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Technical features and Italian regulations for small hydropower plants: a case study in Southern Italy

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Abstract. The exploitation of small waterfalls to produce electricity is a topic of considerable interest today, not only for the benefit that it can draw the small community but also for the opportunity to further increase the electricity derived from renewable sources. Then, after a historical examination of hydropower in Italy, technologies, constructive features and guidance on best choice of sites with particular reference to small system will be shown, other than the main legal references and incentives. In conclusion, a study conducted in the late 80s, following an agreement between ENEL and seven Italian University, with the aim to examine in detail the feasibility and affordability of small hydropower in some Italian regions, will be described. In particular the results derived in this study for the Region Campania and Basilicata will be explored.

Key words

Small hydropower plants; technologies; Italian regulation; case study.

1. Story of hydropower in Italy

The use of potential water energy, available between two river cross sections, found back application, already in past centuries, to produce mechanical energy to activate machineries, as mills, rotating chains of small textile workshops, presses, forges and other industrial or seed-industrial applications. Memoirs of a past time, by now, rather far. Then, the water energy was initially exploited by man only to activate his machineries, after that wood had been the only source (that continuous however still, in many countries of the South Hemisphere of the Earth) to be used for the energy production for millennia.

The exploitation of water energy through hydraulic wheels spread in Europe between the XII and the XIII Century and the construction of turbines began in the middle of the nineteenth century. With the following coming of electricity, mechanical uses disappeared without electric energy passage, probably because of problems of irregularities in the outflows distribution in time. With the hydroelectric use, the scheme of a hydraulic plant is defined in a more and more clear way: the water-flow in a stream, passing from a section to another with a smaller elevation, dissipates, to win resistances, the potential energy corresponding to the difference of level. If it's possible to have small water losses when water passes from a cross section to another one, a geodetic jump is available and it's useful to activate a hydraulic machine, whose energy can be used for various purposes. The jump can be created realizing an artificial reservoir, intercepting the river by a dam (it means that the energy that the flow would have spent for resistances is entirely recovered), and/or delivering water through channels and conduits with minor losses. In the following figures (Fig. 1 and Fig.2) the classical scheme of a reservoir hydropower plant (reservoir, gallery, piezometric tower, penstock, power house, outflow) and of a run-of-river water one (weir, channel, forebay, penstock, power house and outflow for whirled water) are shown.

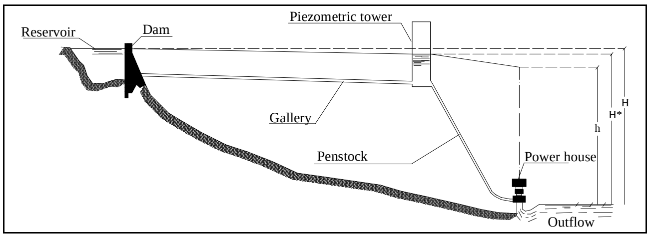

Figure 1. Reservoir hydropower plant

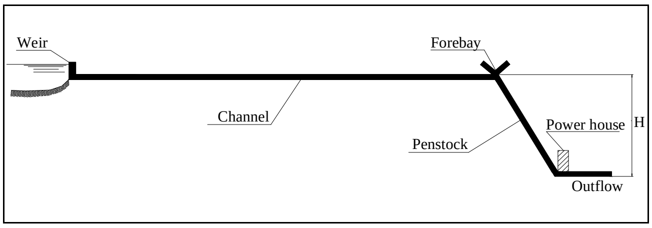

Figure 2. Run-of-river water hydropower plant

The development of hydropower plants in Italy has tightly been tied to that economic and industrial one. Italian society changing, begun at the end of the Nineteenth Century, had full development only in the first post-war period, while it was already under way for few decades in the most advanced countries that were oriented toward fossil fuels employment. Instead in Italy, because of coal was not available, water source was considered the most favourable: water flows were not too high but concentrated and at elevated levels. It was the so-called "white coal".

The first run-of-river water hydropower plant was built in Italy in the late Nineteenth Century: the Tusciano river plant, in 1890. The problem of water storage didn't exist yet because power requirement was also guaranteed in the rush hour. Between the two World Wars, reservoir hydropower plant were built, with integrated systems also among linked basins and with the connection of networks; in this period, the run-of-river water plants were designed with smaller duration flows and therefore with a great exploitation of the outflows.

