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Sharing Water: Multi-Purpose of Reservoirs and Innovations

Effects of climate change on future energy production of Namakhvani HPP

Effets des changements climatiques sur la production énergétique future à Namakhvani

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Abstract. Climate change may be considered relevant for hydropower production schemes all over the world. Despite this, the assessment of the impact of climate change on hydropower is uncertain and must be interpreted with that in mind. The paper focuses on the Namakhvani HPP (400 MW), a new project under development in the Rioni River, in Georgia. Using it as an example, the paper emphasizes the critical role that is played by uncertainty in climate impact risk assessments and explores the interpretation of simulation results, providing ways in which they can be transformed in actionable information for decision-making.

Résumé. Les changements climatiques peuvent être considérés importants pour des aménagements hydroélectriques autour du globe. Néanmoins, l'évaluation des impacts de ces changements est incertaine et doit être interprétée comme tel. L'article se focalise sur le projet Namakhvani HPP (400 MW), un nouvel aménagement en cours de développement sur le fleuve Rioni, en Géorgie. En prenant l'exemple de Namakhvani, l'article met en évidence le rôle joué par l'incertitude dans les évaluations des risques liés aux changements climatiques et explore comment les résultats des simulations peuvent être interprétés de manière à les transformer en information utile pour la prise de décision.

1 Introduction

Climate change constitutes a major challenge of our time. Of interest to the ICOLD community, climate change has the potential to disrupt dam operations and hydropower

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particularly strongly when compared to other infrastructures or energy sources. Potential impacts are not confined to any particular type of dam nor to a restricted number of locations or climatic zones – on the contrary, dams all over the world can be affected. Evidently, a clear understanding of what climate change is and what can its impacts be is vital to prepare the industry and make it more resilient [1].

The difficulty lies in what is not yet known about climate change, specially when focusing on specific locations and periods. Indeed, climate change impact assessments are inherently uncertain and must be interpreted with that in mind. Even if general trends such as the increase in mean global temperature are unavoidable, the extent and evolution of that increase depend on future Green House Gas (GHG) emissions and random effects. In simplified terms, the projections of future climate that are used in practice are uncertain depictions of possible futures, themselves a function of scenarios of GHG concentrations in the atmosphere (also known as Representative Concentration Pathways or RCP). The latter, of course, depend on political, economic, social, and technological issues.

Following the outstanding efforts of the Coupled Model Inter-comparison Project (CMIP) and the Coordinated Regional Climate Downscaling Experiment (CORDEX), timeseries of projected temperature, precipitation, and other useful variables can conveniently be retrieved for most parts of the globe. While these data are extremely valuable, it can be tempting to mistake timeseries of projected climate scenarios for actual observations and draw conclusions from them as if that were the case. Recognizing what are the limitations of contemporary climate projections is an essential part of sound climate change risk assessment and well-informed decision-making.

This paper explores ways in which climate projections can be used to inform decision-makers in the hydropower sector. It focuses on the nature of climate projections and the uncertainty that is inextricably linked to them, exploring ways in which to use them and highlighting what they should and what they should not be used for. All of this is made based on a real case – that of the Namakhvani HPP (400 MW) – and the text borrows from the evaluation of future energy production potential of the Namakhvani HPP that was prepared by Stucky [2].

Following a brief description of the Namakhvani HPP, the data used to conduct the evaluation is introduced in section 3. The analysis itself is portrayed in section 4. Results are presented and discussed in section 5 and, finally, conclusions are drawn in section 6.

2 Namakhvani

Situated in Georgia, the catchment of the Rioni River, where Namakhvani lies, is mountainous and partially covered by glaciers (**Fig. 1**). At the Namakhvani gauging station, the watershed has a surface of roughly 3450 km^2. The glacier cover is relatively small, of only about 40 km^2. The altitudes range from roughly 225 m asl at Namakhvani to 4350 m asl at the highest point of the catchment.

The average discharge at Namakhvani has been evaluated at about 120 m^3/s. The natural hydrological behaviour of the upstream catchment has been altered due to the construction of the Ladjanuri HPP (catchment area of 1472 km^2) and the Shaori HPP (catchment area of 124 km^2). The Ladjanuri HPP diverts water into the Rioni basin since 1960 whereas the Shaori HPP draws water from the Rioni to the Tkibuli reservoir (outside the Rioni catchment) since 1954.

Fig. 1. Catchment and location of the Namakhvani HPP (lower Namakhvani).

3 Data

3.1 Historical data

The available ground station data is unfortunately limited in their spatial coverage and temporal coverage. Despite the limitations of its use over the Rioni River catchment, ground data reflects particular orographic and other regional effects that are not easily captured by distributed data sources such as climate reanalyses or satellite products. This is particularly important in mountainous catchments whose surface does not suffice to average out the local inadequacies necessarily associated with the distributed sources.

