Energy revenue in irrigation systems: a case study

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Abstract

Irrigation systems are generally characterized by a greater discharge than that which usually flows in drinking water supply systems. Moreover, they are supplied in limited periods of the year (irrigation periods) and sometimes a pump station with a high level of energy consumption could be needed. Therefore, when the geodetic heads are relevant it is possible to produce hydroelectric energy from these systems. Through the application on a real case study, i.e. an irrigation system managed by Consorzio Valle del Liri in Southern Italy, a simple optimization method of the system efficiency is herein illustrated. This work results in a feasibility study of the investigated system, leading to increasing social and environmental benefits.
Keywords: irrigation systems, energy revenue, hydroelectric plants, sustainable development.

1 Introduction

The diversification and the environmental sustainability of the energy production represent a fundamental aspect for the social and economic development of modern society. The need to reduce the strong dependence by oil and coal represents a new and hard challenge for the future: the economical costs to buy raw materials and the environmental costs that follow the energetic provisioning by traditional techniques clash both with the sustainable development idea and need of lower manufacturing costs. For this reason the new European laws go to liberalization of the energy production market with economical incentives to new private producers. In this context the energy revenue could have an important

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role as done by existing systems at lower initial investment cost (Celentani and de Marinis [1]). The Italian laws allow energy production by private companies but the distribution must be made only by GRTN (*Gestore della Rete di Trasmissione Nazionale* – Government controlled company which has the monopoly of the electric energy transmission in Italy). Moreover the government gives further economic incentive to private producers for the initial eight years as shown in the following table [2–6]:

Table 1: Amount of economic incentives to private energy producers.

	Production range [kWh / year]	GRTN	Incentive	Total (0-8 years)	Total (> 8 years)
		€ / kWh	€ / kWh	€ / kWh	€ / kWh
1	0 – 500000	0.09565	0.09739	0.19304	0.09565
2	500000 – 1000000	0.08054	0.09739	0.17793	0.08054
3	> 1000000	0.07048	0.09739	0.16787	0.07048

1.1 The opportunity represented by irrigation systems

Irrigation systems are usually characterized by great discharge during limited periods of the year (irrigation periods) commonly shorter than inactivity periods: in Italian regions the irrigation periods go usually since May to September. Conversely, if high discharge is a common peculiarity for all irrigation systems, the geodetic heads can change from case to case. In fact this aspect depends on different reasons, like the distance between the source and farthest network sites, the geodetic head difference between these sites and, in general way, the orography of irrigated lands. Therefore only where geodetic head is sufficient the hydroelectric energy production becomes an interesting opportunity.

Under these assumptions it is possible to convert the normal network operation from an energy consuming system to a hydroelectric energy producing system, utilizing the main pipes to carry the water from the highest points of the network to the lowest ones. Sometimes this system modification implies an inverse working of the network without excessive costs as shown in the present paper in reference to a real-life case study.

2 Irrigation system description

The irrigation network presented here is part of a whole irrigation system managed by Consorzio di Bonifica Valle del Liri. It is located in Lazio region (southern Italy) and it comprises among the towns of Cassino, Piedimonte San Germano, Aquino, Castrocielo and Pontecorvo. The served area is about 100 km^2. The system includes 637 km of pipes and it is divided in two different parts. The first part is composed of two interconnected lots indicated with letter A and B in Figure 1, while the second part, unconnected with the former, is indicated with the letter C in Figure 1.

In Figure 2 is shown the working scheme of the irrigation system using the same numeration as the hydraulic elements in Figure 1. The characteristic data of the reservoirs, tanks and natural sources and the characteristics of the main pipes of the network are reported in Table 2 and Table 3, respectively.