In the '50, electric energy requirement was almost entirely satisfied by hydraulic resource, certainly the best of the renewable sources. The annual electric production was of around 50 GWh, of which 65% hydroelectric.

From 1960 to 1975, the majority of sites for great hydroelectric plants installations (both of generation and generation/pumping) were employed; the increasing requirement was covered by thermoelectric plants, by the first nuclear plants (in 1966, Italy was the third producer in the world of energy from nuclear source, after USA and the United Kingdom) and by purchasing from the foreign countries, for which the hydroelectric production began to the 30% of that total one (160 GWh). This was the passage from an "hydro" economy to a "mixed" one.

But the Arab-Israeli wars, the oscillating price of petroleum, the extreme dependence from the foreign countries and the ostracism to nuclear plants (nuclear energetic source was deserted in 1987, after the Chernobyl disaster), made the politics of the production change by the ENEL (Electric Energy National Company), reawakening the interest toward renewable sources; among these ones, the water source was favoured for its concreteness, for the consolidated and reliable technology and for the long life of hydropower plants.

In the last twenty years, in fact, the ENEL developed a considerable number of projects relative both to new plants, to renewals and improvement of plant into service (of nominal power not lower than 10 MW) and to the reactivation of disused ones, to allow a better use of water resource, with the aim of increasing hydroelectric production up to reach 60 TWh, within 2012, in comparison to the technically total exploitable annual potential, esteemed equal to 65 TW.

But such objectives has not been reached, at least partly. In fact, with reference to 2008 and 2009, in the following Table I the values related to the budget of the electric energy in Italy are shown.

Table I. – Budget of electric energy in Italy (GWh). Year 2008 and 2009* (data by Terna S.p.A.).

	2008	**2009**
A) Gross Production	319130	289164
B) Auxiliary services Consumption	12065	11034
C) Net Production (A-B)	307065	278130
D) Production for pumping stations	7618	5727
E) Received by foreign suppliers	43433	46570
F) Surrendered to foreign clients	3399	2121
G) Demand	339481	316852

**Data of 2009 are not final*

These data are given by Terna S.p.A.. It's the Italian company responsible of electricity transmission at high and very high voltage in the Nation.

The maximum power supplied in the 15 December 2009 was of 51164 MW (15,9% hydroelectric), 2% lower than the value 52187 MW recorded in the 10 of December 2008 (16,8% was hydroelectric).

The decrease in demand in the whole 2009 versus 2008 is of 6,7%. As regard December 2009, the demand was of 26573 GWh, with a decrease of 1,4% respect December 2008 (26945 GWh). In addition, in December 2009 the 87,3% of national demand was satisfied by Italian production and the 12,7% by international exchanges (-8,1% in comparison to December 2008). In deep detail, the net Italian production (23739 GWh) has a decrease of 0,5% respect December 2008; hydroelectric production is decreased of 14,4%.

The hydroelectric net contribution was of 47227 GWh in 2008 and 51743 GWh in 2009, and therefore it was equal to the 13,9% of the general demand in 2008 and 16,3% in 2009 (in 2009, the hydropower production has substantially increased over the previous year, registering an increase of +9,5% on 2008).

Concluding the story of the hydroelectric energy, Italy has been one of the pioneer Countries in the use of the water source that reached the maximum intensity from 1950 to 1965 (the years of the "economic miracle"), thanks also to the role of the scientific research developed by the Italian hydraulic university school that trained engineers and entrepreneurs with great successes in the whole World, up to Japan with the design and the construction of a big arc-gravity dam. Concerning this, it's opportune to remember that in 1947, in Padova, the first National Conference of Hydraulic and Hydraulic Constructions (in Perugia, last September, the 31° Conference was hold) on "Hydropower Plants" was hold.

