Refurbishment of small hydropower plants and green certification: the first successful case in Italy

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1 Introduction

Up to now two main systems have been implemented in European Union to promote the energy production from Renewable Energy Sources: feed-in and green certification.
As the first one has been successfully introduced in Germany and Spain, the second one has so far no complete application and where some attempts were made, e.g. in Austria, the system didn't succeed and was removed.
By the other side, Green Certification for energy produced by Renewable Energy Sources is now a reality in Italy.
In the last three years hundreds of requests for green certification of energy produced by hydroelectric plants were submitted to the relevant authorities (GRTN, the National Transmission Grid Operator, put in charge of the technical and administrative handling of the whole certification procedure).
Up to now only few hydroelectric plants obtained the certification because of the strict requirements needed.
The content of the paper can be summarised as follows:

- the normative frame and the mechanism of the green certification in Italy with particular reference to uprating and refurbishment of hydroelectric plants;
- the overall effect on the hydroelectric Italian system;
- the opportunity offered to investors by green certification: why green certification is boosting the market of plants uprating and refurbishment
- the description of the first Italian project – Lesina hydroelectric plant, located in North of Italy (Valtellina, 100 km North East from Milan) which obtained green certification, paying particular attention to:
  - the preliminary study and the different design steps, required both from the necessity of implementation and from the administrative procedures for green certification
  - the interaction between technical, environmental and economic requirements to be met to obtain green certification
  - the interaction between administrative procedures and development of the project
  - the technical solutions adopted to meet the green certification requirements, out of which:
    - bioengineering technologies for environmental restoration along the penstock
    - optimisation of the typology of the generating units (number of units, jets, installed power) to achieve the best exploitation of the available water resource
    - advanced technologies for storage basin internal coating and for basin structural joints
- Problems faced during the whole track, both administrative and technical, in particular:
  - A multiplicity of public bodies to obtain environmental authorisations, building licenses, etc., which affected the time schedule of the project
  - The optimisation of the hydraulic design of units to improve the overall efficiency required to obtain certification
- Economics of the project
- Perspectives for the future applicability.

2 The Legal Framework

2.1 Nature and function of Green Certificates

In March 1999 an Italian law (Legislative Decree n. 79 issued on March 16th) stated for both producers and importers of energy the obligation, starting from 2002, to put in the national electric system a fixed portion of renewable energy.
The obligation applies to importation and production of energy exceeding 100 GWh/yr, once deducted self-consumptions, co-generation and exportations.
For 2002 the portion of renewable energy to be put into the grid was fixed at 2 % of the total amount of energy imported or produced.
The obligation can be fulfilled by putting into the system energy produced by Renewable Energy Sources plants or by purchasing certificates of energy production from Renewable Energy Sources (the so called Green Certificates, issued by GRTN, the National Transmission Grid Operator, put in charge of the technical and

administrative handling of the whole certification procedure) corresponding to the production put into the grid by plants from Renewable Energy Sources.
In both cases the plants must have been commissioned after 1st April 1999 or have been refurbished or upgraded after this date.
The acknowledgement of the label of "Plant Fed by Renewable Energy Sources" is not automatic. A special Decree on the Minister of Industry stated in 2002 the criteria to acquire the label and stated also, in case of refurbishment or upgrading, the amount of *old* energy which can get the Green Certification.
The plants acknowledged as "Plant Fed by Renewable Energy Sources" have the right for Green Certificates emission for eight years starting from the end of the commissioning and testing period. The Green Certificates refer to the whole expected production for new plants and to the higher expected production plus a part of the production before refurbishment for old refurbished or upgraded plants.
To get Green Certification at least the old hydroelectric unit (turbine and generator) must be replaced.
For this reason Green Certification represents a powerful incentive to recover the full efficiency of old and obsolete plants from Renewable Energy Sources.