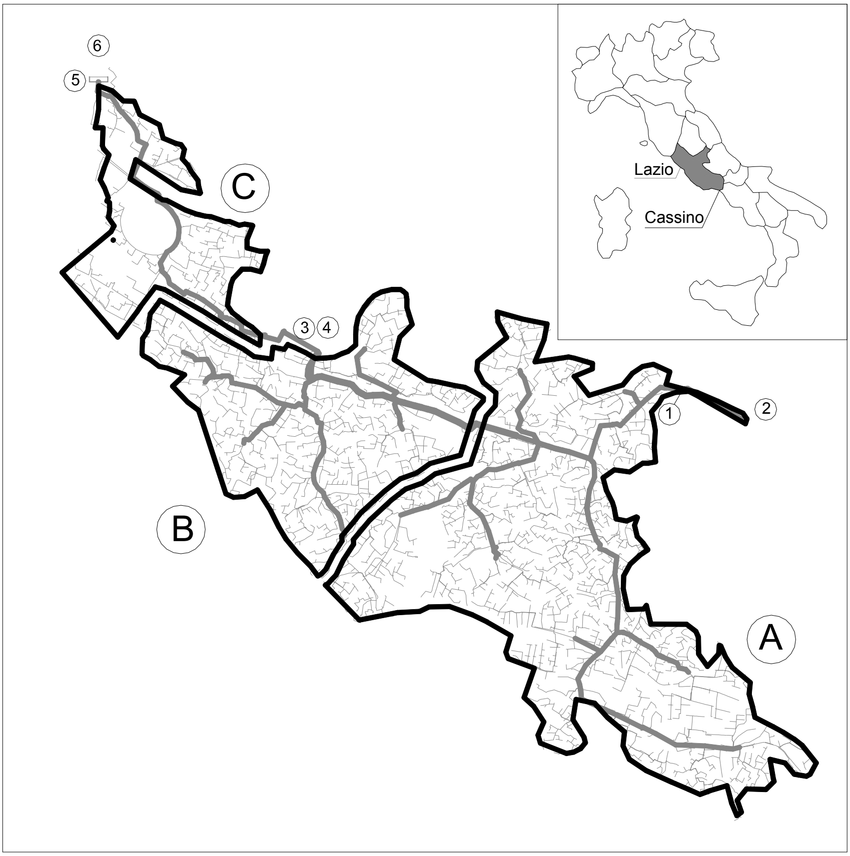

Figure 1: Map of the irrigation network.

Table 2: Characteristic data of the natural source, reservoirs and tanks.

number	type	volume	height
		m^3	m asl
1	river	-	31.00
2	reservoir	120000	102.00
3	reservoir	18000	90.00
4	tank	150	137.00
5	lake	-	115.33
6	tank	150	149.00

Table 3: Characteristic data of the main pipes of the network.

pipe	material	diameter	K_{ST} Strikler coefficient	length
		mm	$m^{\frac{1}{3}} \cdot s^{-1}$	m
5 – 14	concrete	1600	65	158
14 - 11	cast iron	1000	70	487
12 - 10	steel	700	80	8716
3 - 9	cast iron	900	70	4728
9 - 8	cast iron	1000	70	200
8 - 13	steel	1200	80	1079
13 - 7	steel	1400	80	1824
7 - 6	steel	1500	80	665

A discharge of 1100 l/s is taken from Gari river (1 in Figure 2) and is pumped from a head of 31.00 m to 102.00 m in the reservoir of Monte Trocchio. Hence it is distributed in the network: the 60% of discharge is supplied in lot A, while the residue feeds the reservoir of Piumarola (3 in Figure 2). Another pump station works from this reservoir to a tank 4 (Figure 2) and from here the discharge is supplied in lot B. The part C of the network was fed by Castrocielo lake (5 in Figure 2). From here a discharge of 480 l/s was pumped in the tank 6 and consequentially it is distributed in the network.

3 Feasibility study for hydroelectric system

Taking into consideration the main pipes of the same network system and adding some small structural and operational works, it is possible to convert the normal irrigation running into energy production plan at the end of the irrigation period. The new hydroelectric system can work 8 months per year, 24 hours per day.

The modifications that will be carried on the original system are shown in Figure 3. Two by pass from point 11 to 12 and from point 10 to back site of reservoir 3 are introduced. In this way it is possible to generate a unique water pipe penstock, 18 km long, from Castrocielo lake at 115.33 m on the sea level to Gari river at 31.00 m on the sea level. In this way, the available geodetic head (ΔH_G) is 84.33 m. It is necessary to evaluate the couple of values Q, ΔH_A that maximizes the produced energy, where Q is the discharge and ΔH_A the available head which is lesser than ΔH_G. We assume that the water pipe penstock is constituted by different pipes in diameter, roughness and material. If T is the number of pipes, the Q$[m^3 s^{-1}]$ can be obtained from the following relationship:

