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The Role of Hydropower in Climate Change Mitigation and Adaptation: A Review

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ABSTRACT

Hydropower is a clean, renewable, and environmentally friendly source of energy. It produces 3930 (TW·h)·a^{-1}, and yields 16% of the world's generated electricity and about 78% of renewable electricity generation (in 2015). Hydropower and climate change show a double relationship. On the one hand, as an important renewable energy resource, hydropower contributes significantly to the avoidance of greenhouse gas (GHG) emissions and to the mitigation of global warming. On the other hand, climate change is likely to alter river discharge, impacting water availability and hydropower generation. Hydropower contributes significantly to the reduction of GHG emissions and to energy supply security. Compared with conventional coal power plants, hydropower prevents the emission of about 3 GT CO_2 per year, which represents about 9% of global annual CO_2 emissions. Hydropower projects may also have an enabling role beyond the electricity sector, as a financing instrument for multipurpose reservoirs and as an adaptive measure regarding the impacts of climate change on water resources, because regulated basins with large reservoir capacities are more resilient to water resource changes, less vulnerable to climate change, and act as a storage buffer against climate change. At the global level, the overall impact of climate change on existing hydropower generation may be expected to be small, or even slightly positive. However, there is the possibility of substantial variations across regions and even within countries. In conclusion, the general verdict on hydropower is that it is a cheap and mature technology that contributes significantly to climate change mitigation, and could play an important role in the climate change adaptation of water resource availability. However, careful attention is necessary to mitigate the substantial environmental and social costs. Roughly more than a terawatt of capacity could be added in upcoming decades.

1. Introduction

Electricity is essential for human life, welfare, and sustainable development. Images of the earth at night show the areas of prosperity—those people with access to electricity. However, about 20% of the world's population remains in the dark (with no access to lighting, refrigeration, computers, good education, or running water). Light means socioeconomic development, while darkness is a major concern for sustainable development. Today, more than 1.2 billion people around the world lack access to electricity, mainly in Asia and Africa (about 80% are in rural areas) [1]. Socioeconomic analyses on electricity and development are based on correlations between the main electricity indicators (i.e., consumption per capita per year, kW·h per year per capita, and the percentage of the population with access to electricity (AE%)) and the macro-socioeconomic indicators (i.e., gross national income (GNI) per capita and human development index (HDI)). All socioeconomic analyses show that in developed countries (those with high income (HI) and a high HDI), 100% of the population has access to electricity, and the average consumption is about 8500 kW·h per year per capita. In contrast, in countries with low income and low HDI, only about 25% of the population has access

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to electricity, and the consumption is less than 500 kW·h per year per capita. Thus, there is a strong correlation between electricity indicators and socioeconomic development [2].

Currently, humanity faces the challenge of reaching the new Sustainable Development Goals (SDGs) by 2030. These goals are a sustainable development agenda to guide development actions for the next 15 years. They include 17 goals and 169 targets, and require an annual investment evaluated at 3.3 trillion–4.5 trillion US dollars per year. Energy-related challenges are in Goal 7, which has the aim of ensuring access to affordable, reliable, sustainable, and modern energy for all. Goal 7 has four targets to be met by 2030; these focus mainly on ensuring universal access to energy, increasing the share of renewable energy in the global energy mix, improving energy efficiency, and expanding infrastructure and upgrading technology for supplying modern and sustainable energy [3–5].

2. Electricity and climate change

Greenhouse gas (GHG) emissions due to human activity have been altering the energy and climatic patterns of our planet. The main gas involved is carbon dioxide (CO_2), which represents 76% of total GHG emissions. These emissions have increased the atmospheric concentration of CO_2 from ~277 ppm in 1750 to 397 ppm in 2014, an increment of about 43%. In 2015, CO_2 levels registered several peaks over 400 ppm in March and December. In relation to economic activities, the burning of coal, natural gas, and oil for electricity and heat is the largest single source of global GHG emissions.

