Water scarcity risk in an alpine area: analysis of water allocation within climate change scenarios.

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Abstract: Climate change dynamics have significant consequences on water resources at the watershed scale. With water becoming scarcer and susceptible to variations, the planning and reallocation decisions for the watershed management need to be reviewed. This research is focusing investigations on the in-depth understanding of the current allocation balance of the water resources among competitors; the analysis concerns the hydroelectric power production system. The relationship between the volumes involved and the amount of energy produced is the main purpose of this treatment. The study of annual trends will be useful to improve the water management system.

Key words: hydroelectricity production, climate change, water management.

Introduction

A number of recent studies has shown the effects of climate change dynamics on water resources. This work is part of RICLIC project, funded by the Regional Public Authority of Lombardy, to develop a scientific methodology to assess climatic impacts on water resources at a regional scale. The study area is the Adda River basin, one of the most representatives in northern Italy, either for his extension and for his socio-economic role. The upper part of the watershed runs along Valtellina, an alpine glacial valley, characterized by a high hydroelectric exploitation that has a strong influence on the landscape and the water balance. The release of water from the reservoirs is planned to satisfy the peaks of electric energy demand as to control the output flows from Valtellina to the lowest parts of the watershed, when water scarcity conditions occur. In fact, the important role of the Adda River is also to provide a water input to Lake Como, an area with tourist attractiveness, and to Padana Plain, a highly populated area that is also characterised by the presence of intensive economic activities. In the summer period, when in the lower basin the irrigation activities begin, the demand of water dramatically increases. During this period, when water allocation becomes critical, the regulatory agency (the Adda River Authority) plays a central role in the decision making process. It involves the stakeholders to negotiate for the best compromise and it finally adopts the regulatory measures for an equitable water distribution. This system of regulation gives rise to a number of adverse effects on the water supply system of the mountain communities. The Italian law acknowledges this damage on the local municipalities and fixes a compensation for the alteration of water cycles, paid by the hydroelectric power producers. Climate change processes might lead to an exacerbation of this situation, since a further decrease in water stocks and distribution might not be economically compensated. This research is focusing investigations on the in-depth understanding of the current allocation balance of the water resources among competitors. Hydropower production holds a very important role in the national economic system and a growing number of incentives are provided for the production of energy from renewable resources; nevertheless, the mountain communities suffer the worst costs and benefits ratio for water resources explotation.

The concept of drought

The discussion about the problem of water scarcity needs a careful definition of the different meanings ascribed to the term “drought”. Following the central aim of this work, here will be discussed only the “disciplinary perspective of drought”, because the interest is on the distribution of water among different users. The United States National Drought Mitigation Centre (NDMC, 2006) offers different definitions, to distinguish between the alternative disciplinary perspectives of drought. In the proposed analysis only the socio-economic drought will be considered, a phenomenon that occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. This definition relates the demand and supply of some economic good with elements of meteorological, hydrological and agricultural drought. The socio-economic drought lags the occurrence of meteorological drought, because it depends on time and space of productive processes.

Study area

The area object of study is one of the greatest River basins in Northern Italy, the Adda River Basin. Adda River is the fourth river in Italy for length (313 km) and the second tributary of the Po for discharge. The whole area covers a surface of 7.979 km^2, and presents in the plain area a strong interconnection between different watercourses; in order to analyse the socio-economic effects of the management of Adda water resources, it has been chosen to consider only the 169 municipalities that are closely connected with Adda waters, covering a surface of about 5.031 km^2. Then, to simplify the analysis, this area has been divided into three sub-areas, different from a physical point of view, as from a socio-economic point of view. The northern part of the basin is Valtellina, a wide Alpine Glacial Valley, U-shaped, which runs from east to west in the central part of the Alpine mountain range system; after Colico, Adda flows into Lake Como, outflowing in Pianura Padana, until the joining with Po River. In the treatment of the socio-economic consequences of hydroelectric production on mountain communities, only the Valtellina area will be considered, taking the southern parts of the basin as output areas, expressing a certain water demand.

