Impact of climate change on the sustainability of projects dealing with agricultural economy and hydroelectric power generation

Ch. Skoulikaris* and J. Ganoulis
UNESCO Chair & Network INWEB, Department of Civil Engineering, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece

*Corresponding author: E-mail: hskoulik@civil.auth.gr, Tel +30 2310 995682, Fax: +302310995681

Abstract
The design and functioning of water infrastructures have direct impacts on the ecological and social landscape in which they are located and vice versa, as the prevailing social systems and processes form the physical infrastructure used for the management of water. This research work evaluates the way social benefits, in terms of farmers' compensations and environmental sensitivity expressed in terms of rehabilitation costs due to lack of water, affect the economic viability of hydropower projects in the case of two climate change emission scenarios. The results demonstrated that, apart from the evident macro scale decrease of water discharges, the economic sustainability of large scale projects is also connected to the fluctuations of the wholesale prices of electricity.
Keywords: climate change; project financing; hydroelectric plants; sustainable development; water resources management.

1. INTRODUCTION

The economic sustainability of project financing is ultimately linked to sufficient cash flow that can provide a return payment of the project expenditures within an appropriate period of time. The a priori identification and evaluation of the impacts attributed to specific project risks is a matter of great importance for the viability of the project. For renewable energy projects, the attributed risks can be classified in five principal categories, namely intrinsic, production and technical, economic, political, and management risks [7]. The intrinsic risk in particular is related to unforeseen problems that may emerge after the completion of the construction works and the start of production, and corresponds to an overestimation of the natural resources under exploitation. In the case of hydropower plants, insufficient water volumes drained from the upstream river basin of a reservoir, i.e. hydrological risk, could jeopardize the investment during its life cycle.

In the past, hydropower acted as a catalyst for economic and social development by providing both energy and water management services, and it can continue to do so in the future [4]. However, since the fuel of a hydroelectricity installation is water, variations caused by climate change in this natural resource are bound to affect its operation. According to the assessments of projected climate change for the Mediterranean basin [2] annual precipitation is very likely to decrease as is the number of precipitation days. Furthermore, the risk of summer drought is likely to increase in the Mediterranean area. Concerning the hydrological risk due to climate change, even though the climate change concept has been widely accepted since the early 1990s, its systematic inclusion in the vulnerability evaluation of hydropower projects financing is still in its infancy. Since the majority of investments in hydropower generation is realized by the private sector, the lack of knowledge and experience in the assessment of the impact due to climate change on project feasibility acts as a repellent for investors. Particularly, a deteriorating macroeconomic climate and questions over national commitments to tackling climate change are among factors that affect the financing for renewable energy projects.

The present work is based on two main issues and proposes a specific methodology for the sustainability of new hydropower projects under climate change conditions. Firstly, the traditional design method of the hydropower installations, i.e. reservoir amplitude, turbines capacity etc, based on historical flow data as a predictor of future flow variations, is considered inadequate. Secondly, the integration of the sustainable development concept into water resources management practices is crucial for the successful protection of the water resources and the fulfillment of the water demands of economic development. Thus, the objectives of this work are to initiate an integrated and coherent approach for evaluating the sustainability of projects generating renewable energy from water, and also contributing to the agricultural economy while maintaining at least the minimum environmental flow under conditions of climate change. The impact of the wholesale electricity price is also been demonstrated thought a sensitivity analysis.

2. MATERIALS AND METHODS

2.1 Case study: The Nestos river basin

The Nestos Basin is an internationally shared basin in South Eastern Europe lying between Bulgaria (upstream country) and Greece (downstream country). According to the Water Framework Directive nomenclature the upstream part belongs to the East Aegean river basin district (RBD BG4000), while the Greek part belongs to the Water District of Thrace (WD GR12). The basin covers a total area of 6,219 km^2, 46% of which belong to Greece, while the 255.0 km of the river's length are almost equally shared between the two countries[10]. Before discharging into the Northern Aegean Sea, the river forms a deltaic area of approximately 550.0 km^2 attributed with both socioeconomic and environmental services. Especially, the delta of the river Nestos is a highly agricultural area and is of great importance to the regional economy, while the river estuaries are protected by the Ramsar Convention and are part of the NATURA 2000 network.