Data from 5 ground stations in the area were used, being the available series considered from 1979 onwards.

Besides ground data, the WATCH-Forcing-Data-ERA-Interim (WFDEI) [3] dataset was used.

3.2 Climate projections

Climate projections used in hydropower typically rely on General Circulation Models (GCM) that have been regionalized with a Regional Climate Model (RCM) and bias corrected. To find appropriate climate projections to the case of Namakhvani, the several regional CORDEX domains were evaluated. It so happens that Georgia coincides with the margins of 5 CORDEX regions (Europe, Africa, South Asia, Mediterranean, and Middle east and North Africa), and is also close to the margin of the Central Asia region. Due to this, there was no clear choice regarding the RCM region to employ. A decision to use the Europe region relied on two main reasons: 1) the number of models including the Europe region was larger than in the other cases and 2) working with the Europe RCM meant that the Clim4Energy [4] data could be used. The latter reason is interesting, because the Clim4Energy data was corrected for greater reliability in hydrological studies.

Finally, 8 regionalized projections were analysed at the daily timestep for two RCPs (see subsection 4.2.1). The smoothed evolution of average temperatures and precipitations is shown in **Fig. 2** and **Fig. 3**. On these data, two main remarks are warranted:

1. Climate projections are not forecasts; they do not aim to nor can they predict the weather in advance – that would be impossible – but simply to generate series whose statistical properties are likely to be observed in the future. Accordingly, it only makes sense to compare climate projections when they are averaged (or smoothed) over sufficiently long periods.
2. While all projections clearly show a steady increase in the average temperature, there is an enormous divergence when it comes to future precipitation – even on average terms. This tendency, which is observed in many places across the globe, means that impacts directly associated to temperature can be predicted with much more certainty that those depending on precipitation.

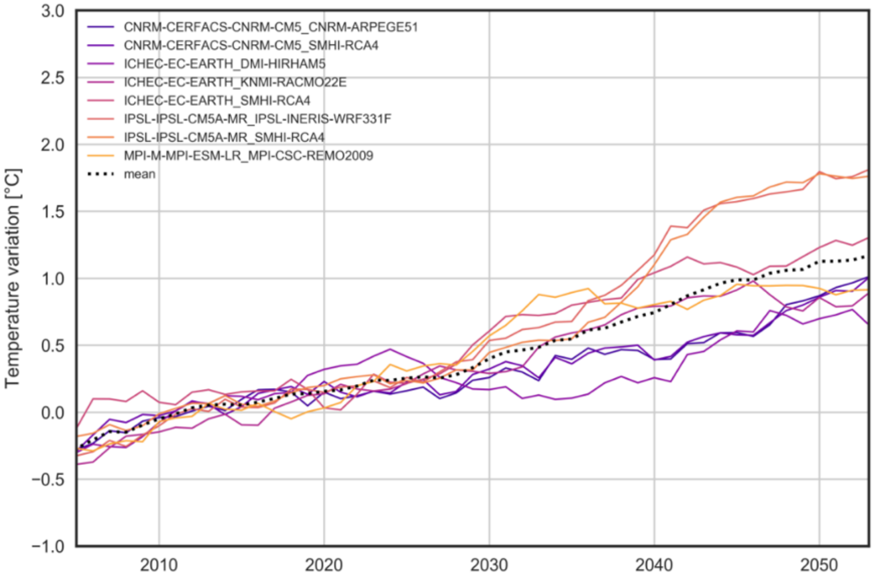

Fig. 2. Smoothed evolution of average temperatures for RCP 4.5 Clim4Energy projections.

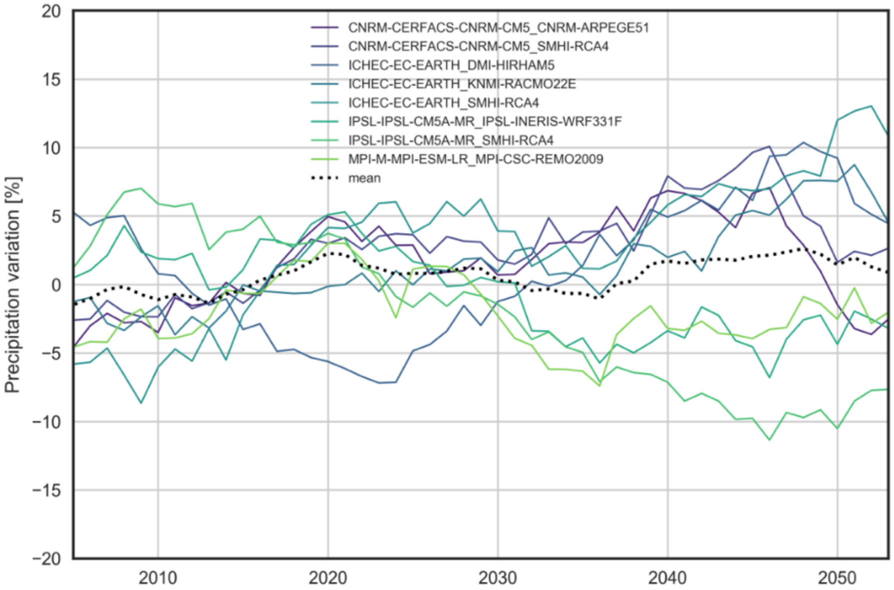

Fig. 3. Smoothed evolution of average precipitation for RCP 4.5 Clim4Energy projections.