Hydroelectric system and water exploitation

The whole territory of Sondrio Province (both Valtellina and Val di Mera) is characterized by an intense hydroelectric exploitation. In fact, the 80% of rivers and streams within the watershed is diverted for hydroelectric power production purposes (Bettini, 2003). Table 1 shows the specifics of the hydroelectric power plants and the related facilities, divided by the four main companies that detain the right of exploitation of Sondrio Province waters: EDIPOWER (8 plants), ENEL (18 plants), EDISON (8 plants) and A.E.M. MILANO (7 plants). This complex system of channels, diversions, dams and plants strongly alters the natural water cycles, since it has the effect of converting the flows and storing them into stocks, releasing water after a certain period of time. Moreover, since turbines are often opened intermittently, rapid or even daily fluctuations in river flow are observed.

Table 1: Number and characteristics of the hydroelectric facilities of the Sondrio Province (Source: Songini 2003).

		WATER CHANNELS AND PIPES				RESERVOIRS	
	Water plugs	Free	Pressurized	Turbines	Average annual production (1997-2001)	Amount	Overall capacity
	n	Km	Km	n	kWh x 1000	n	m3
EDIPOWER	53	27,397	34,054	21	1.108.514	14	59.332.500
ENEL	70	31,919	76,359	31	1.777.595	17	93.544.600
EDISON	73	18,806	42,352	18	855.305	12	76.823.500
A.E.M. MILANO	61	11,47	126,52	19	1.991.887	8	189.315.000
OTHER	46	-	17	33	90.000	5	39.400
OVERALL	**303**	**89,592**	**296,285**	**122**	**5.823.301**	**56**	**419.055.000**

The hydroelectric exploitation has been weakly regulamentated by the Public Authority for many decades, without any specific law that could guarantee a sustainable water management. The Italian law fixed a compensation damage on the local municipalities for the alteration of water cycles by the hydroelectric power producers, with the introduction of a general water exploitation fee in 1953 (L. 959/1953); the calculation of rent for diverting public water is based on the installed capacity of plants and is fixed in 18 €/kW. The money collected from this fee are proportionally distributed every year among the municipalities that suffer the consequences of this activities. Only during the early ‘90s with the introduction of DMV (low flow limit) law, n. 183/1989 and n. 36/1994, the Public Authority aknowledges that hydroelectric activities can be disruptive to surrounding aquatic ecosystems and that the presence of hydroelectric power plants changes the downstream river environment. The low flow limits are calculated according to the formula DMV=1.6xS where S represents the surface of the drained basin and must be respected during the whole year.

The recent laws about the introduction of the Green Certificates into the energy markets, is being a boost for a faster rise of hydraulic potential exploitation. In Sondrio Province, in particular, there is an increasing interest on small hydroelectric plants (the so called *mini-hydro*, with an installed capacity up to 3000 kW). At the moment the Regional Authority is considering 74 new *mini-hydro* water exploitation requests.

Hydroelectricity demand/supply dynamics

Most of the hydroelectric power of Sondrio Province comes from dammed water which is driven into water turbines in response to peak in electricity demand. For this reason, the hydroelectricity production from this area plays a strategic role in the national energy demand-supply dynamics, thanks to its high flexibility, provided by its capacity of modulating the production during the day (by simply activating the turbines) without energy costs. Indeed, while other sectors of energy production (mainly thermoelectric plants) provide the base load supply, hydroelectric production is strongly related to the oscillation of energy demand. Figure 1 shows the average hourly trend of electricity demand in Italy within the day (TERNA 2005).