Since 1995-1996, in the mountainous Greek part of basin, 2 large hydroelectric power stations have been constructed and are operating (serially), namely Thisavros and Platanovrisi, for energy production and irrigation purposes. water for irrigation. The initial plan of the feasibility study of the specific multi project was to build a third power station, namely Temenos, downstream of the other two, however due to lack of funds the project has not been finalized. Nevertheless privatization policies have recently revived interest in its completion. The characteristics of the existing and future hydraulic projects are presented in Table 1.

Table 1. Characteristics of existing and future hydropower plants in the Nestos River

	Existing infrastructure		**Future project**
	Thisavros dam	**Platanovrisi dam**	**Temenos dam**
Upper operation level (UOL) (m)	380	227.5	158.0
Volume in UOL 10^6 m^3	750	84	11.35
Useful volume 10^6 m^3	565	11	6
Reservoir surface in UOL (Km^2)	18	3.25	1.05
Height (m)	175	95	45
Number of units/Total power (MW)	3/300	2/100	3/19.5

2.2 Hydrological modelling

The hydrological modelling of the whole basin was performed with the spatially distributed hydrologic model MODSUR [5,9]. The model bases its operation on a progressive grid system with varying cell sizes ranging from 250 m for the smallest to 2000 m for the largest, Figure 1. The hydraulic and topographic characteristics of the basin, such as the stream definition and accumulation terrain slopes, were derived from the processing of a global digital elevation model, namely GTOPO30, with a horizontal grid spacing of 30 arc seconds. The aforementioned data, as well as land cover and geological data, were integrated into the mesh with the use of geographical information systems. Meteorological parameters such as precipitation and temperature were available for 27 stations at monthly time step for the period from January 1987 to December 1995.

The meteorological data, as well as the calculated evapotranspiration, were spatially distributed over the basin and allocated to the grid. The model calibration was based on monthly river flow measurements, both in Bulgaria and Greece, for the period 1987 to 1992, while the model validation was successfully conducted for the period 1993 to 1995 [10].