2.2 Green Certificates Market

Since October 2002 Green Certificates have begun to be exchanged at the so called Energy Stock Exchange, but the direct bilateral trading is possible out of the Energy Stock Exchange.
As we said purchasers of Green Certificates will be energy producers and importers which can virtually fulfil their obligation of putting into the grid renewable energy by acquiring Green Certificates from real producers of energy from Renewable Energy Sources.
The final purchaser of the Green Certificates every year must deliver their certificates to GRTN for cancellation in order to demonstrate to have fulfilled (directly or virtually) their obligation.
The sell price of Green Certificates will be determined by trading in the Energy Stock Exchange, but also out of it in bilateral trading, so that price can't be in advance estimated. A cap price for 2002 was 8,418 €cent/kWh.
In the long transition period from feed-in price system to "free" energy market, this price will be anyway strongly influenced by the supply price of Green Certificates issued by GRTN in its own favour.
In fact the whole energy produced by old small hydroelectric plants which had energy prices incentives contributes to Green Certificates owned by GRTN.
Green Certificates owned by GRTN will gradually expire so that within few years the whole energy will be produced by private plant owners and the Green Certificates market shouldn't be anyway distorted.

2.3 Calculation of the old energy which can get Green Certificates

As I said, if a plant is duly refurbished or upgraded, a portion of the energy already produced by the plant can obtain Green Certificates.
That portion is stated by law and can be calculated as a function of:

- Actual installed power (Pp)
- Energy produced in the last ten years (Es)
- Investment to refurbish or upgrade the plant (Cost)
- Installed power after refurbishment or upgrading (Pd)
- Expected energy production after refurbishment or upgrading (EAi)

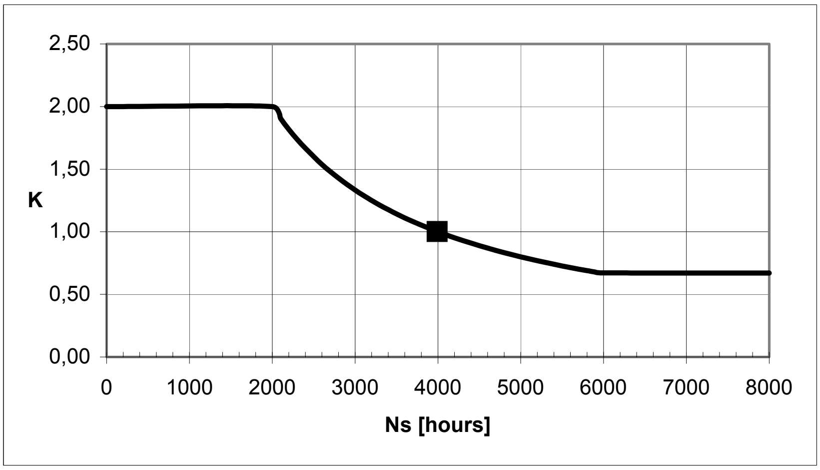
The following parameters must be calculated:

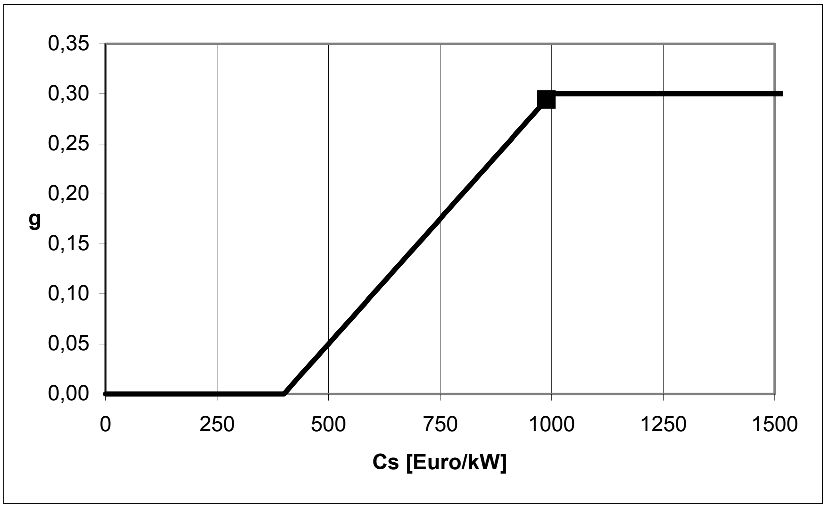
$N_s = \frac{E_s}{P_p}$	theoretical operating hours at installed power		
K	multiplying factor	= 2	if $N_s < 2.000$
		= 0,67	if $N_s > 6.000$
		$= \frac{4.000}{N_s}$	if $2.000 \le N_s \le 6.000$
f	constant	= 0,2	
C_s	specific cost	$\frac{Cost}{P_d}$	
g	correction factor	= 0	if $C_s < 400$
		= 0,3	if $C_s > 1.000$
		$= \frac{C_s - 400}{1000 - 400} \cdot 0{,}3$	if $400 \le C_s \le 1.000$

