CLIMATE CHANGE ADAPTATION : A GOLDEN OPPORTUNITY FOR DEFINING NEW VISION AND MISSIONS FOR DAM AND HYDROPOWER DEVELOPMENT IN IRAN

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ABSTRACT

Climate change has been expanding its umbrella throughout the Middle East. In Iran particularly, unprecedented floods in unexpected timings have caused painful damages. Despite these inconveniences, tremendous amount of water has been flowed in main rivers in Iran, a semi-dried country that suffers from water scarcity. This is a unique opportunity for the dam industry in Iran.

Iran Water and Power Resources Development Company (IWPCO) is the largest dam and hydropower plant owner and developer in Iran with several projects under operation and many under construction. The recent floods have boosted the role of IWPCO in two aspects: (1) controlling floods by its huge hydropower under operation dam reservoirs and thus, preventing serious damages to the downstream communities; and (2) considerable increase in renewable electricity generation by its hydropower plants and thus, improving revenue. This paper presents how IWPCO's top management decides to use this golden opportunity and defines an innovative business plan. The procedure of new vision and missions are elaborated and four new strategic directions for business development are introduced including: (1) tourism attraction using beautiful dam lakes scene; (2) strengthen international collaborations; (3) longitudinal organization alongside main rivers; and (4) promote small and medium hydropower potentials.

1. INTRODUCTION

One of the action areas for the 2019 year's UN Climate Action Summit is energy transition, which includes accelerating the shift away from fossil fuels (responsible for climate change) and towards renewable energy (IPCC, 2007a, b). Hydropower offers significant potential for carbon emissions reductions. The installed capacity of hydropower by the end of 2008 contributed 16% of worldwide electricity supply, and hydropower remains the largest source of renewable energy in the electricity sector (Iimi, 2007). On a global basis, the technical potential for hydropower is unlikely to constrain further deployment in the near to medium term. Hydropower is technically mature, is often economically competitive with current market energy prices and is already being deployed at a rapid pace. Situated at the crossroads of two major issues for development, water and energy, hydro reservoirs can often deliver services beyond electricity supply. The significant increase in hydropower capacity over the last 10 years is anticipated in many scenarios to continue in the near term (2020) and medium term (2030), with various environmental and social concerns representing perhaps the largest challenges to continued deployment if not carefully managed (Lehner et al., 2005). The impacts of

climate change on hydropower development are complex and often interactive issues (Shu et al. 2018). This research aims at discussing how climate change increased precipitation in Iran and as such, hydropower industry was boosted. This paper is organized as follows. A brief overview of climate change is presented in Section 2, followed by Section 3 which presents interaction between climate change and hydropower. The usefulness of IWPCO in preventing floods damages and generating clean energy is discussed in Section 4, and the new vision and missions defined in IWPCO are introduced in Section 5. Finally, some concluding remarks are highlighted in Section 6.

2. CLIMATE CHANGE OVERVIEW

Climate Change is one of the growing 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 Green House Gas (GHG) emissions, is one of the most severe effects of climate changes. Recent data confirm that consumption of fossil fuels such as coal, oil, and gas, account 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).

2.1 Climate Change in Iran: Current Condition

The Intergovernmental Panel on Climate Change (IPCC) estimates an increase in temperature in the Middle East up to 2 °C in the next 15–20 years and over 4 °C by the end of the century. This fact is combined with a decline in precipitation by 20% (IPCC 2007). Hence, the Middle East countries are very vulnerable to facing climate change effects. Among the Middle East countries, Iran will experience an increase of 2.6 °C in mean temperatures (NCCOI 2014). Hence, the climate change fact of Iran is more severe than the Middle East region. As shown in Figure 1, Iran is the first responsible country to climate change in the Middle East, and seventh in the world. The high-level contribution of Iran to emissions of GHG depends on a significant production of oil, gas, and rapid urbanization.

Based on the above facts and figures, Iran in recent years has been taking more decisive actions in the field of climate change, inspired by Article 50 of its Constitution to insure legal protection of the environment. In this continuous process, the Third National Communication (TNC) to UNFCCC is also fulfilling the country's commitments. Iran has also a great capacity to implement the strong actions needed to address climate change (Hamududu & Killingtveit, 2010). However, there are still many areas that need improvement and enhancement of national capacity including cross-sector coordination, inadequate data and information collection, as well as other uncertainties and constraints that hinder the smooth implementation of the project for preparation of National Communications (the Third National Communication (TNC)-2017).

