

Impacts of climate change on hydropower development and sustainability: a review

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Abstract: The impacts of climate change on hydropower development are complex, often interactive, issues. Many studies have already focused on climate change impacts on the hydrologic cycle. This paper downsizes the analysis and focuses on water resources for power generation. The concentration is on a review of the impacts of climate change on hydropower development from three different spatial scopes; i.e., global, national and regional scales. Climate change is a global phenomenon; however, the effects of climate change on hydropower generation are not uniform over different spatial scales. The diverse effects depend on such factors as local hydrological conditions and geographic features. This demonstrates the necessity of drilling down the analysis of climate change impacts to the sub-national, or local scale of hydropower generation. This paper characterizes both direct and indirect factors of climate change impacts on hydropower, and, elaborates on how several supporting elements contribute to these two categories. It also attempts to provide two strategies for mitigating climate change impacts on hydropower generation and maintaining global energy sustainability. One strategy is to increase the proportion of hydropower generation as a renewable energy to reduce greenhouse gas emissions. The second strategy is to optimize hydropower operation and management to adapt to the varied climate conditions. Finally, some suggestions on how to cope with climate change and hydropower development have been put forward to facilitate discussion on these important issues with policy decision makers.

1. Introduction

Climate change is one of the great challenges of the 21st century. The United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alter the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' Climate change imposes severe stress on the global ecosystem with consequences such as extreme climate events including flood, drought, heat wave, cold stream, melting of Himalayan glaciers (IPCC 2012). Global warming, mainly caused by greenhouse gas (GHG) emissions, is one of the most severe effects of climate changes. Recent data confirm that consumption of fossil fuels (coal, oil and gas) accounts for the majority of global anthropogenic GHG emissions. Emissions continue to grow and CO₂ concentrations have increased to over 390 ppm, or 39% above pre-industrial levels, by the end of 2010 (IPCC 2011). GHG emissions continue to increase at an accelerated pace as citizens of all the countries consume more fossil fuels. There is an urgent demand to decelerate the rate of GHG emissions to help ease conditions favorable for global warming.

It is noteworthy that the hydropower potential, in many cases, is dependent on climate, and climate change will affect both-hydropower resource and generation. The relationship between hydropower



resource and climate change is a very complex interaction. Greater attention has been given to climate change impacts on water resources used for hydroelectricity since the late 20th Century. However, significant research on climate change impacts on hydropower is urgently needed to gain a better understanding of and to quantify the estimates and analyses of these potential effects.

2. Current status of climate change impacts on hydropower

Several research findings published worldwide involve the climate change impacts on hydropower resources. Best known is the work by the Intergovernmental Panel on Climate Change (IPCC) since 1990, which paid considerable attention to the effects of climate change on energy sources including water resources for hydropower and other uses (IPCC 1990, 1996, 2001, 2012). The IPCC noted that the installed capacity of hydropower by the end of 2008 contributed 16% of worldwide electricity supply, and hydropower remains the largest resource of renewable energy in the electricity sector. Thus, it is critically important to study the comprehensive impacts of climate change on hydropower and the influence of global warming. Some earlier studies also could be found. Regional research had been addressed in Jones et al. (1996) and Lem-mel ä& Helenius (1998). The European and UK perspectives have been studied in depth by Arnell (1996, 1999), and a North American perspective can be found in the work by Loukas & Quick (1999). These incipient studies were illustrated in Bergström et al. (2001). Based on these previous studies, this paper tries to categorize the climate change impacts on hydropower at global, national and regional scales.

2.1. Global scale of climate change on hydropower

IPCC presented a special report on renewable energy sources and climate change mitigation in 2012, which provides a full view of climate change impact on hydropower in different continents based on research results of a number of experts around the world. Most of the results were summarized in Bates et al. (2008) and IPCC (2007a).