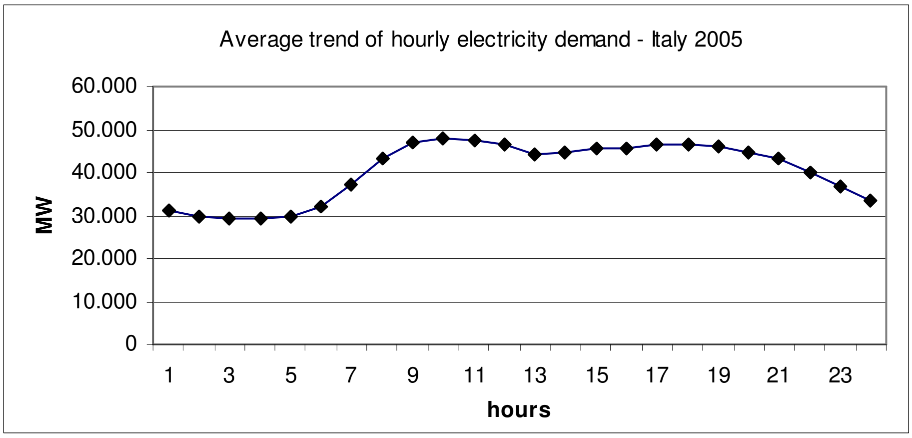

Fig 1: Trend of hourly electricity demand within the day, Italy. (own elaboration based on TERNA 2005).

This trend is easily explained, since most of the electricity is demanded by industry (49,2%) and tertiary sector (27.05%), while only the 21,60% is used for civil purposes (TERNA 2005); therefore, the most energy demanding periods of the day are registred during the central hours of the morning (9-12) and of the afternoon (14-19). According to these trends, year by year, the manager of the electricity wholesale market fixes the time-bands prices. The term time-band refers to the assignation of different prices (€/Mwh) to different sectors of the day, according to higher or lower electricity demand. Fig. 2 shows the monthly aggregation of the amount of hours classified within the four time-band prices, from F1 (very high request peak) to F4 (low request).

	Overall monthly hours for each time-band			
MONTH	F1	F2	F3	F4
Jan	0	192	32	520
Feb	0	240	40	392
Mar	0	147	161	436
Apr	0	60	220	440
May	0	176	132	436
Jun	133	160	25	402
Jul	147	168	21	408
Aug	40	117	41	546
Sep	60	178	94	388
Oct	0	147	147	450
Nov	16	155	123	426
Dec	50	100	60	534

	time-band	wholesale prices (€/MWh)
F1	very high request peak	122,83
F2	high request	73,23
F3	average request	57,91
F4	low request	39,84

Fig 2: Monthly aggregation of the amount of hours belonging to different time-bands and time-bands prices (€/MWh). (Own elaboration based on TERNA 2005)

As stated before, the distribution of the low/high request time-bands during the day follows the trends shown in Fig 1. The yearly time-band distribution shows differences between high energy demanding months (June, July, September) and months with very low number of F1 and F2 time-bands, such as August, April and October. This situation determines a significative oscillation of the average prices of the MWh in the different months. This prices are calculated aggregating, for every month, the overall number of hours belonging to each time-band, multiplying them for their prices, and finally dividing by the amount of hours in the month. The results of this elaboration are shown in Table 2. It is important to say that calculated prices might result underestimated, since the calculation assume unchanging levels of energy production throughout the day, while the actual activity (and selling) is concentrated in the most profitable hours of the day (demand peaks).

Table 2: Detail of the monthly average wholesale prices, expressed in €/MWh. (Own elaboration based on TERNA 2005).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average MWh price (euro)	49,23	52,84	50,35	48,14	50,94	63,22	64,29	50,55	57,37	50,01	51,96	51,36

Effects of hydroelectric production on Adda River water balance

The managers of the hydroelectric reservoirs modulate their accumulation and release strategies both considering natural cycles and energy demand peaks, with the aim to maximize the overall company income. In these alpine areas, snow storage and snow melt strongly influence the annual cycle of river runoff. In fact, during the snow accumulation periods, the level of water retained into the reservoirs is very low, it reaches its minimum at the end of the winter season and start to increase with the beginning of spring season (April) and last until the end of August. The huge amount of snow, accumulated during the winter season, are gradually released by the melting processes and retained into the reservoirs.

As stated in the previous paragraph, water is driven into the turbines when electricity demand is higher and, at the same time, its selling is more profitable. The result is a strong interconnection between river discharges (along his course through Sondrio Province), electricity demand (that determines its wholesale price) and electricity production. Figure 3 and Figure 4 show the average monthly discharges variations of Adda River, measured at the very bottom of the valley (Fuentes section), and its comparison with the trend of the average MWh prices and with the average monthly production, respectively (the data refers to the year 2005).

