Training Course

Climate Change and its Impact on Water Resources

[May 17 - 21, 2010]

LECTURE - 8

VARIOUS CLIMATE CHANGE SCENARIOS

By

M.K. GOEL

Organised by

National Institute of Hydrology
Roorkee- 247 667
&
Indian Institute of Technology
Roorkee -247 667

VARIOUS CLIMATE CHANGE SCENARIOS

Introduction

Climate is one of the key parameters in the earth's environment. Climate is usually defined as the average weather and in broad sense, it is the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. Human activities that could possibly change the climate include as a result of emission of gases in the atmosphere, industrial activities, development of extensive cities, pollution of water ways and cities, creation of thousands of dams and lakes, conversion of grassland or forest to cropland, agricultural activities.

The average global temperature rose by 0.74°C over the last hundred years (1906-2005), with more than half of these rises, 0.44°C, in the last 25 years. Most of the warming over the last 50 years is very likely to have been caused by anthropogenic increases in Green House Gases (GHGs). Since 1750, atmospheric concentrations of GHGs have increased significantly. Carbon dioxide has increased by 31 percent, Methane by 151 percent and Nitrous oxide by 17 percent. Higher carbon dioxide concentration is caused due to burning of fossil fuels (coal, oil and natural gas) and deforestation.

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, for decades or still longer. The United Nations Framework Convention on Climate Change (UNFCC), in its Article 1, defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. Global warming is a major factor to be climate change. Even a conservative estimate of 1^{0}C increase could have dramatic effects for all aspects of human life.

Impacts of climate change can be categorized through positive and negative aspects. Less chilly winters and greenery in high altitudinal areas can be considered as some positive impacts due to global temperature rise. However, the adverse (negative) impacts are seen very highly in compared to the positive impacts. Some of the adverse impacts caused by climate change especially related to water in global and Asian context can be categorized as:

- It is seen that the global temperature has on rising trend since mid-20th century.
- Hot days, hot nights have become more frequent in most parts of the world.
- Due to rising temperature, it causes abrupt glacier ablation. The formation of lakes is occurring as glaciers retreat from several steep mountain ranges, including the Himalayas. These lakes thus have a high potential for glacial lake outburst floods (GLOFs).
- Climate change has changes on surface and ground water systems. At the global scale, there is evidence of a broadly coherent pattern of change in annual runoff. Some regions like China, higher latitudes regions experiencing an increase, and West Africa, southern Europe and southern Latin America experiencing decrease in runoff.
- Many natural systems on all continents and oceans are affected due to global warming.
- Diseases related to warming and mosquito problems are seen even if in high altitudinal regions.
- Changes in water quantity and quality due to climate change affects on food production leading to decrease food security.
- It is found that the rate of sea-level rise during the 20th century was about 10 times higher than average rate during the last 3000 years.
- Sea-level rise is projected to extend areas of salinization of ground water, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas.

Particularly in context of the Asian region, the possible impacts of the climate change are:

- The frequency of occurrence of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides, debris and mud flows, while the numbers of rainy days have decreased.
- The increasing frequency and intensity of droughts in many parts of Asia are attributed largely to rising temperatures, particularly during the summer.
- On average, Asian glaciers are melting at a rate that has been constant since at least the 1960s. The frequency of glacial lake outburst floods (GLOFs) in the Himalayas of Nepal, Bhutan and

Tibet has increased from 0.38 events / year to 0.54 events / year in the 1990s.

- The adverse impact of climate change is one of the reasons for creating water shortage problem in many parts of South Asia. It is because changing in climatic condition affects on water demand, supply and water quality.
- Decreasing trends in annual mean rainfall were observed in many parts of Asia.
- It is found that production of rice, maize and wheat has declined in many parts of Asia due to increasing water stress, mainly arising from increasing temperature, reduction in number of rainy days.
- Due to gradual reduction in rainfall, aridity has increased in central and west Asia in recent years.
- Spreading of diseases like malaria, viral influenza, encephalitis in many parts of South Asia are caused in recent years due to temperature rising.
- Drying of wetlands and severe degradation of ecosystems has resulted in delta regions of South Asian countries caused due to precipitation decline and droughts.

A scenario is a plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). Other terms that have been used as synonyms for scenario are "characterisation", "storyline" and "construction".