2. Small plants: technical and economic features

A. Small plants

A high increase of energy can be obtained, without building new big hydropower plants, using the not yet exploited potential of the micro and mini hydraulic, with small values of head and flow, up to a nominal power of 3000 kW (destined primarily to private operators according to the Law 308/82 on energetic saving and the renewable resources). Many researches show the feasibility and the convenience of such small hydropower plants, considered interesting in Italy and abroad too. In fact, the community objectives on the energy production by renewable resources (it has environmental impacts smaller than conventional sources) in the electricity market today are clear. For instance, energy's production with the best of the renewable resources, the water, has an environmental impact 300 times lower than that provoked by the coal and by the petroleum. Insofar, the renewable sources must be in the centre of the energetic politics of each Government, so that to reduce the entity of the climate-changing discharges, eventually arranging with the Regions the percentages of them, with the purpose to respect the values of the parameters in the protocol of Kyoto. Recent studies confirm that small plants could increase the hydroelectric power up till 30.000 MW. Incentives are expected for such plants: for example, those ones with a power lower than 20 kW can exchange the produced electric energy on place; the "Green Certificates" are other kind of incentives that will be described subsequently.

Plants are generally, classified according to the nominal power [18]:

- Micro-plants, with a power lower than 100 kW
- Mini-plants, with a power from 100 to 1000 kW
- Small-plants, with a power from 1000 to 10000 kW
- Big-plants, with a power upper than 10000kW.

In Italy, the upper limit for small hydropower plants is fixed at 3 MW. In this paper, only micro, mini and small plants will be analyzed; in this field it's possible to reach great and concrete developments within the renewable sources.

Which are the opportunities in such field? Certainly opportunities are not negligible, as it will be written after. Besides, small hydroelectric plants were abandoned and disarmed during the nationalization of the electric energy; many of them could be reactivated today in Italy.

B. Metodologies to find sites

To evaluate better sites where install small plants, it is necessary to find suitable morphological, geological, hydrological and environmental conditions as the following:

- presence of not too wide river cross sections (max 30-40 m) to build weir with lower costs;
- high slopes of river channel to have higher heads;
- suitable water-flows;
- easy access to places;
- favorable geological and geotechnical characteristic;
- absence of constraints;
- absence of interferences among constructions to be realized and existing ones;
- identification of a suitable area for the construction of the powerhouse;
- distance from the nearest ENEL electric line;
- evaluation of the environmental impact;
- minimum instream flow.

As regards geological and geotechnical characteristic, the surveys should be very detailed to avoid damages to plant, as it sometimes happens (weir piping and channels downfall) .

Obviously, the greatest possibility of realizing small plants is in mountain areas, where these ones can be built on in spate or permanent stream, often serving small local communities.

The engineer's job to evaluate the economic meaning of the resource is rather difficult for two reasons:

- the cost of investigations and studies has to be modest;
- if river flows are small, the gap is greater between maximum and minimum value (flow is one of the most important variable that state the power of a plant).

Chosen the location of the plant, the available flows are esteemed, throughout the duration curve; it's obtained plotting recorded values of flow during the year on number of days in which this value has been reached or overcome. But such studies, other than very hard-working, have great uncertainties because of small dimensions of the catchment upper the weir. For this reason, an accurate investigation in site is very important. In Italy, a small water resource can be better used if a copious spring can be individualized in its, because of it has a more favourable duration curve. Ancient mills, in fact, were located down springs. But today, more easily that in the past, such water resources are been used, at least partly, as drinking waters. Nowadays springs can disappear because once they had origin from alluvial heaps from which currently water is extracted with the pumps.

Obviously, it's difficult to establish the upper limit for the power of a small plant. But for these plants (unlike big ones), it is well difficult to be able to count on.

It's rather possible, according to own requirements, to appraise the convenience to have in certain periods the supply of the ENEL's deficiencies to which, in periods of great flows, give the surplus. In such cases tariff conditions have to be considered.

C. Economic analisys

To evaluate the economic convenience of a plant, it is necessary to calculate investment costs, management ones and proceeds for the produced energy.

To contain management costs and to assure the maximum use of the available hydraulic resources, you need the following solutions:

- to build plants with automatic functioning without supervision;

- maximum electronic and oleo dynamic schemes and automatisms simplification, for pumping groups;

- accurate choice of components of elevated reliability, so that to reduce control and maintenance operations;

- use of electro-mechanic machines to contain costs.