In Africa, few studies could be found on climate change impacts on hydropower due to the lower percentage of resource applications. (IPCC 2012, Hamududu et al., 2010). In Asia, potential changes were found in runoff, which had a potentially significant effect on the power output in particular to the Himalayan countries. Notably, they were prone to be influenced by landslides and glacial lake outbursts. The possibility of accommodating increased intensity of seasonal precipitation by increasing storage capacities may become of particular importance (Iimi, 2007). In Europe, the average change of hydropower potential was estimated to potentially decline by 6% by the 2070s. From a national perspective within Europe, there were varying degrees of increase or decrease by country (Lehner et al., 2005), but the estimated overall change by 2050 was determined to be -0.2% (Milly et al., 2008). It was difficult to explain the disparity between the continental decline and the average of national expectations. In North America, several examples illustrated that hydropower production was sensitive to total runoff and reservoir levels. Warmer weather led to more precipitation and higher water levels for hydroelectricity to meet the peak demand; while lower water levels led to less hydropower production. In South America, large-scale and persistent rainfall anomalies were associated with climate changes due to El Nino and La Nina. These events were well-documented in Argentina, Colombia, Brazil, Chile, Peru, Uruguay and Venezuela. Glacial retreat is also affecting hydropower generation, as observed in the cities of La Paz and Lima (IPCC 2012). In Oceania, low hydropower generation was similar to Africa; however, the reasons are very different. In Oceania, size, climate and topography were the predominant reasons, while Africa has large undeveloped potential hydropower.

Table 1 shows the continental power generation capacity and estimated changes by 2050, based on an analysis using the SRES A1B scenario in 12 different climate models (Milly et al., 2008), and world regions and data of the United Nations Environment Programme for the hydropower system in 2005 (US DOE, 2009).

Table 1. Power generation capacity in GW and TWh/yr (2005) and estimated changes (TWh/yr) due to climate change by 2050 (Hamududu and Killingtveit, 2010).

Region	Power Generation Capacity (2005)		Change by 2050
	GW	TWh/yr	TWh/yr
Africa	22	90	0.0
Asia	246	996	2.7
Europe	177	517	-0.8
North America	161	655	0.3
South America	119	661	0.3
Oceania	13	40	0.0
TOTAL	738	2959	2.5

2.2. National scale of climate change on hydropower

This section focuses on nationwide analyses of climate change impact on hydropower. This type of analysis serves the useful purpose of providing some technical suggestions to decision makers on how to develop national hydropower effectively in future. However, only a few countries have been involved in this detail of analysis so far.

For the United States (USA), the Department of Energy (DOE) has prepared a comprehensive assessment examining the effects of climate change on available water for federal hydropower, which accounts for approximately half of the USA's installed conventional hydropower capacity. The assessment highlighted the direct effects of climate change, including drying trends and decadal-scale changes that are likely to have adverse impacts on federal hydropower in many regions over the next 25 years. On a longer-term basis, looking beyond the 2010-2039 time period, climate change is likely to become even more challenging for hydropower operations if warming, drying, and seasonal shifts in hydrological trends continue on their projected trajectories (Sale and Kao 2012), (DOE 2013). The findings and recommendations were posted across all four of the Power Marketing Administration regions, including the Bonneville region, the Western region, the Southwestern region and the Southeastern region, separately.

There was another in-depth analysis of climate change on water resources for hydropower in Nepal, in which climate change was identified as the most likely impact on Nepal's hydropower production capacity over the next few decades. A significant warming trend in recent decades was revealed in the analysis, which was even more conspicuous at higher altitudes. The Himalayan glaciers will gradually melt as a result of global warming in the future, resulting in increased snow-fed rivers that flow through Nepal. However, after a certain critical point, snow-fed river flow will decrease due to the greatly reduced and subsequently melted Himalayan glaciers

(http://www.myrepublica.com/portal/index.php?action=news_details&news_id=73723). This analysis also highlights a trans-boundary or regional dimension to climate change impacts, highlighting the need for regional coordinated strategies to cope with such impacts of climate change (Agrawala et al. 2003).

In Sweden, the Swedish regional climate modelling programme (Bergström et al. 2001) simulated the scenarios of river runoff for six selected basins covering the major climate regions, based on the combination of global climate models, dynamical downscaling and hydrological modelling. Changes in runoff totals, runoff regimes and extreme values were analyzed. The results from this programme agreed well with earlier studies in the Nordic countries that water would be more abundant in the north but drastic effects can be seen in the annual river flow cycle.

2.3. Regional scale of climate change on hydropower

Most of the previous emphasis of climate change studies on hydropower has focused on regional areas, such as basins and valleys, which are the basic units for any global and national level study. Jones et al.

(1996) discussed many more issues related to the regional impacts. In this paper, many different regional results in Europe, the USA and China were presented. Some typical findings are listed below.

