RENEWABLE ENERGY SOURCES: ADVANCED SOLUTIONS FOR FLOATING PHOTOVOLTAIC SYSTEMS

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ABSTRACT
In times of crisis, the need to achieve higher levels of competitiveness and reduce costs has driven many companies to use renewable energy sources and take advantage of the related incentives. In addition, the need to reduce delivery service costs and keep good quality standards is noticed by local authorities whose monetary transfers from the central government have been decreased. Moreover Land reclamation and drainage authorities are not exempt from the considerations made above; in fact, they are required to pursue their mission toward the land and the associated farms regardless of the monetary transfers received from the Government.

Within this framework, this research work is intended to find new opportunities and new ways to exploit the available resources better. This study has been carried out in collaboration with The University of Calabria, The Land reclamation and drainage authority of Cosenza and the Association Fattorie del Sole - Coldiretti Calabria.

In particular, it aims to prove that solar powers from innovative photovoltaic systems, wich are installed on the watersheds managed by the Italian Land Reclamation Consortia, can provide tangible benefits.

To this end it has been shown that the most important factors to be considered are: the production capacity for each investigated location, the systems structural design and the verification of economic and financial sustainability.

Keywords: Renewable energy, Photovoltaic systems

1. INTRODUCTION

Photovoltaic systems suitability for electric power production has been widely demonstrated (Ciriminna et al. 2011). As a matter of facts, in the last few years the installation of such systems has grown exponentially in Italy (from 2010 to 2011 the electric power increased from 3.470 MW to 11.340,4 MW, GSE).

This result has placed the Italian market first in Europe for installations number, electric power produced and turnover. The plant designs that have been used are both rooftop installations (which require an authorization process quite simple) and ground installations that require more costly and complex authorization processes (Camilleri, 2011). Lately, floating photovoltaic systems (including both traditional and Floating, Tracking, Cooling, Concentrators) have been proposed and are still under study; they allow using bodies of water for energy production. In Italy such systems can be dated back to 2008 (Solarolo RA) and since then many companies and research centres are seeking for more efficient and effective engineering solutions. Some of them have also developed patented in-house solutions. Certainly, mirrors of water exploitation results in higher costs and requires more complex structural solutions compared to conventional installations (on roofs or on ground) but allow achieving relevant advantages:

- There is no need to reduce the areas intended for agricultural crops;
- They allow obtaining considerable performances enhancements (in summer and in winter). In summer, the mitigating effect of the water allows the panels to work at lower temperatures whereas, in winter, the panels defrost more quickly therefore daily production can be increased.
- They allow using simpler and more effective solar tracking systems; as a result the average yield can be increased by 20%.
- They allow reducing the water evaporation: floats and panels have a covering effect that limits the direct exposure to sunlight and the catchment areas overheating.
- They allow reducing theft or damage risks owing to the lower accessibility.
- They allow an easier maintenance; water availability speeds up surfaces cleaning therefore the efficiency of panels can be kept high.
- They allow obtaining greater incentive rates thanks to their innovative nature.

2.

3. THE ENERGETIC ISSUES OF THE LAND RECLAMATION AND DRAINAGE AUTHORITY OF COSENZA

The Land reclamation and drainage authority of Cosenza covers an area of 110,000 hectares, includes 46,000 associate companies, encompasses 32 unicipalities and its energetic expenditures can be attributed to 40 sites (i.e., administrative headquarters, representation offices, operational offices, support offices, lifting systems, water scooping).

The assessment of the energy consumptions reveals that the installed electrical power capacity is about 7 MW and costs for power supply are about 500,000 €/year. These data highlight the need for technical solutions, able to reduce the energy consumptions, and for real opportunities of in-house energy production. In order to address this problem organically and evaluate different options, a group of experts from the Mechanical Department of the University of Calabria and from the Land reclamation and drainage authority was set up. The working group, after evaluating different options, find out that solar energy is the most viable choice that could take advantage from the numerous reservoirs managed by the Consortium.