4 Analysis

4.1 Overview

The modelling analysis necessary to assess climate change risks includes several phases. These are: 1) collection of historical data; 2) preparation and validation of a hydrological and hydropower production model based on historical data; 3) collection and validation of multiple projections covering the emission scenarios of interest; 4) bias removal of the projections; 5) simulation 6) result processing and analysis.

Of these phases, it is particularly important to understand the need to analyse multiple projections and appreciate the role of bias removal in the process. Multiple projections should be included in the analysis because of the uncertainty that is always associated with them – relying on one or only a few projections may convey a false sense of certainty. Bias removal is essential when the hydrological and production models are calibrated based on historical data and, therefore, it must be ensured that over the historical period (until the present, for example) projections and observations share the same statistical traits.

4.2 Scenarios

4.2.1 Representative Concentration Pathways

The choice of future scenarios to analyze is central to the climate risk assessment. The GHG emission scenario – represented as a Representative Concentration Pathway (RCP, see **Fig. 4**) is at the base of every projection but, as the reader can imagine, future GHG emissions depend on political choices, societal trends, technological advancements, etc. Accordingly, the RCPs to be investigated are a choice of the decision-makers.

Of the four RCPs, the ones for which more projections have been calculated are RCP 4.5 and RCP 8.5. RCP 4.5 corresponds to a moderate scenario where the GHG emissions are curbed during the 21st century, leading to a stabilization of the GHG concentrations towards its end. RCP 8.5 represents a pessimistic scenario where the emissions are not reduced and, therefore, the Earth is exposed to ever-increasing concentrations of GHGs. Condensed information about RCPs can be found in [5].

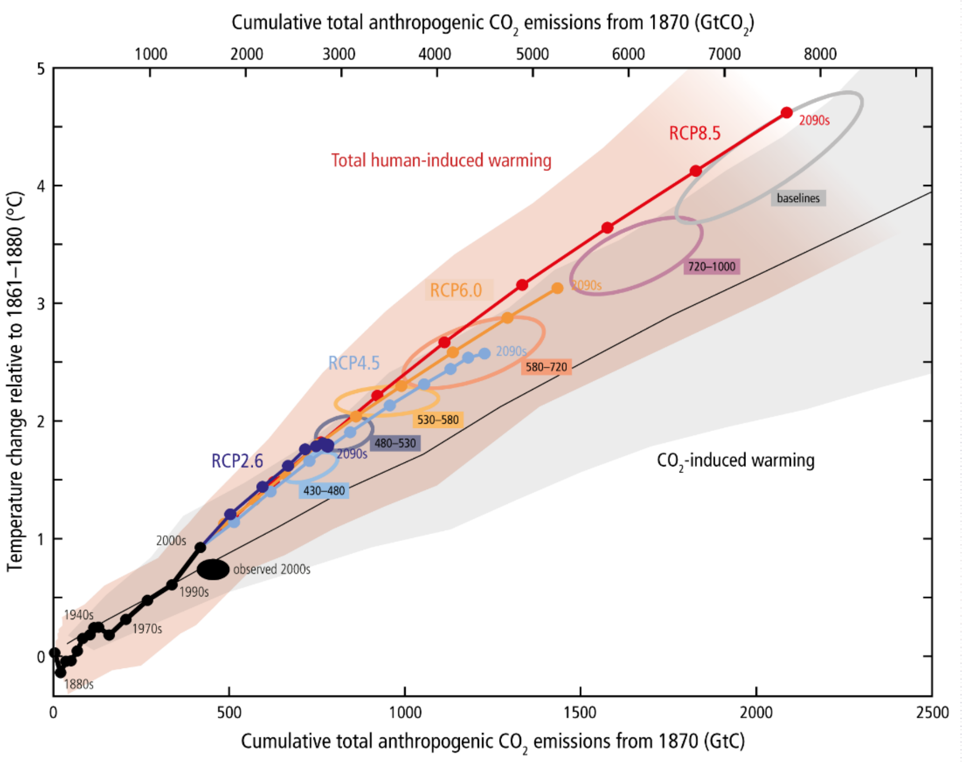

Fig. 4. Global mean surface temperature increase as a function of cumulative total global carbon dioxide (CO2) emissions from various lines of evidence [...]. From [6].

