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# Estimation of the hydropower potential of irrigation networks

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ABSTRACT

Over the last decade, the increase in the costs of non-renewable energy sources and a growing environmental awareness have led research institutions and companies to show more interest in renewable energy, and that derived from hydraulic sources has been undergoing a resurgence of interest, especially concerning Small Hydropower Plants.

In this context, it could be interesting to consider the role of irrigation networks and set up methodologies to estimate the hydropower potential of canal systems as a preliminary analysis to guide feasibility analysis. This work reviews different methodologies for the computation of the hydropower potential and presents a method that can be used to analyze irrigation networks in order to establish their hydropower production potential. The proposed methodology is simple and it allows: i) an irrigation network to be characterized and networks with higher hydropower potential to be identified, ii) the actual combination between irrigation and hydroelectric usage to be quantified and iii) hydropower development scenarios to be drawn up.

The presented methodology can be considered a preliminary analysis tool, although detailed site-specific studies are necessary for feasibility analysis. In order to show an application example, the methodology has here been applied to the Piedmont Region irrigation system, considering data obtained from computerized databases.



**Contents**



## 1. Introduction

With the Kyoto Protocol (1997), industrialized countries committed themselves to reducing greenhouse gas emissions by 5.2% by 2012, compared to 1990. With Directive 2009/28/EC, the European Union, through the definition of national action plans, established a common framework for the use of renewable energy sources in order to limit greenhouse gas emissions and promote cleaner transport

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before 2020. This policy has created much interest in renewable energies, including hydropower. At present, approximately 20% of the electricity produced in the world comes from hydroelectric sources. According to the latest available data, the installed capacity of the hydroelectric plants throughout the world is now close to 900 GW [1]. In order to increase hydroelectric production, a great deal of attention is currently being paid to Small Hydropower Plants [2], since their environmental impact is more easily accepted and because, at least in Europe, sites suitable for large plants have already been exploited [2,3]. There is not one single definition of Small Hydropower Plants (SHPs). UNIDO, for instance, fixes the upper bound of SHPs at 10 MW of the installed capacity. SHPs include mini and micro hydro plants, whose classification changes from country to country. The increased interest in hydropower and in Small Hydropower Plants in recent years can also be pointed out considering the interest shown by research centers and industries in developing appropriate turbines, such as, for example, the Very Low Head (VLH) turbine, the Siphon turbine [4], and the hydraulic screw [5], which is becoming popular because of its almost uniform efficiency, or wheels such as the rotary HPM [6] or the Straudruckenmaschine [7]. It is also worth mentioning kinetic turbines, for example, the Darrieus turbine [8] and the Savonius turbine [9].

In order to assess the impact of micro and mini hydro energy production classes, it is necessary to consider that it is not the production of each plant that is relevant, but the number of feasible plants. The installation of micro and mini hydro plants does not generally involve the creation of huge impressive works throughout the territory, like dams or water storage systems [10,11]. The installation of these plants satisfies a two-fold purpose: on the one hand, the costs of installation and management are reduced, compared to larger hydroelectric plants, on the other, the environmental impact is reduced.

In this scenario, irrigation networks have to be considered to generate a significant amount of hydropower [12]. Small Hydropower Plants can easily be integrated into existing irrigation canals, as was done in ancient times with old mills. Using water for irrigation and hydroelectric purposes, a multiple usage of water is obtained: this creates an important benefit for society, as the importance emerges of irrigated agriculture, which is often criticized by urban populations as being an inefficient use of water [12]. Hydropower development in an irrigation network is influenced by technical, economic and political factors. The technical factors are related to the possibility of using, or building, bed drops in canals and/or to the presence of an adequate water discharge. The economic factors are instead related to the fact that irrigation districts have to face the installation costs of hydropower plants and obtain a reasonable payback period, while the political factors are related to the management decisions of the irrigation districts, which are often influenced by national incentives introduced to encourage the adoption of renewable energy sources.