Therefore the identification and analyzes of the main features of the reservoirs located all over the consortium territory, was the first step of this research.

By doing so, approximately 30 catchments were detected and examined in order to identify the most interesting sites that were selected considering: catchments size, geographical location, possibility of an easy connection with electricity networks, topography of the area, etc. Table 1 reports the main reservoirs, their extent and the potential energy production of the photovoltaic systems that can be installed on.

Table 1: The catchments under study

Municipality	Catchment denomination	Area (mq)	Capability (kWp)
Corigliano Calabro	Bacino Mandria del Forno	5.570	200
Corigliano Calabro	Vasca 4	795	53
Trebisacce	Vasca Saraceno	35.000	2.300
Trebisacce	Vasca 9 – Rovitti	800	53
Rocca Imperiale	Vasca 5	4.290	330
Rocca Imperiale	Vasca 6	3.050	200
Cerchiara	Vasca del Caldanello	2.300	155
Amendolara	Vasca 6	700	47

Afterwards the energetic capability of the selected catchments was calculated (Cucumo et al, 1994). To this end, the best computational and simulation tools, currently available, were used and the features of a broad spectrum of photovoltaic panels (marketed in the main international markets) were considered. With regard to the computational approach, it is worth saying that the main underlying tools were PVGIS and SAM; the results obtained by applying these tools have been accurately analyzed and compared.

The former (PVGIS) is currently used in Europe and it allows having an estimate of the energy output from the photovoltaic system taking into account the geographical location, the type of system (power, exposure, etc.) and the potential losses (Suri et al., 2008). The latter (SAM - System Advisor Model) has been developed by the National Renewable Energy Laboratory (NREL) in collaboration with the Sandia National Laboratories and the U.S. Department of Energy within the SETP project framework (Gilman and Dobos, 2012). SAM is more flexible since it allows inserting and managing more data and therefore its results are more accurate and reliable.

Moreover to achieve the research goals above mentioned, 14 different types of photovoltaic panels (whose main features are reported in table 2) have been investigated and compared.

Table 2: Features of the analyzed photovoltaic panels

Panel type	Power	Efficiency	Typology	Weight	Area
Aleo S166 185	185 W	13,42%	Mono – Cri	17 Kg	1,378 mq
BP Solar BP 585	84 W	13,14%	Mono – Cri	7,7 Kg	0,634 mq
BP Solar BP 4175	174 W	13,88%	Mono – Cri	15,4 Kg	1,260 mq
Sanyo HIP-190 BE11	180 W	14,09%	Mono – Cri	15,5 Kg	1,277 mq
BP Solar SX 170B	170 W	13,52%	Poli – Cri	15 Kg	1,258 mq
Evergreen ES195	195 W	13,05%	Poli – Cri	18,2 Kg	1,494 mq
Kyocera Solar KC130 TM	130 W	14%	Poli – Cri	11,9 Kg	0,929 mq
Mitsubishi Pv UD190 MF5	190 W	13,78%	Poli – Cri	17 Kg	1,383 mq
SunPower SPR – 210	210 W	16,89%	Poli - Cri	15 Kg	1,244 mq
Suntech STP180s 24AC	180 W	14,09%	Mono - Cri	15,5 Kg	1,277 mq
Solyndra SL200-220	220 W	16%	-	31,8 Kg	2,485 mq
SunPower E20/333	333 W	20,40%	Mono – Cri	18,6 Kg	1,631 mq
Suntech STP 280-24 Vd	280 W	14,40%	Poli – Cri	27 Kg	1,940 mq
Sanyo HIT-H250E01	250 W	18%	Mono – Cri	16,5 Kg	1,386 mq

At this stage the technical features of the panels (dimensions, weight, efficiency, power) together with the size of the reservoirs under study have drawn the attention on the panel SunPower E20/333. Therefore the two previously mentioned software tools have been applied to assess the capability of this particular panel for each considered catchment. Results are reported in Table 3.

