

# CLIMATE CHANGE IMPACTS ON HYDROELECTRIC POWER

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## ABSTRACT

Anthropogenic emissions of greenhouse gases are expected to lead to significant changes in climate over the next century. One of the many potential effects is that river catchment runoff may be altered. This could have implications for the design, operation and viability of hydroelectric power stations. This describes attempts to predict and quantify these impacts. It details a methodology for computer based modelling of hydroelectric resources and proposes analysis of the impacts on the electrical system and on the investment performance of hydro.

## INTRODUCTION

Climate change or global warming is the expected outcome of increases in atmospheric concentrations of "greenhouse" gases resulting from human activities. Many greenhouse gases, including carbon dioxide (CO<sub>2</sub>), occur naturally and keep the earth warm by trapping heat in the atmosphere. However, since the Industrial Revolution, anthropogenic sources of CO<sub>2</sub> have added greatly to the atmospheric concentrations, and in particular, transportation and the burning of fossil fuels for electricity generation are frequently cited as major sources. Other man-made greenhouse gases, such as CFC's, are believed to exacerbate the process. Enhanced levels of greenhouse gas concentrations are predicted to cause a significant rise in temperature over the next century. The rates of increase are anticipated to be greater than at any time in the past. The current scientific consensus is that under present rates of economic and population growth global mean temperatures will rise by 3°C by the end of the next century. This is expected to be accompanied by increases in global precipitation levels of 15% [1].

Predictions of future climate are based on the output of complex numerical Global Circulation Models (GCM's) which simulate physical processes in the atmosphere and oceans. A number of research groups have developed GCM's including the UK Meteorological Office (UKMO), the Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton University, and NASA's Goddard Institute for Space Studies (GISS). Although different GCM's simulate current climate with varying degrees of precision most agree on the general trends.

The main technique for avoiding the worst extremes of climate change is to limit the increase in greenhouse gas concentrations by reducing emissions. As electricity production is responsible for a significant portion of the emissions, much of the burden will fall on the energy sector. Possible measures include transferring to lower carbon fuels like natural gas,

together with increased use of renewable energy sources including hydropower [1].

Hydropower is an attractive energy source as it is renewable with minimal operational emissions of greenhouse gases. In addition, there are no fuel charges and the civil works have a long useful life. However, large dams may necessitate population displacement and can impact on the ecology of the basin [2, 3]. Exploitation of hydropower potential is considered by many governments and international bodies to be a key feature in economic development, especially in less developed countries (LDC's).

At first glance, increased global precipitation would appear to suggest more water available for hydroelectric power production. However, higher temperatures will lead to increased evapotranspiration levels. Whether increased global precipitation is seen as increased river runoff depends on the regional climate and hydrology. In the past, feasibility studies have relied on historical rainfall and river flow data for the assessment of hydroelectric potential at a proposed site. However, climatic change means that these can no longer be relied on to indicate future potential [2]. It is perhaps ironic to consider that attempts to reduce climatic change by switching to non-fossil fuels could be hampered by the legacy of their use.

## CLIMATE CHANGE IMPACTS ON HYDROPOWER AND ENERGY SECTORS

Changes in the quantity and timing of river runoff, together with increased reservoir evaporation will have a number of effects on the production of hydroelectric power. These include impacts upon system operation, financial effects and impacts on other energy sectors.

### System Operation and Development

Changes in the availability of existing hydroelectric plant, together with system constraints will affect the ability of the electricity supply system to meet average and peak demands. In the longer term, as demand levels increase, system planning may have to address

any predicted shortfall in hydro output by constructing additional generating plant [4]. The likelihood is that fossil fuels will be used, further enhancing radiative forcing [2]. Climate change may also result in some planned projects being cancelled or adapted.

### Financial Effects

Hydroelectric stations are characterised by low operational costs but high capital costs. Generally, revenue from electricity sales is the only way of servicing the capital debt. Thus reductions in electricity sales will affect the return on investment and hence the viability of the plant [2]. The loss of hydroelectric generating capacity will require additional plant to be constructed to meet demand, requiring additional capital and thus reducing overall system returns.

