SYNOPSIS OF THE ENVIRONMENTAL IMPACTS OF LARGE HYDROELECTRIC POWER DAMS

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Abstract

The entire world has tremendously relied on power generation through the technologies of fossil fuel consumption for many decades. From an environmental perspective, the scenario of excessive combustion of fossil fuels has critically affected the global warming potential. Increasing global warming potential is against the context of sustainable development. Therefore, increasing efforts toward the deployment of renewable and sustainable energy technologies such as solar energy, wind turbine, hydropower, geothermal, and biomass have been a focus of global energy stakeholders. The current developmental stride of the global hydropower projects is fast growing meanwhile efforts towards the mitigation against climate change scenario are also encouraged to be improved. The present situation around the world is that there is growing advocacy for sustainable development that involves taking actions for the mitigation of activities with consequential environmental impacts. The construction and operation of hydropower systems have some negative environmental impacts at different stages of construction and operation, therefore early project planning stage must identify and define clearly all the possible environmental mitigation efforts. Carbon emissions are produced during the construction of hydropower dams while there is also the possibility of destruction of the ecosystem resulting from modification of the existing natural landscape and natural water flow regimes. Therefore, this paper presents a review of the environmental impacts of large hydropower dams. It also highlights the core benefits of hydropower systems as a renewable energy technology and the study concludes with some suggested mitigation actions against the identified environmental challenges presented in the study.

Keywords: Hydropower; Environment; Emission; Dam; Renewable energy; Sustainable development

Introduction

The situation of the 21st Century energy demand is such that is dynamically changing due to increasing socioeconomic activities. Continuous growth in the human population and rapid socioeconomic transformation in our modern society is skyrocketing the demand for electricity and transportation fuels. Energy stakeholders and government policymakers have enormous

tasks to accomplish several sustainable development projects such as poverty alleviation in developing countries and mitigation of climate change which are tied to the demand for electricity [1]. It was reported that the global demand for electricity between 2010 and 2035 is expected to rise from 5.2 terawatts (TW) to 9.3 TW [2]. However, some activities relating to power generation pose some environmental consequences like climate change to humanity. Anthropogenic Greenhouse Gases (GHGs) orchestrating from the combustion of fossil fuels are gradually increasing the level of global warming potential GWP). Over the years, reliable, secured, and sustainable electricity generation has found several technological approaches due to the dynamic of the research activities involved. In this context, renewable and clean energy development mechanism is fast gaining a global center of attention. There are various kinds of renewable energy (RE) such as solar, hydro, wind, biomass, geothermal and tidal wave. Hydropower generation is the most widely used renewable energy (RE). Despite being favorably used, it is associated with some environmental impacts by its potential capability to change its surrounding environment.

Hydroelectric power generation utilizes water captured and stored in artificially created or natural dams for generating electricity. Water falling on the hydroelectric power turbines spins the turbine and provides the needed mechanical energy to rotate the prime mover turbine system to produce electricity. The involvement of large water bodies and alteration of the natural ecosystem has some negatively threatened environmental impacts. Hydropower generation has the potential to renewable its source of energy constantly and lower emissions compared to fossil fuel and coal power plants but cannot be totally pronounced to be environmentally friendly due to some associated unsustainable activities. For example, large hydro dams have the potential to destroy the natural ecosystem and alter the smooth migratory pathway of aquatic organisms such as fish. Humans and wildlife can also be affected by the activities involved in the construction and operation of large hydropower stations. The hydrological regime of a hydropower dam impacts the natural ecological cycles, migration of aquatic organisms, phenology and other influential factors. Fishes usually migrate from one place to another for different reasons such as reproduction. The presence of obstacle during the migration of fish interrupt their movement and could result in a change in the environment. For a very long period of time in the development of hydropower, the associated undesirable environmental impacts are somewhat overlooked and considered inconsequential compared to their benefits. Therefore, this paper presents a review of the benefits and impacts of large hydropower dams on the natural environment. It makes some suggestions on conservation actions that could help to foster environmental compensation and possible mitigation actions.

Global Potential of Large Hydropower Projects

Large hydropower projects have gained tremendous research recognition in different parts of the world such as China [3-5], Brazil [6-8], and Europe [9-11]. Protagonists of large hydropower