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.

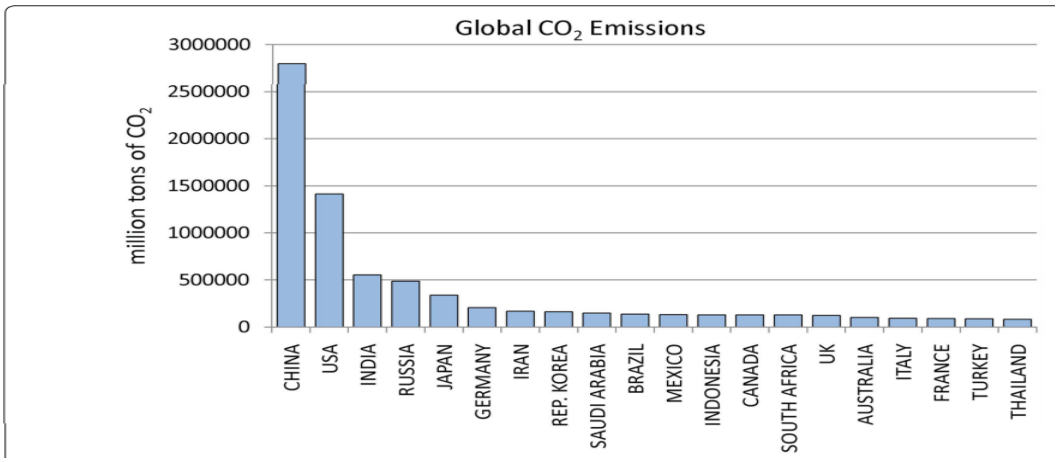

Figure 1 : Ranking of the world's countries contributed to total CO2 emissions (in a million tons of CO2) in 2013, after CDIAC (2014)

3. CLIMATE CHANGE AND HYDROPOWER FLEET: CURRENT STATUS IMPACT

Among many research investigating the subject issue worldwide, 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. As such, it is crucially 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-melä & 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). The impact of climate change on hydropower fleet has also been categorized and then, assessed at global, national and regional scales (Shu et al, 2018).

There is clearly an urgent need to effectively generate and integrate climatic projections into investment and decision making processes for the planning, design, and operational management of hydropower schemes. With a growing awareness and recognition of the risks, this process should be accelerated. Having said that, the most important climate change effects impacting future hydropower generation are likely to be earlier snowmelt, change of runoff seasonality, and increasing frequency of extreme high- and low-runoff events. Such phenomena bring threats or negative risk such as disaster floods and may also create opportunities or positive risks such as more clean electricity generation by hydropower plants or flood controlling, the key opportunities that are the subject of this paper.

Given the projected shift in hydrological conditions, water resource managers may need to allocate their water usage more cautiously. U.S. federal hydropower reservoirs with relatively large storage capacity have the ability to absorb some increased runoff variability and will likely continue to provide stable annual hydropower generation in the projected near-term and midterm future periods. The flexibility that currently exists in PMA Marketing practices will likely continue to allow the PMAs to fulfill their missions in the face of climate variability (Bates et al. 2008) and (IPCC, 2007a).

3.1 Causes of Climate change impact on hydropower

Despite many uncertainties involved, it is undeniable that clime change has significant direct and indirect impacts on water resources and hydropower industry. (Jones et al. 1996, Bergström et al. 2001). With respect to the direct impacts, four factors are the main impacts (Shu et al. 2018): Global warming, humidity, cloudiness, and precipitation. The first one is however, the most important factor influencing 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. Precipitation is also, in 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 (Shu et al. 2018).

With respect to the indirect factors affecting hydropower generation, 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).

3.2 Climate Change Mitigation Strategies: Lowering Impacts on Hydropower

Although the effect of climate change on hydropower is unavoidable, 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. Here are two main strategies explained below (Shu et al. 2018).

Strategy 1 – *Increasing the proportion of hydropower generation*

In the arduous process of responding to climate change and climate change mitigation, multi-various efforts have 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. 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. 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.

With respect to 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, where the energy development rate is still lower than 30%, and, there is immense potential capacity available for exploration.