Various Climate Scenarios of IPCC

According to the IPCC, a scenario is a coherent, internally consistent and plausible description of a possible future state of the world. A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections. The IPCC published a set of emissions scenarios in 2000 for use in climate change studies, known by "Special Report on Emissions Scenarios (SRES)". The SRES were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol emissions. The SRES scenarios cover a wide range of the main driving forces of future emissions, from demographic to technological and economic developments. The set of SRES emissions scenarios is based on an extensive assessment of the literature, six alternative modeling approaches, and an "open process" that solicited wide participation and feedback from many groups and individuals. The SRES scenarios include the range of emissions of all relevant species of greenhouse gases (GHGs) and sulfur and their driving forces.

What is an emission scenario?

When anybody mentions that the global temperature increase that the world might experience in 2100 as a consequence of our greenhouse gas emissions could be 1.4 to 5.8 °C, the recipient only thinks that this large gap (almost 4 times of 1.4 °C) results from the imperfect knowledge that scientists have of the climate system. If we can't say whether the increase will be of 1.4 °C or of nearly 6 °C in 2100, it's because our world remains very mysterious: we are so ignorant of the way marine currents, ice caps, carbon sinks, etc, will behave, that any forecast could only be very speculative. Actually, this intuitive conclusion is only partially true, and therefore also partially false. Two main reasons explain this large gap between the two extremities:

- Climate models are still failing to take into account all the detailed aspects of clouds. These have two antagonist effects on the ground temperature: being composed of water vapour (or droplets) that is a greenhouse gas, they are part of the "heat trap", but, as they are highly reflexive for the sun rays, they also exert a "cooling effect" on the climate, preventing solar energy to reach the ground. There is no clear consensus on the exact way climate change will modify from these two antagonist effects in the future. Clouds are not explicitly taken into account in present climate models (small scale processes responsible for the formation of clouds are not treated one by one, but on a more global scale). This approximate way to represent clouds generates an error range, of course, which is considered to amount to 1 to 2 °C on a prediction for 2100.
- Second source of fluctuation, that we can will address, is that the state of the world in 2100 not only depends on the amount of greenhouse gases that we already have put in the atmosphere, but also, and mainly, on the amount we are about to put from now on until 2100.

That's why scientists use emission scenarios, that each describe how greenhouse gases emissions could evolve between 2000 and 2100, depending on various hypothesis. Such scenarios are indispensable to compare between them the results of the various climate models, by looking at what are the different results (depending on the models) with the same hypothesis. Indeed, comparing between them the results obtained with different hypothesis would be little like comparing the price offers for a vacuum cleaner, a computer and a stove: not much can be concluded then...

As there are infinite possibilities to describe future emissions, scenarios are necessarily conventional. It does not mean that they are totally arbitrary: each of them reflects a plausible state of the future world, meaning that it is not possible, today, to state that one of them is incompatible with the information that we have, even if some of them might seem "extreme".

These emission scenarios are not designed by climatologists, but by various people (demographers, energy specialists, sociologists, economists...). These scenarios neither boast to cover the whole bracket of possible futures, nor propose a hierarchy, that the authors of the scenarios refuse to say whether some of them are more certain than others.

Of course, some of these scenarios suppose availability in fossil fuels that some might consider "over-optimistic", and others are based on a spreading of nuclear energy that may be considered not realistic, and some others still require a surface covered by forests in 2100 that might seem amazing. No scenario can be totally ruled out taken into account what we know of the world. The IPCC has published a voluminous book describing the 40 scenarios used, that are grouped in 4 main "families". Each "family", named by an abbreviation (A1, A2, B1, B2), is supposed to reflect a particular evolution of humanity, and the main hypothesis (concerning demography, agricultural practices, technology spreading, etc) are then turned - through simple models - into energy consumption and food production, the latter being then converted into greenhouse gas emissions. Following terminology is used to define these scenarios:

- Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.
- Scenario: projections of a potential future, based on a clear logic and a quantified storyline.

- Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

The SRES team defined four narrative storylines (see Figure 1), labeled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways.