A study on management adaptation potential of the water resource system at the Peribonka River (Quebec, Canada) indicated that annual mean hydropower would decrease by 1.8% for the period 2010–2039, and then increase by 9.3% and 18.3% during the periods 2040–2069 and 2070–2099, respectively. The trend to increase is statistically significant starting from 2061. Overall, the reliability of a reservoir would decrease and the vulnerability would increase as the climate changes (Minville et al. 2009).

The Northwest Power and Conservation Council (NWPCC), an interstate compact agency, has conducted long term planning for the USA Pacific Northwest (PNW) electricity supply in its 2005 Power Plan. An initial assessment was made of potential impacts of climate change on the hydropower system, but these results were not incorporated into the risk model upon which the 2005 Plan recommendations are based (Northwest Power and Conservation Council 2005). Later, Markoff and Cullen (2008) presented an assessment of uncertainty in future PNW hydropower generation potential based on a comprehensive set of climate models and greenhouse gas emissions pathways. It was found that the prognosis for PNW hydropower supply under climate change is worse than anticipated by the NWPCC's assessment.

There were many studies, including Yao and Georgakakos (2001), VanRheenen et al. (2004), and Tanaka et al. (2006), on the impacts of climate change on hydropower systems in California. Most of them have focused on hydropower systems located at low elevations (less than 1,000 ft). These studies found that hydropower production from the major water supply reservoirs would be mostly affected by the amount of available water, with wetter scenarios showing an increase in generation and revenues proportional to the change in streamflow and drier scenarios displaying the opposite pattern. Vicuna et al. (2008) formulated a linear programming model of an 11-reservoir hydroelectric system operated by the Sacramento Municipal Utility District in the Upper American River basin to study the potential effects of climate change-induced hydrological changes on high elevation hydropower generation in California. Madani and Lund (2010) developed an Energy-Based Hydropower Optimization Model (EBHOM) to facilitate practical climate change for three climate warming scenarios (dry warming, wet warming, and warming-only) and found that the system was sensitive to the quantity and timing of inflows.

Nash and Gleick (1993), Wolock and McCabe (1999), Christensen et al. (2004), and Christensen and Lettenmaier (2007) studied the effects of climate change on the variation of hydrology and water resources of the Colorado River Basin. Their results revealed different degrees of impacts on streamflow and hydropower generation with varying predictions of temperature and precipitation.

Concern for responsiveness and vulnerability of tropical areas to climate change in of Central America is most prominent. Recent studies have found increases in Central American precipitation intensity. Christensen et al. (2007), Neelin et al. (2006), and Rauscher et al. (2008) have examined climate model consensus of future drying projections. Maurer et al. (2009) created the climate model based consensus on the hydrologic impacts of climate change to the Rio Lempa Basin of Central America, and revealed that the frequency of low flow years would increase. Correspondingly, the hydropower capacity would decrease 33% to 53% by 2070-2099.

These case examples presented above illustrate the typical climate change impact on hydropower. Although they used different models, scenarios, and methodologies in numerous regions of selected countries, all of these papers revealed that climate change has already begun to increasingly affect hydropower capacity and operation mode, and, will further impact hydropower in the future.

2.4. Climate change impact on small hydropower (SHP)

Almost all of the hydropower studies presented in this paper have focused on large or medium spatial scales. There are no technical or economic reasons constraining the further development of large or medium-scale hydropower, but usually they were built with a reservoir which would submerge plants and forests, reduce in carbon sequestering ability and then lead to methane emission. Therefore, SHP

stations, most of them are runoff type, without dam and reservoir, play a key role for rural electrification in many countries, and are generally supported after prosperous period of large or medium-scale hydropower development. The maximum capacity of the SHP are distinctively defined in different regions. For example, the SHP maximum capacity in European Union is 20MW; while in USA and China, the maximum capacity of SHP is 30MW and 50MW, respectively. There is no worldwide consensus on classification by installed capacity due to varying policies of different countries. It typically takes less time and effort to construct and integrate SHP schemes into local environments (Egre and Milewski, 2002). The deployment of SHPs is increasing in many parts of the world, especially in remote areas where other energy sources are not viable or economically attractive. SHPs are gradually coming under the umbrella of most renewable energy support mechanisms.