Strategy 2 – *Optimizing hydropower operation and management*

In terms of coping 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. 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 inter-annual climate variability during the year (Shu et al. 2018). 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 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 electricity production, transmission and distribution, as this happened last year in IWPCO. The frequency and intensity of regional extreme weather caused by climate change is clearly evident (Jones et al. 1996). This places potentially severe stress and high risk on hydropower systems. Therefore, it is critically significant for hydropower planners and decision- (e.g., IWPCO) 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 not only increase their generation revenue but also play a significant socio-economic role for societies (Bates et al. 2008).

The possibility of accommodating increased intensity of seasonal precipitation by increasing storage capacities may become of particular importance (Iimi, 2007). In Iran, like 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.

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, 2017). As observed in Table 1, hydropower generation is still a reliable source of energy by 2050 throughout the world.

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**

4. CLIMATE CHANGE AND HYDROPOWER DEVELOPMENT IN IRAN: NEW OPPORTUNITY

For some years mainly between 2016 and 2019, the amount of precipitation in Iran was decreasing and as such, hydropower plants in Iran were not working with full capacity and consequently, the share of electricity generation nationwide dropped from 10% to about 6%. However, series of unexpected floods took place almost throughout Iran in late March and early April 2019 and hydropower industry in Iran was absolutely boosted in two aspects: (1) flood prevention using Integrated Flood Management (IFM) policy; and (2) considerable increment in electricity generation by hydropower plants. Each is briefly discussed below.

4.1 Flood Prevention

Due to the geo-topographic nature and precipitation pattern in Iran, devastative floods occur mainly in southeast region of the country, where the three main basins are located: Karun, Karkheh, and Dez. Total volume of 9683 million cubic meters (MCM) (4736 MCM in Karun, 2696 MCM in Karkheh, and 2251 MCM in Dez) floods were flowed in the three basins where majority of hydropower dam reservoirs constructed by IWPCO could successfully dampen the devastative flood energy. The location of large HPP on Karun and Dez basins are displayed in Figure 2.

Figure 2 : Dam Reservoirs in Karun and Dez Basins

Integrated Flood Management (IFM) process promotes integrated rather than fragmented approach to flood management. IFM improves the functioning of the river basin as a whole, recognizing that floods have beneficial impacts and can never be fully controlled (Lehner et al. 2005). IWPCO employed IFM to seek maximizing the net benefits from the use of floodplains and to minimize loss of life, subordinating flood loss reduction to the overall goal of maximizing the efficient use of the floodplain. To this extend, a procedural guideline was defined in IWPCO as shown in Figure 3, and accordingly, the following steps within the three basins were carried out: Step 1: anticipate the pick daily discharge (m^3/s) and flood volume per Million Cubic Meter (MCM) for each basin. Step 2: Based on the results of the first step, reservoir water level for each reservoir was lowered, in an integrated approach with other reservoirs, in order to provide flood damping capacity. This was done by adjusting the daily inflow and outflow rates for each reservoir. This was a delegate balancing task because the outflow should be more than the inflow and the dam reservoirs in Karun basin are cascaded and adjusting the upstream reservoir would impact the downstream one and so on. Step 3: Manage electricity generation based on the adjusted level and report the available capacity to the national dispatching headquarters. Step 4: Implement Emergency Action Plan (EAP) for the reservoirs' downstream regions. Step 5: Monitor and control the flood event and prepare for unexpected events. Step 6: Compare and analyze the anticipative flood volume and discharge with the observed ones, and update lessons learned.