Many large hydropower developments in LDC's are built with the intention of stimulating economic development. Generally, this requires international financing with a requirement for the loan repayments to be in hard currency. Reductions in revenue may affect the ability to repay the hard currency debt and this may severely stress a weak economy. In addition, the fall in electricity availability will hamper Governments' attempts to aid economic development.

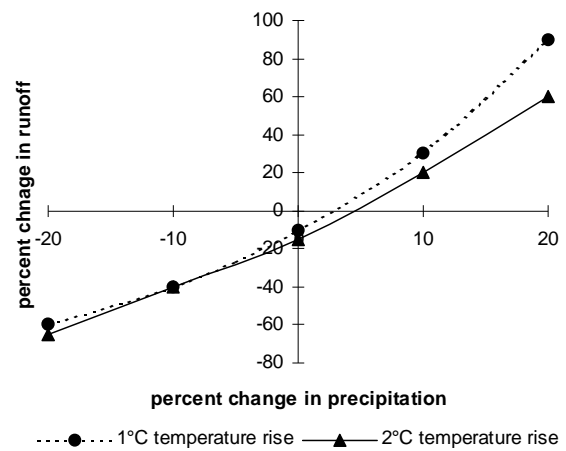
### Effects on other Energy Sectors

Climate change will have impacts on both electricity demand and supply. Higher air temperatures will tend to lower winter heating demands but increase summer cooling demand. Thermal generating stations requiring rivers for cooling water may suffer operational constraints due to reduced river flows [2, 5, 6]. Warmer river and sea water will reduce the efficiency of steam cycles, resulting in lost output or increased fuel consumption. Predicted sea level rise may also threaten coastal stations; climate change may lead to more extreme weather patterns causing increased system damage costs. Climate change may affect other renewable technologies: wind patterns may change as a result of changed temperature gradients, and changes in cloud cover may affect the performance of solar panels [7].

## CLIMATE IMPACTS ASSESSMENT

The potential impact of climate change on water resources has been suggested since the 1980s, as work progressed on predicting climate change [5]. Although GCM's can be used to predict runoff directly, the coarse scale used means that this information is only useful for the most general studies. As a result, many studies have been carried out on individual basins, showing that river basins display a range of sensitivities to climate change [8]. Figure 1 shows the response of a typical river basin to variations in precipitation and temperature. It can be seen that

increased temperature results in non-linear variations in runoff due to changes in precipitation.



**Figure 1: River Basin Response To Climate Change**

Later studies have considered not only the effect on river flows but also the impact on generation from hydroelectric stations [9]. In particular, one study examined a number of international river basins [4]. The study drew upon existing hydrological and dedicated basin models and the experience of international experts. For example, for one GCM scenario (GFDL), hydroelectric production on the Indus River would fall by 22%. Another study [2] qualitatively examined the effects of reduced hydroelectric output on sub-Saharan Africa and central Europe. However, to date, studies have failed to quantify the impacts in terms of the investment performance of plant or on the electrical network.

### Modelling Impacts

Climate impact assessment requires scenarios of future climate to be translated into potential changes on natural and human systems. To assess climate impacts on hydropower production a number of key steps must be taken [4]:

1. A river basin is selected and its rainfall-runoff processes are modelled and calibrated;
2. Climate data emanating from different GCM or arbitrary climate scenarios is applied to the model and the runoff computed;
3. River runoff values are converted into estimates of hydroelectric power production.

The first step involves the accurate modelling of the hydrology of the chosen river basin. A wide variety of modelling techniques have been applied to simulating runoff processes [10]. Three basic approaches exist:

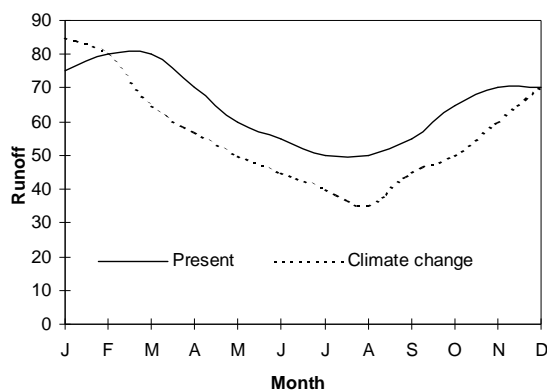
- Empirical
- Conceptual

- Deterministic

The first type requires a relationship to be established between climate inputs (e.g. rainfall) and hydrological outputs (i.e. runoff). The second type uses a simplified representation of the physical processes to mimic the storage and flow of water. The technique requires such models to be calibrated for each catchment using relevant climate and river flow data. The final approach is based on complex physical theory and most examples are spatially distributed in two or three dimensions. Such models claim to give a more explicit representation of hydrological processes, but suffer from the requirement for significant quantities of information for operation.