Analyzing the data reported on table 3 it is possible to notice that, for each reservoir, the results obtained by using SAM are greater than those obtained by using PVGIS, the mean difference is 13,9%.

These findings allow estimating the total potential energy: 4,235,400 kWh per year using PVGIS and 4,780,933 kWh per year by using SAM. These results have been the starting point for the subsequent economic evaluations.

4. TECHNICAL AND STRUCTURAL DESIGN.

The design of the floating structures, allowing The stability and the functionality of the solar panel, has been set up to obtain the following results:

- modularity of building and assembling;
- low weight;
- low cost;
- high structural stiffness;
- weather resistance;
- easy assembly and maintenance;
- easy to move, connect and wire;
- high durability (25 years min.);
- optimal exploitation of free surfaces;
- maximum energy performance through the reduction of shading.

The initial data covered: the weight of the panels, their size, the standard and accidental loads, the dynamic actions of the water, the disruptive actions of the wind, the flotation coefficients (DM14-01-2008), the durability of materials, the sunpath study (UNIEN10002-1:2004), the shape of the reservoirs.

In order to solve the complex structural problem, a 3D truss has been realized, by means of steel tubular elements connected to form several square base pyramids, joined using other tubular elements as shown in Figure 1(CNR 10011–1997).

Table 3: Estimate of annual electricity production for each reservoir (SunPower E20/333)

Site	PVGIS [kWh] year	SAM [kWh] year	Gap
Corigliano Bacino Mandria del forno	250.000	285.064	14,03%
Corigliano Vasca 4	66.100	75.109	13,63%
Trebisacce - Vasca Saraceno	2.940.000	3.292.988	12,01%
Trebisacce - Vasca Rovitti	67.800	75.361	11,15%
Rocca Imperiale - Vasca 5	408.000	470.037	15,21%
Rocca Imperiale - Vasca 6	247.000	288.340	16,74%
Cerchiara - Vasca del Caldanello	196.000	225.226	14,91%
Amendolara - Vasca 6	60.500	68.808	13,73%

In this way, the goals of modularity and easy workability have been reached; in fact different series of linear assembling could be set up in laboratory by opportunely yielding the linear elements, together with the surface treatments, while the final assembling could be easily reached using different types of patented structural joints, ensuring a very low corrosion level due to a very few in-situ operations.

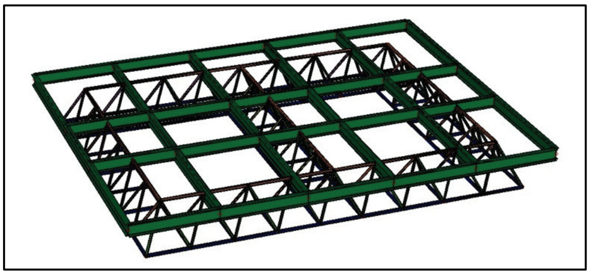

Figure 1 - Structural solid scheme.

Once made and designed the structure, it has been modeled by means of linear two-joints finite elements, connected in joints which allow the complete transmission of axial and shear stresses, together with a small percentage (20%) of flexural and torsion ones; in this way it has been taken into account that hinge node is a theoretical abstraction, and actually a transmission of moment stresses is active between the elements of a truss (Badalamenti et al., 2008). Then, defined both standard and accidental loads, has been taken into account also the anchorages to the basin bottom, and a dynamical analysis has been carried out by means of a SAP-type FEM software, which solves the dynamical equilibrium equation (1):