Old production having right for Green Certificates:

$$E_{oGC} = K \cdot (f + g) \cdot E_s$$

The following diagrams show the trend of factors *K* and *g* when *Ns* and *Cs* vary (square points show the specific case of Lesina plant).





It’s immediately evident that the more you spend for refurbishment or upgrading the more your old energy can get Green Certificates, with an upper threshold rather high.
In such a way the law tends to promote highly intensive investments under the supposition that the more you spend for refurbishment or upgrading the higher the future efficiency and reliability of the plant producing renewable energy is.

3 The overall effect on the hydroelectric Italian system

The entering in force of the new rules about Green Certification is having a remarkable effect on the Italian hydroelectric system.
Despite of the fearful perspective of a complete stop to new hydroelectric initiatives connected with the adoption of the new European Water Framework Directive 60/2000, hydro people will almost certainly have great benefit from Green Certification.
In fact most of the hundreds of the Italian small hydroelectric plants were built in before the 50s of the 20th century, so that most of them are near to the end of their technical life and subject to quick obsolescence.
Green Certification offers to owners and operators the opportunity for refurbishment or upgrading their plants with the reasonable expectation of quick return of investment thanks to the excellent revenue coming from the trading of Green Certificates.
The next table show you some examples coming from the direct experience of Studio Frosio, based on an expected price for Green Certificates of 0,065 €/kWh and on a current energy tariff of 0,055 €/kWh (globally 0,12 €/kWh for the first 8 years after refurbishment).

Type of unit	Actual production	Expected production	Actual installed power	Future installed power	New energy with right to Green Certificates	Old energy with right to Green Certificates	Investment	Payback period	$NPV_{30/7,5\%}$
	kWh/year	*kWh/year*	*kW*	*kW*	*kWh/year*	*kWh/year*	*€*	*Years*	*€*
Kaplan	18.530.000	23.500.000	4.400	5.380	4.970.000	8.800.000	5.500.000	***6***	970.000
Pelton	12.500.000	17.300.000	6.000	6.000	4.800.000	5.900.000	2.950.000	***5***	4.240.000
Kaplan	2.900.000	4.500.000	480	960	1.600.000	971.500	1.530.000	***7***	490.000
Francis	7.420.000	8.260.000	1.240	1.415	840.000	1.850.799	1.056.000	***6***	514.000
Kaplan	3.500.000	4.500.000	800	800	1.000.000	1.600.000	1.150.000	***7***	490.000
Pelton	17.960.000	19.140.000	3.481	3.580	1.180.000	6.417.486	3.300.000	***7***	360.000
Francis	2.000.000	4.500.000	634	840	2.500.000	1.268.000	2.440.000	***8***	620.000
Kaplan	4.100.000	6.000.000	1.760	960	1.900.000	3.520.000	1.342.800	***4***	1.970.000
Pelton	5.400.000	8.300.000	2.280	3.145	2.900.000	4.306.264	2.970.000	***6***	1.660.000
Kaplan	27.745.000	29.807.300	6.489	7.131	2.062.300	5.191.452	2.709.000	***6***	1.390.000
Kaplan	8.000.000	9.000.000	3.000	3.500	1.000.000	2.400.000	1.400.000	***6***	920.000

As you can see, the situation seems to be particularly favourable to hydroelectric people.

That's why since the law entered in force, GRTN has received till to 31st May 2003 165 requests for Green Certification of existing hydro plants.

4 Lesina hydroelectric plant – a successful case study

4.1 The plant before upgrading

The whole plant is located in the municipality of Delebio, province of Sondrio, just 90 km North of Milan at the beginning of Valtellina a long valley through which Adda River flows before entering the Lake of Como.

The plant was commissioned in the late 40s of the 20th century and the scheme is quite usual: diversion works, side hill open channel, storage basin, penstock, powerhouse and tailrace channel.

