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The Small-Scale Hydropower Plants in Sites of Environmental Value: An Italian Case Study

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Abstract: Since ancient times water has been accompanying technological change in the energy sector. Used as a source of hydraulic energy, it currently generates one-fifth of the global electricity production. However, according to collective imagination, hydroelectric plants are constructions of high environmental, acoustic, and visual impact, which may harm the preservation of the territory. This paper intends to address the topic of mini-hydropower that, in addition to providing the production of renewable energy, ensures a limited environmental impact even in delicate contexts with high landscape values, by elaborating a research methodology that makes these interventions compatible with them. The process of "global compatibility" checks developed to assess the feasibility of the intervention will be explained in the paper. We intend to describe here the research process undertaken to make the planning of this type of system sustainable, in contexts that need to be rehabilitated in relation both to the accessibility of citizens and to the environmental enhancement. The intervention planned will be characterized by the combined use of other renewable energy sources, in addition to water. The proposed methodology has been tested on a case study in the village of Roccacasale, in the province of L'Aquila.

Keywords: hydroelectric energy; small-scale hydropower; compatibility; renewable energy

1. Introduction

Currently, there are many advantages in building plants to exploit water as a renewable resource. The most important ones are: zero CO_2 emissions, high energy efficiency, and competitive installation costs [1]. From this perspective, the research has deepened the exploitation of water with the general objectives of promoting small-medium-scale initiatives for the construction of mini-hydropower plants in sites of environmental value [2], while also watching with interest the combination with other renewable energy sources [3,4]. The importance of the hydraulic energy is, in fact, acknowledged at the international level. Paish states that where a hydropower resource exists, experience has shown that there is no more cost-effective, reliable, and environmentally-sound means of providing power than a hydropower system [5].

There are many studies confirming the economic advantages of installing hydropower plants, as will be highlighted in the following paragraphs, which aim to examine the ecological sustainability of such interventions on the environmental ecosystem, as well as to evaluate the impact on it [6–9]. However, there is not a unique way of determining the level of compatibility of these plants in sites of high environmental value.

This study, after examining the state of the art and its criticalities, aims to elaborate an operational tool, called the "environmental compatibility matrix", which takes into account the main aspects needed to develop a sustainable project in contexts of high environmental value. This definition refers to all those contexts as bearers of value that the national laws want to protect and safeguard through ad hoc laws. The use of this tool allows designers and public administrations to assess not only the economic advantages of the plants, but also the way to minimize the impact on the environment. This tool, validated with a case study, can be enhanced by reducing the subjective rating variable through confrontation with national and international contexts and with long-term practical use.

1.1. Hydropower and the Current Situation

Hydropower exploitation to obtain mechanical work has a long history: the first system used to exploit hydropower was the water mill, whose spread was facilitated by the introduction of floating mills [10]. Then, with the advent of the steam engine powered by fossil fuels, hydraulic energy was set aside because, compared to the previous one, it involved different problems, like the need to site the plants away from inhabited areas and the road system. This factor penalized some of the economic aspects of this type of energy production.

The advent of electricity and, therefore, the possibility of overcoming this problem by decoupling the site of energy production from that of energy utilization, has stimulated the development of new types of hydraulic turbines of great efficiency, such as Francis and Pelton turbine [11]: "So, the scale of hydropower plants began to grow and, in the late nineteenth and early twentieth century, hydropower became for many countries, including Italy, the engine of industrial development: in addition to large dams even small-sized plants were built, exploiting the existing waterfalls" [12].

Despite the significant contribution given to the start of the Italian industrialization in the nineteenth and twentieth centuries, this energy resource has gradually lost its importance in favor of other forms of usable energy production. However, today there is a renewed interest in this specific area, many small plants are re-opening, while new ones are being constructed. Several factors have helped to create again the economic conditions that favor their exploitation like, for example, the fact that the hydrographic system in Italy is very developed, the development of the automatic control and regulation systems, and the allocation of government incentives. In fact, in 2015 in Italy hydropower contributed to 16.5% of the total electricity produced in the peninsula [13].

Currently there are 1503 municipalities that have, on their territory, at least one hydropower plant, both large-scale and small-scale types, with a total capacity of 21,454 MW.

In 2015, 44,751 GWh of electricity were produced exploiting this technology, which corresponds to the energy needs of more than 16.5 million households [13].

1.2. Small-Scale Hydropower Plants and the Relevant Legislation

Small hydropower is a mature technology that is economically implementable and, if properly planned, has minimal impact on the environment.

According to Reichl and Hack: "It has significantly contributed to solving the problem of rural electrification through improving living standards and production conditions, promoting rural economic development, alleviating poverty, and reducing emissions" [14]. Overall, approximately 36% of the total global small hydropower (<10 MW) potential has been developed as of 2016 [15].

Probably, in Italy, the most favorable and convenient sites, from the technical and economic point of view, have already been used and the construction of new large-scale hydropower plants involves technical, environmental, and economic issues. Therefore, the future of hydropower aims at implementing small-scale hydropower plants. Currently, in fact, along with large and invasive projects realized during the twentieth century, there is the tendency to put back in operation many small hydro stations decommissioned in the past and to construct new ones (Figure 1).

The use of small hydroelectric plants can also ensure compliance with environmental compatibility in naturalistic contexts of value [16], of which Italy is rich.

In addition, the government, in light of Europe's directive to exploit renewable energies, has also established a new framework of benefits for self-generation of electricity [17].