However, many economic evaluation methods exist: static and dynamic. The first ones are independent from the opportunity cost of the capital; the second ones that consider the total costs and the benefits during the whole duration of the investment and the moment in which, the cash flows take place. Among these, there's the method of the VAN (Net Actual Value), often selected for projects and the relative cash flows evaluation. They are also available software for feasibility studies as "Flash", elaborated by the Spanish Department of the water and the electric energy.
In references at the end of the paper, it's possible to delve into all these topics.

D. Electromechanical equipment

Electromechanical equipments most commonly used for small plants can be classified as follows:

- Pelton micro-turbine: used for high heads (one hundred or so meters);

- Turgo micro-turbine: much used in Italy, similar to Pelton one and operating under a head in the range of 20-300 meters;

- Cross-flow turbine: it can operate with heads from few meters to 100 m and flows between 20 and 2000 l/s. Nowadays, Banki-Michell are more widespread and can operate with very variable flows respect to maximum one (until 1/6 of Q_{max});

- Francis micro-turbine: used for power lower than 100 kW and for medium-heads;

- Screwpump (Archimedes screw): recently patented as hydroelectric turbine. Used for heads until to 10 meters and flows between 500 and 5000 l/s and for flows with detritus.

E. Technical and technological simplification for small hydropower plants

The parts of a small hydropower plant, usually the run-of-river water one, tend to reduce dimensions and disappear sometimes, as the inflow channels. Plants, therefore, much smaller than the classical ones. To this purpose, in the Fig.3 are shown three situations in which, closing the stream course by a weir, on one side of the outlet section the powerhouse is built. In all three cases, the turbine shown is the propeller type; this kind of turbine reduces the overall dimensions much.
In detail, in the Fig.3 are shown three possible solutions that must be carefully examined:
a) horizontal axis turbine which drives directly the electric generator;
b) inclined axis turbine which drives, even it, directly the generator;
c) horizontal axis turbine that drives the vertical axis generator by a mechanical gear.

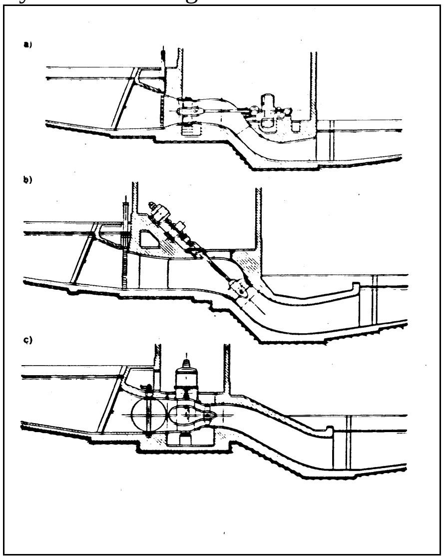

Figure 3. Possible turbine-generator coupling [19]

Are also available on the market [18]:

- inflatable weirs or dams that require limited civil and hydraulic works;

- plastic pipes for penstocks;

- Turbine-generator completely submerged;

- siphon turbines (for jump up to 10 meters): from the barrage, the water is collected and conducted to the turbine installed straddle the dam;

- automatic control units, which allow a nearly constant flow operation;

- modern and simple systems for monitoring and supervising to obtain information at a distance and send commands to the system.

Obviously, it will be the responsibility of engineers to study and design small plants, assessing the most reliable and convenient case.

3. Italian regulation

A. The Bersani Law Decree and incentives

In 1999 the Decree requiring the approval of Parliament on liberalizing the electricity market (The Bersani Law Decree) was approved, with the aim of fostering a competitive system. This Decree is an important turning point in the promotion of renewable sources and, specifically, in the establishment of the obligation for producers or renewable sources electricity importers to put into the grid a share of electricity from new plants or repowering ones powered by renewable sources.

Particular attention is given also to run-of-river water hydropower plants to grant less than 3MW. In Resolution 82/99, the Authority for Electricity and Gas provides a mechanism to pay scales of production, indexed by the National Institute of Statistic (ISTAT), intended to support this type of installations under the contribution they make to reducing emissions.