$$M \cdot \ddot{u} - C \cdot \dot{u} + K \cdot u = p \qquad (1)$$

In equation (1) $\boldsymbol{M}$ is the mass tensor, $\boldsymbol{C}$ is the damping tensor and $\boldsymbol{K}$ is the stiffness tensor, while $\boldsymbol{u}$ and $\boldsymbol{p}$ are the displacement and load vectors, respectively. The former equation has been solved in terms of eigenvalues and eigenvectors of the structure, corresponding to the natural resonance frequencies and the relative displacements, and 150 vibrating modes have been computed, to take into account the higher resonance frequencies also. The static and dynamic solutions have been combined following the instructions of the Italian building standards (N.T.C. 14-01-2008 and the related rule book), using the standards combination coefficients and considering the loss of elasticity as the limit state, in order to avoid corrosion, located to the yielding points above all. However, the achieved stress levels (see Figures 2, 3, 4, and 5) are low if compared with the maximum elastic stresses of the chosen material, and the material weight is the main load condition for these structures, which are specifically designed to be installed in fresh water basins, such as small lakes or artificial water basins for agricultural irrigation (Chakrabarty, 2010).

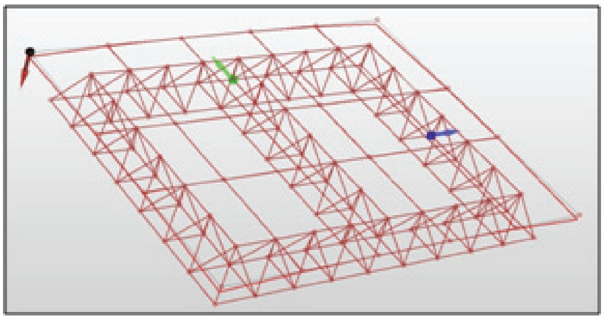

Figure 2 – Structural FEM model.

The reached solutions refer to two modular structures ensuring an installed nominal power of 3 kWp and 5 kWp each. It is evident that composing these basic modules it comes to saturate the available surfaces of the various basins, reaching the estimates of performances already shown in table 1.

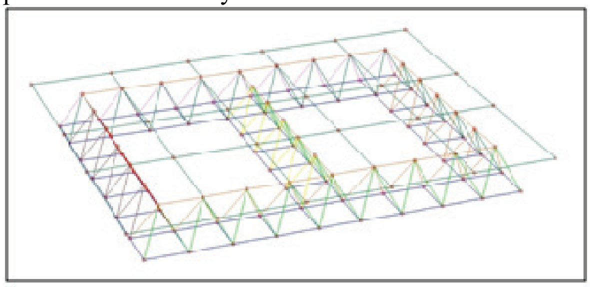

Figure 3 – Static displacements

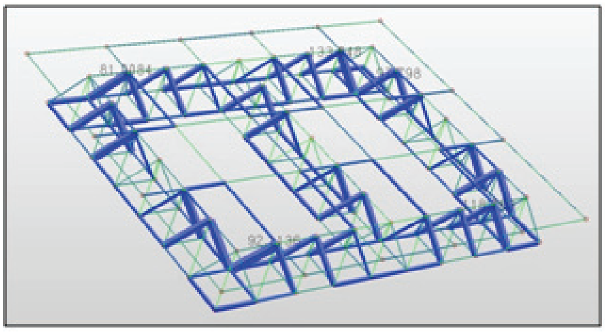

Figure 4 – Axial stresses [kg].

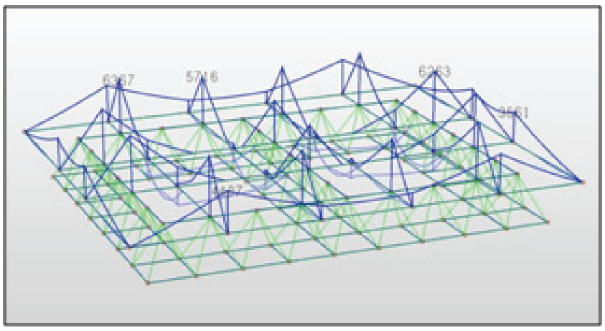

Fig. 5. - Flexural stresses [kg·cm].

The essential features of the modular structures are summarized in Table 4, while the figures 6, 7, 8, 9, and 3 show views in plant and section of the designed structures.