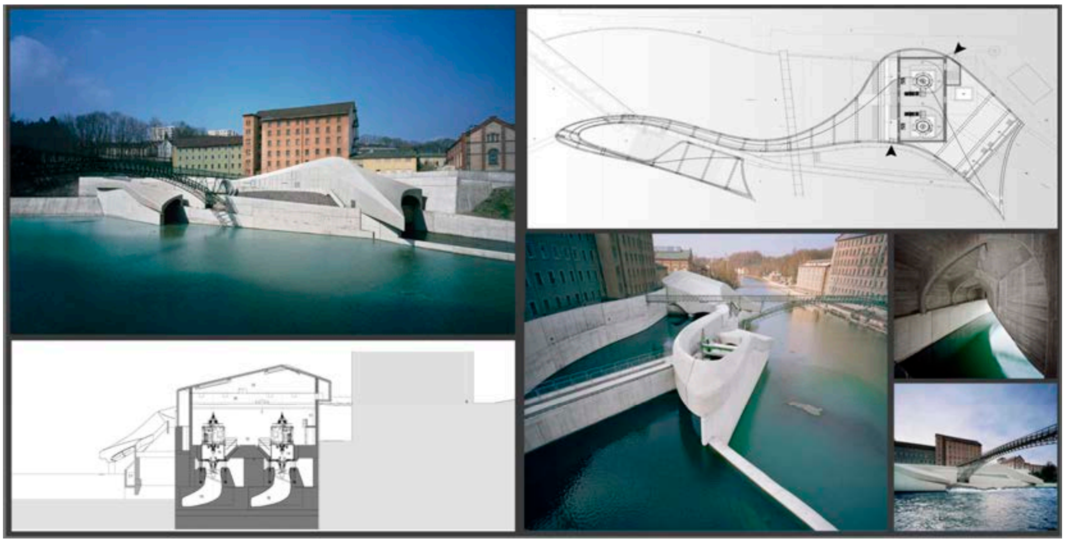


Figure 1. Example of a small hydropower plant of recent construction. The hydropower station in Kempten (2010).

Finally, the renewed interest is due to technical evolution, which has also allowed to considerably increase the performance levels of the small-scale hydropower plants, very useful in mountainous and internal areas, which cannot be easily served by the national electricity grid [18].

Small hydro is the term by which the UNIDO (United Nations Industrial Development Organization) identifies hydroelectric power of less than 10 MW. In addition, "the small-scale hydropower" category includes further classifications: small hydropower producing up to 10,000 kW electricity, mini hydropower, producing less than 1000 kW, micro hydropower ($P < 100$ kW), and pico hydropower ($P < 5$ kW). However, the classification of small hydropower is a useful convention to identify different modes of implementation and operation [19].

To date, 1503 Italian municipalities have at least one hydroelectric plant on their territory, and 1275 municipalities have a hydroelectric plant generating up to 3 MW [13].

The small hydropower plants have been installed mainly in the municipalities located along the Alps and the Central Apennines, but there are also plants in Apulia, Sicily, and Sardinia. Overall, the small-scale hydropower plants are able to satisfy the electric energy needs of approximately two million households, avoiding the emission of 3.2 million tons of CO_2 per year. For this technology, "there has been a significant growth in the installed capacity of the plants and in the number of municipalities involved" [13].

The National Guidelines (Ministerial Decree of 10 September 2010), in fact, introduced a series of simplified procedures for the construction of small-scale hydropower plants which have encouraged their development. The Annex to Article 12 of Legislative Decree no. 387 of 2003, basic rule of the Guidelines, indicates 100 kW of electric power as the maximum limit above which the hydroelectric plants must be authorized through a single procedure. On the contrary, below 100 kW of electricity, a simplified authorization procedure (PAS) can be used [20]. In fact, such systems are considered electrical workshops, therefore, they must be registered with the Technical Department of Tax and Finance, (U.T.F.) for taxation. They can self-consume the energy produced, in whole or in part, but also sell the surplus electricity, taking advantage of the planned incentives. For their implementation, a preliminary hydrological study is necessary to assess the watercourse flow rate, feasibility study, and cost-benefit analysis.

On the contrary, bureaucracy to run micro hydropower plants is much more efficient: Law no. 133/99 has determined the absence of taxation for hydropower plants producing less than 20 kW, used for internal consumption and not for sale; they must not be registered to the Technical Department of

Finance. The only requirement is that the project must be submitted to the Region, which has the faculty of requesting or not the environmental impact assessment procedures, according to Legislative Decrees n. 152 of 2006 and n. 4 of 2008 (The Italian legislation provides, in fact, the prior assessment of the environmental implications resulting from the construction and operation of any relevant work, through the Environmental Impact Assessment (EIA). In the case of small-scale hydropower plants, the authority for the plant's environmental integration aspects belong to the regions.).

In general, several documents are necessary to start a small-scale hydropower plant, including:

(1) the environmental impact assessment (if the system exceeds 100 kW), comprising the analysis of the consequences of the hydropower plant on animals, vegetation, water quality, noise impact, hydrogeological setting, etc. The assessment must also include the calculation of the minimum instream flow [21], a fundamental parameter for the planning of water resources and for the preservation of the hydrological and morphological balance of the basin;
(2) the authorization of the Region or the Province to use the water;
(3) the authorization to connect to the national grid;
(4) the building permit from the Municipality involved; and
(5) the authorization to use the land.

However, in Italy the rules to evaluate the projects are inefficient almost everywhere, both with regard to the protection of water and the biodiversity. For this reason there is the need to develop a technology that can protect drainage basins and water, excluding the areas that still maintain naturalistic features and reviewing the calculation of the minimum instream flow in order to use the most effective policies in a context of climate change.

1.3. The Basic Components of Hydropower Technology

All hydropower plants, including the "mini" and "micro" ones, may be classified according to the head (difference between head and tail water levels).

Beyond the specific differences between "mini" and "micro" hydropower plants, there are four basic system components that characterize small-scale hydropower plants: water turbine, generator, electric switchgear, and control system. The project may also include a heat sink for the households isolated from the national electricity grid, so that electricity that is not used is diverted to electric resistors that allow heating the water for sanitary and heating purposes.

Normally both the mini and micro hydropower plants have a low environmental impact, since they also allow to use of artificial or semi-artificial water systems, such as the water mains and irrigation canals. In any case, all the hydropower plants are required to respect the river minimum flow.

