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POTENTIAL OF MINI-HYDRO IN MALTA. APPLICATION IN A PIPELINE

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ABSTRACT: This paper evaluates the potential of mini-hydro applied to an existing or a new pipeline design. High pressure pipelines may have special installations installed on it, to extract energy from the outlet side. This is demonstrated for a specific installation at the sewage treatment plant of Ta' Barkat, Malta. The paper also presents an economic plan and summarises the regulations and incentives that are adopted in Italy and Europe in the area of mini-hydro.

Keywords: Mini-hydro, renewable energy.

1 INTRODUCTION

1.1 The only renewable resource.

The use of a system able to generate energy in a clean and sustainable way has increased considerably in recent years. This was a direct result of greater interest in climate issues and concern on energy resources of our planet, which was addressed by the Kyoto Protocol and its resulting commitments. Also, the Renewable Energy Directive became a policy tool to assist the EU in the development of a sustainable energy sector.

On 1 May 2004, ten Eastern European and two Mediterranean countries (the Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania) joined the EU. For more than 100 years the energy from hydropower has been harnessed in these countries, with the exceptions of Malta and Cyprus [1]. The use of the potential energy of the water available from a higher level and a lower finds its applications already existing centuries back. Water mills were employed as a force made available by nature to perform work.

Since the end of the nineteenth century the use of water resources for electricity generation has been the most popular option, since it did not attribute any harm on the climate, as opposed to that produced by coal and oil power plants. Technology in the field of hydropower is currently fully mature, and the industrial use of water resources , at least in European countries - after almost two centuries of exploitation - has almost reached its technical potential. However, there are possibilities for the use of the hydropower resource on a small scale. [3]

Different applications may come to mind such as the use of energy generation from waterfalls or aqueducts, micro-hydro energy generation in streams, irrigation canals, drainage and waste water treatment plant pipelines.

1.2 Definition of small hydropower

There is no consensus in EU member states on the definition of small hydropower (SHP): Some countries like Portugal, Spain, Ireland and now, Greece and Belgium, accept 10 MW as the upper limit for installed capacity. In Italy the limit is fixed at 3 MW (plants with larger installed power should sell their electricity at lower prices) and in Sweden 1.5 MW. In France the limit has been recently established at 12 MW, not as an explicit limit of SHP, but as the maximum value of installed power for which the grid has the obligation to buy electricity from renewable energy sources. In the UK 20MW is generally accepted as the threshold for small hydro. For the purposes of this text any scheme with an installed capacity of 10 MW or less will be considered as small. This figure is adopted by five member states, the European Small Hydro-Power Association ESHA, the European Commission and UNIPEDE the (International Union of Producers and Distributors of Electricity) [4].

1.3 Site configurations

The objective of a hydropower scheme is to convert the potential energy of a mass of water, flowing in a stream with a certain fall to the turbine (termed the "head"), into electric energy at the lower end of the scheme, where the powerhouse is located. The power output from the scheme is proportional to the flow and to the head. Schemes are generally classified according to the “Head”:

- High head: 100-m and above
- Medium head: 30 - 100 m
- Low head: 2 - 30 m

These ranges are not rigid but are merely means of categorizing sites. Schemes can also be defined as:

- Run-of-river schemes
- Schemes with the powerhouse located at the base of a dam
- Schemes integrated on a canal or in a water supply pipe or waste water treatment plant [4].

1.3.1 Run-of-river schemes

Run-of-river schemes are where the turbine generates electricity as and when the water is available and provided by the river. When the river dries up and the flow falls below some predetermined amount or the minimum technical flow for the turbine, generation ceases. Medium and high head schemes use weirs to divert water to the intake. It is then conveyed to the turbines via a pressure pipe or penstock. Penstocks are expensive and consequently this design is usually uneconomic.

An alternative is to convey the water by a low-slope canal, running alongside the river to the pressure intake or forebay and then in a short penstock to the turbines. If the topography and morphology of the terrain does not permit the easy layout of a canal, a low pressure pipe can be an economical option. At the outlet of the turbines, the water is discharged to the river via a tailrace. Occasionally a small reservoir, storing enough water to operate only on peak hours, when prices for electricity are higher, can be created by the weir, or a similarly sized pond can be built in the forebay.

Low head schemes are typically built in river valleys. Two technological options can be selected. Either the water is diverted to a power intake with a short penstock, as in the high head schemes, or the head is created by a small dam, provided with sector gates and an integrated intake, powerhouse and fish ladder [4].