Particularly favorable and encouraging prices for production and sale of energy are in force for Hydropower plants up to 3 MW. The "Green Certificates" are further incentive instruments for renewable sources (which demonstrate that a new or renovated plant meets the requirements of producing electricity from renewable sources) and Renewable Energy Certificate System (RECS) certificates (voluntary system of certification at European level). As for "Green Certificates" (GC), producers and importers of electricity from conventional sources are required to enter a market share of electricity produced from renewable sources compared to total production, whether self-generated or acquired by others.

This implies a demand for energy from renewable energy that can be satisfied by a Green Certificate certifying the production of energy from renewable sources available to the System Operator (GRTN), or from private plants. The latter is given the priority of sale. The GC of the plant give rise to the selling price of the grid, which should offset the additional costs incurred to the manufacturer for this type of intervention.

Entrepreneurs, who after 1 April 1999 produce new energy from renewable sources in excess of 50 MWh per year, can obtain Green Certificates to sell on the Stock Market or directly to parties who have a purchase obligation. To obtain Green Certificates the plant should be pre-qualify as IAFR (Plants using renewable sources) at the GRTN.

B. Financing methods

The following activities may be funded, through the Law 488/99:

- feasibility studies;
- environmental impact studies;
- construction of new power plants;
- reworking of existing plants.

In particular, it provides repayable contributions to small and medium companies in the southern Italy (excluding Calabria Region), equivalent to 40-50%.

Resolution No. 34/05 sets out the terms and economic conditions for the withdrawal of the electricity mentioned in Article 13, paragraphs 3 and 4 of Decree requiring the approval of Parliament of December 29, 2003, No. 387, and paragraph 41 of the Law of 23 August 2004 No. 239.

C. Permits required

Below the main permits, to be performed for installations over 20 kW of power or that otherwise have a substantial impact on the river, are listed:

- permissiveness for the caption of water for hydroelectric purposes and related policy; the application is forwarded to the related Region through its Office of Civil Engineering, accompanied by the design of the plant;
- presentation of a copy of the design to the Department of National Heritage and Cultural Activities if the plant is installed in an area with environmental constraints;
- notice of Intent to the Ministry of Productive Activities;
- notice of intent to the local electrical distributor;
- notice of Intent to the Office of Financing (UTF);
- request to the State Forestry Department, if the plan interferes with its jurisdiction;
- application for Building permit issued by the municipality of jurisdiction.

D. Statement

The energy production by renewable energy (including hydropower one) is governed by the following rule:

- Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC (on the promotion of electricity produced by renewable energy sources in the internal energy market) and 2003/30/EC (on the promotion of the use of biofuels or other renewable fuels for transport).

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4. Availability of sites for small plants in southern Italy: a case study

During an extensive survey sponsored by the EEC, which aims to identify the possibility of use for energy of small hydraulic resources in mountainous areas of southern Italy and in some regions of Central Italy, in 1989 it was stipulated a agreement between ENEL and seven Italian Universities with the aim to examine in detail the feasibility and affordability of small hydropower in the following regions: Abruzzo, Molise, Campania, Basilicata, Calabria, Puglia, Sicilia, Sardegna, Lazio and Marche.

In particular, with regard to Campania Region, the survey was addressed in the mountain areas of the Volturno river, Sele river, Mingardo river, Bussento river and Picentino river; for Molise Region it was addressed in Biferno river, Ofanto river and Fortone river catchments. The total length of river courses was of 280 km; the aim of the survey was to identify suitable sites for installing plants with a nominal power lower than 3000kW and no less than 100 kW/km.

At the conclusion of the investigation, divided into three phases, sixteen plants were considered feasible; it's possible to draw from them a total power efficiency of about 10 MW and an average annual production of about 47 GWh.

With regard to hydraulic turbines, it was thought appropriate to provide, in each plant, two equal groups for splitting the flow, especially during operation. As a result of the considerable flow variation in during the year, compared with the maximum sizing flow, in order to achieve a high exploitation for the hydroelectric sources, the range of operation of each machine was extended up to one-third the maximum incoming flow. This is a reliable hypothesis because hydraulic turbines are manufactured by industry for limited powers, with performance even near to optimal value corresponding to the dimensioning flow of each group (1/2 Q_P). By this way, the producibility could be extended to flow values equal to 1/6 Q_P. Plotting points of coordinates (1/2 Q_P, H_u) in the schedules specified in the figures below, the most appropriate type of turbine were identified for each of the sixteen plants.