Table 4 – Main features of the designed structures

Module	3 kWp	5kWp
Dimension [m]	4 x 5	6,5 x 5
Main structure	3D truss	3D truss
Secondary structure	IPN 140	IPN 140
Material	S350 type Steel	S350 type Steel
Total weight	1250 kg	1850 kg
Bridging service	Orsogrill type panels	Orsogrill type panels
Surface treatment	Hot dip galvanizing (triple treatment)	Hot dip galvanizing (triple treatment)
Solar panels	10 panels	15 panels
Floaters	12 units	16 units
Cost	5.000 €	9.000 €

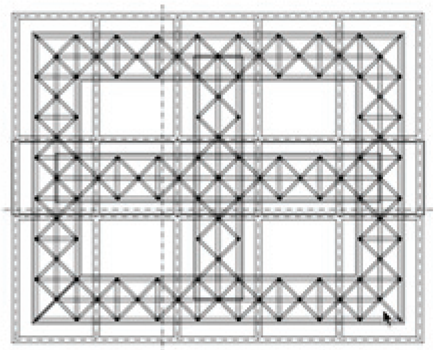

Figure 6 – Layout of the 3 kW module

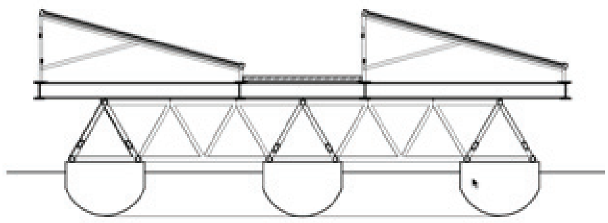

Figure 7 – Section of the 3 kW module
Figure 8 – 3 kW Module

5. ECONOMICAL EVALUATIONS

In order to verify the project efficiency and financial sustainability further research activities have been carried out and the economical outcomes have been estimated.

Revenues have been assessed considering both the incomes from energy sale and the incentives provided on the Italian territory through the Fifth Energy Bill approved in July 2012 (DM 5 July 2012).

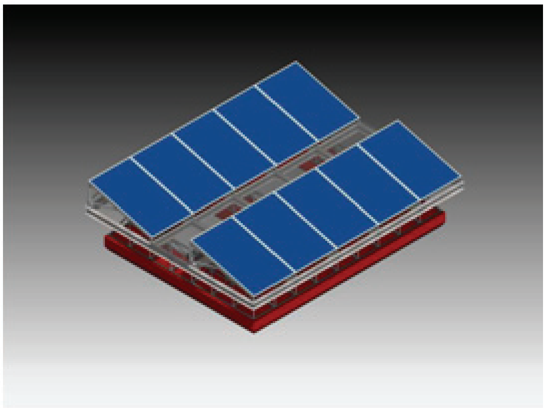

Figure 8 – 3 kW Module

The current rules in this field establish that incentives vary depending on the installed power. In particular, there are two forms of incentive. The former is directly provided by the Energy Services Operator (GSE) and aims to reward the use of renewable sources.

On the other hand, the latter rewards those subjects who use the self-produced energy without feeding it into the grid. However, it should be noted that the guaranteed minimum price, which is paid to the producer when the system is connected to the grid, is defined and periodically updated by the Authority for Electricity and Gas (AEEG). These prices are paid by the GSE only for the first 2 MWh of power fed into the grid in one year. Furthermore the incentive policies of the GSE for the floating photovoltaic systems are more rewarding than those applied for traditional systems. In this study the ministerial tables (for systems that have been installed since September 2012) have been referred to. In tables 5 and 6 the incentives have been reported (DM 2011).

Table 5 – Gse Incentives , From September 2012

Power Of The System	Minimum Guaranteed Incentive
[KWP]	[€/KWH]
1< P ≤ 20	0,288
20< P ≤ 200	0,276
P > 200	0,255

In order to estimate the energy produced in one year, the panels efficiency has been reduced by 0.9 % compared with the previous year. This calculation procedure estimates 18% reduction of the panels overall efficiency over the last operating year. The cost assessment allows identifying two different categories: set-up costs and operating costs. (Li Calzi et al., 1995) In addition, to make the economic findings more usable, a "parametric cost" has been introduced; to this end the single kWp of installed power was used as a reference. In this way, it is possible to find out aseptic monetary values that can be used to estimate the total costs changing the potentials of the system.