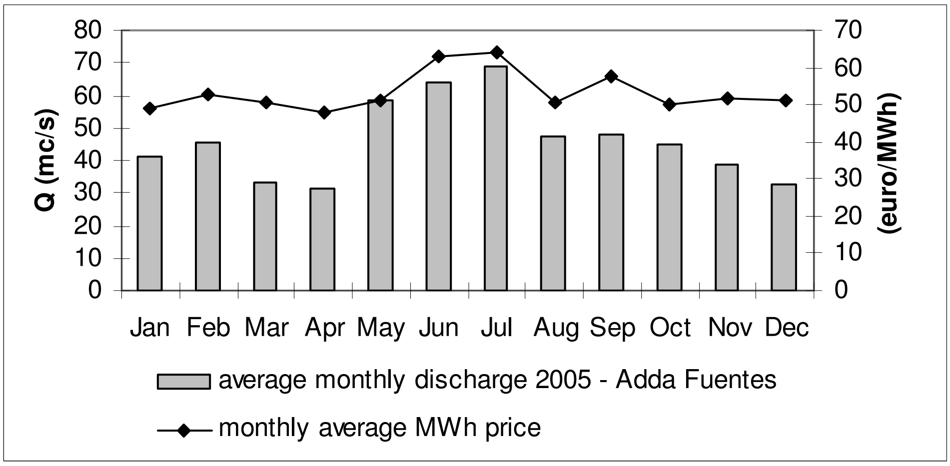

Fig 3: Monthly average wholesale price (own elaboration based on TERNA 2005) compared with average monthly discharge of Adda River in Fuentes (source: Consorzio Adda, 2005).

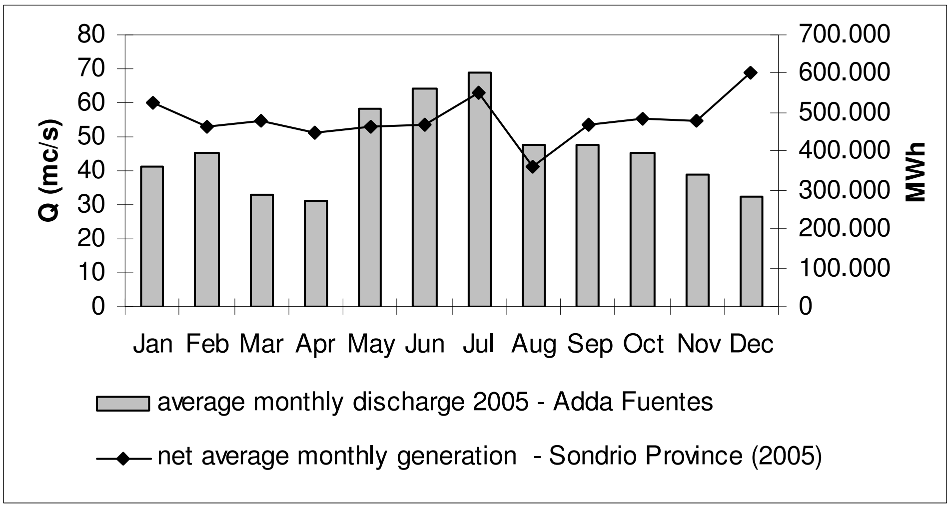

Fig 4: Monthly average hydroelectricity production of Sondrio Province (own elaboration based on TERNA 2005) compared with average monthly discharge of Adda River in Fuentes (source: Consorzio Adda, 2005).

The MWh price curve (Fig 3) can be considered a representation of the electricity demand side, while the monthly generation curve shown in Fig 4, describes the actual electricity supply side, provided by Sondrio Province's hydroelectricity plants. As expected, in both cases there is a good correlation between the trends, especially during the period May–August. A significant positive peak can be observed in correspondence with the month of July, when the highest discharges are registred. The month of August (very low electricity demand) is characterized by a dramatic decrease in both flows (-32%) and hydroelectricity production (-35%). The hydroelectric production activities fluctuate according to electricity demand dynamics, which are dependent to wider (national) scale dynamics. Nevertheless, they directly affect the river dynamics, both at a local and at the watershed scale. The oscillations of Adda River have a direct effect on the local communities of Sondrio Province, affecting the general water availability, which, in this area, has an environmental and a recreational importance. Moreover, the outflows from Fuentes influence the availability of water for the competing water uses downstream, such as irrigation, run-of-river hydroelectric diversions, industrial and thermoelectric captations. Furthermore, they are directly related with the Lake Como hydrometric levels, that are very important for navigation and detain a great environmental and recreational value, especially during summer, when the tourist flows peaks are registred.