4.2.2 Glacier evolution

Glacier retreat was not simulated in this study, but the presence of glaciers in the Namakhvani catchment may influence future discharges and therefore production. Three glacier evolution scenarios in the basin were investigated: a) the present glacier cover is kept; b) glaciers retreat to altitudes above 3500 m asl, and c) all glaciers disappear. In every scenario, the transition of the present to the future state is concluded by 2060.

4.3 Bias correction

As mentioned previously, bias correction is an essential step of the climate change assessment. Without making sure that each of the projections to be simulated match meteorological observations for the historical period there is no way to guarantee that the results of the hydrological and hydropower production model can be trusted.

Details about the bias correction methodology go beyond the scope of this paper. Notwithstanding, two key aspects the reader should have in mind are:

1. If bias correction is not done correctly the analysis will lose validity. This is because models calibrated based on historical observations are not prepared to

process the raw climate projections (with statistical properties that typically do not match those of historical observations). In other words, bias correction is trying to avoid a “garbage in, garbage out” scenario.

2. Precipitation and temperature timeseries reflect different processes and must be handled differently. For precipitation a technique known as quantile mapping is commonly used. Problems may arise if the climate projections show a greater percentage of dry days than historical observations (but that is not common). There is often a temptation to apply the same quantile mapping technique to temperature. That should be avoided because most projections indicate rising temperatures and directly applying a quantile mapping technique to them would just limit future potentially high temperatures to today’s upper boundaries. Better alternatives for bias correction in temperature are modified quantile mapping techniques or even simple linear transformations.

4.4 Numerical modelling

Numerical modelling is necessary to translate bias-corrected projections of temperature and precipitation into time series of flows and energy production. To achieve this a model capable of simulating hydrological processes and dam operations must be prepared, calibrated, and validated.

On the one hand, climate projections do not aim to exactly reproduce the meteorology that was or will be observed, but rather to reproduce its main properties (*e.g.* mean, standard deviation, seasonality, long-term trends, etc.). On the other hand, the calibration and validation of hydrological models must rely on observed discharges. Because there is no direct correspondence between climate projections and observed discharges (even thinking about the historical period), their use for calibration and validation should be avoided. Accordingly, the hydrological and energy production model is best calibrated and validated according to traditional practice – resorting to observed historical data.

Once a validated model is available, the bias-corrected climate projections can used as model inputs. By looking at simulated discharges for the period that overlaps with observations, one can validate the bias-correction process and ascertain whether the hydrological and energy production model can cope with the climate projection timeseries.

In our case, the free RS-Minerve software was used for the numerical modelling – from hydrology to energy production [7] and [8]. In **Fig. 5**, a comparison between observed discharges and simulations made with climate projection data is done for the Alpana gauging station (upstream of Namakhvani). As can be seen in the figure, there is an excellent correspondence between observations and simulations except, perhaps, during winter months (which may be due to snow and ice accumulation and melt processes). Overall, the largest volume error among all considered projections was in the order of 6.2%.

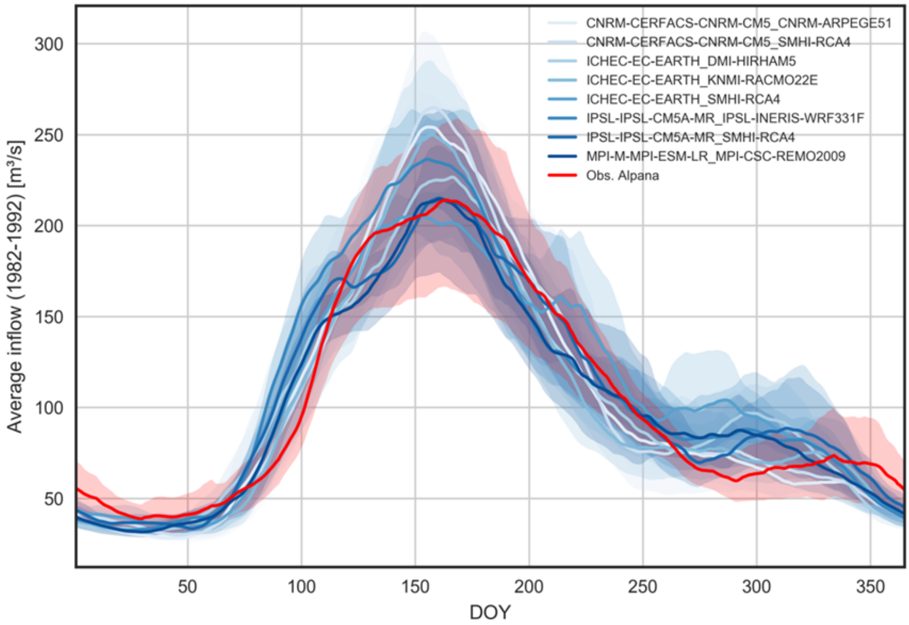

Fig. 5. Comparison of mean monthly discharge observations and simulations of the RS-Minerve model proposed for the Rioni River Catchment at Alpana from 1982 to 1992. The forcing data for the simulations are transformed Clim4Energy projections. DOY stands for Day of Year. Shading depicts inter-annual standard deviations.