Table 6 – Incentive For Self-Consumption From September 2012

Power Of The System	Minimum Guaranteed Incentive
[KWP]	€/KWH
1< P ≤ 20	0,186
20< P ≤ 200	0,174
P > 200	0,153

The obtained parametric costs are reported in table 7 whereas table 8 provides the overall costs for installing such systems in the analyzed basins (Longo et al., 2006).

Table 7 – Parametric costs [€/kWp]

Description	[€/kW]
3kW Floating module	1850
5 kW Floating module	1750
Panels	1000
Wiring and hookings	240
Structure and connections	230
Special systems and lighting	260
Inverter and wiring	300
Increase for connection in MT	200

Table 8 – Estimated installation costs [€]

Site	[€]
Corigliano Calabro – Vasca 4	200.000
Corigliano Cal. – Bacino Mandria del Forno	756.000
Trebisacce – Vasca Saraceno	8.694.000
Trebisacce – Vasca Rovitti	200.000
Rocca Imperiale – Vasca 5	1.247.000
Rocca Imperiale – Vasca 6	756.000
Cerchiara di Cal. – Vasca del Caldanello	586.000
Amendolara – Vasca 6	177.000
Totale investimento	12.616.000

Besides set-up costs, operating costs including maintenance, insurance and general expenses have to be considered. These costs are estimated as a percentage, ranging from 0.075% to 0,095%, of the initial capital expenditure. Furthermore the calculation procedure being adopted in this work is based on the following assumptions:

- the total revenue includes the incentives related to the self-consumption and those granted by the GSE;

- the initial outlay is the total cost of the system and can be obtained multiplying the parametric costs by the installed power;
- the operating financial requirements are calculated as percentage of the overall set-up cost;
- cash flows are calculated as the difference between income and expenditure.

Moreover the economic assessments have taken into account the current economic scenario, therefore two main options have been considered. The former consists of supporting the investment with both equity and borrowed capital; the equity capital is 20% of the total set-up costs, and the borrowed capital stems from a fifteen-year mortgage with a 6% interest rate. The latter consists of financing the whole amount with equity. In addition, the first option is based on an amortization schedule where the depreciation charge is constant; thereby the debt can be wiped out before the service life is exhausted and the profits can cover the risk capital since the first years. These options have been assessed by using two well-known and well-established methods: the Net Present Value (NPV) and the Discounted Cash Flow Rate of Retourn (DCFRR) (Simeoni and Vigolo, 2006; Iotti and Bonazzi, 2012). Tables 10 and 11 report the results that have been obtained for the basin Vasca 4 located in Corigliano Calabro.

Table 10 – Discounted cash flows ***i*** = 7.82% (Equity Level = 20%)

Year	Revenues (€)	Costs €)	Fk €)	Fk dis.(€)	∑ Fk dis. €)
0	0	200.000	-200.000	-200.000	-200.000
1	33.799	15.435	18.364	17.029	-182.971
2	33.495	15.023	18.473	15.884	-167.087
3	33.194	14.585	18.608	14.837	-152.250
4	32.895	14.122	18.773	13.880	-138.369
5	32.599	13.631	18.968	13.005	-125.364
6	32.306	13.110	19.195	12.204	-113.161
7	32.015	12.558	19.457	11.470	-101.690
8	31.727	11.973	19.754	10.799	-90.891
9	31.441	11.353	20.088	10.183	-80.708
10	31.158	10.695	20.463	9.619	-71.089
11	30.878	9.999	20.879	9.101	-61.988
12	30.600	9.260	21.340	8.625	-53.363
13	30.324	8.477	21.847	8.189	-45.174
14	30.051	7.647	22.404	7.787	-37.388
15	29.781	6.767	23.014	7.417	-29.971
16	29.513	5.835	23.678	7.076	-22.894
17	29.247	5.835	23.412	6.488	-16.406
18	28.984	5.835	23.149	5.949	-10.457
19	28.723	5.835	22.888	5.454	-5.003
20	28.465	5.835	22.630	5.000	-3

Figure 4 illustrates how the cash flows recover the initial investment for both the options under study; the actualization index has been set equal to the minimum guaranteed return of the investment (7%).