In view of the significant role of the SHP in energy systems of the future, it is crucial to gain a better understanding of the effects of climate change. There are only a limited number of studies on climate change impact on SHPs; however, it doesn't mean SHPs are not influenced by climate change. On the contrary, SHPs are more sensitive to climate change when compared with conventional hydropower due to their smaller scales. Small changes in climate conditions can lead to relatively large percentage changes in SHP generation. The location of SHPs are more likely to rely on runoff availability that becomes more dependent on hydrologic conditions. The generation and efficiency of a SHP power plant will vary with associated changes in runoff, which is directly influenced by the temperature and precipitation patterns. Because of their relatively small capacity, SHP plants are constrained by fluctuating reservoir supplies. The available reservoir water supply increases in during periods of abundant seasonal precipitation and decreases to potentially low levels during prolonged periods of dry weather. In this sense, the SHPs are more vulnerable to the impacts of climate change compared to large-scale hydropower plants. There are many challenges that have to be addressed in order to reap the full benefits of SHP resources.

3. Causes of Climate change impact on hydropower

Despite large uncertainties in the results and predictions of different model output, there is no doubt that climate change during the next decades will have potentially dramatic impacts on water resources and hydropower (Jones et al. 1996, Bergström et al. 2001). Since the importance of hydropower generation and its potential sensitivity to climate change have already been realized in recent years, some quantitative estimates of the technical potential for hydropower have been established. However, relatively few studies have addressed the specific factors of climate change impact on hydropower. Based on previous studies, this paper focuses on the causal analysis of these impacts, and categorizes them as either direct and indirect impacts.

3.1. Direct factor of climate change impact on hydropower

Global warming is one of the foremost climate change factor compared with other factors such as humidity, cloudiness, and precipitation. It has an important influence on hydropower generation and water resource supplies. Global warming increases global temperature patterns which then, in turn, alters the precipitation patterns. One consequence of these alterations tends to be earlier spring snowmelt which has direct effects on hydropower generation.

It is well-documented that temperatures have been rising across the world and impacting the hydropower resource. Temperature is more likely to affect the operations of high elevation hydropower reservoirs with low storage capacity. High temperatures lead to more snowmelt and, often, more intense periods of seasonal precipitation. Particular concern had been noted for the Himalayan countries with high elevation hydropower (Agrawala et al., 2003). The increased snowmelt and seasonal precipitation gather much more water, which is not advantageous for hydropower generation nor for the security of downstream areas. An over-filled waterhead in front of the turbine will cause low generating efficiency because the excess hydraulic state biases the optimum operating condition. Compared to the high elevation hydropower, low elevation plants are more likely to be influenced by precipitation than temperature. Precipitation is generally the form of runoff affecting the available water used for

hydropower. However, precipitation is not independent of rising temperatures that also leads to changes in power generation. Many studies showed similar sensitivity of hydropower resource or hydropower generation to both precipitation change and temperature increase. The elasticity of energy production of the Batoka Gorge scheme to temperature and precipitation changes have been estimated and are shown by Harrison et al. in 2011. *The temperature degraded 0.44 while precipitation increased 0.77*. It indicated that the case study was more sensitive to precipitation change than temperature change (Harrison et al., 2006). The relative impact of changes in temperature and precipitation on hydropower generation is also explored by Markoff and Cullen (2008). In the period of the 2080s, the isolines and the data suggested that a 3% change in precipitation had a similar impact on hydropower to a 1 °C change in temperature. It meant every 1 °C increase in temperature requires an approximately 3% increase in precipitation to maintain current levels of hydropower generation. Figure 1 shows the relative impact of changes in temperature and precipitation on hydropower generation.

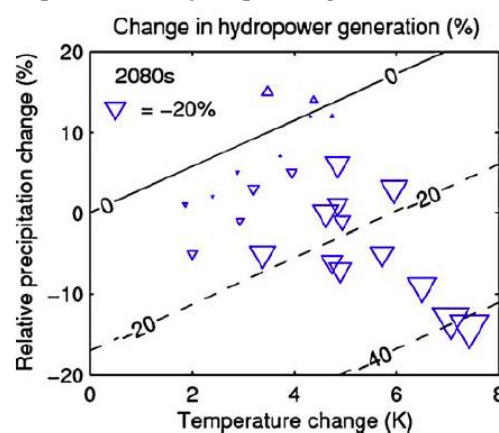


Figure 1. Predicted change in annual hydropower generation (%) as a bivariate function of change in temperature and precipitation from GCM output for the 2080s of Pacific Northwest Hydropower (Markoff and Cullen, 2008).