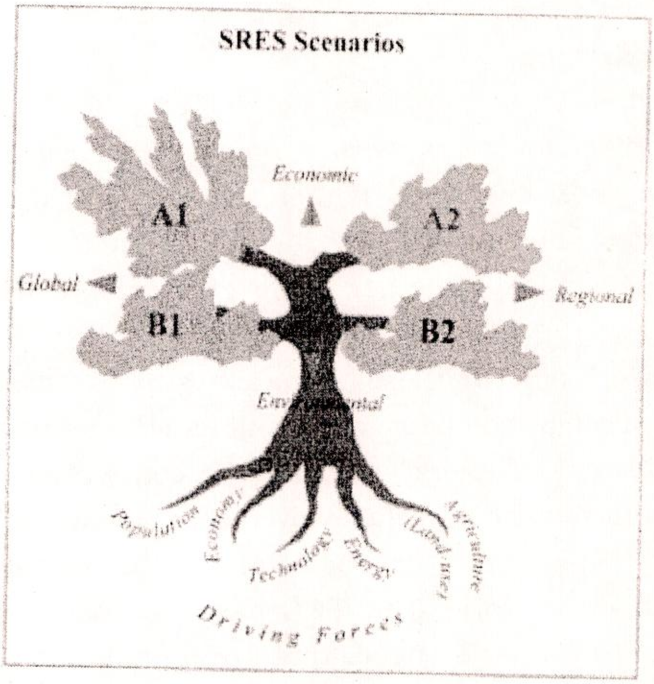


Figure 1: Schematic illustration of the four SRES storylines

In simple terms, the four storylines combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization . The storylines are summarized as follows:

- A1 storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
- A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented

economic growth that is more fragmented and slower than in other storylines.

- B1 storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- B2 storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

After determining the basic features of each of the four storylines, including quantitative projections of major driving variables such as population and economic development taken from reputable international sources (e,g, United Nations, World Bank and IIASA), the storylines were then fully quantified using integrated assessment models, resulting in families of scenarios for each storyline. In all 40 scenarios were developed by six modelling teams. All are equally valid, with no assigned probabilities of occurrence. Six groups of scenarios were drawn from the four families: one group each in the A2, B1 and B2 families, and three groups in the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil intensive), A1T(predominantly non-fossil) and A1B (balanced across energy sources). Illustrative scenarios1 were selected by the IPCC to represent each of the six scenario groups.

Causes of climate change: driving forces and emissions

The IMAGE 2.2 model (Integrated Model for Assessment of the Greenhouse Effect) considers two major closely interlinked driving forces:

- Population development
- World Economy

which, in turn drive the major "emitters"

- The energy system
- Land use (change)

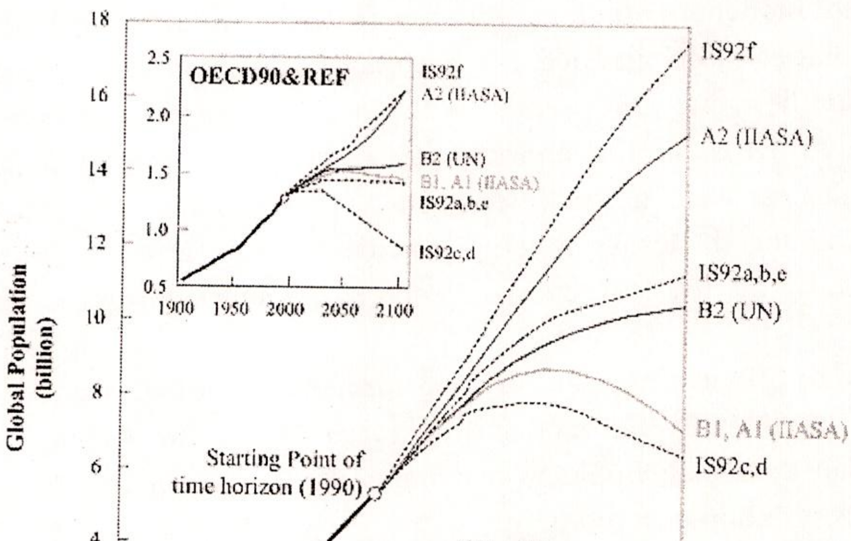
a) World Economy: growth, distribution, technology

Economic development is expressed in GNP (Gross National Product). The SRES scenarios span a wide range of future levels of economic activity. The highest overall prediction is for the A1 scenario; an estimated GNP of US$529 trillion (1990 US dollars) in 2100. The lowest overall prediction is for the B2 scenario; an estimated GNP of US$235 trillion in 2100. This means that globalization combined with an emphasis on wealth would generate the highest economic growth. This is mainly because population growth is lower in a global scenario, causing a narrower division of the GNP. The emphasis on wealth rather than on sustainability also increases the GNP. It is estimated that the future income gap between developed and developing countries will be smaller than was initially estimated in the IS92 scenarios.