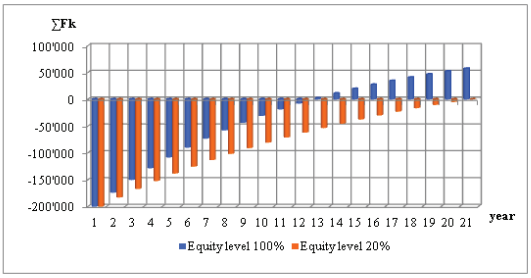

Fig. 4 – Discounted cash flows (***i*** = 7 %)

6. CONCLUSIONS

The research activities that have been carried out allow pointing out the technical feasibility of floating photovoltaic systems as well as the related benefits. The proposed solution is easy and inexpensive to put in practice, safe, easy to inspect and maintain.

Furthermore, some simple constructive measures allow load-bearing structures (platforms flotation) to be assembled with different kinds of commercial photovoltaic panels in order to fill the available spaces fully.

However, it should be noted that today in Italy there is a unified regulatory framework therefore the various local authorities grant authorizations for the exploitation of reservoirs based on autonomous rules and regulations. Furthermore in implementing implementation of such photovoltaic plants the availability of water resources for civil purposes (i.e. fire-fighting systems) has to be ensured.

Table 11 – Discounted cash flows ***i*** = 11.64% (Equity Level = 0%)

Year	Revenues (€)	Costs €)	Fk €)	Fk dis. €)	∑ Fk dis. €)
0	0	200.000	-200.000	-200.000	-200.000
1	33.799	5.835	27.964	25.047	-174.953
2	33.495	5.835	27.660	22.191	-152.762
3	33.194	5.835	27.359	19.659	-133.103
4	32.895	5.835	27.060	17.416	-115.687
5	32.599	5.835	26.764	15.429	-100.258
6	32.306	5.835	26.471	13.668	-86.590
7	32.015	5.835	26.180	12.108	-74.482
8	31.727	5.835	25.892	10.725	-63.757
9	31.441	5.835	25.606	9.501	-54.256
10	31.158	5.835	25.323	8.416	-45.840
11	30.878	5.835	25.043	7.454	-38.386
12	30.600	5.835	24.765	6.603	-31.783
13	30.324	5.835	24.489	5.848	-25.935
14	30.051	5.835	24.216	5.180	-20.756
15	29.781	5.835	23.946	4.588	-16.168
16	29.513	5.835	23.678	4.063	-12.105
17	29.247	5.835	23.412	3.598	-8.507
18	28.984	5.835	23.149	3.187	-5.320
19	28.723	5.835	22.888	2.822	-2.497
20	28.465	5.835	22.630	2.499	2

The Reclamation Consortia, may achieve significant advantages from these systems: they can reduce the cost of the services provided to its members (i.e. water supply for irrigation purposes) and acquire financial resources to maintain their own infrastructures or support new ones internally.

The economical evaluations have shown that profitability ratios range from 5% to 12% with estimated payback periods of about 10 years , either by obtaining external loans or by using equity capital.

Therefore the financial commitment required to implement such initiative is high extremely important and hardly feasible in the short period. A good solution could be to start the process focusing on small installations that require lower financial contributions and then consider larger systems taking advantage of the acquired experience.

In conclusion, it should be noted that if the outcomes are considered from an entrepreneurial perspective may appear not particularly rewarding. The point of view of public authorities, instead, may lead to better ratings because ethical and social are taken into account.

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