3.2. Indirect factor of climate change impact on hydropower

Compared with the two important direct parameters of temperature and precipitation, there are still many indirect factors that need to be discussed. They have relatively mild climate change effects on hydropower; however, these effects are difficult to quantify. Some of these indirect effects are likely to be experienced, in varying degrees, across all regions, and some of them are region-specific (Sale and Kao, 2012). Indirect effects on water availability for energy purposes may occur if water demand for other uses such as irrigation and water supply for residential households and industry rises due to the climate change (IPCC, 2012). This paper provides a qualitative analysis of the indirect climate change factors impacting hydropower based on limited reference to previous studies.

Firstly, as the temperature increasing, the evaporation potential also increases, resulting in more liquid water evaporating into the gaseous state in the lower atmosphere. In turn, the temperature-driven increase in evaporation from reservoir surfaces potentially reduces the available water supplies for hydropower.

Secondly, high temperature and increased variability of precipitation tend to increase the demand for irrigation water in agricultural regions due to the increase of total soil evapotranspiration. This occurs even if the total precipitation during the growing season remains the same.

Thirdly, the quantity of water is not the only important variable. Changes in water quality can also have substantial impacts on hydropower generation. Increased precipitation intensity may periodically result in increased turbidity of the water heading to the hydraulic generator. The sediment rush from upstream will increase the wear of the turbines. It would also increase the clean-up costs and reduce the operating lifetime of the turbine and its power generation efficiency.

Finally, extreme weather is very likely to accompany global warming. The increased risks of landslides, glacial lake outbursts and floods make it particularly important to accommodate increased flow by reservoir regulation and water management. During extremely warm, dry weather, increases in both irrigation and total electricity demand will place greater stress on the available water supply for power generation.

In addition, because of the significant municipal use of water resources, there are still other climate change impact factors to hydropower. *These* indirect effects may be region-specific to meet local demands for sustainable development of society and the ecological environment. For example, the PNW Electric Power Planning Act of 1980 mandated that the federal dams in the Columbia River Basin be managed not only to provide inexpensive power, but also to protect fish and wildlife (Callahan et al., 1999; Cohen et al., 2000; and, Markoff and Cullen, 2008). In order to ensure the bio-diversity or endangered species in the river system and along the river banks, the fish and wildlife protection is of significant importance in how the hydroelectric resource is managed in the years and decades to come. These many demands on the system are often in conflict, particularly as the total supply of water is limited.

4. Strategies for mitigating climate change impacts on hydropower and promoting long-term sustainability

Even though climate change impact on hydropower is irreversible, there are still many methods to mitigate the potentially damaging effects and to protect the critical sensitivity of hydraulic resources from the effects of climate change. With the development of advanced technology, models, methods and improved algorithms, more precise and accurate planning and forecasting performance of climate change is greatly enhanced. A key questions are: how to decrease the impacts of climate change on hydroelectric resource, and, how to promote long-term sustainability of hydropower development? The remainder of this paper focuses on these questions.

4.1. Increasing the proportion of hydropower generation

In the arduous process of responding to climate change and climate change mitigation, multi-various efforts has been underway at many institutions and organizations. To limit global warming, GHG emissions need to be substantially reduced in all sectors of economy development. There are multiple mitigation pathways leading to this ambitious goal. As a renewable energy, hydropower plays a significant role in the global energy balance because there are almost no GHG emission during the power production process, though it generate GHG when manufactured. The quantity of GHG emission during construction period could be weakened compared with its contribution to mitigate the GHG emission in the whole life of hydropower generation. Hydropower is a reliable and complementary energy supplier, in addition to wind power and solar energy, for the entire power supply system. In a hybrid energy supply system with wind and solar power, hydropower will boost the stability of the system. Global energy utilization is undergoing an important period. Vigorous development of hydropower and other renewable energy sources is the urgent direction of energy development in the future to respond to climate change impacts and to assist global sustainable development.

In the energy system as a whole, more hydropower generation will lead to less fossil fuels consumption and, subsequently less GHG emissions into the air. Thus, the most direct way to mitigate climate change is to accelerate hydropower development, especially in Africa, Asia and Latin America. In these regions, the energy development rate is still lower than 30%, and, there is immense potential capacity available for exploration.

As discussed earlier, SHPs play a key role, not only in rural energy generation, but also to mitigate climate change impacts. It is a win-win potential to develop SHPs in the next decades due to: (1) SHP plants presents an excellent substitute to fossil fuel plants for no carbon emissions and negligible local environmental footprints, and, with few of the negative impacts on fishery resources and riverine ecosystems; and, (2) They provides electricity in remote areas where there are no appropriate opportunities or locations to establish larger-size power stations.