"Hydropower plants are often classified in three main categories according to operation and type of flow: run of river (ROR), reservoir based and pumped storage type projects are commonly used for different applications and situations" [22].

Thus, the general plant scheme of a hydropower station may include one or more intake gates, which can be followed by a settling basin for the sedimentation of sand carried by the stream; a diversion channel, which can be wholly or partly in a tunnel; a forebay reservoir; one or more penstocks that convey the water to the turbines; a powerhouse for power generation, containing one or more turbine-generator sets; and a downstream outlet channel.

The intake gates collect the water and convey it in the settling basin from which the channels and/or penstocks branch out and bring the water to the turbines. The shaft of the turbine runner is connected to an electric generator, called an alternator.

Usually, the selection of the best turbine for any particular hydropower site depends upon the site characteristics, the dominant ones being the head and flow available. However, other considerations, such as whether the turbine will be expected to produce power under reduced flow conditions, also play an important role in the selection [5].

The power obtainable from hydropower plants, considering an equal flow rate and head, depends on the overall efficiency of energy conversion of the hydropower plant, which is the product of at least four partial efficiencies: the hydraulic efficiency, the volumetric efficiency of the turbine, the mechanical efficiency of the turbine-generator, the electrical efficiency of the generator, and the efficiency of the transformer [19].

2. Materials and Methods

Considering the widespread use of the hydroelectric resources in the Italian context, the research intends to illustrate the methodology developed to exploit this resource, according to the principles of environmental respect and compatibility with the contexts of high environmental values. In Italy, particularly in the Abruzzo region, they are mapped in the regional "PAI" maps (Interim Basin Plan for the Hydrogeological Arrangement of the Main Basins of the Abruzzo Region and of the Interregional Basin of Sangro River—Gravitational Phenomena and Erosive Processes), on the "PRP" maps (Regional Parks Plan), on the "PSDA" maps (Interim Flood Protection and Contigency Plan), namely those maps that give information on the nature of the sites for conservation and protection purposes, both of the environment and of the fauna.

While complying with all relevant laws, the research has gone beyond the standards, as it has questioned how to implement small-sized plants with reduced environmental impact.

Indeed, the new technological and political-administrative opportunities allow producing energy off-grid [18]: the use of renewable energies, which, by their nature, are widespread and non-transportable, shows, in fact, the territorial coincidence between the availability of the source energy and its transformation and use. In fact, there are many hilly or mountainous regions of the world where the grid will probably never reach, but which have sufficient hydro resources to meet basic domestic and cottage industry needs of the local populations [5].

The basis of the research is, therefore, the intention of implementing a series of micro- interventions on different levels [23], in order to include more factors in the project so as to save money and maximize the exploitation of available resources. Thus, the goal of our work becomes to trigger a double process: on the one hand, the sharing of resources and, on the other hand, the rediscovery of the region's potential [24]. In this manner, the entire project may become compatible, and therefore feasible, even in historical contexts of value or inner regional areas, located far away from production centers.

The elaborated methodology has consisted of two main phases: a thorough knowledge phase, characterized by the implementation of analyses to study the context, and a meta-design phase, characterized by the implementation of a series of global compatibility checks that have led to the subsequent development of the feasibility study.

The first phase had the purpose of analyzing the area of interest and its features, in order to identify the best location for the planned hydropower plant in the involved context. The assessment study has been carried out both to estimate the electric power production of the hydropower plant, and the compliance to the existing constraints.

Once all the general variables are defined, another series of analyses have been implemented to verify if the planned plant was eligible according to the urban planning regulations.

Then, the research has identified the most appropriate solution, amongst the many possible ones, by examining a series of indicators: environmental, economic, technical, and aesthetic.

This process has allowed to develop a "global compatibility" level, evaluated with a score, which will be the synthesis of all preliminary analyses and evaluations carried out [25]. This compatibility is assessed through a series of indicators, of which the first is the preliminary one. In fact the indicator relating to environmental and regulatory compatibility has higher priority than the other ones: if it is not satisfied, the relating design solution cannot be implemented. We have verified, in fact, the presence of minimum instream flow, of minimum flow rate, of minimum head, and the absence of landscape constraints and environmental risks.

Among other indicators, there are those relating to:

(1) "technical compatibility": this refers to the implementation of the technological intervention, evaluating the capability of the designed plant not to interfere with the existing context but, on the contrary, to increase its performance. Such verification needs to assess the technical feasibility of the intervention, with a preference for the use of dry systems and compatible materials;

(2) "aesthetic compatibility": this expresses the respect for the original spatial layout, and the preservation of the perceptual aspect. In this case the knowledge of the context, its phases of transformation and valuable elements is fundamental. When possible, it would be necessary to relocate the interventions with respect to the historic center or areas of high landscape value and ensure their reversibility.

(3) "economic compatibility": it has been evaluated according to the presence or not of government incentives, the payback period of the investment and ease of management of the intervention over time. A positive valuation of the economic compatibility encourages the implementation of the design choice.

Thus, a matrix of compatibility, a synthesis of the proposed indicators (Figure 2) has been developed, that is, a tool for assessing all the environmental, technical, and economic aspects in relation to the best location of the plant from the point of view of regulatory compliance, power plant productivity, economic return on investment, and lower environmental impact [25].

