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Impact of climate change and water use policies on hydropower potential in the south-eastern Alpine region

Bruno Majone [a,*], Francesca Villa [a], Roberto Deidda [b,c], Alberto Bellin [a]

[a] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, I-38123 Trento, Italy
[b] Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, I-09123 Cagliari, Italy
[c] CINFAI, Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere, Piazza N. Maurizi 17, I-62029 Camerino, Italy

HIGHLIGHTS

- First assessment of climate change impact on hydropower in South-eastern Alps, Italy
- Significant differences in the impacts between hydropower plants within the catchment
- Relevant effect of minimum ecological flow regulation on hydropower potential

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ABSTRACT

Climate change is expected to cause alterations of streamflow regimes in the Alpine region, with possible relevant consequences for several socio-economic sectors including hydropower production. The impact of climate change on water resources and hydropower production is evaluated with reference to the Noce catchment, which is located in the Southeastern Alps, Italy. Projected changes of precipitation and temperature, derived from an ensemble of 4 climate model (CM) runs for the period 2040–2070 under the SRES A1B emission scenario, have been downscaled and bias corrected before using them as climatic forcing in a hydrological model. Projections indicate an increase of the mean temperature of the catchment in the range 2–4 K, depending on the climate model used. Projections of precipitation indicate an increase of annual precipitation in the range between 2% and 6% with larger changes in winter and autumn. Hydrological simulations show an increase of water yield during the period 2040–2070 with respect to 1970–2000. Furthermore, a transition from glacio-nival to nival regime is projected for the catchment. Hydrological regime is expected to change as a consequence of less winter precipitation falling as snow and anticipated melting in spring, with the runoff peak decreasing in intensity and anticipating from July to June. Changes in water availability reflect in the Technical Hydropower Potential (THP) of the catchment, with larger changes projected for the hydropower plants located at the highest altitudes. Finally, the impacts on THP of water use policies such as the introduction of prescriptions for minimum ecological flow (MEF) have been analyzed. Simulations indicate that in the lower part of the catchment reduction of the hydropower production due to MEF releases from the storage reservoirs counterbalances the benefits associated to the projected increases of inflows as foreseen by simulations driven only by climate change.

1. Introduction

European Alps are hydrologically relevant since they represent a reliable source of freshwater supply to lowland regions (Viviroli and Weingartner, 2004). Furthermore, the Alpine region has been recognized as a particularly sensitive environment where climate change is expected to influence the river regime with consequent effects on the services offered by the freshwater ecosystem as well as on water resources availability for users in several socio-economic sectors (Viviroli et al., 2011; Beniston, 2012a,b). Current and expected future global warming will cause alterations on streamflow regimes and freshwater ecosystems (Kundzewicz et al., 2014), but impacts on anthropogenic activities such as agriculture, tourism (Rixen et al., 2011) and hydropower are also expected (see e.g., Gaudard et al., 2014).

Given the far reaching services of water resources of the European Alps in sectors ranging from energy production to agriculture and tourism, the need of catchment-scale studies addressing implications of climate change on water availability and flow regime is urgent (Beniston et al., 2011). Several recent studies highlighted that warming will lead in the next decades to changes in the seasonality of river flows as a consequence of less winter precipitation falling as snow and the melting of

* Corresponding author.
E-mail address: bruno.majone@unitn.it (B. Majone).

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winter snow occurring earlier in spring (see e.g., Laghari et al., 2012; Finger et al., 2012). Furthermore, a moderate decrease of snow and ice storage is in general projected for 2020–2050 with more drastic changes simulated for the second half of the century (see e.g., Lambrecht and Mayer, 2009; Farinotti et al., 2012). High altitude first order streams, with glaciers in their catchment, are expected to experience an increase in winter streamflow, accompanied by a reduction in summer streamflow when the transitional increase in glacier melting will initially compensate for runoff losses due to the reduction of snow melt and precipitation (Bavay et al., 2013).

While almost all climate models (CMs) provide a clear indication of a warmer climate in the future, climate projections of precipitation are much more uncertain due to difficulties of CMs to correctly represent physical processes and local features in the complex orography of the greater Alpine region (GAR). Analyses on instrumental time series from 1800 to 2000 (Brunetti et al., 2006, 2009; Brugnara et al., 2012) give evidence of i) opposite trends in different subregions of the GAR (with significative positive trends in the northern parts and less significative negative trends in the southern parts) and ii) alternations of opposite trends depending on the starting time and the time window length selected for the trend analysis. Contradicting trends of future annual precipitation in the GAR emerge also when comparing different CM projections, as well as alternations of periods characterized by opposite trends are often present within the temporal evolution of some CM runs (e.g., Gobiet et al., 2014; Finger et al., 2012; Cane et al., 2013).

However, despite the uncertainty related to the identification of possible trend of annual precipitation, most CMs agree in predicting a tendency of higher precipitation in winter/spring and lower precipitation in summer/autumn (Beniston, 2012a; Cane et al., 2013; Finger et al., 2012; Gobiet et al., 2014), in agreement with the trends detected in instrumental time series (Brunetti et al., 2006, 2009; Brugnara et al., 2012). Another problematic issue is related to the seasonal distribution of precipitation: indeed, unimodal (with peak in summer) and bimodal (with peaks in autumn and spring) distributions coexist in the GAR depending on the location and altitude of the investigated station (Brunetti et al., 2006, 2009; Beniston, 2006). Such local features as well as the complexity related to the GAR orography cannot be properly represented by CMs due to their coarse scale resolution and thus require ad hoc error corrections before CM output can be used as forcing of hydrological models (e.g., Finger et al., 2012).