The international political response to global GHG emissions and climate change began in 1992 with the constitution of the United Nations Framework Convention on Climate Change (UNFCCC), which set out a legal framework for stabilizing atmospheric concentrations of GHGs in order to avoid dangerous anthropogenic interference with the climate system. After many annual meetings, with advances and failures, the 21st session of the Conference of the Parties (COP21) occurred in Paris from November 30 to December 11, 2015. The Paris meeting was a world-leading event that brought together over 150 heads of state and governments to generate political will toward an agreement. The conference brought together over 36 000 participants; nearly 23 100 government officials; 9400 representatives from United Nations (UN) bodies and agencies, intergovernmental organizations, and civil society organizations; and 3700 members of the media.

In Paris, parties agreed to limit the increase in global average temperature to well below 2 °C above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that such a limitation would significantly reduce the risks and impacts of climate change. Each party is required to—shall prepare, communicate, and maintain successive Intended Nationally Determined Contributions (INDCs) for themselves to achieve. Countries must make a progressive voluntary pledge, one that is not fully binding, of mitigation efforts of GHG emissions. This is the first global agreement to mitigate climate change that includes all the countries in the world, and is a first keystone step [6]. However, the INDCs that have been provided to date by most countries only extend to the year 2030, and would suppose an increase in temperature of about 3 °C to 3.5 °C—far greater than the proposed scenario of 2 °C and 450 ppm of CO_2. Therefore, it will be necessary for countries to make promises and additional efforts regarding GHG emissions after the year 2030 [7].

The UNFCCC is under way to reach global agreement on the reduction of GHG emissions. Moreover, there is a general consensus on key points regarding the mitigation of electricity-related emissions. These key points include: the important development of renewable energy—that is, solar, wind, geothermal, bioenergy (green power), and hydropower (blue power); an improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; combined heat and power; and early applications of CO_2 capture. In addition, the approved COP21 Paris Agreement acknowledges the need to promote universal access to sustainable energy in developing countries, and particularly in Africa, through the enhanced deployment of renewable energy.

3. Hydropower and climate change

Hydropower is a clean, renewable, and environmentally friendly source of energy, which produces an average of 3930 (TW·h)·a^{-1} and yields 16% of the world's generated electricity, representing 78% of renewable electricity generation in 2015 (Fig. 1). Global hydro capacity is 1100 GW (mainly in Asia and Latin America), and has increased at a compound annual rate of about 3.5% over the last five years. About 160 GW of hydro capacity are currently under construction, and more than 1000 MW are planned.

There are currently about 1200 large dams under construction in 49 countries around the world, mainly in Asia. Of these, 347 are major dams (with a height over 60 m) located in 49 countries. For the majority of these major dams (202, or 58%), hydropower is one of the main objectives, and more than 50% are multipurpose reservoirs [8].

Hydropower has been extensively implemented in developed countries, which have tapped more than 50% of their technical feasible potential. Although emergent economies have developed between 20% and 30% of their hydropower potential, developing countries have a large remaining hydro potential. Africa is an extreme case, where only 7% of economically feasible hydropower potential has been developed (Fig. 2). In general, developed countries have already exploited much of their hydropower potential, while emergent and developing countries still have a long way to go [1].

Hydropower and climate change show a double relationship. On the one hand, hydropower is an important renewable energy resource that contributes significantly to the avoidance of GHG emissions and the mitigation of global warming. On the other hand, it is likely that climate change will alter river discharge, resulting in impacts on water availability, water regularity, and hydropower generation [9].

3.1. The role of hydropower in climate change mitigation

Renewable energy technologies, such as hydropower, contribute significantly to the reduction of GHG emissions and to the security of the energy supply. In comparison with conventional

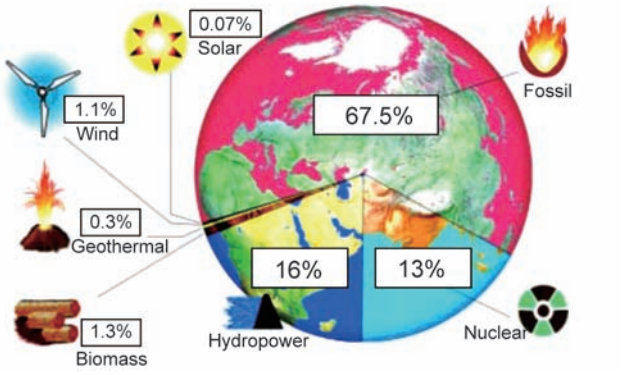

Fig. 1. Main sources of electricity generation in 2015.