	ESTIMATE	
PRIORITY COMPATIBILITY: **- environmental and regulatory compatibility**	Verify / No verify	
✓ minimum instream flow		
✓ minimum stream flow rates		
✓ minimum head		
✓ absence of landscape constraints		
RESULT	**VERIFY**	**NO VERIFY**
- **technical compatibility**	High (8 – 6); Medium (5 – 4); Low (3 – 0); None (-1 – -4)	/
✓ not to interfere with the existing context		
✓ technical feasibility		
✓ use of dry systems		
✓ use of compatible materials		
RESULT		
- **aesthetic compatibility**	High (6 – 5); Medium (4 – 2); Low (1 – 0); None (-1 – -3)	/
✓ respect of the original spatial layout		
✓ respect of built heritage		
✓ reversibility of the intervention		
RESULT		
- **economic compatibility**	High (6 – 5); Medium (4 – 2); Low (1 – 0); None (-1 – -3)	/
✓ presence of government incentives		
✓ payback period of the investment		
✓ ease of management		
RESULT		
GLOBAL COMPATIBILITY	**High (20 – 16); Medium (15 – 8); Low (6 – 0); None (-1 – -10)**	/

Figure 2. Compatibility matrix.

Each indicator is, therefore, characterized by a set of sub-parameters chosen following the analysis of the relevant legislation, current practice, and environmental assessment, which the designer must take into account in their assessment. This preliminary evaluation is obtained by assigning a numeric score to each of them, whose final sum will determine a high, medium, low, or null compatibility level.

In fact, the matrix elaborated is to be intended as a tool for the local administration to quickly assess the “feasibility" of the construction of this type of facility. Following the above-mentioned considerations, the matrix has been applied in a real case study in order to identify the various factors involved and to validate the proposed methodology.

3. Results

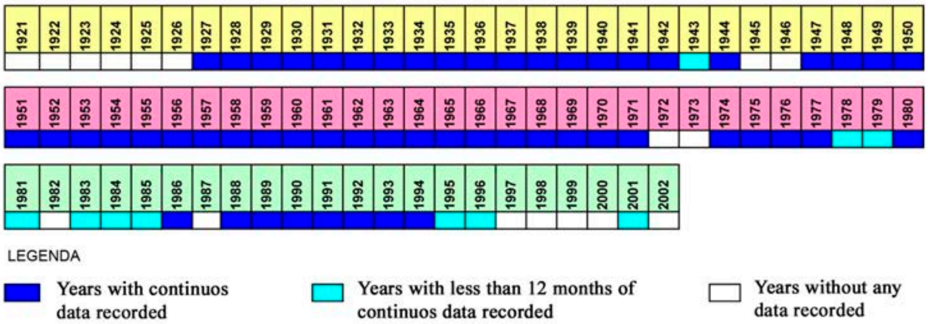
3.1. Case Study: Site Selection

Among the sites surveyed in the “Study to support the management of Water Resources for Hydropower Generation” of the Abruzzo Region [26], one has been chosen to test the proposed methodology that met the preliminary survey criteria: it is located in an isolated mountainous area and in a place of high landscape value. The site is made up of a stretch of the river Aterno, where the water course flows towards the city of Pescara (Figure 3). The subsequent choice of the most suitable section of the river to build a mini hydropower plant has been determined by the preliminary compatibility studies and the availability of historical data.

Figure 3. Map of the Abruzzo region.

In this section of the river adequate minimum flow and suitable head [27] have been detected. In fact, some river channels considered suitable have been analyzed and submitted to a comparison, showing that the tributary from Lake Scanno, the river Sagittarius, has a high flow rate and a duration of the average daily flow rates compatible for the installation of a mini hydropower plant. In fact, even the section in the area of Molina-Aterno showed compatible environmental conditions, but it was excluded because there is already a medium-large-sized hydropower plant.

In addition, there are two weirs in sequence on the course of the river Sagittarius in the area of Roccacasale (in the province of L'Aquila), with a geodetic head of 2.03 m. They allow, from the hydraulic and technological point of view, the possibility of exploiting the river course as a source to generate electricity. Another important aspect is that there are the historical records about the river flow rate as measured by the hydrometric station of Capocanale (in the province of L'Aquila) (Figure 4).



ID STATION	FLOW GAUGING STATION	BRANCH	PERIOD OF RECORD WITH CONTINUOS DATA (NUMBER OF YEARS)	Q_{mis}	Q_{nat_cal}	$R=Q_{mis}/Q_{nat\_cal}$
1069	SAGITTARIO RIVER AT CAPOCANALE	413->521	55	6.825	12.107	0.564

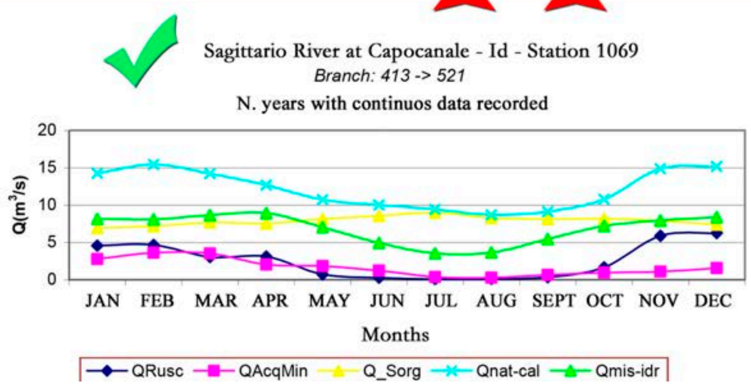


Figure 4. Hydrological balance tests at the gauging stations (Water Protection Plan of the Abruzzo Region)—Sagittario River at Capocanale.

The presence of the historical records, as defined by the Regional Law n. 19 of 16 July 2013 has also allowed avoiding the obligation of annual monitoring and helped to quantify the available data, by synthesizing them in the flow duration curve of the available and derivable flow rates. In this way we have obtained the "curve of utilization", which has been useful to establish the size of the hydropower plant.

In our case, the area of interest is inserted in an environmental context free of landscape constraints, but requiring special environmental attention (Figure 5). This finding has been reached thanks to the compatibility check carried out with the following plans: hydro-geological risk map, hydro-geological structure plan; map of protected areas; map of natural parks; interim flood protection plan; map of degraded areas; and the regional landscape plan. Only in this latter document the area is defined as "A2", namely "a zone of partial preservation", but the technical standards of the above-mentioned plan in Art. n. 67 state that the construction of a small-sized hydropower plant in this area can be considered as a compatible land use.