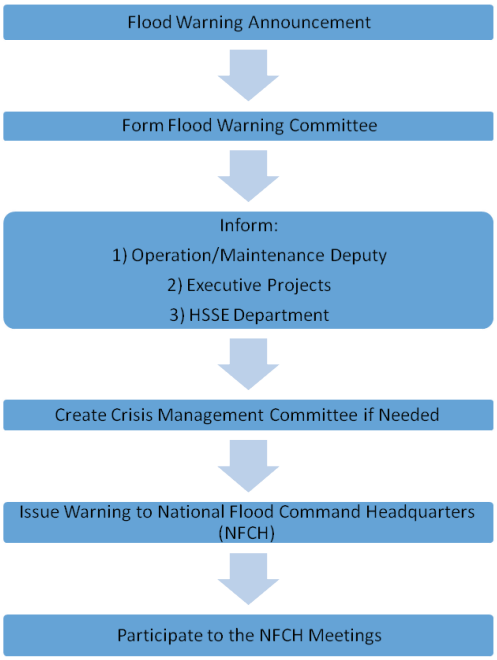

Figure 3 : IFM Procedural Guideline Defined in IWPCO

The flood management of Karun 4 dam reservoir as a key and first cascaded reservoir in the Karun basin, for example, is considered. As shown in by point A in Figure 4, the reservoir's water level was lowered by decreasing the inflow (dash line in Figure 4) and increasing outflow (solid line in Figure 4) in early October 2018. Such decision successfully helped to dampen a pick flood of about 1100 CMS in October 20, 2018. From late October 2018 to Early March 2019, the inflow and outflow were simultaneously kept low and carefully managed by early March when snow and sudden showers in upstream create unexpected floods. Due to the successfully implementing IFM and in March 22, 2019, a huge flood with a pick of 2600 CMS was controlled by Karun 4 dam reservoir as shown by the dash line graph on the right side of Figure 4. This policy could prevent potential downstream damages.

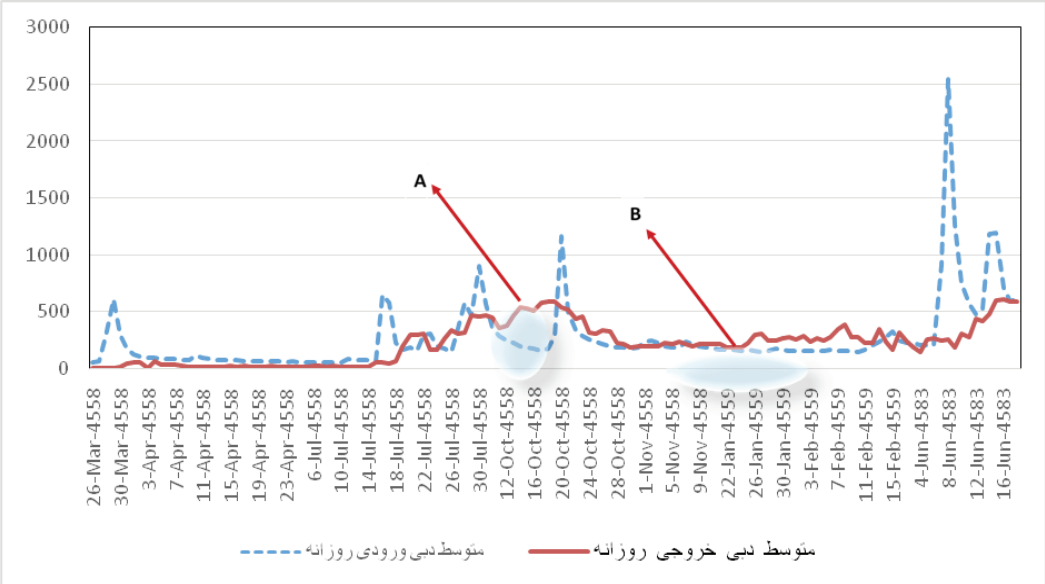

Figure 4 : Karun 4 Reservoir Management for the Anticipated Flood

4.2 Increment in Electricity Generation

The dampened water in the hydropower dam reservoirs created a unique opportunity to boost clean electricity generation in Iran after the floods so that not only the decreasing capacity of previous years was compensated but also, new generation is recorded to be 33000 Gwh in September 2019. The total hydropower electricity generation in September 2018 was 10640 Gwh and the difference shows a jump of 300% in generation. This increase in clean energy generation means that less fossil fuels were consumed, less environmental effects were caused, and more natural resources were saved.

It will be necessary to bear in mind that such considerable boost in energy production brought many benefits in various aspects for IWPCO and as such, top management decided to define an improved business plan explained in the next section.

5. NEW VISION AND MISSIONS IN IWPCO: A SMART ROADMAP FOR HYDROPOWER SUSTAINABILITY

Recent floods and great performance of hydropower dam reservoirs in turning implicit threats into explicit opportunities provided a unique opportunity for top management in IWPCO to improve the IWPCO's business plan. Lots of discussions took place and different possibilities and potentials were explored. Among them, four new strategic directions for business development were finalized including: (1) tourism attraction using beautiful dam lakes scene; (2) strengthen international collaborations; (3) longitudinal organization alongside main rivers; and (4) promote small and medium hydropower potentials. Each will be briefly explained below.

