particularly that use  $\text{CaCO}_3$  to produce shells, tests and skeletons.

- ix. There are two great ice sheets left on the planet, the Greenland ice sheet and the Antarctic ice sheet. The former has the potential to raise global sea level by 7 m whereas the latter has a much bigger potential of 60 m rise. Yet the risks associated with them are closer since but the Arctic is warming nearly twice as rapidly as the rest of the world while trends have been mixed in Antarctica.

### **Changes in Climate and Weather Events in India**

There are some observed changes in climate parameters in India. As regards the temperature increase, it has been reported<sup>8</sup> that 2009 was the hottest year ever recorded in India with annual mean temperature of 26.55 °C. Of the 12 hottest years in India in the last century, 8 have been in the past decade. The India's Initial National Communication, 2004 (NATCOM Report, 2004) to UNFCCC has consolidated some of the changes:

- Decreased snow cover, affecting snow-fed and glacial systems such as the Ganges and Brahmaputra.
- Erratic monsoon with serious effects on rain-fed agriculture, peninsular rivers, water and power supply
- Drop in wheat production by 4-5 million tones, with even a 1°C rise in temperature
- Rising sea levels causing displacement, threatened freshwater sources and mangrove ecosystems

---

<sup>8</sup> Times of India, February 7, 2010

- Increased frequency and intensity of floods with Increased vulnerability of people in coastal, arid and semi-arid zones of the country
- Shift in forest types, adversely impacting associated biodiversity, regional climate dynamics as well as livelihoods based on forest products.

## **Mitigation and Adaptation**

Dealing with climate change involves acting globally and locally and the key component is building 'climate-neutral energy infrastructure' (Johansen, 2006). Mitigation consists of reducing emissions of greenhouse gases (GHG) at the beginning of the chain and adaptation responds to economic damages of climate change at the end of the chain. The adaptation can be proactive or reactive depending upon the time of action. Shukla, et al. (2003) indicate that for developing countries the major adaptation strategy involves accelerated achievement of development goals to increase the capacity for adaptation. Adaptation further comprises the measures taken to minimize the adverse impacts of climate change, e.g. relocating the communities living close to the sea shore, development of crops that can withstand higher temperatures, Coastal area protection measures etc.

Energy is a vital ingredient in the economic growth of any country. The world economic trend suggests below 3% annual growth through 2030. The growth of world energy demand would be more than 40% by 2030 to keep pace with the envisaged economic growth. Though the necessary nature of the link between economic growth and energy use or between energy use and emissions is still

being researched, it is well recognized that these are key factors to be considered in the climate change debate. While the emission intensity depends substantially on the carbon intensity of energy than on the state of development, energy intensity and energy demand would impact on the overall emissions. Gautier et al. (2008) suggest the following five elements of a long term strategy:

- (i) *Saving energy and developing new and efficient technologies*
- (ii) *Cleaner technologies for electricity generation*
- (iii) *Reducing transportation sector emissions*
- (iv) *Developing renewable sources of energy*
- (v) *Getting ready for the indispensable adaptation to future challenges in the climate system.*

Johansen (2006) identifies, inter alia, the following specific actions with substantial potential for emission reduction:

- (i) Prevention of deforestation: This is even better than reforestation as the albedo of forested landscape is generally lower than that of cultivated land and old forests lock up much more carbon than young plantations.
- (ii) Wise use of new technology to improve energy efficiency of buildings: Energy consumption of heating and air conditioning systems could be reduced by as much as 90% in new buildings.
- (iii) Use of carbon dioxide as refrigerant in air conditioning
- (iv) Improvements in farming technology: no- or low-tillage methods, crop rotation, buffer strips, nutrient management, water conservation, growth of energy crops on spare lands etc.

- (v) Control or capture of methane emissions: Methane has been easier to reduce than CO<sub>2</sub>. Cattle respiration accounts for nearly 20% of methane emissions. Food additives are being developed to reduce the methane emissions and also to block enzymes in the cow's rumen that are required to produce methane.
- (vi) Promotion of mass transport: Atmospheric emissions from aircraft include nitrogen oxides and other greenhouse gases. IPCC estimate that commercial jets are responsible for 3.5% of man-made global warming. Aircraft vapour trails form cirrus clouds that contribute to global warming. Air travel distances have risen hundredfold during the last half of the twentieth century and the exponential trend continues. Passenger cars are also growing dramatically in many countries adding to the emissions. Substitution of these mass transport systems has substantial impact on emission savings.
- (vii) System of carbon tax or carbon dioxide permits for all producers of carbon dioxide. By improving the viability of non-fossil fuel energy, the tax could ease reliance on imported energy and boost the country's energy security.
- (viii) Wind power generating capacity growth.
- (ix) Exploiting solar energy: The potential of solar energy in emission mitigation is very high. The total reserves of fossil fuels originally stored in the earth's crust before they were equivalent to an energy equivalent of only about a fortnight of incident sun radiation (Smith et al., 1994). In southwestern Germany, Freiburg has become the world's first solar city with a solar powered train station, energy efficient row

houses with innumerable photovoltaic systems. Given the trends in research and cost reduction, solar energy in regions with abundant sunshine is cost effective.