Figure 5. Pictures of the Sagittario River at Roccacasale. On the left, a crossing before the weir; in the center, a view of the weir and the existing bike path; and on the right, an overall image.

3.2. The Design Phase

The synthesis of the research and analyses carried out as described above has allowed the choice of the most suitable river section to validate the methodology that has helped to decide where to locate the mini hydropower plant and the methods to exploit other renewable sources, like solar energy.

The area involved in the project is located in a marginal zone of Roccacasale (in the province of L'Aquila), a small mountain town in the Peligna Valley, located in the center of the Abruzzo Apennines and perched on the slopes of Monte della Rocca. The village, constructed on rock, extends towards the underlying valley, enjoying a sunny location.

The project area is very close to the commercial and residential areas mapped in the General Urban Development Plan and is adjacent to State Road S.S. 17 and Regional Road Dir. 5. It is a green zone surrounded by agricultural fields and wooded areas, apart from the populated area.

Then, the data of average daily flow rates have been extrapolated from historical records, allowing an estimate of the hydrological component of minimum flow, which was equal to 1.39 m^3/s. Taking into account this latter value, the available flow values, and the derivable ones, it has been possible to establish the "size" of the hydropower plant in terms of potential power generation. For our project the choice has fallen on a run-of-river system: water is picked up, sent to hydraulic units and returned immediately downstream of the intake structure.

Being a run-of-river hydropower plant, the head is variable, depending on the flow passing through it. According to the estimations made, the head will be 2.03 m during the average flow and the plant will operate with a power output of 70.15 kW, an annual average flow rate of 4.232 m^3/s, with an expected average annual power output of 0.339 GWh (Table 1).

Table 1. Parameters of the plant.

River	SAGITTARIO
Annual Mean Flow Rate	**4.232 m^3/s**
Maximum Flow Rate	**5.5 m^3/s**
Minimum Flow Rate	**1.1 m^3/s**
Head	**2.03 m**
Minimum Instream Flow	**1.39 m^3/s**
Rated Power	**70.15 kW**
Annual Average Electricity Expected to be Generated	**0.339 GWh**

The reference to these values has allowed the determination of the most appropriate equipment to convert the mechanical energy of water into electrical energy. The choice has fallen on the hydrodynamic screw, also known as an "Archimedes' screw", because it is one of the few systems able to ensure high efficiency with low costs and high environmental friendliness.

Therefore the project has focused on the design and planning of a mini hydropower plant, characterized by the construction of a structure for flow diversion, the works for the installation of the augers, and a walkable green roof.

In addition, the project has included the overall rehabilitation of the neighboring area, through the implementation of complementary actions. The existing bike/pedestrian trail, in fact, has been diverted from the main track and a new service area has been included. This area will host two new wood-framed constructions, one serving as an information office and the other one as a bike-sharing station.

The charging points of the electric bikes have been placed under two photovoltaic shelters, complementary to the hydropower station in terms of power generation.

In fact, the systems for the active exploitation of solar radiation have been inserted in the project to allow the recharging of electric bikes even in summer, when the river is lean and there is a lower production of electricity from the hydropower plant. In this way the photovoltaic shelters operate at full capacity in the season where the power production of the hydropower plant is at a minimum.

To complete the project, further elements have been introduced to limit the environmental impact, like a rainwater harvesting system, inserted below the green covering, and permeable pavings both in the area of the hydropower plant and in the bike-sharing station.

4. Discussion

The verification of the methodology through the development of a case study has led to an analysis of the compatibility levels of the hypothesized facility, synthesized in the above-mentioned matrix. More specifically, after the verification of the environmental and regulatory compatibility, preparatory to the formulation of the project proposal, the study has moved to verify further levels of compatibility.

As for the aesthetic aspect, particular attention has been paid to the hydropower station, designed as to create the least possible visual impact. In fact, the visitor arriving in the area involved in the project will see only the three volumes with a wooden frame structure, totally removable, that host the rooms for the measurements and management of the hydropower station. Not far away, there are two small buildings containing the information office and bike-sharing station (Figure 6).

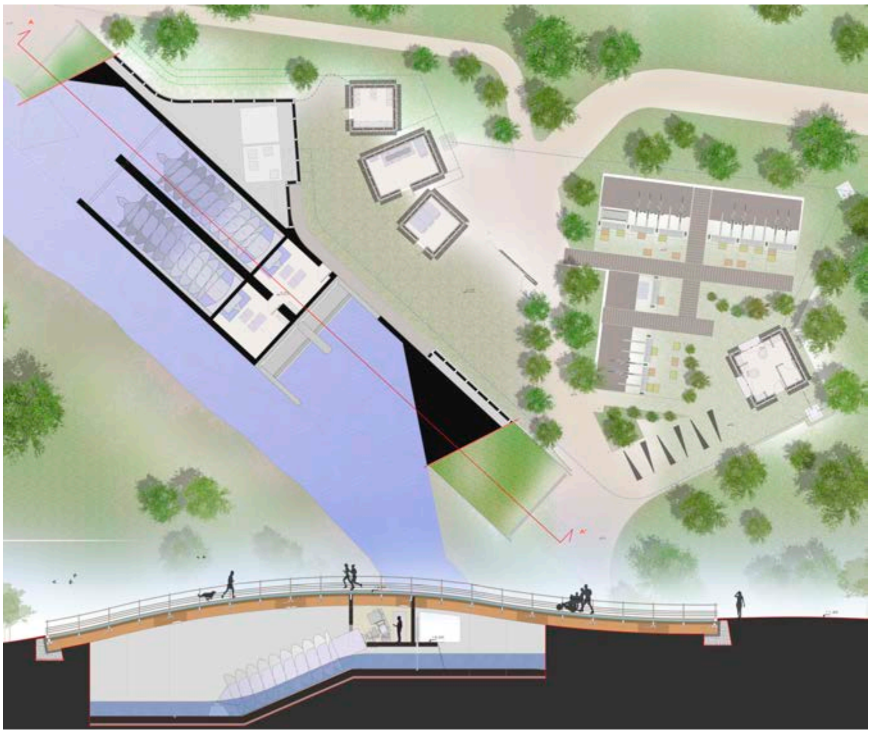


Figure 6. Design view—Ground floor plan and section AA′. On the left, the mini-hydropower plant, in the center the rooms dedicated to the measurements and technical maintenance; on the right, the bike-sharing station and information office.