In Fig. 4 the locations of the sixteen small plants considered feasible and in subsequent tables (see Table II and Table III) the summary posters of the characteristics of the sixteen plants deemed convenient, the operating range of the turbines expected (Fig. 5 and 6) are shown.

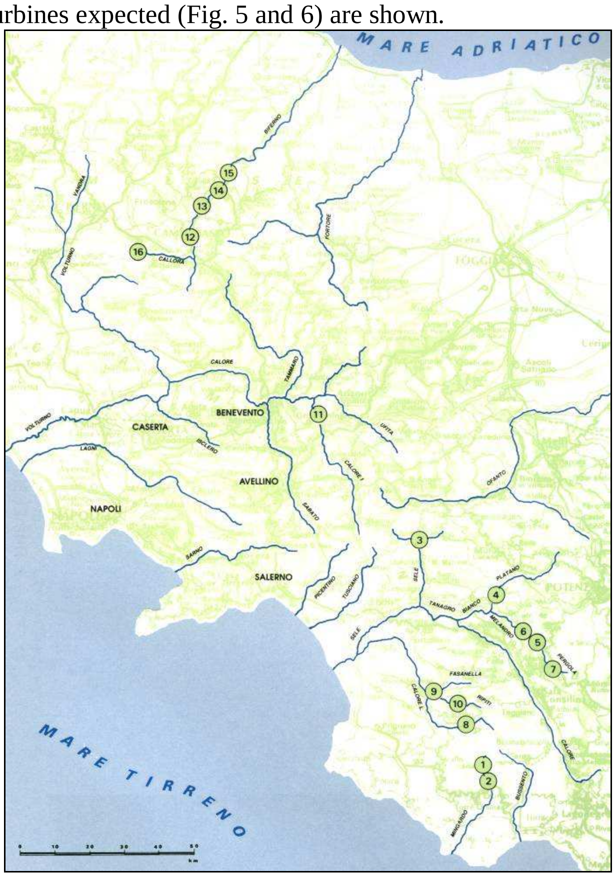

Figure 4. University of Naples: Hydropower plants localization in Campania Region [15]

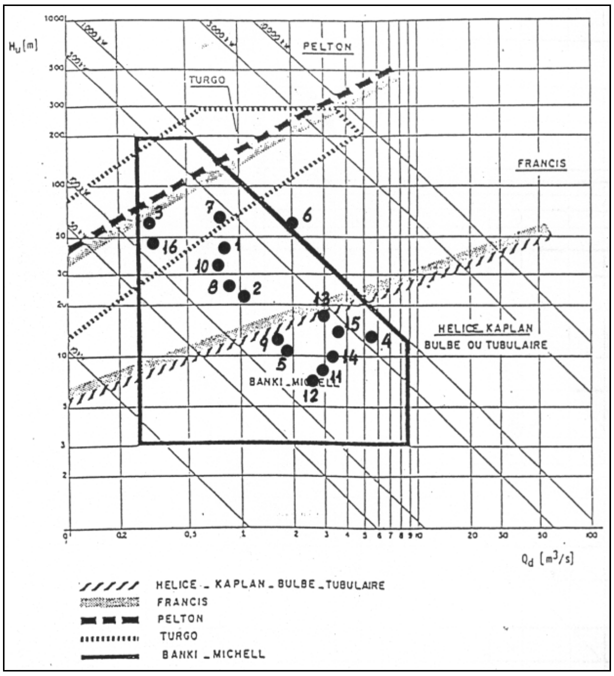

Figure 5. Operating range of turbines (1) [15]