5 Results

5.1 Glacier retreat

The three scenarios of glacier retreat (see section 4.2.2) have been simulated for RCP 4.5 (**Fig. 6**) and RCP 8.5 (**Fig. 7**). The effect of glaciers on the average discharges at Namakhvani may range from -5 to 5% until the middle of the century. In scenarios of increasing temperature, accelerated ice melt can offset the additional evaporation and even translate into net gains in runoff – at least while the glaciers cover a sufficient surface of the catchment. In Namakhvani, the impact of glacier changes on runoff is comparable to the uncertainty of the climate projections, particularly for RCP 4.5. Under RCP 8.5 a noticeable decrease in runoff should be expected.

With little changes between the b) and c) hypotheses, the remainder of the simulations is based on a gradual glacier retreat to elevations above 3500 m asl by 2060.

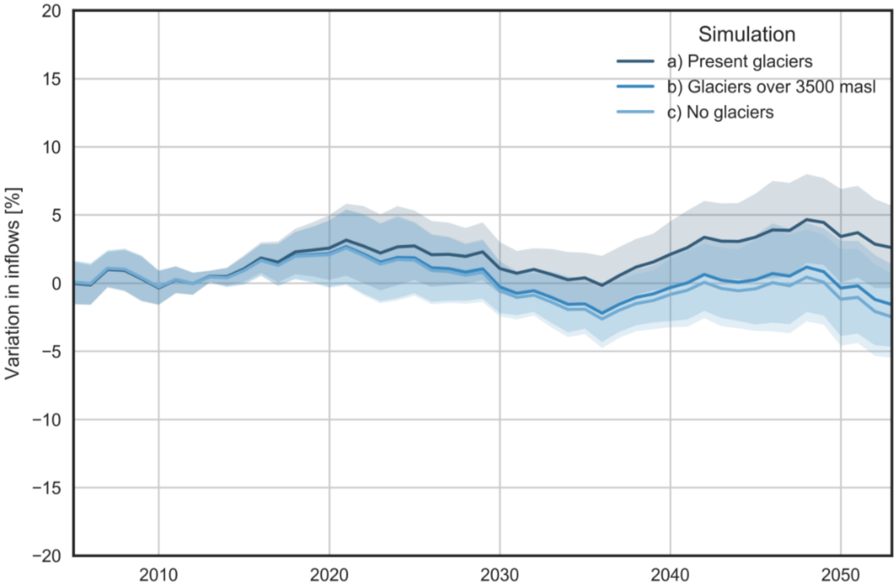

Fig. 6. Mean evolution of average inflows to the Upper Namakhvani dam for RCP 4.5 Clim4Energy projections. 68% confidence intervals displayed.

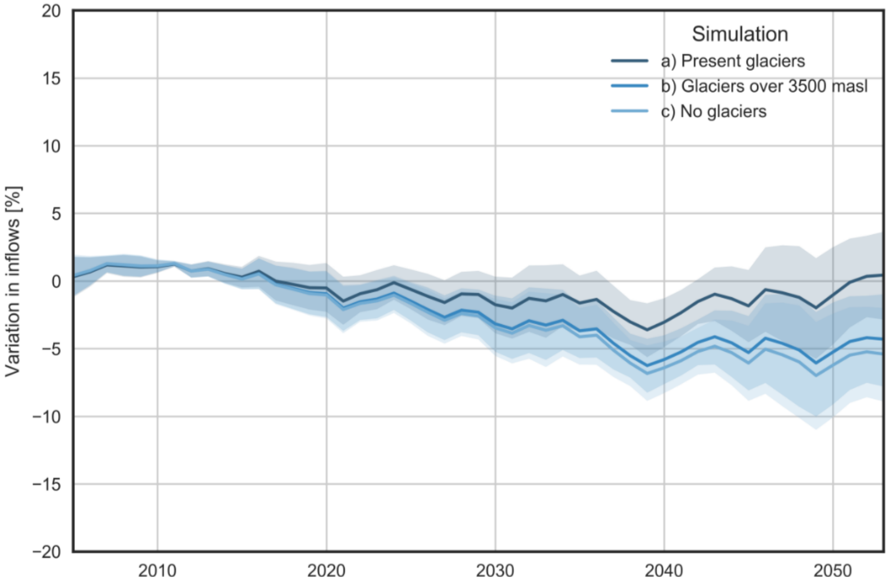

Fig. 7. Mean evolution of average inflows to the Upper Namakhvani dam for RCP 8.5 Clim4Energy projections. 68% confidence intervals displayed.