In order to minimize the visual impact of the plant, a walkable green-roof top has been installed on the hydropower plant, serving as a "green platform" capable of accommodating cyclists, allowing them to enjoy the view of the river from another point of view (Figures 7 and 8). This is made of laminated wood, associated to the concrete substructure, and is composed of three pairs of main beams. These are linked to secondary modular beams, strengthened by steel cords; the cantilevers are supported by struts anchored to the concrete walls. The upper surface finishing package is composed of two layers of multilayered boards between which the insulation has been inserted, the anti-root waterproofing membrane, the rainwater collection tanks, the geotextile and, finally, the extensive green-roof top.

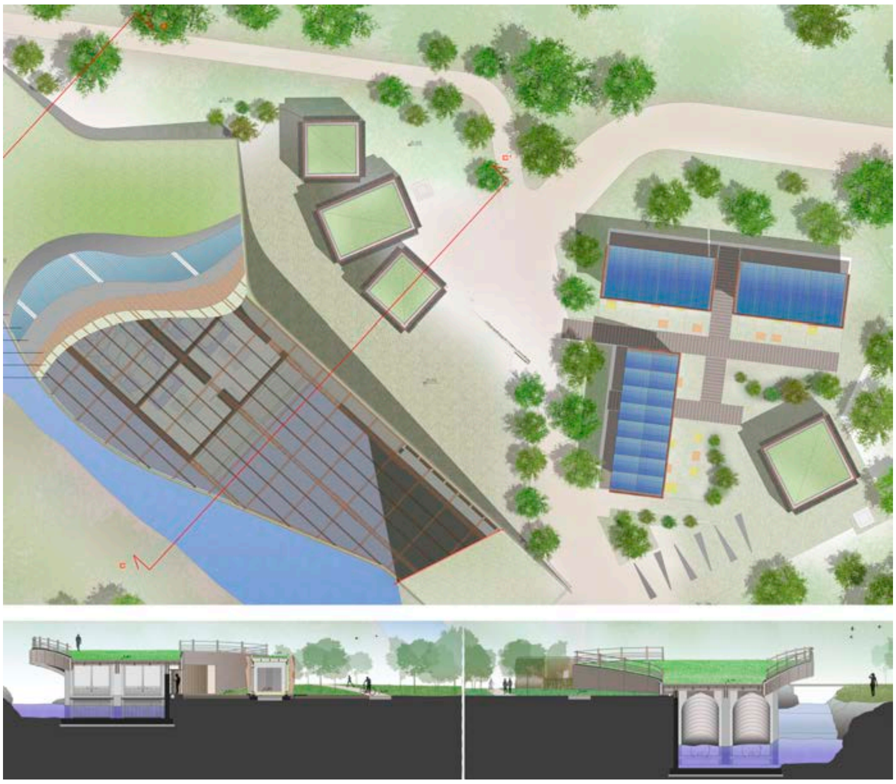


Figure 7. Installation projections on horizontal and vertical section planes.

Figure 8. Rendering picture. The mini-hydropower plant and the information office.

As for the technical compatibility, the project proposes the use of dry technologies for the construction of all new building additions, because they are reversible solutions. Furthermore, except for the elements that make up the hydropower plant, eco-friendly materials have been used, such as wood. Energy-efficient structures have been built, such as the green-roof top of the plant and the photovoltaic shelters of the bike-sharing station. In particular, the platform-frame system has been used to build the new additions, characterized by reduced size on the floor plan (4 × 4 m and 4 × 6 m). This system has a multi-layer composition that ensures a good level of thermal comfort and the sheet-shaped coating ensures a good aesthetic result.

From an economic point of view [28], considering also the operating costs of the hydropower plant, the payback period is good. The research suggests that small-scale renewable energy systems are cost-effective for both private entities and governments [29]. In fact, in general "With respect to the nature of small hydropower plants (lower than 5 MW), the costs are evaluated to be approximately US$500 per kW (including turbines, generators, governors, gates, control systems, power substation, electrical and mechanical auxiliary equipment, etc.) of power installation" [30].

In Italy, however, the costs are much higher, as demonstrated by a study conducted by the Polytechnic University of Milan, which carried out a study on the costs of production of electricity from renewable sources, interviewing both independent electricity producers and electricity producer associations [31]. According to this study, this is due to the prevalence in Italy of plants with a low head that, for this reason, need to use very advanced machinery, as well as to the very long bureaucratic process required for the issue of water concessions. For a plant with installed power up to 100 kW the production costs extrapolated from the above-mentioned research are as follows (reference year 2012):

(1) Investment costs: 10,000 €/kW;
(2) Personnel costs 100 €/kW;
(3) Maintenance costs 285 €/kW;
(4) Insurance costs 40 €/kW;
(5) Fees 90 €/kW; and
(6) IMU costs (municipal service fee) 60 €/kW.

Applying these costs to the plant planned in our project, whose expected average annual electricity production is 0.339 GWh and whose installed power is 70.15 kW, the total amount of investment is approximately equal to €740,250.

The European Community has been granting incentives to encourage the production, supply and grid-integration of electricity from RES since several years now. However, recently a number of EU members has substantially shrunk their support for renewables. Regarding Italy, there is a state-owned company, Gestore Servizi Energetici (GSE), which promotes sustainable development by granting incentives for electricity generation from renewables. The energy produced can be sold at an all-inclusive rate that is currently 210 €/MWh for a period of 20 years (Ministerial Decree of 23 June 2016).