As part of the clean development mechanism (CDM) which was introduced in 'Kyoto Protocol' (UNFCCC), some SHP plants help developed countries achieve emission-reduction along with other CDM projects. This application of SHP technology will also be helpful for energy development in developing countries, as well. In addition, SHP can also reach full benefits with other RE resources such as solar energy, wind energy etc., especially in remote areas. Multi-energy, complementary power generation can maximize these benefits depending on the specific technology, management, and site characteristics.

4.2. Optimizing hydropower operation and management

Special attention should be devoted to adaptation measures to cope with the varied climate environment. Two prime options are addressed on operation and management of hydropower generation to adapt climate change.

The first option is to enhance the optimal operation of cascade hydropower stations or single hydropower station with reservoir. Scheduling optimization could reduce the water spill with available capacity and storage. There is a persuasive case made by Madani and Lund (2010) showing the annual marginal benefits of capacity expansion were higher for storage than for generation. Although the Dry scenario examined in that study had 20% less runoff than the base historical hydrology, system-wide, revenues decrease by less than 14% through optimally re-operating storage and generation facilities within existing capacities. Scheduling optimization of hydropower station group on a river or a basin, is easy to make full use of water resource at all levels, it also can adjust and compensate for the effects on each single station due to interannual climate variability during the year. In this case, the most important thing is to optimize the hydropower operation pattern to maximize the revenue with limited capacity and available ancillary facilities (Zhang et al. 2012).

The second option, and not mutually exclusive, is to conduct an in-depth risk analysis of climate change impacts on hydropower generation and prepare emergency plan for climate extremes. Changes in mean climate impact caused by global warming on hydropower are relatively limited and easier to be controlled, but the extreme weather events such as floods and drought will seriously affect the production, transmission and distribution of hydropower generation. The frequency and intensity of regional extreme weather caused by climate change is clearly evident. This places potentially severe stress and high risk on hydropower systems. Therefore, it is critically significant for hydropower planners and decision-makers to analyze the potential risk of climate extreme events during the operation. Based on hydrological model forecasts and predictions, emergency plans under different extreme conditions should be established. By optimizing power generation operation and management, the more efficient hydropower stations could not only increase their generation revenue but also play a significant socio-economic role for society.

5. Summary and Discussion

Both large and small scale hydropower stations offer a significant potential for near and long term GHG emissions reduction. It is necessary to understand how to sustain and facilitate hydropower production under the adverse effects of climate change impacts. Despite many achievements that have been published on improving the understanding of and how to cope with the climate change effects on water resource and hydropower, there are still large uncertainties with the dynamic hydrological processes. Climate change and hydropower development interact with each other in the natural process, so any variation that occurs with one of them will lead to a change in the other. Several problems must still be further investigated.

First of all, it is most critical to improve the forecast and prediction of changes in the hydrological regime caused by global warming related climate extreme events. With more spatial and temporal accuracy, these forecasts and predictions will help to make better and more accurate assessments of the hydropower development potential while coping with climate change.

Secondly, all of the research presented in this paper were large-scale studies. Most of these studies lacked the unique local hydrographic conditions for project-specific research. Because of the diversity

and distinctiveness for each hydropower station, it is extremely difficult to establish universal measures to mitigate the climate change impacts. Thus, site-specific research can focus better analysis on cumulative climate change impact assessments on hydropower. These results may provide more useful idiographic measures for local hydropower generation.

In addition to technological efforts, government intervention in hydropower management and regulation should not be ignored. National, regional and local governments can establish effective measures to promote the implementation of hydropower and other renewable energy projects, to regulate and govern hydropower electricity utilization, to assist managers with flood-control operations during high flow episodes and improve water usage procedures during drought periods, and, to ensure the safety of environmental, eco-system, and socio-economic sectors.

Planning and implementation measures need sufficient time to ensure appropriate actions are taken. Hydropower is already meeting the global energy challenges as a renewable and sustainable energy resource. It has great potential to increase its contribution in the future. As time passes, climate change impacts on hydropower development and hydropower sustainability will increase and place greater stress on the entire energy continuum around the world. With appropriate and feasible mitigation and adaptation strategies, hydropower can promote and enhance the development of local society and communities, and improve the quality of the environment and the socio-economic well-being of society.

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