5.2 Long-term evolution

The long-term evolution of production is depicted in **Fig. 8** (RCP 4.5) and **Fig. 9** (RCP 8.5). Future changes in RCP 4.5 fall well within the projections' uncertainty, with no clear trend being established. For RCP 8.5, however, a decrease down to -10% in energy production should be expected.

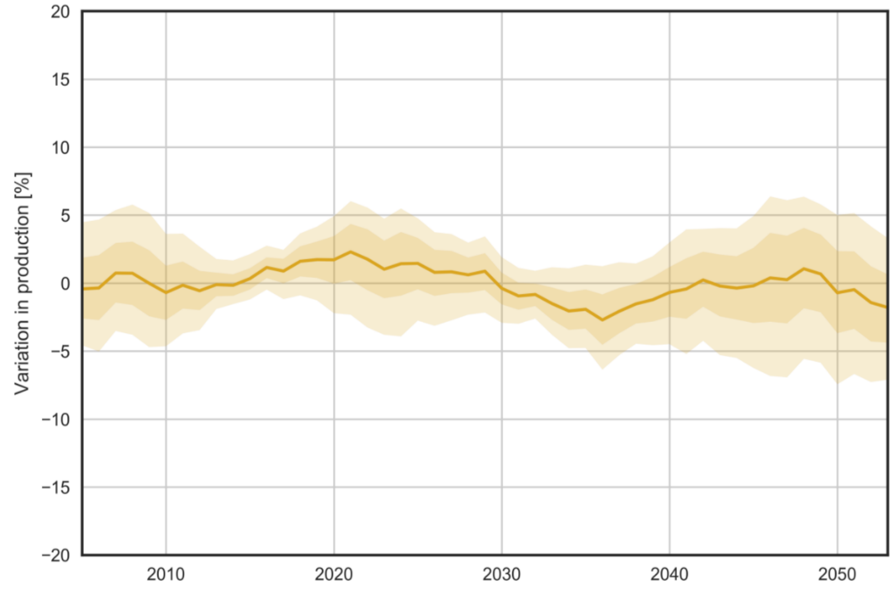

Fig. 8. Mean evolution of average production of the Namakhvani HPP for RCP 4.5 Clim4Energy projections. 65% and 95% confidence intervals displayed.

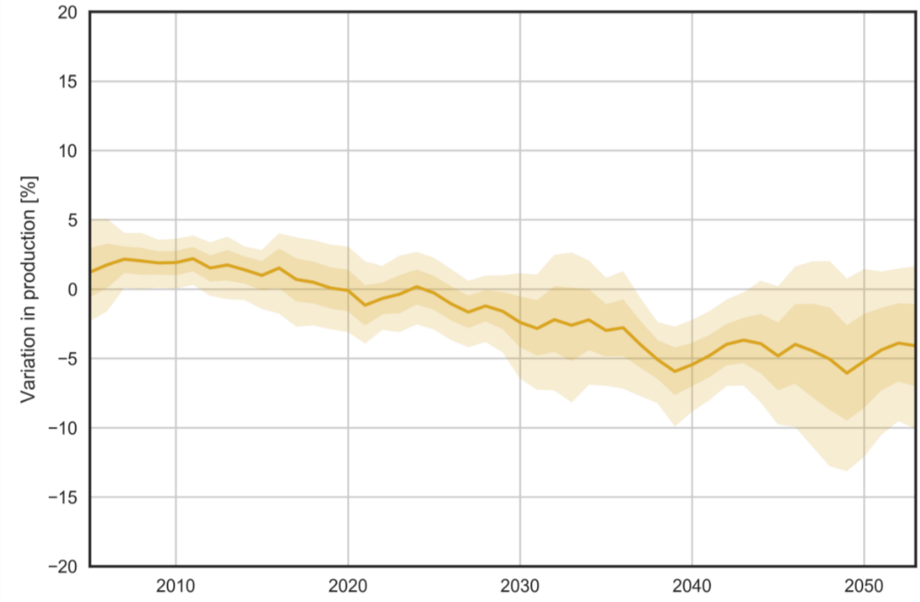

Fig. 9. Mean evolution of average production of the Namakhvani HPP for RCP 8.5 Clim4Energy projections. 65% and 95% confidence intervals displayed.

5.3 Seasonal effects

Being flexibility one of the strong points of hydropower, beyond the total amount of energy that is produced (represented by the long-term evolution analysed above), the sector is also sensitive to when this production may take place.