Therefore, in the case of hydropower output of 70 kW, the earnings amount to €71,190 for every year. Thus, the payback period for the owner's equity is little more than 10 years. In detail:

(1) incentive year 2016 (for a period of 20 years): 210 €/MWh;
(2) annual earnings: 71,190 €/year; and
(3) payback period: little more than 10 years.

In addition to this advantage, there are two other factors that favor the investment on this type of systems. The first one relates to their estimated long service life of more than 50 years [5]. The second one is their high utilization factor, that is, a high number of equivalent annual full-load hours of operation of the plant.

Finally, we have proposed an energy audit of the urban lighting of the town of Roccacasale, thanks to the large amount of energy generated by the hydropower plant, which allows to benefit from an economic contribution of GSE, through the Net Energy Metering Program, and profitable payback periods.

Following the synthesis of all the choices made from the environmental and regulatory, technical, aesthetic, and economic points of view, the planned hydroelectric plant has obtained a global compatibility score of 25, or "high", according to the matrix values described in Figure 9. If there was a need for different choices (administrative, planning, investment, etc.) for reduced technical availability, technical difficulties, different environmental contexts, etc., it is obvious that the level of global compatibility would have been different. In this manner, considering different design scenarios that correspond to different global compatibility assessments, the town and regional planning administrations have an immediate and valid tool to guide the choice towards the implementation of a type of a plant rather than another type.

PRIORITY COMPATIBILITY	ESTIMATE
- Environmental and regulatory compatibility (verify / no verify)	
✓ Minimum instream flow	Verify
✓ Minimum stream flow rates	Verify
✓ Minimum head	Verify
✓ Absence of landscape constraints	Verify
✓ Absence of environmental risks	Verify
RESULT	**VERIFY**
	⇩
- Technical compatibility (values from 2 to -1)	High (8 – 6); Medium (5 – 4); Low (3 – 0); None (-1 – -4)
✓ not to interfere with the existing context	1
✓ technical feasibility	2
✓ use of dry systems	2
✓ use of compatible materials	2
RESULT	**7**
- Aesthetic compatibility (values from 2 to -1)	High (6 – 5); Medium (4 – 2); Low (1 – 0); None (-1 – -3)
✓ respect of the original spatial layout	2
✓ respect of built heritage	2
✓ reversibility of the intervention	0
RESULT	**4**
- Economic compatibility (values from 2 to -1)	High (6 – 5); Medium (4 – 2); Low (1 – 0); None (-1 – -3)
✓ presence of government incentives	2
✓ payback period of the investment	2
✓ ease of management	1
RESULT	**5**
GLOBAL COMPATIBILITY High (20 – 16); Medium (15 – 8); Low (7 – 0); None (-1 – -10)	**16 (= High)**

Figure 9. The compatibility matrix of the case study.

5. Conclusions

The small-scale hydropower plants are an important source of electrical energy to date in Italy, and also in many other European countries [32,33].

The methodology illustrated strives to ensure, in a country like Italy, rich in environmental sites of value, the compatibility of the intervention aiming at introducing forms of exploitation of renewable energies, such as water, in the inner areas, characterized also by environmental, historical, and cultural values. Thus, in light of these observations, the designer will have a global compatibility tool to identify the various discriminating factors to take into consideration in their project. The evaluation approach chosen is partially linked to subjectivity, even though there is the belief that it is the only one possible when the design intervention concerns contexts of high value, characterized by several territorial peculiarities. However, this limit can be overcome through long-term practical use and through confrontation with national and international cases.

The process, which concerns various aspects, must therefore be based on a multidisciplinary approach, involving several professionals with their different skills, so as to ensure a broad and specialized knowledge.

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References

1. Aggidis, G.A.; Luchinskaya, E.; Rothschild, R.; Howard, D.C. The costs of small-scale hydro power production: Impact on the development of existing potential. *Renew. Energy* **2010**, *35*, 2632–2638. [CrossRef]
2. Pinho, P.; Maia, R.; Monterroso, A. The quality of Portuguese Environmental Impact Studies: The case of small hydropower projects. *Environ. Impact Assess. Rev.* **2007**, *27*, 189–205. [CrossRef]
3. Francois, B.; Borga, M.; Creutin, J.D.; Hingray, B.; Raynaud, D.; Sauterleute, J.F. Complementarity between solar and hydro power: Sensitivity study to climate characteristics in Northern-Italy. *Renew. Energy* **2016**, *86*, 543–553. [CrossRef]
4. Rosa, C.O.C.S.; Costa, K.A.; Christo, E.S.C.; Meza, L.A.; Bertahone, P.B. Complementarity of Hydro, Photovoltaic, and Wind Power in Rio de Janeiro State. *Sustainability* **2017**, *9*, 1130.
5. Paish, O. Small hydro power: Technology and current status. *Renew. Sustain. Energy Rev.* **2002**, *6*, 537–556. [CrossRef]
6. Gorla, L.; Perona, P. On quantifying ecologically sustainable flow releases in a diverted river reach. *J. Hydrol.* **2013**, *489*, 98–107. [CrossRef]
7. Dee, N.; Baker, J.; Drobny, N.; Duke, K.; Whitman, I.; Fahringer, D. An environmental evaluation system for water resource planning. *Water Resour. Res.* **1973**, *9*, 523–535. [CrossRef]
8. Botelho, A.; Ferreira, P.; Lima, F.; Costa Pinto, L.M.; Sousa, S. Assessment of the environmental impacts associated with hydropower. *Renew. Sustain. Energy Rev.* **2017**, *70*, 896–904. [CrossRef]
9. Schramm, M.P.; Bevelhimer, M.S.; DeRolph, C.R. A synthesis of environmental and recreational mitigation requirements at hydropower projects in the United States. *Environ. Sci. Policy* **2016**, *61*, 87–96. [CrossRef]
10. Forbes, R.J. Energia motrice. In *A History of Technology. Volume 2: The Mediterranean Civlizations and the Middle Ages-c.700 B.C. to A.D. 1500*; Singer, C.J., Ed.; Bollati Boringhieri: Torino, Italy, 1993.
11. Smil, V. *Storia Dell'energia*; Il Mulino Ed.: Bologna, Italy, 2000.
12. Butera, F.M. *Dalla Caverna Alla Casa Ecologica. Storia del Comfort e Dell'energia*; Ambiente Ed.: Milano, Italy, 2008.
13. AA. VV., Legambiente, Rapporto Comuni Rinnovabili 2016. Available online: http://www.comunirinnovabili.it (accessed on 16 October 2017).
14. Reichl, F.; Hack, J. Derivation of flow duration curves to estimate hydropower generation potential in data-scarce regions. *Water J.* **2017**, *9*, 572. [CrossRef]
15. Liu, H.; Masera, D.; Esser, L.E. *World Small Hydropower Development Report 2013 Executive Summary*; United Nations Industrial Development Organization: Vienna, Austria; International Center on Small Hydro Power: Hangzhou, China, 2013.
16. Abbasi, T.; Abbasi, S.A. Small hydro and the environmental implications of its extensive utilization. *Renew. Sustain. Energy Rev.* **2011**, *15*, 2134–2143. [CrossRef]