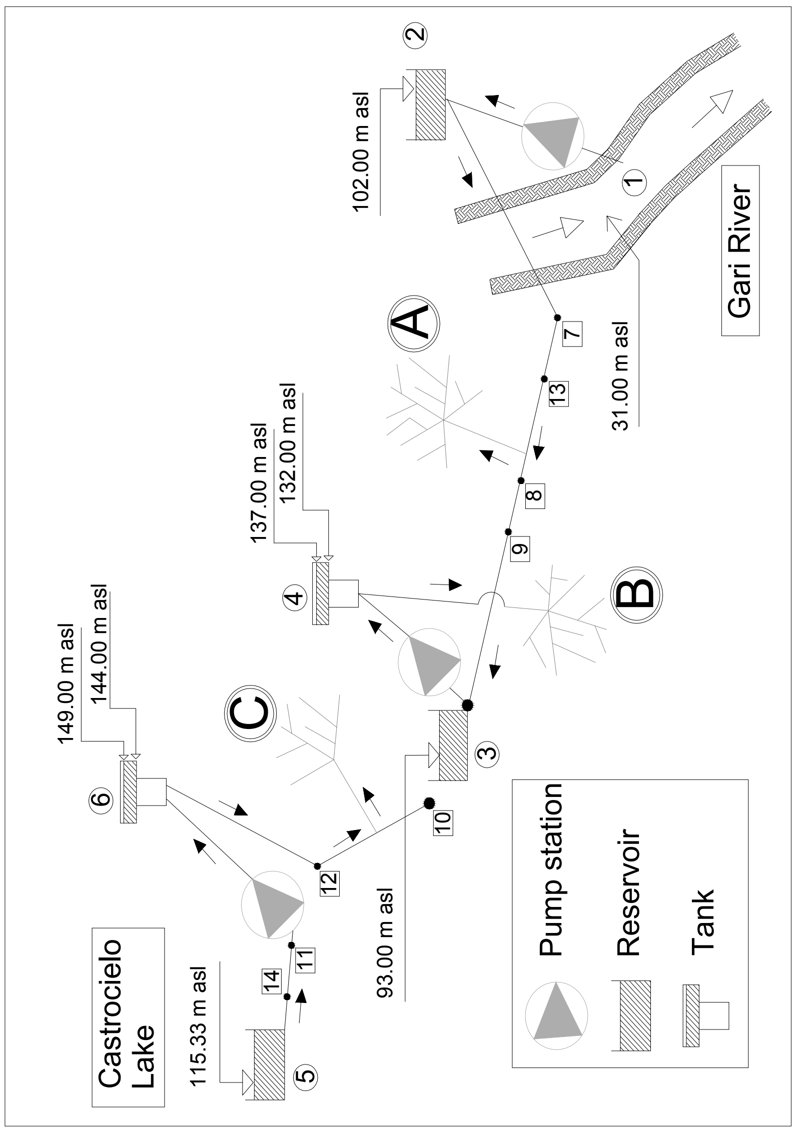

Figure 2: Working scheme of the irrigation system.

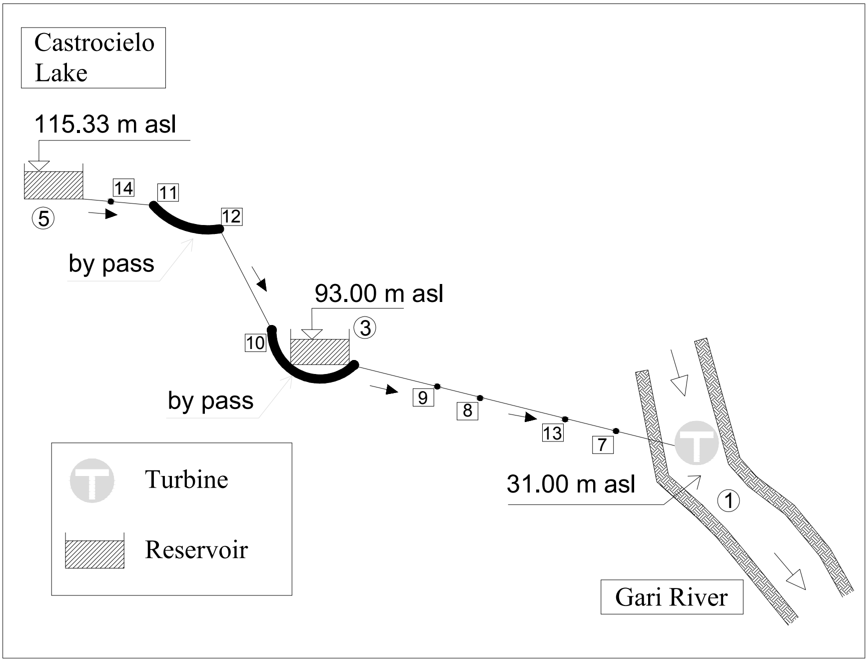

Figure 3: Working scheme of the hydroelectric installation.