The diversion weir is located at 547 m.a.s.l. just downstream of the confluence of two Lesina torrent branches.

It's composed by a masonry weir founded on good rock and by two openings closed by slide gates manually operated. Once diverted the water flows through a small desilting basin to remove gravel and cobbles from water.

At the end of the desilting basin is located the side hill channel entrance protected by a small slide gate.

The concrete channel has a 1,00 m square closed cross section, with a maximum wetted area of 0,75 m^2 (0,75 m maximum water depth) due to the realisation of 16 small spillways at the beginning of the channel.

A great number of 10 x 5 cm small windows open along the channel give the air circulation between the channel ceiling and the top of water.

Part of the channel, 1.752 m long with a 0,243% average slope, is inside five tunnels.

The side hill channel ends in a storage basin with a maximum exploitable volume of 32.000 m^3.

Once the water flowed through a small channel-shaped stilling basin equipped with an automatic trash rack cleaner, it goes through a system of coupled gates allowing the water for entering directly to the penstock without passing through the storage basin.

During normal operation water enter in the storage basin which, as usual, is equipped with low level outlet protected by a slide gate and with a spillway to give back water to Lesina through a very steep chute.

In the vicinities of the basin there are the dam keeper house, nowadays no more used but housing the electrical panel necessary for all devices operation, a toolshed and the penstock valve house.

As I said, it's possible to feed the penstock directly from the stilling basin or from the storage basin, so that in the valves house a trifurcation with two slide valves at the upstream side are located. Downstream of the trifurcation, as usual, there's a butterfly valve which closes in case of overspeed in the penstock and an air inlet to avoid implosion in case of break of the penstock and contemporary butterfly valve closing.

The 600 mm diameter, 730 m long steel penstock reaches the powerhouse following the maximum hill slope. As usual for that construction period, the penstock was longitudinally welded and transversally spiked.

At the entrance of the powerhouse the penstock bifurcates in two 350 mm pipes to feed the hydroelectric units installed.

The powerhouse is a building composed of three parts: the machine hall which houses the units, the toolshed and the electric panels room.

In the machine hall are located two single jet Pelton turbines built by Riva in 1942 to operate under a head of 280 m with a maximum flow rate of 0,5 m^3/s each.

The produced energy was put into the national 130 kV grid.

Once the water flowed through the turbines, it is normally discharged by means of a short pressure pipe into the Lesina river. As an alternative the water can feed a small channel which operates a mill.
To sum up, the main characteristics of the plant are:

• Maximum discharge	1,00	m^3/s
• Average discharge	0,47	m^3/s
• Average net head	280	m
• Average power	1.025	kW
• Installed power (Pp)	2.250	kW
• Yearly energy production (Es)	8.980	MWh

Fig. 1: the machine hall before upgrading

4.2 The plant after upgrading

The works made at the plant were intended to optimise the water resource exploitation according to modern design and operation criteria.
If the plant hadn't modernised within few years the whole energy production would be lost and the plant abandoned. The works allowed for increasing the installed power and consequently, thanks to a favourable hydrological situation, increasing the expected production.

4.2.1 Storage basin

The last emptying out before modernisation put into evidence the worst state of the walls of the basin: lots of micro cracks, reduction in the gunite coating thickness with partial detachment, increase in water leakages through the downstream side, detachment of the concrete beams which cover structural vertical joints.
To restore the safety and the reliability of the structure the following actions have been done:

- Removal of the sediment inside the basin to increase the water storage
- Inner face
  - Demolition of the old mortar and gunite coating till to reach the masonry core of the dam for almost 100% of the overall surface
  - Complete demolition of the concrete beams which cover structural vertical joints
  - Cleaning by high pressure water of the demolished area to increase surface roughness necessary to get new coating grasping at the substrate.
  - Realisation of new joints
  - New coating with special fibre reinforced mortar in two layers

4.2.2 Penstock

The old penstock was removed. A new 800 mm diameter penstock was installed. The greater diameter allows for a better exploitation of the higher flow rates of the new hydroelectric units. A smaller diameter in fact causes too high head losses so that the increase in units flow rates wouldn't result in any benefit without enlarging the penstock.
The new penstock was longitudinally welded from inside and coating even inside to get minimum roughness and head losses. Thanks to these design choices an average net head of 5 m was recovered.