Projected percentual variations of monthly production by decade are depicted in **Fig. 10** (RCP 4.5) and **Fig. 11** (RCP 8.5). For both RCPs, there is a clear trend of increased production in winter and decreased production in summer as the century advances. For example, by 2050 hydropower production in February may exceed what would be today's values by 40% or more. That would be compensated by decreases in the order of 20% during summer. This is the result of the trade-off between decreased snow and ice accumulation and increased evaporation that is typical of mountainous regions.

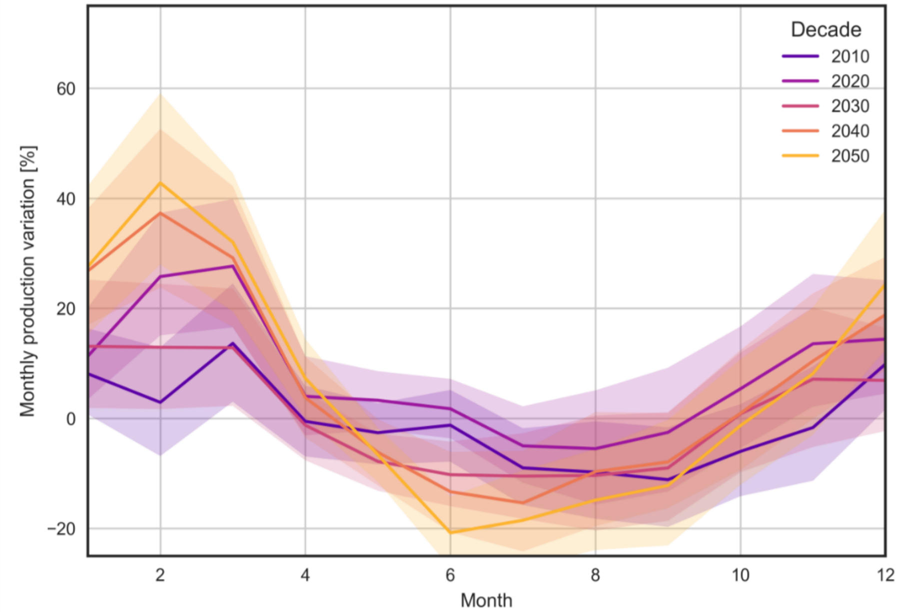

Fig. 10. Changes in the monthly energy produced by the Namakhvani HPP by decade. RCP 4.5.

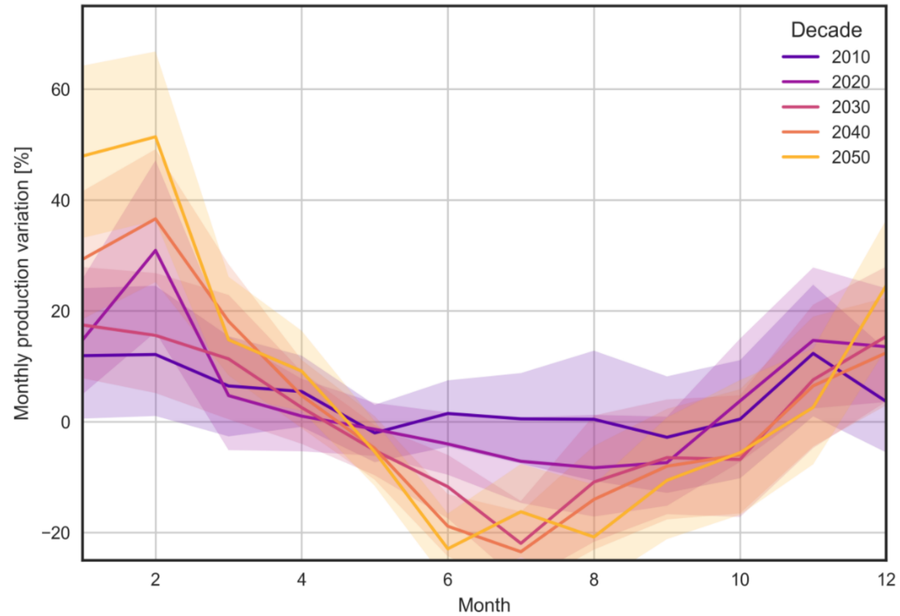

Fig. 11. Changes in the monthly energy produced by the Namakhvani HPP by decade. RCP 8.5.

5.4 Variability

Finally, inter-daily production variability is assessed. In **Fig. 12** (RCP 4.5) and **Fig. 13** (RCP 8.5), a (moving) standard deviation metric is used to represent how the production may vary within a period of a few days as a consequence of hydrological variability. The two peaks that can be identified in the figures correspond with the rise and fall of the yearly hydrograph. No significant changes in the amount of inter-daily variability are predicted. However, its timing may be affected.