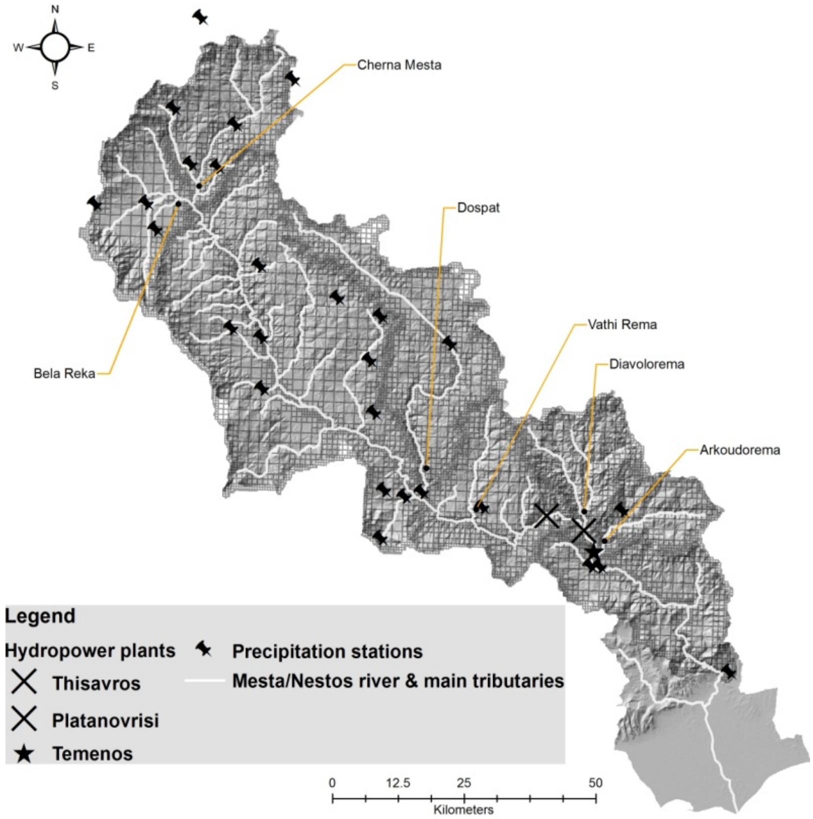

Figure 1. Overlay of the hydrological model grid on the Mesta/Nestos river basin with emphasis given to the existing hydropower projects (X symbol) and the future project (star symbol).

2.3 Simulation of hydropower operation

The main tool used in this study for the current and future hydroelectricity power stations was the WEAP21 model [11]. The technical characteristics of the dams were retrieved from the literature , while the inflow discharges to the reservoirs were derived by the hydrologic model outputs. WEAP21 uses a linear programming (LP) solver to allocate the available water resources across the hydrosystem. The objective of the LP solver is to maximize satisfaction of demands, subject to demand priorities, mass balances and other constraints. This routine ensures a physically-consistent description of the hydrosystem and the satisfaction of all constraints. Due to the fact that irrigation water demand is of importance to the downstream deltaic area and a constant environmental flow requirement is set to 6.0 m^3/s by legislation, the demand priorities of environmental flow, irrigation and hydropower production were set to 1, 2 and 3, respectively as the priority operational rules of the dams .

2.4 Regional climate models

For the assessment of climate change impact to the hydrosystem, the future climatic predictions of an European Regional Climate Model (RCM), namely CLM, were included to the proposed sequence of mathematical models. RCMs use as forcing conditions the results produced by General Circulation Models (GCMs) in order to simulate finer-scale physical processes consistent with the large-scale weather evolution prescribed by a GCM [8]; the specific process being known as dynamic downscaling technique. Table 2 provides information relative to the utilized RCM, such as name and acronym of the regional model, institute, parent model, grid resolution and emission scenarios.

Table 2. Characteristics of the utilized Regional Climate Models

Model	Acronym	Sponsored Institute	Parent GCM	Resolution (km)	Emission Scenario
CLM-RCM	CLM	Max Planck Institute for Meteorology in Hamburg	ECHAM5/MPIOM	20*20	B1, A1B

2.5 Discounted cumulative cash flow tool

The economic viability of the new project over its life cycle, which in the case of hydroelectric plants is 50 years, was assessed with a custom developed tool based on the discounted cumulative cash flow (DCCF) model. The latter is one of the most commonly used tools for project financing evaluation and decision making [1] and consists of a valuation method used to estimate the attractiveness of an investment opportunity. Discounted cash flow (DCF) analysis uses future free cash flow projections and discounts them to arrive at a present value, which is used to evaluate the potential for investment. In the present study, the quantitative criterion of the Net Present Value (NPV) [7] was integrated into the custom tool in order to define the sum of the series of discounted cash flows, as given in Equation 1.

$$NPV = \sum_{n=0}^{N} \frac{I_n - C_n}{(1+r)^n} \tag{1}$$

where I are the incomes, C are the costs, r is the discount rate of return and n is the number of years from final return payment, i.e. the project's life time.

The project revenues are summarized as i) the sale of electricity to the market, ii) the sale of water for irrigation, and iii) the profit from the pump storage procedure with the upper dam. On the other hand, the project costs consist of i) the capital expenditure, ii) the operational expenditure, iii) the compensations to farmers in case of lack of water, and iv) the cost of rehabilitation of the environment in case the minimum environmental flow is inadequately maintained. Both revenues and costs have been incorporated in annual step in the tool.