$$\Delta H_{GA} = Q^n \cdot \sum_{i=1}^{T} \left(\beta_i \frac{L_i}{D_i^m} \right) \quad (1)$$

where ΔH_{GA} is the dissipated head, L_i the length of the i-th pipes, D_i the diameter and β_i the roughness coefficient. Moreover, it is possible to write:

$$\Delta H_{GA} = \alpha \cdot \Delta H_G \quad with \quad \alpha \in [0,1] \quad (2)$$

where ΔH_G is the available geodetic head.

Replacing eqn (2) in eqn (1) the searched Q is:

$$Q = \alpha^{\frac{1}{n}} \cdot \Omega_1 \quad (3)$$

where:

$$\Omega_1 = \left[\Delta H_{GA} \Big/ \sum_{i=1}^{T} \left(\frac{L_i}{D_i^m} \cdot \beta_i \right) \right]^{\frac{1}{n}} \quad (4)$$

The available head, ΔH_A [m], instead, according to eqn (2), can be formulated as:

$$\Delta H_A = (1-\alpha)\cdot \Delta H_G \quad with \quad \alpha \in [0,1] \tag{5}$$

In addition, the produced electric power [kW] can be expressed by the following relationship:

$$P = 9.81 \cdot Q \cdot \Delta H_A \cdot \eta \tag{6}$$

where η is the turbine efficiency.

Replacing eqn (5) and eqn (3) in eqn (6) a relationship between the produced electric power and the α coefficient is obtained:

$$P(\alpha) = \Omega_2 \cdot (1-\alpha)\cdot \alpha^{\frac{1}{n}} \tag{7}$$

where:

$$\Omega_2 = 9.81 \cdot \eta \cdot \Omega_1 \cdot \Delta H_G \tag{8}$$

Imposing the minimum condition for the function $P(\alpha)$, the best value of α coefficient is obtained:

$$\frac{dP}{d\alpha} = 0 \Rightarrow \alpha = \frac{1}{1+n} \tag{9}$$

Using the Gaukler-Strikler headloss relation, $n = 2$ and consequently $\alpha = 0.3333$. In the case study herein under consideration, using the K_{ST} coefficient value reported in Table 3, the following values of Q and ΔH_A are obtained:

$$\begin{cases} Q = 496 \dfrac{l}{s} \\ \Delta H_A = 56.20\, m \end{cases} \tag{10}$$

Considering the values (10) jointly with those one reported in Table 1 and assuming that is possible to withdraw the discharge 24 hours per day in 8 months per year (inactivity period for irrigation system), it is possible to realize the profit illustrated in Table 4.

The investment outlays for this scheme are about 400.000€ that can be amortized in the first two years.

4 Final considerations

In order to protect the environment and to guarantee socio-economical development, it is not possible to neglect the renewable energy production and in particular hydroelectric energy production. The present work showed the possibility to produce hydroelectric energy from existing irrigation plants adding some small structural rehabilitations and with an opportune management programme. Referring to the case study under consideration - the irrigation system managed by Consorzio di Bonifica Valle del Liri located in Southern Italy - it is analysed the possibility to produce about 1.340.000 [kWh / year] of energy, utilizing the available water resource unused during inactivity period. Moreover, incentives to private energy production, made by Italian and European laws, permit to amortize the investment outlay in the first two years. For this reason, since the planning phase, it seems suitable to anticipate the conversion of great irrigation, industrial and urban systems into energy producers. Furthermore, for many existing systems, it appears interesting to note that with small economic outlays it is possible to produce a high sustainable energy level.

Table 4: Produced energy and relative profit.

Range	Produced energy	Profit € / years	
	kWh	0 - 8 years	> 8 years
1	500000	96520	47825
2	500000	88965	40270
3	339811	57044	23950
Total	1339811	242529	112045

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