A key element, however, is technological development and the implied energy efficiency of future economic development.

b) Population development

Population growth is determined by fertility and mortality rates. Global population projections range from 7.1 to 15 billion people (or more than double the minimum estimate, i.e., an "uncertainty" of a factor of two in this key driving variable) by 2100 across the scenarios, depending on the rate and extent of the demographic transition.

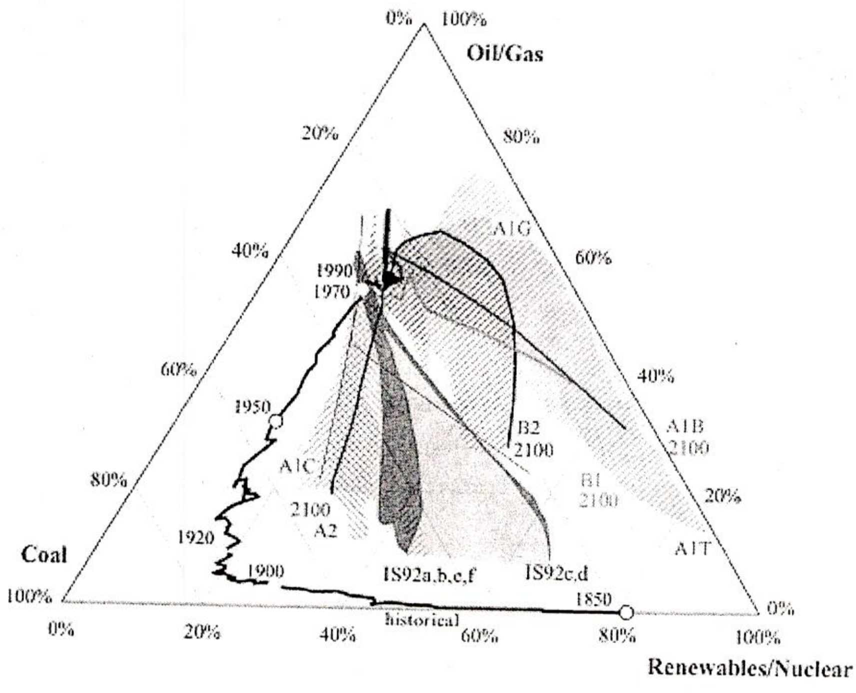


This figure shows that population growth is strongest in the regional and material scenario (A2) for 1992 results. Regionalization causes more population growth than does globalization. The figure shows population projections - historical data from 1900 to 1990 (based on Durand, 1967; Demeny; 1990; UN, 1998), and SRES scenarios (based on Lutz, 1996, for high and low, and UN, 1998, for medium) and IPCC IS92 scenarios (Leggett et al., 1992; Pepper et al., 1992) from 1990 to 2100.

Emission, clearly are not only driven by the population number, but also as much by lifestyles, and the associated economic activities and technologies used. Pattern of production and consumption are bound to change with changing population densities, and the ratio between rural, agricultural population and activities and the urban. industrial or service sector employed (or unemployed) parts of the total population also determine the resulting emission patterns.

c) Energy system

The impact of future energy use will largely depend on the fuel type. Both global scenarios depict a transition towards more non-fossil fuel sources. In the regional sustainable scenario the transition towards non-fossil fuel sources is much more gradual. The regional wealth scenario marks a stark transition back to fossil fuels. In all scenarios the share of oil and gas declines and more coal will be used for energy generation in future.