Instead of saddles every 6 m as the old one, the new penstock stands on completely new reinforced concrete saddles every 12 m.
The profile of the penstock wasn't changed but the typology of saddles and anchoring block is completely new. Especially for blocks was adopted the solution not embedding the penstock with less environmental impact due to minor visual intrusion.
At the head of the penstock a new mechanical overspeed device and a new inlet valve hydraulically driven were installed.

4.2.3 Powerhouse

After almost 60 years of continuous operation the electromechanical equipment reached the end of its technical life.
In order to avoid the complete loss of production within few years, most of the equipment must be replaced. During the design stage, the hydrological study put into evidence the availability of greater water volumes for energy production. To exploit these volumes a larger penstock and hydroelectric units with higher installed power were necessary. As a consequence of the increased installed power all the electrical equipment (main and auxiliary transformers, MV and LV panels, electrical protections, etc.) was replaced.
The main change in the turbines was the choice of two jets Pelton units instead of one jet and the increase of maximum flow rate from 0,5 m^3/s to 0,75 m^3/s. These larger machines and high hydraulic efficiency new inlet bifurcations required difficult civil works inside the powerhouse because of lack of space. The machine room was almost completely emptied out and the perimetral walls only were standing.
The results in terms of efficiency are remarkable for these small units, with an average overall efficiency, tested by thermodynamic method, of 84,13%, keeping into account even the uncertainty of measures.
Finally, to facilitate erection and future operation and maintenance a new 10 t overhead travelling crane was installed. The typology of the crane had to meet the strict requirements connected with space optimisation necessary for housing the new equipment.
The main characteristics of the plant after upgrading are:

- Maximum discharge 1,50 m^3/s
- Average discharge 0,55 m^3/s
- Average net head 285 m
- Average power 1.210 kW
- Installed power (Pp) 3.500 kW
- Yearly energy production (EAi) 10.600 MWh

Fig. 2: the machine hall after upgrading

4.2.4 Tailrace channel

In the preliminary stage of design the capability of the existing tailrace of discharging the increased flow rates was verified. To reduce localised head losses due to sudden expansion and contraction the inlet and outlet section were remade with smooth special mortar surfaces and larger hydraulic transitions.

4.3 The long road to certification

In November 2000 the owner of the plant - one of the most important European aluminium semifinished products manufacturers - entrusted Studio Frosio to carry on all the design stages to get the plant uprated.

At that time there was no certainty about Green Certification. The decree issued in April 1999, as it often happens in Italy, had no complete application because the precise rules for its application weren't issued yet.
Anyway, the main steps and the relevant deadlines were:

- Preliminary design 31-01-2001
- Discussion of the design with the owner and final definition of the project 16-02-2001
- Tender design and technical specifications for electromechanical equipment 31-03-2001
- Offers from supplier 30-04-2001
- Contract assignment for E/M equipment 31-05-2001
- Works at the basin 15-09-2001/31-12-2001
- Works for penstock replacement 1-10-2001/30-06-2002
- Replacement of electromechanical equipment and relevant civil works 15-11-2001/31-07-2002
- Commissioning of the plant and beginning of commercial operation 20-08-2002
- Efficiency testing 15-03-2003
- Final supply acceptance 30-07-2003

The parallel path to reach Green Certification is summed in the following steps:

- Submission of the first request 06-11-2001
- Visit on site of the GRTN official 07-12-2001
- Request from GRTN of updating the Green Certification request to take into account the new regulation for refurbishment or upgrading of existing plants issued in march 2002 26-04-2002
- Submission of the updated request 04-06-2002
- Request of integration from GRTN 05-08-2002
- Submission of the integration requested 27-09-2002
- Final acknowledgment of the plant as Plant Fed by Renewable Energy Sources 11-10-2002
- Final Green Certification of the plant 04-11-2002

As you can see, the road was not certainly straight and easy, especially for the intersection between administrative procedures and design stages. In fact when the final and construction design was completed and the works already ongoing, some remarkable modifications were made to fulfil the requirements of environmental officers of GRTN.
Anyway within one year the administrative procedure was completed and after 14 months from the beginning of works all the targets, technical, administrative and economical, were hit.
As usual, the administrative path suffered of the uncertainty typical of transitory periods (entering in force of new rules and procedures), but anyway the global results were very good. The secret of this success lies on a continuous contact among GRTN, Studio Frosio and the owner to find quick solutions to every kind of problem, helping officers in finding the way through a road never walked before. Lesina has been in fact a sort of prototype from the administrative point of view.