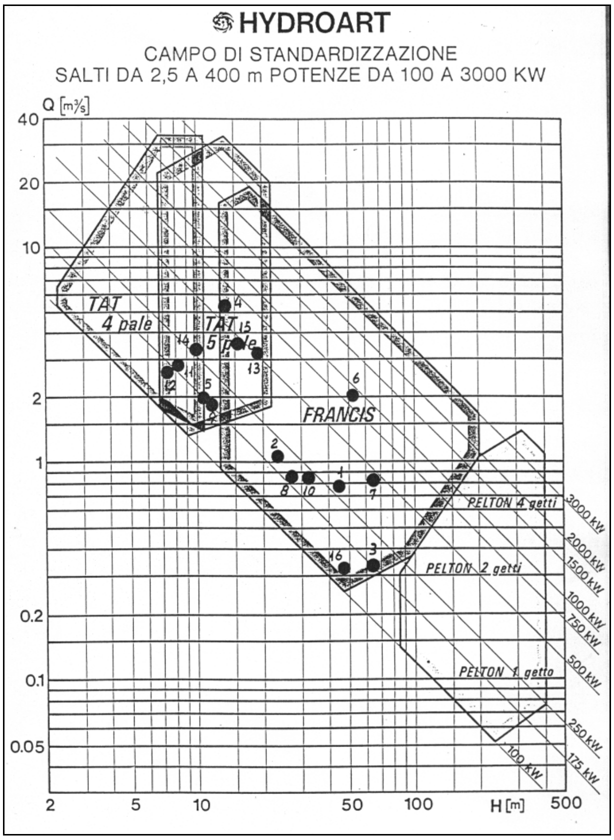

Figure 6. Operating range of turbines (2) [15]

Table II. – Hydropower plant features

n.	River	Main Catchment	Surf.	Lower river level		Average	Design	Geodetic	Net	Max	Average
				Inlet	Outlet	flow	flow	head	head	power	feasibility
			km²	*m a.s.l.*	*m a.s.l.*	*m³/s*	*m³/s*	*m*	*m*	*kW*	*GWh*
1	Mingardo (1°jump)	Mingardo	76	329.0	283.0	1.86	1.57	46.0	46.04	606	2.813
2	Mingardo (2° jump)	Mingardo	102	208.5	188.0	2.44	2.07	20.5	23.13	402	1.833
3	Sele	Sele	22	356.0	293.0	0.62	0.50	63.0	62.24	261	1.100
4	Platano	Sele	537	248.0	237.0	12.75	10.70	11.0	12.90	1158	5.526
5	Melandro (1° jump)	Sele	185	450.0	440.0	4.65	3.83	10.0	11.55	371	1.871
6	Melandro (2° jump)	Sele	195	435.0	381.0	4.87	4.01	54.0	53.61	1802	8.816
7	Pergola	Sele	71	655.0	584.0	1.91	1.62	71.0	65.08	884	4.069
8	Calore L.	Sele	75	395.0	365.0	2.34	1.79	30.0	26.59	399	1.901
9	Fasanella	Sele	212	121.0	108.0	4.64	3.62	13.0	12.16	369	1.970
10	Ripiti	Sele	50	270.0	237.0	2.03	1.69	33.0	32.06	454	2.648
11	Calore I.	Volturno	474	171.0	162.0	6.39	5.81	9.0	7.81	381	1.630
12	Biferno (1° jump)	Biferno	461	436.0	428.0	9.11	5.65	8.0	7.74	367	1.557
13	Biferno (2° jump)	Biferno	547	348.0	326.0	9.67	6.09	22.0	18.45	942	3.918
14	Biferno (3° jump)	Biferno	600	314.0	305.0	10.24	6.54	9.0	9.98	547	2.341
15	Biferno (4° jump)	Biferno	668	281.0	266.0	10.97	7.12	15.0	14.83	886	3.710
16	Callora	Biferno	24	745.0	690.0	0.83	0.67	55.0	46.33	260	1.206

Table III. – Net heads – Design flows - Turbines

n.	River name	H_u	Q_p	Turbine
		m	*m³/s*	*type*
1	Mingardo (1°jump)	46.04	1.57	F
2	Mingardo (2°jump)	23.13	2.07	F
3	Sele	62.24	0.50	F
4	Platano	12.90	10.70	T or B
5	Melandro (1° jump)	11.55	3.83	T or B
6	Melandro (2° jump)	53.61	4.01	F
7	Pergola	65.08	1.62	F
8	Calore L.	26.59	1.79	F
9	Fasanella	12.16	3.62	T or B
10	Ripiti	32.06	1.69	F
11	Calore I.	7.81	5.81	T or B
12	Biferno (1° jump)	7.74	5.65	T or B
13	Biferno (2° jump)	18.45	6.09	T or B
14	Biferno (3° jump)	9.98	6.54	T or B
15	Biferno (4° jump)	14.83	7.12	T or B
16	Callora	46.33	0.67	F
			F=Francis	
			T=T.A.T.	
			B=Banki	

In Basilicata Region, only the mountain section of the Sinni river and two of its tributaries (Frido and Cogliandrino streams) were considered and five smaller plants were found possible, with a feasibility of about 6 GWh / year and total power of 898 kW. In Fig.7 the location of five possible facilities deemed feasible.