Climate change and the exacerbation of competition for water

Water resource management is becoming a more and more important strategic tool in the search of sustainability of competing water uses at the watershed scale. The uncertainty of future climate change scenarios needs to be taken into account. Figure 5 shows the variation of the annual and the summer (May-Aug) average discharge of Adda River, in Fuentes section. The trends of both curves show a significant decrease of discharges for the period 2002-2005. This reduction is comparable with the one observed during the period 1987-1991 but more evident, especially for the year 2005 (-49% and -52% compared with the average annual and summer values, respectively). This recent decrease in the general water gave rise to a number of adverse effects which, especially during the summer of 2003, affected the main water-dependent sectors of the economy along the watershed and, in some areas of the Sondrio Province, a general water shortage for civil uses. With water becoming scarcer, the allocation strategies between competing users need to be adapted both to optimize the uses and to preserve the local environment and communities welfare.

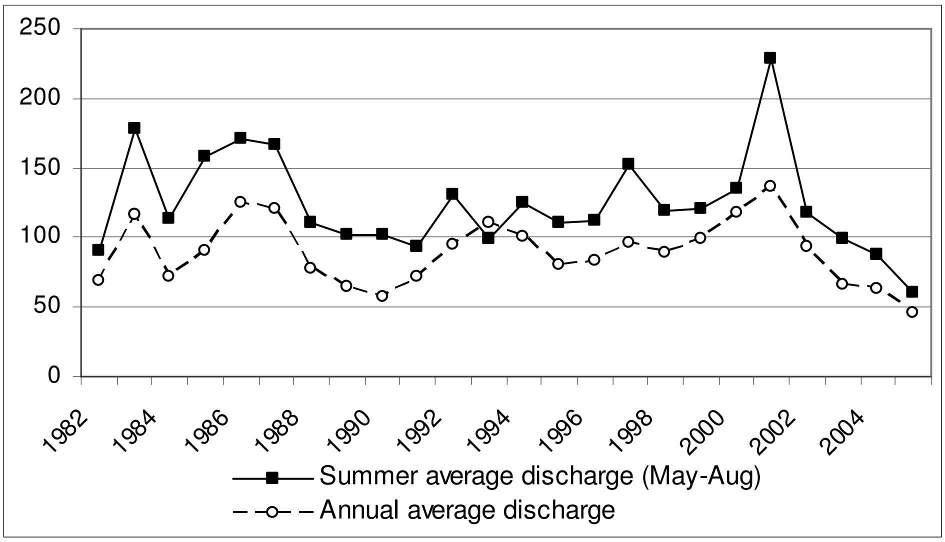

Fig 5: Annual and summer (May-Aug) average discharge of Adda River, measured in Fuentes section during the period 1982-2005. (source: Consorzio Adda, 2005).

Lombardy Region is committed to face this situation, involving all the water users into the allocation decisions, not only during emergency periods but also while planning the ordinary water management strategies; hydroelectric reservoirs provide a strategic water resource stock, which need to be managed accordingly. This work has described a single aspect of a more complex frame, which will be integrated with the other dynamics of resource exploitment, during the following steps of the project, to get a exaustive tool for water management within climate change scenarios.

Project description

This research is carried out in the framework of RICLIC project, funded by Università degli Studi di Milano Bicocca, Fondazione Lombardia per l'Ambiente (Lombardy Environment Foundation) and Regional Agency for Environmental Protection. This paper has been discussed by the authors. Paolo Giacomelli wrote the paragraph 7, Marta Brambilla wrote the paragraphs 2, 5, Valentina Carboni wrote the paragraphs 1, 3 and Andrea Rossetti wrote the paragraphs 4, 6.

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