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Carbon dioxide emission accounting for small hydropower plants—A case study in southwest China

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A B S T R A C T

Small hydropower plants, which are one of most important means for producing clean energy, have a high prestige in the carbon trade market. In this paper, a method for accounting the carbon dioxide emission of small hydropower plants is proposed. Twenty-six small hydropower plants (SHPs) in southwest China are chosen as a case study. The following results were found: (1) the carbon dioxide emission during the construction period (COE^c) per installed capacity ranged between 0.01957 t/kW and 0.1926 t/kW, with its average value 0.04592 t/kw; (2) the carbon dioxide emission during the construction period is classified into two groups; for each group, there is a reciprocal relationship between the installed capacity and the annual COE^c per installed capacity, and (3) the annual CEO^o (carbon dioxide emission during the operation period) declines with increasing installed capacity, the two related by a straight line. Specifically, when the installed capacity increases by 1 kW carbon emissions are reduced by 16.33 t. COE^o is directly determined by hydropower. In addition, (4) the trend of carbon dioxide emission during the system lifecycle of SHPs is determined by COE^o. The most important factor in determining the carbon dioxide emission of SHPs is to ensure the precise hydropower of SHPs.

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1. Introduction

Energy plays an important role in each field of commercial and human activities. It is a driving factor of economic and social development in both developed and developing countries [1]. The demands of energy rapidly increase with economic growth; meanwhile, environmental degradation and climate change have become very critical issues [2]. It is well known that the use of renewable resources (such as hydro, wind, biomass, solar and geothermal) is the most effective solutions to solve the environmental problems associated with fossil fuels.

It is also well known that small hydropower plants (SHPs hereafter) have been evaluated as candidates for the reduction of carbon dioxide emission [3–5]. However, there is also the critical view that the biophysical impacts of SHPs may exceed those of large hydropower plants, particularly with regard to habitat and hydrologic change [6,7]. Although SHPs would emit fewer greenhouse gases (GHG), they may cause several environmental problems such as eutrophication [8] and ecological deterioration [9–11]. Exploiting hydro resources is an energy development strategy in some developing countries such as China [12], India [2], and Brazil [13].

SHPs use renewable hydrologic resources, which could directly reduce carbon dioxide emission [14]. Thus, the carbon trading market would be willing to provide opportunities or funding to build SHPs [15]. Before 2012, the new and recently built SHPs could reduce approximately 3.15 million tons of carbon dioxide equivalents [15]. Generally, the reduction of carbon dioxide emissions by SHPs depends on their annual power generation. The annual power generation always depends on their installed capacity and usage time. Therefore, the annual gross of carbon dioxide emission reduced by SHPs is calculated by their installed capacity, time usage, and electricity emission factor [16].

China has a large quantity of rivers—more than 50,000 of which cover a basin area of over 100 km^2, and 3886 of which have a hydro potential of over 10 MW [17]. The annual power generation and gross theoretical hydropower potential are 6080 TWh/year and 694 GW, respectively. These are the most worthwhile hydropower resources in southwest China (which includes Sichuan, Yunnan, Tibet, and Guizhou provinces), making it significant and representative to investigate the relationship between installed capacity and carbon dioxide emission of SHPs. This approach could be beneficial to accurately calculate the carbon dioxide emission of SHPs.

This paper is structured as follows. Section 2 proposes a method to calculate the carbon dioxide emission of SHPs (including construction period and operation period). Section 3 overviews from the sources of data, then, an analysis of the relationship between SHPs' carbon dioxide emissions and their installed capacity is presented. Section 4 explains the relation obtained in Section 3. Finally, we summarize previous work and future work in Section 5.

2. Methods

2.1. Carbon balance analysis for SHPs

The carbon dioxide emission of SHPs was organized into two time periods: a construction period and an operation period [18]. For the construction period, carbon dioxide emissions include energy consumption—such as using coal, fuel oil (including that used for transporting building material), gas and electricity—the consumption of building materials—such as cement, steel, adornment and power generation equipment (including dynamo, turbines, and so on)—the temporal land occupancy, and their living activities of construction workers. For the operation period, carbon dioxide emissions include permanent land occupancy and the workers' living activities. Only the life cycle of SHPs is considered, which is often 30–50 years [19]. The processes of SHPs' carbon dioxide emission are shown in Fig. 1.

There are three potential emission sources for SHPs. First, there are human living activities—such as building dams, dikes and power stations—which are relevant to carbon dioxide emissions generated by energy intensive activities. Second, land plays two roles in carbon dioxide emission. One is the decaying biomass in flooded land will produce carbon dioxide emissions; this part almost could be ignored as flooded land associated with SHPs is often very small. The other characteristic of land important to CO_2 emissions is the capacity of carbon sequestration by photosynthesis occurring in plants. If this land is industrialized, this sequestration capacity of the land disappears. Third, the substitutes of hydropower must be considered. If the total power demand is a constant value, hydropower would reduce the requirement of thermal power.

2.2. The carbon dioxide emission in the construction period

The carbon dioxide released during construction period mainly comes from the raw materials consumption (including energy consumption), land occupancy, and the builders' living activities. The carbon dioxide which is released in the construction period (short as COE^c), is defined as follows:

$$COE^c = COE_{BM} + COE_{TL} + COE_W \tag{1}$$

where COE^c is the carbon dioxide which is released during the construction period; COE_{BM} is the carbon dioxide which is released by providing building materials; COE_{TL} is the carbon dioxide which is released by temporary land occupancy; COE_W is the carbon

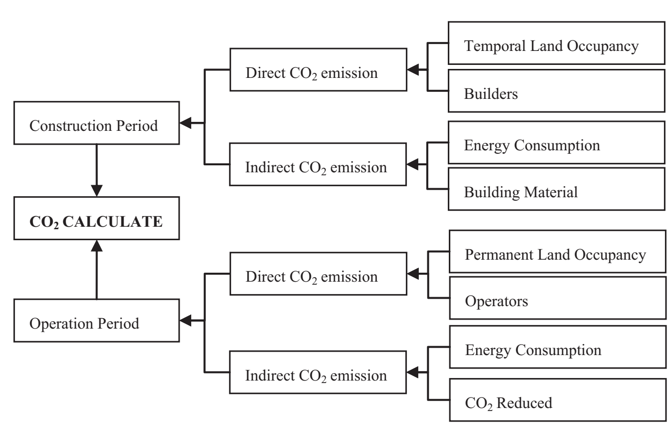

Fig. 1. SHPs' carbon balance analysis diagram.

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