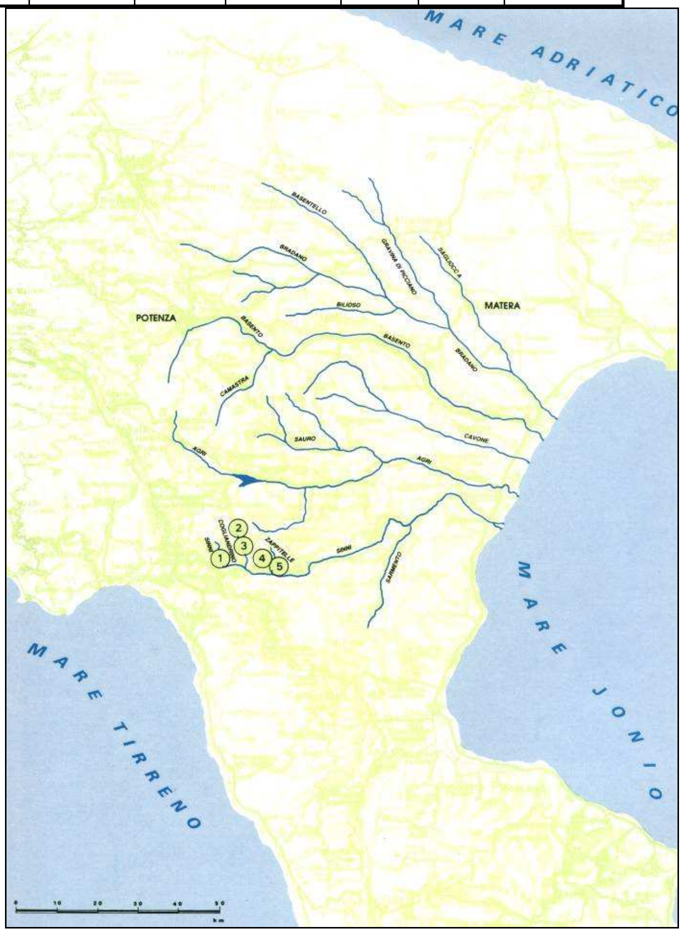

Figure 7. University of Potenza: Hydropower plants localization in Basilicata Region [15]

All data relating to investigations carried out in these ten Regions were published by ENEL, in 1990, in the report "Survey on residual small hydroelectric resources in southern Italy. Proceedings of the National Conference sponsored by ASMEZ, ENEL, IASM" [15].

From these surveys, the realization of 70 small plants is possible, for a total capacity of 33.5 MW and a producibility of about 158 GWh per year.

Further investigation, under the schemes implemented by the Ex-South Foundation for the use of water at waterworks and irrigation purposes, was done in the 90s in the same regions already mentioned; the purpose was of incorporating plants using dissipated loads as exuberant than those required for the conveyance of flow rates near users. According to these investigations, around 120 plants are possible, most with less than a power of 100 kW, for a total annual producibility of about 200 GWh and a total capacity of 40 MW.

Few of these possible small installations have been fulfilled. Therefore, a large number of small hydroelectric plants are still possible, which can produce clean energy with the use of the best of renewable sources: the water.

5 Conclusion: the future?

Given the growing demand for energy in the World, the increasingly widespread use of natural gas as fuel for power plants and the purchase of energy from abroad is to be expected in the near future.

Considerable interest in recent years is directed to the use of biomass (referred to in Decree requiring the approval of Parliament 387/2003), renewable and inexhaustible source as long as used at the biological cycle.

With their total availability, it is estimated that it could theoretically meet in Italy to about 14% of energy demand. This objective, however, is very far to reach either because the technological processes of transformation are still under development or partly because in many cases it’s not economically convenient.

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