Despite the sophistication of current hydrological modelling techniques, particular difficulties exist in translating the GCM's large spatial and temporal predictions into a form that can be used by a hydrological model. Techniques to overcome this are termed downscaling methods [5], and attempt to generate local values for precipitation (say) from the large-scale GCM values. Other methods include nesting smaller-scale regional climate models inside the GCM's, creating weather stochastically and using analysis of different weather types.

Given that climate data from GCM's can be converted into a form suitable for use, the output from a suitably calibrated hydrological model would be similar to that shown in figure 2 for present and assumed future climates. In this hypothetical case it can be seen that climate change affects the magnitude and timing of river runoff. Winter runoff is higher as precipitation falls as rain rather than snow, the winter thaw occurs earlier, and summer runoff is also lower.



**Figure 2: Effect Of Climate Change On Runoff**

The potential for hydroelectric generation approximately follows runoff, so here it can be seen that hydroelectric potential would also be affected. A more accurate estimate of climate impacts on hydropower would involve assessment of the relative importance and cost of hydro, the economic

development of the country and the policies of governments and international organisations.

## PROPOSED COMPUTER MODEL

This work is concerned primarily with the design and development of a generic hydropower assessment tool suitable for use with any hydropower scheme and relevant climate scenario. The assessment tool will be implemented on a PC and would consist of:

A (simple) self-calibrating hydrological model that would be able to derive suitable input-response relationships, given suitable climate and river flow data. After calibration, the model will convert input climate data into estimates of river flows. These results would be processed by the hydropower component, which when given suitable technical and operational parameters, would compute the electrical power generated.

With this structure, the model will give indications of the power generated for desired baseline and predicted climate scenarios. This will enable projections to be made concerning the investment performance of the hydroelectric scheme together with assessments of the impact on the economy. In addition, the generation scenarios may be used for analysis of the electrical system, in terms of its generation mix and overall power requirements.

A simplified model may be as effective as a more complex one given that at present climate data from GCM's is available in terms of mean monthly values. Accordingly, monthly river flows are likely to be more meaningful than shorter time frames. Although this time step is too long to allow simulation of hydro-plant scheduling, suitable operational rules can be derived to mimic its output.

In general, consideration of hydropower impacts has been concerned with the potential annual production of electricity, and not the impact of changes in the monthly availability. Month-to-month changes in electricity demand are generally greater than year-to-year, so a consideration of the monthly availability is likely to have more relevance. Consideration of spillage and the likely actual production under climate change will allow a more realistic representation.

It is expected that a number of case studies will be carried out using the software tool. These will tend to concentrate on large strategically important hydroelectric power projects both in existence or planned. The majority of such projects are in LDC's highlighted as being sensitive to climate change. Among the areas under consideration are sub-Saharan Africa and East Asia. In particular, the Three Gorges Dam on the Yangtze River in China will be examined,

due to its key role in China's economic and water resources development, its sheer size and cost, and the alleged potential for environmental and social catastrophe.

### **Application of Proposed Software Tool**

The proposed software tool would have a number of applications. It would:

- allow planners to make projections of changes in future availability of water and power resources.
- enable water resources and hydropower designers to compare competing schemes before detailed feasibility studies commence.
- allow assessment of the impacts of land use changes.
- interface with existing dedicated basin models to allow accurate water flow projections to be input to the hydropower element of the software.

The key outcome of this work will be information on how hydropower may fare as an investment opportunity, and as a driver of economic development in LDC's.

### **CONCLUSION**

Human activities are expected to lead to substantial changes in climate. One outcome may be reductions in river runoff with potentially serious ramifications for the provision of hydroelectric power. Recent attempts at quantifying these impacts have been described and a methodology proposed to enable analysis of the impact on the electrical system as well as the investment performance of hydroelectric plant.

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