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Assessment of the potential for developing mini/micro hydropower: A case study in Beppu City, Japan

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ABSTRACT

Study region: Beppu City, Oita Prefecture, Japan was selected as a site of this study.
Study focus: This study aims to provide quantitative guidelines necessary for capacity building among various stakeholders to minimize water-energy conflicts in developing mini/micro hydropower (MHP), a baseload renewable energy that is socially necessary, not only to reduce greenhouse gas emissions but also to vitalize local economies by creating jobs related to MHP operations. Using three different methods to calculate river water levels and discharges, the potential power generation by MHP was estimated for six rivers in Beppu City.
New hydrological insights: Our results show that installation of MHP facilities can provide stable electricity for tens to hundreds of residents in local communities along the rivers. However, the results are based on the existing infrastructure, such as roads and electric lines. This means that greater potential is expected if additional infrastructures are built to develop further MHP facilities. On the other hand, in Japan, river laws and irrigation right regulations currently restrict new entry by actors to rivers. Therefore, to further develop MHP, deregulation of the existing laws relevant to rivers and further incentives for business owners of MHP facilities, along with the current feed-in tariffs, are required. Meanwhile, possible influences to riverine ecosystems when installing new MHP facilities should also be taken into account.

1. Introduction

1.1. Renewable energy

Reduction of man-made greenhouse gas emissions to the atmosphere is necessary to mitigate global warming and ocean acidification. As the energy transformation sector is one of the largest CO_2-emitting industrial sectors, and CO_2 is the most

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influential anthropogenic greenhouse gas, shifts from thermal power generation using coal, oil, and natural gas to less CO_2-emitting power generation are socially required.

Japan is the world's fifth most CO_2-emitting country, and therefore has a large responsibility to reduce greenhouse gas emissions. Until the end of the 2000s, the Japanese government attempted to reduce CO_2 mainly by shifting from thermal power generation to nuclear power generation. However, after the great east Japan earthquake on March 11 2011, and the following accident of the Fukushima Daiichi Nuclear Power Station, all nuclear power plant operations in domestic Japan have stopped. Instead, dependence on thermal power generation has increased after the great east Japan earthquake, leading to greater CO_2 emissions.

Considering the current situation, development of renewable energy is crucial and pressing. For this purpose, the Japanese government introduced a feed-in tariff (FIT) in July 2012. The strategy attained certain results by providing economic incentives for developing renewable energy, but the effect was relatively limited, primarily to solar power, with little development of other renewable energy sources.

On the other hand, Japan has great potential for developing mini/micro hydropower (MHP). MHP is favorably located at sites with steep geographies and sufficient water, and Japan has a considerable number of favorable sites from this point of view. The main reasons that MHP has not been well developed are the lack of incentives and the many obstacles. For example, to install new MHP facilities, sufficient consensus building with local stakeholders is necessary. The contentions differ among nations and regions with different situations, but in Japan most are strongly related to irrigation rights, fish rights, and riverine ecosystems.

Our ultimate intent is to provide scientific and objective guidelines for developing policy and management options that maximize security and minimize risk within the water–energy-food nexus (Taniguchi et al., 2013), especially focusing on conflicts and trade-offs between energy generated by MHP and food represented by riverine resources such as salmon, trout, eel and sweetfish. The purpose of this study is to establish methods of estimating the potential power generation from MHP that are simple and universal enough to be applied to various regions, both inside and outside Japan. Most previous studies that assessed power generation potential used geographic information systems (GIS) without explicit consideration of artificial influences to river discharge. However, to build a concrete consensus with stakeholders in installing new MHP facilities, scientific, objective, and quantitative data about the effectiveness of MHP in advance are needed. This study aims to provide guidelines based on natural science insights, focusing particularly on the potential power generation, which is information necessary for the next step of consensus building with local stakeholders.

1.2. Mini/micro hydropower

In this study, we focus on MHP, the capacity of which is less than 1000 kW, as defined by the New Energy Law established in 1997. Compared to solar power and wind power generation, MHP has several advantages. First, MHP generation is not strongly affected by weather and the capacity operating rate is as high as 70%. Second, the life cycle CO_2 emission in generating 1 kWh of electricity is 11 g-CO_2, one of the lowest among the various energy sources (Imamura and Nagano, 2010). Third, unlike nuclear power plants, MHP does not require advanced techniques to facilitate and operate, which means that the installation and operation can be done by local communities, leading to local vitalization by creating jobs related to MHP operations.

Until the 1950s, hydropower was the most effective electric energy source and there were many MHP facilities in Japan. Most of the MHP facilities were located in mountainous regions with steep geographies. This is because a natural head and a large amount of running water are necessary to generate electricity effectively, as described in Section 2.3. The rapid decline of MHP after the 1960s was primarily due to Japan's electric energy policy toward thermal and nuclear power.

Therefore, unlike other renewable energy sources, MHP is not "new energy", and the technology is well developed and has the potential to be an important electric energy source once incentives to develop MHP facilities begin again in the future to reduce dependency on thermal and nuclear power.

1.3. Study site

Most previous studies assessing the potential power generation by MHP have used GIS and focused on mountainous regions because such regions generally have steep geographies and rivers that provide natural heads, and therefore, high potential power generation is expected (e.g., Larentis et al., 2010; Yi et al., 2010; Punys et al., 2011). However, if we consider that MHP has an operating life of tens of years and that electricity supply structures are expected to shift from central (such as thermal and nuclear power plants) to more distributed and local facilities in the future, it is possible that MHP facilities would be installed further downstream on rivers near villages and towns, as well as upstream, which would have greater potential power generation, but fewer people. In installing MHP facilities downstream, we might need to consider the human impacts on the rivers and MHP facilities. However, such considerations have rarely been taken into account in previous studies.

This study was performed in Beppu City, Oita Prefecture, Japan. Beppu City is famous as the world's second largest source of thermal spring water, following Yellowstone National Park in the United States of America. Beppu City has both the most headsprings and the most hot springs in Japan. The hot springs attract 8,000,000