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ScienceDirect

Energy Procedia 125 (2017) 405–414

Energy Procedia

www.elsevier.com/locate/procedia

European Geosciences Union General Assembly 2017, EGU Division Energy, Resources & Environment, ERE

Simulation of water-energy fluxes through small-scale reservoir systems under limited data availability

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Abstract

We present a stochastic approach accounting for input uncertainties within water-energy simulations. The stochastic paradigm, which allows for quantifying the inherent uncertainty of hydrometeorological processes, becomes even more crucial in case of missing or inadequate information. Our scheme uses simplified conceptual models which are subject to significant uncertainties, to generate the inputs of the overall simulation problem. The methodology is tested in a hypothetical hybrid renewable energy system across the small Aegean island of Astypalaia, comprising a pumped-storage reservoir serving multiple water uses, where both inflows and demands are regarded as random variables as result of stochastic inputs and parameters.

Keywords: stochastic simulation; hybrid renewable energy systems; reservoir management; parameter uncertainty; pumped-storage system

1. Introduction

Small islands are regarded as promising areas for developing hybrid water-energy systems that combine multiple sources of renewable energy with pumped-storage facilities. The most essential element of such systems is the water storage component (reservoir), which implements both flow and energy regulations. Apparently, the representation

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10.1016/j.egypro.2017.08.078

of the overall water-energy management problem requires the simulation of the operation of the reservoir system, which in turn requires a faithful estimation of water inflows and demands of water and energy. Yet, in small-scale reservoir systems, this task is far from straightforward, since both the availability and accuracy of associated information is generally very poor. In contrast to large-scale reservoir systems, for which it is quite easy to find systematic and reliable hydrological data, in the case of small systems such data may be scarce or even missing, which introduces further uncertainty to the inherently complex water-energy simulation problem.

The stochastic approach is the unique means to account for the multiple uncertainties within the combined water-energy management problem. Using as pilot example the Livadi reservoir, which is a hypothetical pumped storage component of the small Aegean island of Astypalaia (Greece), we provide a stochastic simulation framework, where the time-varying reservoir inputs, i.e., inflows and demands, are subject to two different sources of uncertainty. The first source is the long-term hydrometeorological uncertainty, which is typically tackled by using synthetic time series that reproduce the statistical characteristics of the observed data, while the second source is associated with the complex dynamics of the rainfall-runoff transformation, expressed by means of conceptual parameters. Yet, due to the lack of historical runoff data, it is not possible to infer these parameters through the classical calibration procedure, thus obtaining a unique rainfall-runoff transformation model [1]. For this reason, we take advantage of the limited information about the hydrometeorological regime of the study area, to provide multiple "behavioural" parameter sets, resulting to multiple stochastic responses of the water-energy system. The proposed modelling scheme comprises stochastic and deterministic components, co-operating within a Monte Carlo simulation framework.

2. Study area and data

Astypalaia (*Αστυπάλαια*) is a small Greek island (total area 97 km^2) with 1334 residents (2011 census), that belongs to the Dodecanese complex (Fig. 1, left). The major water infrastructure of the island is the Livadi reservoir (Fig. 1, right), having a useful storage capacity of 875 000 m^3 (against a total capacity of 1 050 000 m^3) and extending over a maximum surface of 105 000 m^2. The reservoir, which operates from 1998, fulfills domestic, touristic and agricultural ware uses. The estimated annual demands are 210 000 m^3 for water supply and 230 000 m^3 for irrigation, most of which implemented during the summer period. The drainage basin upstream of the dam is 8 km^2, producing ephemeral runoff. Unfortunately, across the Livadi basin there are no available any hydrometric data, except for rough estimations about its hydrological regime. In particular, recent hydrological studies estimate that about 15% of the mean annual rainfall is transformed to surface runoff, about 11% are underground losses that are finally conducted to the sea, and the remaining quantity represents the evapotranspiration losses [2].

In the context of this pilot study, Livadi reservoir is assumed as the energy regulation component of a hypothetical hybrid renewable energy system across the island, aiming at ensuring full autonomy against the estimated electricity needs. In this respect, apart from the actual water uses, i.e., water supply and irrigation, we also consider a small hydropower plant, installed at the discharge outlet (with maximum head of 32 m, i.e., equal to the dam height) and a pump-storage tank, implementing daily regulations of energy surpluses and deficits, provided by other renewable resources.

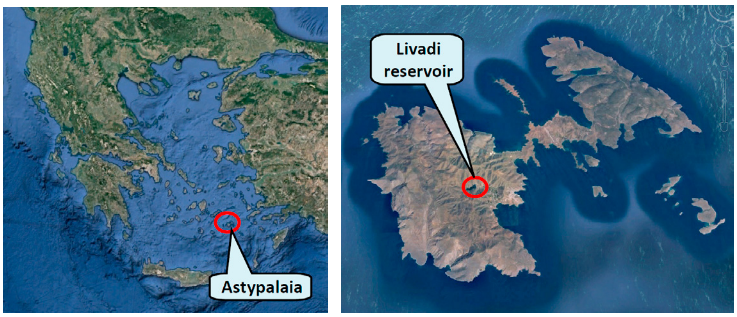

Fig. 1. Study area and location of Livadi reservoir (satellite images from Google Earth).