- (x) Bio-fuels: Bio-fuels hold great potential as in the case of Brazil where use of gasoline has declined since the 1970s. Seven of every 10 new cars are flex-fuel fitted to consume gasoline or ethanol or a mixture of both.

Johansen is sceptical of the potential of Hydrogen as it does not exist in nature in a combustible form unlike oil or coal. Its bond dissociation energies with other elements are high. Moreover, there are problems regarding production (hydrogen usually is produced from fossil fuels), Storage (Hydrogen is a light and volatile gas) and utilization (leakage of hydrogen could cause stratospheric ozone depletion).

### **Emission Reduction Apportionment**

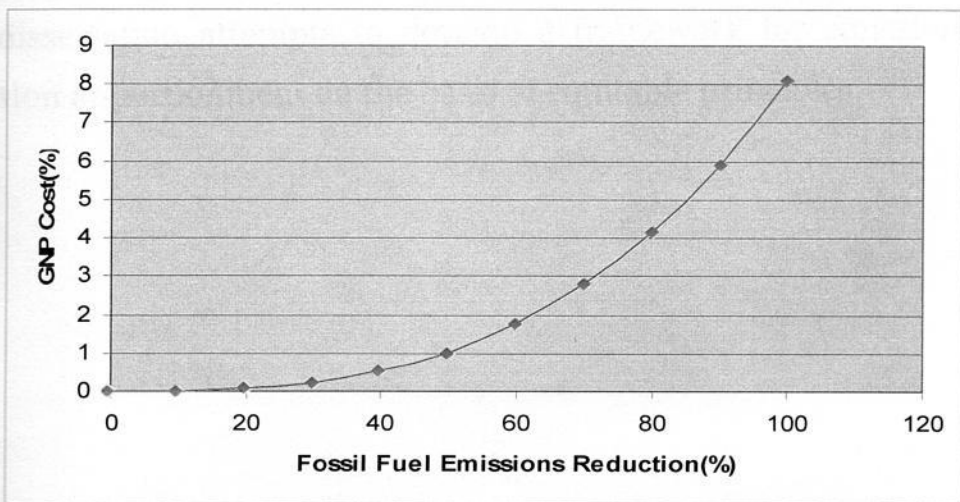
The climate change mitigation involves substantial costs in terms of GNP reduction. There is considerable disagreement within and among nations regarding the mitigation policies and its costs due to the multidimensional nature of such policies which is analyzed by Goulder et al. (2006). There are the price-based instruments like carbon taxes and quantity based instruments like emission quotas to address the mitigation issue. While the former may be more efficient, the latter reduces uncertainty about the level of emissions. Interactions of the policy instruments with the existing fiscal system, such as whether the additional revenues are financed by removal of pre-existing fiscal distortions etc will have an impact on the cost advantage of such policies.

There is policy and resource competition between emission instruments which attempt to regulate or limit emissions and technology-push instruments like R& D incentives which would necessitate an optimal policy mix. A third dimension for policy comparison is introduced by the extent of flexibility of policy over gases, time or location. Jaffe et al. (1999) highlights the need for policies that create clear incentives for changes in energy use and technology. On a much generalized platform, Maddison (1996) estimates a cubic equation linking the percentage abatement costs to the percentage reduction in CO<sub>2</sub> emissions from fossil fuels based on simulations from 10 model studies:

Abatement Cost (t) (%) =

$$8.1 \times \text{Fossil Fuel Emission Reduction (t) (\%)}^3$$

Figure 2: GNP Costs of Carbon Emissions Reductions



(Source: Maddison, 1996)

Figure 2 shows the results generated by the above equation in terms of GNP costs. World Development Report (2010) estimates that in developing countries mitigation could cost \$140 to \$175 billion a year over the next 20 years and adaptation investments could average \$30 to \$100 billion a year over the period 2010 to

2050 as against a current development assistance of roughly \$100 billion a year. In view of the high costs of climate change mitigation, the apportionment of the costs among the various countries becomes necessary which has resulted in continued disputes and protracted negotiations among the global players.

Climate being a global common good, its protection is beset with the free rider problem. Cazorla (2000) describes a basic paradox of international agreement that 'a self-enforcing agreement is most easily maintained when the global net benefits are not much bigger than those in the absence of an agreement.' In view of the global nature of the problem, the apportionment of the emission reduction targets based on equity principles is an important component of addressing the climate challenge, which the world will have to agree upon in view of the high risks of inaction.

This dissertation attempts to develop a framework for emission reduction apportionment on the basis of equitable principles.