dams predict manifold benefits which include savings of fossil fuel consumption for power generation, provision of urban water supply, agricultural irrigation, flood control, job creation, and opportunity for inland water transport [12-13]. There are many large hydropower projects across different regions of the world. The United States of America, Sweden, Brazil, and China host the global largest hydropower dams. The establishment of large hydropower projects requires a large volume of water with the capability to accommodate sustainable water, irrespective of seasonal variation. An illustration of the concept of a large hydropower project is shown in Figure 2. Large hydropower dams are usually capital-intensive projects financed by public borrowings. Due to the large size nature of the project, it has the potential to alter the existing equilibrium between human beings and the environment on quite a tremendous scale. Rural agricultural production including some settlements of the rural people tends to be located along the river line. In this situation, the occurrence of any negative environmental impacts is expected to have more influence on the concentrated rural settlements along the river line or close to the river bank of the dams. The Global map of gross hydropower potential distribution is shown in Figure 1. There are so many interesting developments regarding the development of large hydropower projects across the world. Some countries in the northern hemisphere (Canada, the US, and Norway) with naturally endowed assets like high mountains and high precipitation suitable for hydropower development have implemented large hydropower projects [15]. In Europe, countries like Germany, Scotland and others around the Alps as well as the Baltic regions [16-21] are massively developing large hydropower projects with rapidly increasing capacity in the construction of global water dams [22].

Figure 1: Illustration of the concept of a hydroelectricity dam and the power generation scheme

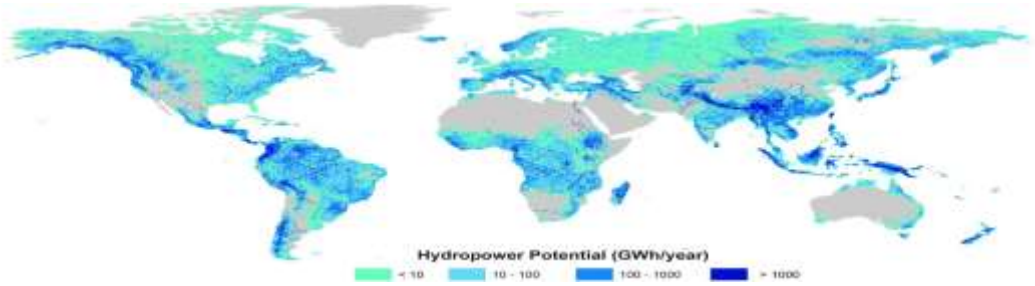

Figure 2: Global map of gross hydropower potential distribution [14]

Benefits of Hydropower Generation

Hydropower projects developed across the world have recorded some notable benefits covering social, economic and environmental aspects. The current potential of hydropower projects in the world is around 20% of the total electricity supply. There are numerous potential sites for hydropower projects that have remained untapped due to reasons covering technical and economic constraints. Development and utilization of hydropower projects across different in the world greatly vary depending on the availability of capital resources and human power. China, Sweden Brazil, Canada, India, Japan, Russia, Norway, Turkey and the United States of America currently have the largest existing hydropower potential. On a global scale, China is leading in terms of the total global existing capacity of hydropower due to the fast-growing economic situation in the country. In China, more than 50% of the national electric power supply is currently being generated from hydropower electricity. The country has constructed many hydropower plants in the last few decades in swift response to the much-anticipated mitigation against global emission reductions. Beyond electricity services, hydropower projects provide irrigation support for agricultural production, provision of clean drinking water and flood control mechanism.

Provision of Sustainable Water Quantity for Aquatic Organisms

Hydropower power dams enable control of water storage and good water quality. The utilization of water in hydropower dams is subject to targeted such that can enable improved environmental flows sustainable for the healthy survival of aquatic species.

Provision of Sustainable Irrigation Water for Food Security

Increasing human populations also requires a corresponding increase in food production. Globally, food security has become an issue of important concern. Due to seasonal fluctuations in the amount of rainfall across different regions of the world, the provision of a reliable source of water for agricultural production is quite essential to farmers. Like in the United States of America, close to 300 dams are used for both hydropower generation and crop production farm services.

Job Creation

As the largest renewable energy in the world, job opportunities provided by hydropower station has been increasing due to the ability of investors to maintain strong and steady growth over the years. The global hydropower industry is expected to grow in its potential to provide high-paying jobs for its thousands of workers over the next few decades. Due to the requirements for multidisciplinary involvement in the construction and operation of hydropower plants, there is a high tendency for massive employment of workers from different technical backgrounds.

Renewable with Less Anthropogenic Greenhouse Gas (GHG) Emission

It is a no-doubt fact that the use of hydropower systems has the potential to reduce emissions of GHGs compared to coal and gas turbine power plants. The principal sources of emissions of GHG for hydropower systems are facilities used during construction. It was estimated that the use of hydropower system for electricity generation reduce as much as 200 million metric tons of carbon annually which equals the number in the number of carbon emissions released by 38 million vehicles [23]. Therefore, the utilization of water for power generation produces cleaner, renewable and more sustainable electricity compared to electricity production through the use of fossil fuel energy technologies. In addition, the renewability of hydropower sources which is water is highly undisputed because natural water tends to be replenished by rainfall and natural river flow from different places. Therefore, a very limited number of toxic products are generated from hydropower projects.