Estimating the hydropower potential of an irrigation network is an interesting goal, but it is not a straightforward task. In this sense, the study on the Japanese irrigation network reported by Ueda et al. [13] is emblematic. The study reports two different analyses to estimate the hydropower potential of the Japanese irrigation network: the first involves the use of a Geographical Information System (GIS) to estimate the slope of the canals, while the second is based on questionnaires distributed to the irrigation districts. The two analyses resulted in significantly different estimations of the hydropower potential: 299 MW for the GIS based analysis and 21 MW for the questionnaire based one, respectively. This difference could be due to the fact that the GIS procedure, besides suffering from technical drawbacks due to the imprecision in the determination of the terrain elevations, does not consider the specification details of canal systems sufficiently [13], while the answers to the questionnaires were influenced by the management policies of the irrigation districts.

A detailed topographic survey and the knowledge of the frequency discharge curves are undoubtedly useful to correctly estimate the hydroelectric potential, but when the analysis considers large irrigation networks this approach is unsustainable for both economic and time reasons. It is therefore necessary to establish a methodology that would allow a preliminary analysis to be made of the irrigation network in order to identify the areas with greatest hydroelectric potential and, according to the established scenarios, to estimate the installable hydropower in order to decide which areas merit detailed surveys.

The present manuscript deals with the use of irrigation networks for hydropower and, after a review of various methods to estimate the hydropower potential, it is aimed at developing a simple methodology that could be used to characterize irrigation networks, and to quantify their usage level for hydroelectric production, as well as at identifying, through a comparison of appropriate indexes, the networks with the highest hydropower potential and at estimating, according to hypothesized scenarios, the hydraulic power of the hydroelectric plants that is likely to be used for hydroelectric production. The methodology, hence, should be able to estimate the percentage of the theoretical hydropower potential that can effectively be used for hydroelectric production, as the latter is conditioned by the irrigation use of the network. The choice of using hydraulic power as a parameter, instead of electrical power, is due to the fact that the power block conversion efficiencies depend on the chosen machinery and they require a site specific study, which is not the aim of this analysis as it considers a regional scale.

The proposed methodology has been applied to the Piedmont Region irrigation network (Northwest Italy).

The manuscript is organized as follows: a review of the actual methodologies used to estimate the hydropower potential is presented in Section 2, the method here proposed is illustrated in Section 3, the Case Study is described in Section 4 and the results of the analysis are shown and discussed in Section 5.

## 2. The hydropower potential: methods for its estimation

The setting-up of plants that exploit a renewable energy source (RES) is the outcome of a decision making process that takes into account different aspects: the availability of the resource, together with technical, economic, environmental and social factors. Dealing with this aspect, Voivontas et al. [14] pointed out the difference between four RES potential terms. They in fact distinguished four levels of potential: theoretical potential, available potential, technological potential and economic potential. The last three potential terms represent a set of restrictions on the exploitation of the theoretical potential. The theoretical potential was defined by Voivontas et al. [14] as the maximum RES energy output in a region, and it is determined by considering all the sites in the region with adequate characteristics that are available. The available potential is the part of the theoretical potential that can be harvested easily and without any environmental impacts; the technological potential, instead, is defined as the energy that can be harvested using existing technology, and it is restricted by the characteristics of the commercially available machinery (i.e. turbines in the case of hydropower or wind energy). Economic potential is defined as the energy that can be harvested using economically feasible installations: infrastructure and technical constraints, such as roads and grid networks, together with economic aspects (energy production, estimated profits) establish the limits of the economic potential [14].

These four different levels of potential are contemplated in most of the analyses that consider the development of hydropower, and in particular small hydropower projects. Rojanamon et al. [15], for instance, proposed a model to address the feasibility of SHP, with reference to Thailand. Their model uses a Geographical Information System (GIS) for site identification, and for those sites that the engineering analysis finds deserving analysis, the economic and