3. RESULTS AND DISCUSSION

Direct application of the output from GCMs is rather inadequate due to the limited representation of mesoscale atmospheric processes, topography, and land-sea distribution in GCMs [3]. Moreover, and of particular concern to precipitation, GCMs exhibit a much larger spatial scale than is usually needed in impact studies. Thus downscaling techniques, such as the dynamic downscaling which is adopted in this work, could be considered as interoperability bridges for the amelioration of the inconsistencies that result from applying large scale and coarse resolution data at regional scales.

According to historic monthly discharge time series (1975 to 1995), the mean runoff at the borders of the two countries was approximately 20.6 m^3/s, while for the period 2015-2065 the discharges at the borders were simulated as 13.55 m^3/s and 11.90 m^3/s for the B1 and A1B scenarios accordingly. The main reason behind the runoff diminution lies essentially in the decrease of the overall amount of precipitation. The qualitative analysis of the discharges decrease, indicates the potential impacts to the downstream water resources management and potential water deficits in covering all the water demands such as power production and irrigation.

The results of the DCCF model, which are presented in Table 3, indicate that climate change has direct impacts to the project viability. This is mainly based on the fact that limited water flows are being coupled with specific demand priorities of the hydroelectricity plant operation, i.e. priority to agriculture, thus the remaining water volume does not facilitate intensive power production operation. Particularly, in almost all cases the NPV values are negative which means that under certain specifications the project may be considered as being inappropriate for financing. The only case where the project presents economic profitability is under Scenario B1 and for the reference year 2001, where the average wholesale electricity price is 28.4% and 18.2% higher than in the years 2010 and 2011 respectively. In both latter reference years, the project presents accumulated losses which are translated into negative NPV values. For the A1B scenario, even with the high electricity price of 2001, the project has negative NPVs, i.e. the returns of the project in its life cycle not only cannot cover the capital cost of the investment but also are systematically less than the costs.

Table 3. NPV values in correlation to electricity prices in selected years and climatic scenarios

Reference year	Average wholesale electricity prices per reference year	NPV (in Million €) for Scenario A1B	NPV (in Million €) for Scenario B1
2001	73.0 €/MWh	-4.5 €	1.82 €
2010	52.3 €/MWh	-13.18 €	-11.4 €
2011	59.7 €/MWh	-7.84 €	-5.78 €

At this point, it should be noted that the large differences in the wholesale price among the reference years is based on the liberalisation of the electricity market in the European Union that was activated in the early 2000s and set new standards for electricity prices. In accordance to the Electricity market Directives, a system of competition was developed to auction spare capacity through a central system. Consequently the day-ahead market yields the reference price for the industry, as it constitutes the major component on which generators' cash-flows are based. This is the reason why the electricity price in reference year 2001 is much higher than in the period after the directives implementation. Furthermore, climatic parameters play important role in electricity price fluctuations. The fact that years 2009 and 2010, for example, were two successive years of intense wet conditions resulted in excess storage capacity of the reservoirs and consequently the substantial capacity surplus in the market set pressure on the electricity price. The prize of 2010 indicates this pressure. On the other hand, water scarcity conditions of 2011 exerted an upward pressure on wholesale prices, due to the need for substitution by more expensive energy, resulting in a 12.4% increase of prices between 2010 and 2011. In general, in Greece hydropower projects produce their maxima from June to August, with a peak-shaving objective.

4. CONCLUSIONS

Apart from new technological approaches, investments in the water sector and particularly in large scale hydraulic projects, such as hydropower plants, should encompass globally accepted environmental concepts which are derived from the Millennium Development Goals (MDGs) and foster water management and sustainable development. Furthermore, current challenges such as those imposed by climate change should also be taken into consideration. Inspired by the aforementioned, this specific work proposes a sequential water resources modelling approach for the development of an integrated, coherent and flexible tool for assessing the viability of large scale water projects. Specific emphasis has been given to the assessment of the economic viability of new dam projects and the evaluation of the sustainable operation of projects generating renewable energy from water, as well as the sustainability of agricultural demands and environmental security in terms of environmental flow under climatic variations. Wholesale electricity price was also been assessed in the economic sustainability of hydraulic projects.

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