Conservation of Fossil Fuels

Fossil fuels have been exploited for power generation for a very long time ago in the history of electric power discovery. The theory of fuel conservation is to prevent waste because they are part of the economically scarce resources in our society. The global energy stakeholders have been advocating for a transition to alternative energy sources with better environmentally friendly nature. Since emissions associated with hydropower are quite minimal, the development of hydropower technologies for electricity generation can help to reduce or conserve the use of natural gas for the production of electricity. For example, the Itaipu Binacional hydroelectric provides electricity for 103.1 MWh to Brazil and Paraguay in 2016 which has the equivalent amount of oil 500,000 barrels of oil per day for the same electrical energy.

Classification of Hydropower Projects Based on Power Capacity

Hydropower projects are classified into three different categories based on the size of the power plants. The categorization of the power facilities is based on the potential amount of electricity that can be generated and supplied to the energy customers. In this regard, there are three categories of hydropower projects which are micro-hydropower, small-hydropower and large hydropower. Micro-hydropower systems are typically operated by individuals for their domestic energy needs but may decide to sell any excess energy produced to the grid. A small hydropower project is usually a community project funded by the host community, or government or could sometimes attract a joint funding scheme. Large hydropower projects are certainly owned by the government or some international energy donors. According to the United States Department of Energy (DOE), the electrical potential of large hydropower (≥ 30 MW), small hydropower (≥ 100 kW ≤ 10 MW) and micro-hydropower (≤ 100 kW) [24].

Environmental Impacts of Large Hydropower

The application of hydroelectric power plants has associated positive economic, social and environmental impacts. It is however obvious to note that there are some negative threats that must be taken into deliberation. Several negative environmental impacts can be encountered not only with large hydropower dams but also with small dams due to some unreasonable effects on the water bodies [25]. In some countries, there are prominent environmental losses due to the construction of large hydropower dams such as land losses, migration of humans and animals, changes in the ecosystem, and safety threats [26].

Environmental Geological Disturbance

The concept of environmental geological survey in the construction of hydropower dam tends to be a very strict requirement. A survey study on the geological strength of the selected site before the construction of the civil work can be commenced. Some places have weak and more unstable geological strength than others. For example, Nepal is commonly identified with unstable topology resulting from seismic activities and can thereby pose a big threat to the establishment of a hydropower dam [27]. It is therefore required that any proposed hydropower dam must be planned appropriately towards the effective mitigation of any unforeseen environmental impacts. This reduces the safety threat to human life for constructing hydropower dams in vulnerable geological failure areas. Commonly environmentally threatening features in dams constructed in geologically disturbance regions include cracking of the concrete structures and shotcrete layers, ballooning and splitting and spalling [28]. Some structural overbearing conditions can trigger the collapse of dams with consequential devastating flooding situations.

Deposition of Environmental Sediment

Deposition of environmental sedimental materials with characteristic hard coarse particles is another major environmental constraint that can be encountered in hydropower dams. There are varieties of unapproved human activities that are capable of causing sedimentation of materials in water bodies and may subsequently result in flooding and erosions. In a situation where flooding occurs in hydropower dams, there are tendencies for the deposition of a significant quantity of organic matter underneath the dam and thus can result in the production of carbon dioxide by decomposition due to the presence of oxygen. Production of methane gas can be generated by the same decomposition process in the absence of oxygen. Methane is one of the component gases that has a strong affinity for the destruction of the ozone layer thereby causing an increase in global warming potential. Experimental results have shown that the global warming potential of methane gas is approximately 21 times greater than carbon dioxide [29]. It is then important to constantly check hydropower dams against the unwanted concentration of organic deposit materials to avoid the production of methane gas.

Distortion of the Natural Course of River Systems

Construction of a water reservoir undisputed goes along with the tactical manipulation of the natural course of river systems feeding the dam as well as the downstream rivers. Changes in the flow of nature can be influenced by the construction of hydropower dams. This can be a consequential impact such as loss of biodiversity and aquatic habitats due to river impoundment and flow reduction [30]. An alteration in the watercourses due to the construction of

hydropower dams can result in a sudden migration of fish as a result of a change in the habitat of freshwater [31]. In addition, changes in water temperature, the concentration of nutrients and the reduction of water may be experienced within the hydropower dams and along the downstream rivers. These distortions of water in hydropower dams can affect the ecological characteristics of waters feeding from the downstream rivers of hydropower dams, thereby affecting the stability of estuaries and the decline in biodiversity with the depletion or loss of native fish populations. A decline or loss of the fish population has severe constraints on the food supply and the expected stability of the marine ecosystem.