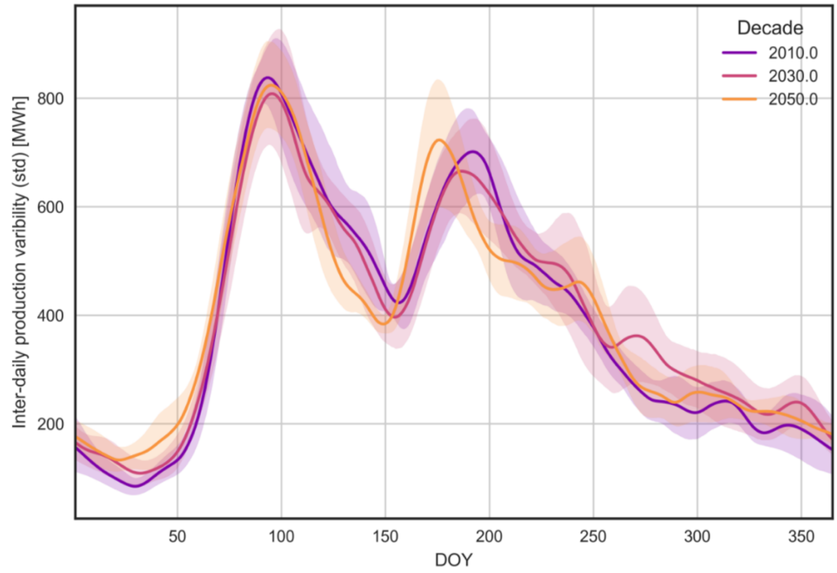

Fig. 12. Evolution of the inter-daily variability of production in the Namakhvani HPP by decade. Represented in terms of Day Of Year (DOY). RCP 4.5.

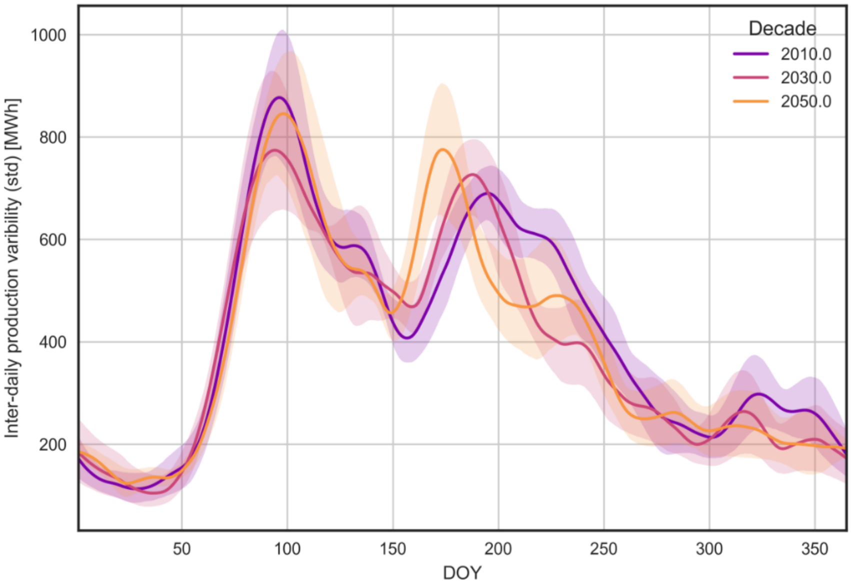

Fig. 13. Evolution of the inter-daily variability of production in the Namakhvani HPP by decade. Represented in terms of Day Of Year (DOY). RCP 8.5.

6 Conclusions

The paper provides a summary view of the climate change assessment carried out for the Namakhvani HPP (400 MW), a new project under development in the Rioni River, in Georgia. Climate projections indicate that, while the tendency for an increase in average temperature is clear, alterations in precipitation patterns over the Rioni River Catchment do not evidence any pronounced medium-term variations (see **Fig. 3**). Changes will most likely be driven by temperature. In predominantly hot climates, the continued increase in temperature that will take place during the coming years will reinforce evapotranspiration and, thus, reduce net runoff. In predominantly cool and mountainous areas – as is the case of Namakhvani – higher temperatures will mostly affect 1) the shape of the annual hydrographs, which reflect later snow accumulation and earlier snow and ice melt, and 2) the volume of the inflows, which reflect and additional volume made available as glaciers retreat.

Correctly employing bias-correction techniques, undertaking thorough numerical model calibration and validation, and analysing results in light of their uncertainty – never relying on one or few projections to draw conclusions – are essential steps to conduct climate change assessments for dams. Of course, climate change will undoubtedly have impacts in the hydropower sector. It raises a lot of questions and adequate planning is needed. This said, some answers fall within our reach, but others will remain elusive. Climate change assessments are an uncertain "business" and sound decision-making should take that into account.

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