5.1 Tourism Attraction

Due to the climate change and unexpected pattern of precipitation in Iran, hydropower dam reservoirs can better regulate water and the reservoirs water level is often in a steady high condition. This situation helps decision makers to invest more on tourism attraction using beautiful dam lakes scene. Iran is a vast country and the reservoirs, distributed throughout the nation, create magic scene of view. Investing reasonably on defining and completing tourism facilities such as hotels, motels, wonderlands, IWPCO can open a reliable source of income that can be used to achieve the company's goals and objectives. Moreover, Because IWPCO is in charge of operation and maintenance of HPPs, the tourism attractions will help in sustainable development of the communities located around the reservoirs.

5.2 Strengthening International Collaborations

Due to the new opportunity, IWPCO has decided to strengthen international collaboration using two approaches: (1) Exporting hydropower experience (in terms of engineering and management services) to other countries particularly, neighboring countries. 2) Inviting international investors and contractors to Iran to complete hydropower projects. In order to implement this intention, an independent international office was defined and added to the IWPCO's organizational structure. This office is directly working with IWPCO's CEO and is responsible for implementing policies and procedures defined in the business plan canvas of IWPCO. To this extend, meetings and negotiations with some countries have been begun. It should be mentioned that within the hydropower industry worldwide, hydropower market in Iran is potentially a great opportunity for international partners since only 35% of the hydropower potential has been invested.

5.3 Improvement of alongside Rivers

Recent floods had a great lesson learnt by IWPCO top management and that is to restore alongside rivers which are impounding by the dam reservoirs. For many years, the alongside of main rivers in Iran have been facing many problems. Due to the lack of serious controls, many facilities and buildings are illegally constructed alongside riverbeds and within river boundaries. Iranian rivers had not witnessed such unexpected huge floods due to the climate change for many decades and now, when such floods flow to the rivers, these facilities represent serious threats. Moreover, the rivers passing through rural areas need restoration and in some areas need upgrading to accommodate unexpected floods and to make sure that the farmlands adjacent to the rivers would not damage. This new IWPCO's mission, added to the business pan, is a substantial task and international experience in this regard is warmly sought and welcomed.

5.4 Promoting Small/Medium Hydropower Potentials

Unprecedented precipitation has somehow changed water runoffs pattern in Iran. Many small rivers throughout the nation had already been dried and they are now restored and provide a good opportunity to better develop small/medium HPPs. The focus of hydropower development in Iran has been mainly on development of large HPPs and less attention had been paid to small ones. It is time to focus more on the benefits of small HPPs such as less financial investment for each project, less environmental effect during construction, less time for return of investment. In this context and within the business plan of IWPCO, a new mission is defined for small/medium HPP Department in IWPCO to carry out an updated feasibility study and promote more internal and external investors.

6. CONCLUSIONS

This paper aimed at presenting recent development of dam and hydropower industry in Iran due to the climate change. Recent floods, due to the climate change impact in Iran and great performance of hydropower dam reservoirs in turning implicit threats into explicit opportunities, provide a unique opportunity for hydropower industry. In fact, 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 one. Since future hydropower generation will be largely controlled by changes in runoff and precipitation conditions, reservoir storage provides a vital buffer to help absorb runoff variability.

In pursuit of the Paris Agreement targets, Iran has boosted clean energy generation and the recent unprecedented precipitation was a unique opportunity for hydropower industry to: (1) prevent devastative floods damages; and (2) considerable increase in hydropower electricity generation in which not only tremendous amount of greenhouse gas emissions were not produced but also, a great source of income was received IWPCO, the largest hydropower owner in Iran. Climate change defined a new opportunity for IWPCO to update its vision and missions within the business plan and 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.

There are still some issues to be taken into account. Growing competition for water uses and environmental services that are likely to be under greater future stresses due to climate change may reduce the Iranian hydropower fleet's ability to mitigate runoff variability and increase the difficulty of future operation. That's why it has been planned to carry out a risk management procedure to better anticipate threats (negative risks) and opportunities (positive risks) and prepare appropriate responses for each risk. It is also worth to suggest that 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.

Last but certainly not least, the climate change has already begun to increasingly affect hydropower capacity and operation mode worldwide, and, will further impact hydropower in the future in Iran. 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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