Displacement of Settlements and Land Use

Displacement of human settlements and land use constraints can severely affect the living condition of the original inhabitants of the areas where the project will be located during the construction of reservoirs for large hydropower plants [32]. Conspicuous change in the ecological system as a result of deforestation is a major environmental impact such as landscape intrusion [33]. A particular ethnic group may be displaced permanently during the construction of a hydropower reservoir due to coverage of the construction activities to their homes, historical landmarks, agricultural land and important natural sites. In most cases, huge resettlement expenses may be required to be paid to the owner of houses to be relocated to avoid the impact of a flood on the people [33], especially where are very large reservoir is to be built. Relocation means is a complete change in the living environment of the people and subsequently, the original hydrological conditions of the rivers can be changed as well due to the regulated flow by the reservoir [34].

Flooding

Flood is a devasting natural disaster with tremendously harmful effects on lives and properties. Traditionally, dams are built for varieties of purposes such as irrigation, electric power generation, municipal water supply and flood control. Regardless of the purpose of building a dam, there are tendencies for upstream flooding to occur if they are not adequately monitored. Flooding has devasted impacts such as loss of lives, and destruction of economic properties and farmlands with attendant food shortages. In some extreme situations, an entire community may be wiped out of existence.

Mitigation Actions

Mitigation actions against any possible environmental threats are a very important development in our present-day global society. Environmental impacts are encountered during the development and operation stages of hydropower systems. In order to reduce the environmental impacts of the hydropower system, some multifaceted actions are required.

- ***Regular checking of dams for safe operations***: dams are required to be checked regularly for the assurance of their safe operations. In this context, old dams are required to either be removed or renovated to safe operational conditions. In some situations, dams that have not been used for quite a long time may tend to lose their reserve capacity and may therefore be prone to ecological disturbances such that they may be required to be restored to avoid harboring unwanted organisms. In the best practice, the removal of hydropower dams that have been damaged beyond repair can

be a good solution for the protection of environmental dignity. It also helps in the free migration of different fish populations such that encouraging more reproduction of different species of fish in free-flowing water with better hydrological continuity. Additionally, after the expiration of the expected lifespan of a hydropower dam, removal of the dam should be priority or renovation actions should be considered with immediate effect.

- ***Construction of Sediment Traps*:** construction of traps for sedimental deposits for removal at a convenient time is a core approach toward the mitigation against sedimentation within the environment of hydropower dams. Trapping of sediment materials requires the construction of small-scale barrages with the ability to trap unwanted sediment particles. A periodic dredging solution may be considered for the removal of the sediment materials from the dam to avoid blocking a free flow of water to the turbine or any possible mechanical damage to the hydropower system.
- ***Creation of Migratory Corridors for Aquatic Organisms*:** preservation of aquatic organisms is a very essential endeavor during the development and operation of hydropower plants. It is thus necessary to construct migration corridors for migrating aquatic animals, especially fish. Millions of fish death by turbines are recorded annually resulting in contamination of water but, in some cases, the inclusion of fish cannons in dams correct the problem. Fish cannons are structures in dams to help support the easy movement of fish without harm but may not easily support the migration of fish. It is currently anticipated that a better solution could rely on the development of turbine technologies with zero fish death or the creation of migration corridors for aquatic animals.
- ***Massive deployment of Run-of-River Hydropower System***: this is a special kind of hydropower technology that does not requires the construction of a hydropower water impoundment system. The structural system of the Run-of-River (RoR) hydropower system does not alter the natural flowing course of the river, therefore comes with great environmental benefits compared to the conventional hydropower systems such absence of alteration of the physical habitat.
- ***Design of Fish-friendly Hydropower Turbines***: The design of suitable turbine systems that allows for the existence of migration of healthy fish populations will help to generate income for people living in the surrounding communities where the hydropower dams are located.

Conclusion

With the current pace of growing global investment in the hydropower industry, it is consequently very important to take into cognizance the bearing of the environmental impact assessment of the projects. It is therefore important that environmentally sustainable management of hydropower is necessary. The entire global community is facing the challenge of increasing demand for electricity and hydropower generation represents an important solution. However, the concern about the environmental issues with consequential impact on climate change associated with hydroelectric power generation led to the presentations in this study. The global total installed capacity of hydroelectric power plant capacity is expected to grow by 73% in the next two decades due to the number of dams under construction [35-38],

thereby calling for action on the associated environmental challenges. Despite the increasing number of dams under construction across the different regions of the world, there is a likelihood that energy demand may still exist due to increasing socioeconomic activities and may result in considerable environmental constraints. Construction of hydropower dams comes with regulated water flow regimes such that can cause serious environmental havoc in the form of destruction of the ecosystem, degradation of freshwater biodiversity, disruption of longitudinal connectivity of rivers, inundation of landscapes, and increasing water temperature. Therefore, from the review conducted so far, mitigation and enhancement measures suggested against the perceived environmental challenges in the framework of this study must be accorded priority for sustainable development.

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