Assessing Climate Impacts on Hydropower Production of Toce Alpine Basin

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Abstract

The aim of the presented study is to assess the impacts of climate change on hydropower production of the Toce alpine river basin, in Italy. A model of the hydropower system was driven by discharge time series at hourly scale with the simulation goal of defining the reservoirs management rule that maximize the economic value of the hydropower production. To this purpose, current energy price was assumed for the future. Assessment of hydropower production of future climate (2041–2050) respect to current climate (2001–2010) showed an increment of production in Autumn, Winter and Spring, and a reduction in June and July. Significant change in the reservoirs management policy is expected due to anticipation of the date when the maximum volume of stored water has to be reached and an increase of reservoir drawdown during August and September to prepare storage capacity for autumn inflows.

Keywords

Alpine basin • Climate change • Hydrological impact • Hydropower production

2.1 Introduction

Climate change has significant implications for environment, water resources and human life in general (Beniston 2004). Changes in temperatures and changes in precipitation patterns can have profound effects on river systems and cause important changes in the management of water, particularly on uses highly dependent on the hydrological regime, such as hydropower production. In several European countries, this source of energy represents an important part of the electric mixt. The hydropower plants with reservoirs deserve a mention because indirectly they allow storing electricity at a relatively low price. Thanks to their flexibility, they significantly contribute to the stability of the international network; to the follow-up of the daily and seasonal load fluctuations; and to the integration of the intermittent energy sources, notably solar and wind energy. Hydropower also represents an important source of revenue for their owners and in particular for the mountain regions.

Although predictions vary depending on the model, in general water availability is likely to increase across northern Europe and decrease in southern and southeastern Europe over the next several decades (Lehner et al. 2005). How these widespread trends will effect hydropower production depends on specific changes in flow regime and characteristics of existing hydropower development.

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The present study aims at quantifying the climate change impacts on hydropower production of the Toce alpine river basin, in Italy, where 18 plants (total installed capacity ≈ 470 MW) and 10 reservoirs with a total storage capacity of about 139 million m^3 were analyzed.

2.2 The Toce River Case Study

The Toce watershed is a typical glacial basin with steep hillslopes bounding a narrow valley located mainly in the north Piedmont region of Italy, and partially in Switzerland (10 % of the total area) with a total drainage area of about 1,800 km^2. A total of 14 major dams are located within the Toce watershed, with a total effective storage capacity of about 151×10^6 m^3 (Montaldo et al. 2004).

The hydrographic area involved in the case study represents the upper part of the Toce river catchment. The drainage surface sums up to 691.7 km^2. The altitude ranges from 300 to 4,100 m a.s.l., with an average value of about 1,900 m a.s.l. and 52 % of the catchment area located above 2,000 m a.s.l.. In the considered hydrographic catchment irrigation is not present and drinking water uses are negligible; it follows that reservoirs management can be simulated as completely oriented to hydropower production.

2.2.1 At Site Bias Corrected Climate Scenario Forcings

For meteorological forcing of future scenarios, two different regional climate models (RCMs) are used, namely a REMO (Jacob 2001) and a RegCM3 (Pal et al. 2007) simulation. Both models cover Europe on a 25×25 km^2 grid, cover the same simulation period (1951–2100) and are driven by the same global ocean-atmosphere-coupled model ECHAM5 (Roeckner et at. 2003) using observed greenhouse gas concentrations between 1951 and 2000 and IPCC's greenhouse gas emission scenario A1B between 2001 and 2100. A quantile based error correction approach was used in order to downscale the RCM simulations to point scale as well as to reduce its error characteristics (Themeßl et al. 2012).

2.2.2 The Model of the Hydropower System

The hydropower system has been represented by a network made up with 27 nodes and 64 arcs. Nodes represent intakes and reservoirs; arcs represent rivers, channels, hydropower plants and water volume stored into the reservoirs. Each node is characterized by an inflow time series that describe natural discharges produced by the upstream sub-catchment. The model is a simplified representation of the real hydropower system and not all the existing intakes are represented as a single node; to keep computational burden within acceptable limits, minor intakes have been grouped in a single node.

2.2.3 The Model of the Hydrologic System

In order to simulate continuous streamflow, FEST-WB, a distributed physically based hydrological model was used (Rabuffetti et al. 2008; Corbari et al. 2011; Ravazzani 2013). FEST-WB computes the main processes of the hydrological cycle: evapotranspiration, infiltration, surface runoff, flow routing, subsurface flow and snow and glaciers dynamics. The computation domain is discretized with a mesh of regular square cells (200 m in this application) in each of which water fluxes are calculated at hourly time step.

The FEST-WB model was subjected to a process of calibration and validation by comparison of daily simulated and observed discharge at Candoglia (basin area 1534 km^2) where discharge observations are available from 2000 to 2008. FEST-WB was used to simulate hourly discharge time series scenarios from 2001 to 2050 in 36 sections representative of the hydropower system.

2.3 Results and Discussion

Impacts of climate changes on hydrological processes are assessed by comparing FEST-WB results driven by REMO and RegCM3 for the decade 2041–2050 respect to decade 2001–2010. REMO and RegCM3 simulate increase of temperature equals to 1.3 K and 1.1 K, respectively and increase of mean annual precipitation equals to 13 % and 25 %, respectively. This reflects an increase of evapotranspiration and discharges for all durations of flow duration curves.