Besides these peculiar features of the GAR area, it is also important to mention that climate change impact assessments on hydrological systems should in principle include an end-to-end consideration of the "uncertainty cascade" (Wilby and Dessai, 2010). In particular, there has been increasing attention to quantify and reduce the many sources of uncertainty related to emission scenarios, climate model selection and initial conditions, downscaling techniques including dynamical or statistical methods, hydrological model structures and parameterizations, land use changes and measurement errors (see e.g., Caldeira et al., 2003; Funtowicz and Ravetz, 1990; Hawkins and Sutton, 2009; Heikkinen et al., 2006; Morgan and Mellon, 2011; Murphy et al., 2004; Tebaldi et al., 2005; Wilby and Harris, 2006). However, due to the intensive computational effort required, only few studies explicitly compared uncertainty in streamflow predictions arising from all the different sources of uncertainty (see e.g., Kay et al., 2009; Chen et al., 2011), concluding that uncertainty derived from global climate modeling is in general greater than that arising from hydrological modeling.

As a consequence of relatively high precipitations and large reliefs, hydropower production largely exceeds the demand of electric energy by the Alpine region. For example, in 2012 hydropower energy accounted for around 13.5% of the national energy production in Italy (GSE, 2013) and was mainly produced by hydropower plants in the Alps, while in Austria and Switzerland hydropower energy satisfies more than 50% of the national request (Zimmermann, 2001). Climate change impacts on hydropower production in the Alpine region may differ depending on both location and typology of hydropower system. Run-of-the-river power plants are directly influenced by the change in the water discharge regime, while hydropower plants with significant storage volume are more flexible and may adopt different management strategies to compensate for modifications, depending also from the evolution of the energy market (Beniston and Stoffel, 2014).

The projection of hydropower productivity of existing power plants is thus a relevant issue worldwide. Kumar et al. (2011) estimated that by 2070, hydropower potential for the whole Europe will reduce of about 6%. However, this estimate is the result of a larger reduction in the Mediterranean area, partially compensated by an increase in the northern and eastern Europe. Markoff and Cullen (2008) found that climate change has the potential to seriously impact the hydropower system of the Columbia river basin (USA) with uncertainty in projections of precipitation change appearing more important with respect to that arising in projections of temperature change. Minville et al. (2009) evaluated the impacts and adaptation to climate change of the water resource management system of the Peribonka River (Canada), which is intensively exploited for hydropower production. By adopting the output of a single Regional Climate Model, they found that annual mean hydropower production would decrease for the period 2010–2039 and then increase by 9.3% and 18.3% during the periods 2040–2069 and 2070–2099, respectively. Vicuna et al. (2008) investigated the impacts of climate change on hydropower generation in the Sierra Nevada chain (USA) by considering climatic outputs from two GCMs under two emission scenarios. In particular, they found that hydroelectric systems, located in basins with significant inflows during the late spring and early summer months, will be significantly affected by projected changes in the timing of streamflows as a consequence of insufficient storage capacity. Vicuna et al. (2010) and Raje and Mujumdar (2010) assessed the effects of climate change on multipurpose reservoirs in the Merced (USA) and Mahanadi (India) river basins, respectively, by considering an adaptive management strategy mimicking a real operational context using climate change scenarios from eleven and three GCMs, respectively. Koch et al. (2011) projected the hydropower production of the Upper Danube basin to the period 2051–2060 by means of a physically-based hydrological model, coupled with a simple hydropower module, and considering 16 climate change scenarios resulting from a stochastic downscaling applied to the outputs of two different regional climate models, under SRES-A1B emission scenario. The main conclusion of this work is that in the period 2051–2060 a moderate to severe reduction is expected, depending on the adopted climate model. Schaefli et al. (2007) analyzed the water resource system connected to the Mauvoisin reservoir (Swiss Alps) focusing on the quantification of uncertainty arising from both climate scenarios and hydrological modeling; results obtained indicate a significant reduction of water resources availability due to the effect of climate change. Hänggi and Weingartner (2012) analyzed the variations of water volumes available for hydropower production at several high-altitude locations in the Swiss Alps during the last century and observed a general increasing trend in the annual water volume. The simulations conducted by Finger et al. (2012), including uncertainty in the climate scenarios, projected a moderate decrease of incoming streamflow to the Mattmarksee lake (Swiss) in the period 2037–2064, followed by a major decrease by the end of the century, with the consequent need to change hydropower production schemes to overfill Mattmarksee lake. Recently, a few studies pointed out the importance of considering both hydrological processes and electricity market behavior in order to perform reliable climate change impact assessments on hydropower production (Gaudard et al., 2013, 2014; Maran et al., 2014). Although the results of these studies, conducted in the Swiss and Northwestern Italian Alps, are to some extent dependent on the position of the hydropower system, they concur in concluding that a new adaptive management of hydropower plants may mitigate projected losses due to modified climatic conditions. All the above studies evidenced a significant dependence of the projected hydropower