17. Carlone, G.; Minichino, S.; Serenelli, C. *Quaderni Della Ri-Vista. Ricerche per la Progettazione Del Paesaggio*; Firenze University Press Ed.: Firenze, Italy, 2012; pp. 4–5.
18. Tanwar, N. Clean development mechanism and off-grid small-scale hydropower projects: Evaluation of additionality. *Energy Policy* **2007**, *35*, 714–721. [CrossRef]
19. Brusa, A.; Guarnone, E.; Smedile, E. (Eds.) *Dossier Micro-Idroelettrico: Progetto RES e RUE Dissemination*; APER (Renewable Energy Producers Association): Milano, Italy, 2012.
20. Banzato, D.; Castellini, A.; Ragazzoni, A. Il micro-idroelettrico per la produzione di energia rinnovabile. *Territori* **2011**, *6*, 45–54.
21. Linee Guida per la Predisposizione del Bilancio Idrico di Bacino, Comprensive dei Criteri per il Censimento delle Utilizzazioni in atto e per la Definizione del Minimo Deflusso Vitale, di cui all'articolo 22, comma 4, del Decreto Legislativo 11.05.1999, n. 152. Decreto 28.07.2004; GU n. 268 del 15.11.2004. Available online: https://www.ambientediritto.it/legislazione/acqua/2004/dm%2028lug2004.htm (accessed on 29 November 2017).
22. Edenhofer, O.; Madruga Pichs, R.; Sokona, Y. (Eds.) *Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change*; Technical Support Unit Working Group III Potsdam Institute for Climate Impact Research (PIK). Available online: https://www.ipcc.ch/pdf/special-reports/srren/SRREN_FD_SPM_final.pdf (accessed on 16 October 2017).
23. Magliocco, A.; Cassinelli, G. Microgenerazione distribuita: Integrazione morfologica e tecnologica. *Il Progett. Sosten.* **2009**, *21*, 10–17.
24. Marchionni, C.; de Berardinis, P. Sustainable networks in the post seismic rehabilitation of the minor centres. In *Rehab 2014, Proceedings of the International Conference on Preservation, Maintenance and Rehabilitation of Historic Buildings and Structures, Tomar, Portugal, 19–21 March 2014*; Green Lines Institute: Barcelos, Portugal, 2014.
25. Marchionni, C. A sustainable methodology for the rehabilitation of minor historic centres. A Case Study in the Seismic Crater of Abruzzo Region. *Tema Technol. Eng. Mater. Archit.* **2015**, *1*, 1–65.
26. Disposizioni in Materia di Esercizio, Manutenzione e Ispezione degli Impianti Termici. Legge Regione Abruzzo n. 17, 2007; art. n. 8. Available online: http://www2.consiglio.regione.abruzzo.it/leggi_tv/abruzzo_lr/2007/lr07017.htm (accessed on 29 November 2017).
27. Cyr, J.F.; Landry, M.; Gagnon, Y. Methodology for the large-scale assessment of small hydroelectric potential: Application to the Province of New Brunswick (Canada). *Renew. Energy* **2011**, *36*, 2940–2950. [CrossRef]
28. Wichelns, D. Sharing the benefits of hydropower: Co-investing the economic rents. *Water Resour. Rural Dev.* **2014**, *4*, 29–39. [CrossRef]
29. McHenry, M.P. Small-scale (≤6 kWe) stand-alone and grid-connected photovoltaic, wind, hydroelectric, biodiesel, and wood gasification system's simulated technical, economic, and mitigation analyses for rural regions in Western Australia. *Renew. Energy* **2012**, *38*, 195–205. [CrossRef]
30. Aslan, Y.; Arslan, O.; Yasar, C. A sensitivity analysis for the design of small-scale hydropower plant: Kayabogazi case study. *Renew. Energy* **2008**, *33*, 791–801. [CrossRef]
31. Politecnico di Milano, Dipartimento di Energia, Costi di Produzione di Energia Elettrica da Fonti Rinnovabili 2013. Available online: https://www.autorita.energia.it/allegati/docs/13/RappPolitecnicoRinn.pdf (accessed on 16 November 2017).
32. Dursun, B.; Gokcol, C. The role of hydroelectric power and contribution of small hydropower plants for sustainable development in Turkey. *Renew. Energy* **2011**, *36*, 1227–1235. [CrossRef]
33. Idso, J. Small scale hydroelectric power plants in Norway. Some microeconomic and environmental considerations. *Sustainability* **2017**, *9*, 1117. [CrossRef]