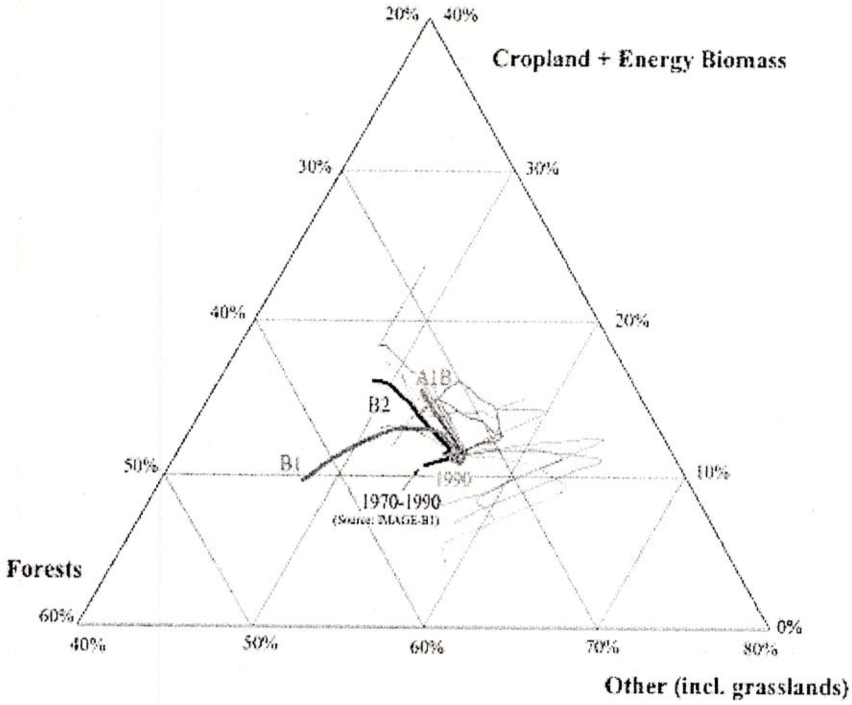


This figure summarizes the global primary energy structure, shares (%) of oil and gas, coal, and non-fossil (zero-carbon) energy sources - historical development from 1850 to 1990 and in SRES scenarios. Each corner of the triangle corresponds to a hypothetical situation in which all primary energy is supplied by a single source - oil and gas on the top, coal to the left, and non-fossil sources (renewables and nuclear) to the right. Constant market shares of these energies are denoted by their respective isoshare lines. Historical data from 1850 to 1990 are based on Nakicenovic et al. (1998). For 1990 to 2100, alternative trajectories show the changes in the energy systems structures across SRES scenarios. They are grouped by shaded areas for the scenario families A1B, A2, B1, and B2 with respective markers shown as lines. In addition, the four scenario groups within the A1 family A1B, A1C, A1G, and A1T, which explore different technological developments in the energy systems, are shaded individually. In the SPM, A1C and A1G are combined into one fossil-intensive group A1FI. For comparison the IS92 scenario series are also shown, clustering along two trajectories (IS92c,d and IS92a,b,e,f). For model results that do not include non-commercial energies, the corresponding estimates from the emulations of the various marker scenarios by the MESSAGE model were added to the original model outputs.

d) Land use change

There are many different land use types. The main land use types that are considered by the IPCC are forests, arable land and grassland. Land use change is largely related to demands for food by a growing population and changing diets.

Currently there is a lot of deforestation. In most SRES scenarios, the current trend of deforestation is eventually reversed because of slower population growth and increased agricultural productivity. Reversals of deforestation trends are strongest in the globalized scenarios. In the globalized sustainable scenario pasture lands decrease significantly because of increased productivity in livestock management and dietary shifts away from meat.



This figure shows global land-use patterns, shares (%) of croplands and energy biomass, forests, and other categories including grasslands - historical development from 1970 to 1990 (based on B1-IMAGE) and in SRES scenarios. As for the energy triangle in Figure 4, each corner corresponds to a hypothetical situation in which land use is dedicated to a much greater extent than today to one category - 60% to cropland and energy biomass at the top, 80% to forests to the left, and 80% to other categories (including grasslands) to the right. Constant shares in total land area of cropland and energy biomass, forests, and other categories are denoted by their respective isoshare lines. For 1990 to 2100, alternative trajectories are shown for the SRES scenarios. The three marker scenarios A1B, B1, and B2 are shown as thick colored lines, and other SRES scenarios as thin colored lines. The ASF model used to develop the A2 marker scenario projects only land-use change related GHG emissions. Comparable data on land cover changes are therefore not available. The trajectories appear to be largely model specific and illustrate the different views and interpretations of future land-use patterns across the scenarios (e.g. the scenario trajectories on the right that illustrate larger increases in grasslands and decreases in cropland are MiniCAM results).

** *** **