4.4 Economics of the project

The cost of the rehabilitation is shown in the following table:

Sidehill channel	50.000
Basin	360.000
Overhead travelling crane	30.000
Access road	30.000
Powerhouse civil works	130.000
Penstock and relevant civil works	1.570.000
Electromechanical equipment	1.140.000
Enginnering	155.000
Total	**3.465.000**

Due to this high cost, the plant had a high portion of *old* energy qualified for Green Certificates:

Energy production having right to Green Certificates [kWh/year]	**6.075.000**
Out of which	
Due to uprating [kWh/year]	1.620.000
Due to partial refurbishment [kWh/year]	4.455.000

The owner of the plant had some offers from different potential Green Certificates purchasers and finally obtained a price of approx. 0,079 €/kWh. By the other side the value of energy is lower than 0,055 €/kWh used in the evaluation made at chap. 0 (0,051 €/kWh), so that the global value of the energy produced is 0,13 €/kWh.
Consequently, thanks to Green Certification of the plant the simple payback period of the investment is 8 years and the 30 years – 7,5 % NPV is 321.841 €.

The result could seem not particularly attractive, but you must remember that the plant is now almost new and the strategic value for the owner, which self consumes the energy produced, wasn't computed, but it's very high.

5 Environmental issues

To obtain the acknowledgement of "Plant Fed by Renewable Energy Sources" you must demonstrate to improve the environment through your refurbishment or upgrading. In case of Lesina the procedure took a long time even because environmental officers in charge of evaluating the project required more and more integrations.
The main environmental improvement in the rehabilitation were:

- Restoration and improvement of the small road connecting the powerhouse to the basin. The improvement facilitates the access to remote mountain areas with small forestry activities.
- Removal of the bad visual impact tracks of the skidway built in 40s to install the penstock
- Reduction of noise due to the installation of 750 rpm instead of the old 1000 rpm units (noise < 84 dBA at 1 m)
- Replacement with a reduced losses resin transformer of the old power transformer filled with 1950 kg of oil
- Continuous monitoring of the leakages from the basin (strongly reduced after the works described at par. 0)
- Fish passages: due to the river morphology no autochtonal fish can pass the high jumps in river. Anyway the owner concurs to the repopulation putting into disposal of fishery authorities 15.000 trout fry.
- Reduction of the visual impact of the penstock by using steel anchoring blocks not covering the penstock with concrete
- Bioengineering techniques for consolidation works along the penstock.
- Better exploitation of the water available by an increased efficiency of the units (from est. 78% to 84,13 %)
- Increase in production from RES for 1.620 MWh corresponding to approx. 405 Toe (2.650 Toe taking into account the risk of no future production in case of no refurbishment).
- Reduction in CO_2 and pollutant emissions:

	Min. [t/year]	Max. [t/year]
SO_2	2,9	22
CO_2	1.249	1.617
NO_X	2,3	5,2
Particulates	0,3	2,3
CH_4	2,3	2,9

6 Perspectives for the future applicability

Green Certification in Italy is ongoing. The first payments to hydro energy producers have been recently done. The perspectives for the near future are very good, but we mustn't forget that the success or failure of the Green Certification still depends on political decisions, because *de facto* there's no free market of Green Certificates neither today nor probably in the future, so that the intrinsic uncertainty of the market is nothing compared to the political fickleness.
Lesina represents anyway the first successful story, from technical, administrative and timing point of view of a plant which acquired Green Certification. Everybody knows in the small hydro field how a peculiar each site is, so that I don't want to suggest general or automatic solutions, but only to point out the good results obtained by the steady contact and collaboration with public officers, to find suitable environmental solutions, the elasticity of the design to adapt to on the road changes and the particular attention and promptness of the owner in each stage of the project.

The Author

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