Once the model of the hydropower system has been set up, natural inflows to the nodes and energy value index time series have been properly defined, the simulation goal is the definition of the reservoirs management rule that maximize the economic value of the hydropower production using BPMPD solver (http://www.sztaki.hu/~meszaros/bpmpd).

Two groups of simulations were performed at bihourly time step: the first one using 6 h averaged discharge data from 2001 to 2050 evaluated on the basis of the REMO regional climate model outputs, the second group employing discharge data modelled starting from the RegCM3 regional climate scenarios.

To evaluate the impact of climate change on hydropower production and on the operational management of the system a comparison of the simulation results for 3 different periods was carried out:

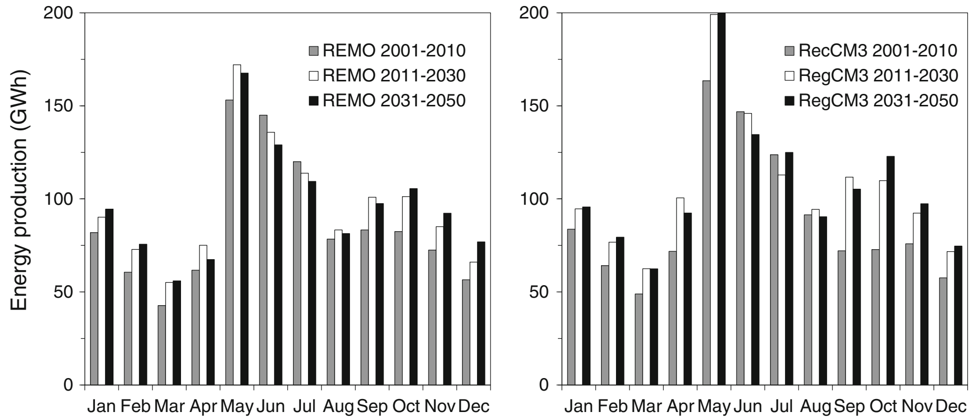

Fig. 2.1 Average Monthly hydropower production evaluated by the simulation model using the discharge dataset built starting from REMO and RegCM3 climatic scenarios

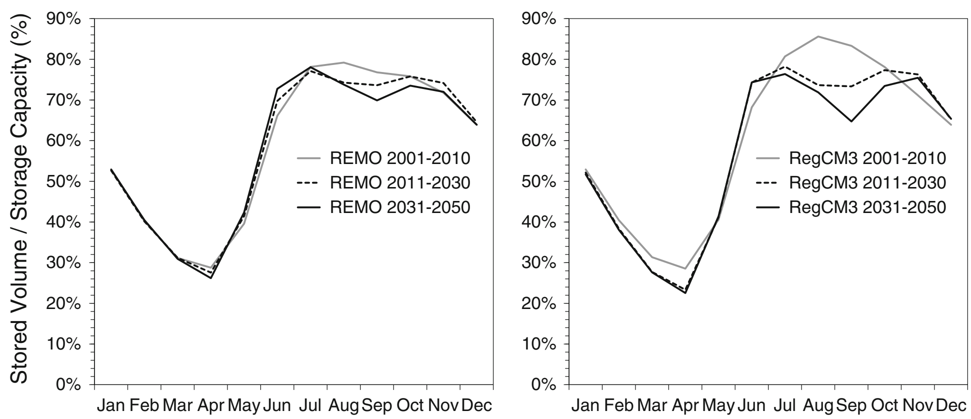

Fig. 2.2 Average monthly stored water volume evaluated by the simulation model using the discharge dataset built starting from REMO and RegCM3 climatic scenarios

- Period A: years from 2001 to 2010 (hereafter "reference period");
- Period B: years from 2011 to 2030;
- Period C: years from 2031 to 2050.

Total hydropower production and water volume stored in reservoirs were compared. Figure 2.1 presents a comparison between the monthly total hydropower system production. Both climatic scenarios highlight a relevant increase in hydropower production: +11 % for REMO dataset and +19 % for RegCM3 dataset. Production increase is expected to be observed in autumn, winter and spring; in summer, expecially in June and July, simulation outputs show a decrease up to −11 % (REMO dataset, June 2031–2050). Analysis of total volume stored in reservoirs allows to investigate possible change in reservoirs management policy (Fig. 2.2). Simulation results show a trend, for both the periods 2011–2030 and 2031–2050, to anticipate the date when the maximum volume of stored water stored has to be reached, which moves from August (reference period) to July (2031–2050). A reduction of maximum water stored may be observed too, as well an increase of reservoir draw down during August and September to prepare empty storage capacity for autumn inflows, which are expected to evidence a relevant increase.

2.4 Conclusions

Assessment of hydropower production of future climate (2031–2050) respect to current climate (2001–2010) showed an increment of production in Autumn, Winter and Spring, and a reduction in June and July.

Significant change in the reservoirs management policy is expected due to anticipation of the date when the maximum volume of stored water has to be reached and an increase of reservoir drawdown during August and September to prepare storage capacity for autumn inflows.

Results of this analysis depend on shift in temperature and precipitation patterns and amount expected for the Toce river case study and cannot be generalized to the whole Alpine region.

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