1.3.2 Schemes with the powerhouse at the base of a dam

A small hydropower scheme cannot afford a large reservoir to operate the plant when it is most convenient. The cost of a relatively large dam and its hydraulic appurtenances would be too high to make it economically viable. But if the reservoir has already been built for other purposes, such as flood control, irrigation, water abstraction for a big city, recreation area, etc, - it may be possible to generate electricity using the discharge compatible with its fundamental use or the ecological flow of the reservoir. The main issue is how to link headwater and tail water by a waterway and how to fit the turbine in this waterway. A siphon intake can be installed, if the dam already has a bottom outlet and provided that the dam is not too high. Integral siphon intakes provide an elegant solution in schemes, generally, with heads up to 10 metres and for units up to about 1000 kW, although there are examples of siphon intakes with an installed power up to 11 MW (Sweden) and heads up to 30.5 meters (USA). The turbine can be located either on top of the dam or on the downstream side. The unit can be delivered pre-packaged from stock and installed without major modifications to the dam [4].

1.3.3 Schemes integrated within an irrigation canal

A lot of small hydropower plants have been erected and are still being realised in irrigation networks or channels, especially in plains where dozens of low head plants exploit the water resource both for irrigation and energy production purposes, supplying energy to the grid or to match electricity demand directly for irrigation (e.g. pumping stations). Two types of schemes can be designed to exploit irrigation canal:

- The canal is enlarged to accommodate the intake, the power station, the tailrace and the lateral bypass. To safeguard the water supply for irrigation, the scheme should include a lateral bypass in case of shutdown of the turbine. This kind of scheme must be designed at the same time as the canal, as additional works whilst the canal is in full operation can be a very expensive option;
- If the canal already exists, the canal should be slightly enlarged to include the intake and the spillway. To reduce the width of the intake to a minimum, an elongated spillway should be installed. From the intake, a penstock running along the canal brings the water under pressure to the turbine. The water passes through the turbine and is returned to the river via a short tailrace. Generally, migratory fish are not present in canals, so fish passes are unnecessary [4].

1.3.4 Schemes integrated in a water abstraction system

Drinking water is supplied to a city by conveying the water from a headwater reservoir via a pressure pipe. Usually in this type of installation, the dissipation of energy at the lower end of the pipe at the entrance to the Water Treatment Plant is achieved through the use of special valves. The fitting of a turbine at the end of the pipe, to convert this otherwise lost energy to electricity, is an attractive option, provided that the water hammer phenomenon is avoided. Water hammer overpressures are especially critical when the turbine is fitted on an old pressure pipe. To ensure the water supply at all times, a system of bypass valves should be installed. In some water supply systems the turbine discharges to an open-air pond. The control system maintains the level of the pond. In case mechanical shutdown or turbine failure, the bypass valve system can also maintain the level of the pond. Occasionally if the main bypass valve is out-of-operation and overpressure occurs, an ancillary bypass valve is rapidly opened by a counterweight. All the opening and closing of these valves must be slow enough to keep pressure variations within acceptable limits. The control system has to be more complex in those systems, where the turbine outlet is subject to the counter-pressure of the network [4].

1.3.5 Recreation purposes

In some pondage plants the water level in the basin has to be kept higher than a prefixed level to allow angling or other recreation activities, so that only part of the water volume available can be stored for hydroelectric purposes [2].

1.3.6 Flood protection

In many small hydropower plants the river banks near to the diversion works must be rearranged and raised above their normal level. Such action results in an increase of the water level and consequently of the flow rate which the river can convey during floods. Another way to achieve flood protection is the use of the basin to store part of the water volume during floods, although the available volume of storage in small hydropower plants is usually very small compared to the demands of flood protection [2].

1.3.7 Creation of adjoining environmental areas

As a mitigation measure to be taken in a small hydropower plant realisation, the creation of adjoining environmental areas is often put into effect. These areas are different from site to site and it is hard to generalise on how to set them up. Nevertheless they undoubtedly contribute to making the small hydropower plant more easily acceptable from the environmental point of view [2].

1.3.8 Waste water treatment plant

There are at least two places within a waste water treatment plant to insert a hydropower installation - above the plant and below the plant. For example in alpine regions sometimes there is a central treatment plant down in the valley where the waste water is collected from smaller villages high up in the mountains. The head in such cases is reasonable. A pre-treatment (e.g. trashrack) before entering the pressure pipe is necessary [2].

In cases of larger treatment plants the head available downstream between the treatment and the river may be used. No additional cleaning procedures are necessary.

2. EVALUATING STREAMFLOW

2.1. Introduction

All hydroelectric generation depends on falling water. This makes hydropower extremely site dependent. First of all, a sufficient and dependable stream flow is required. Secondly, the topographic conditions of the site must allow for the gradual descent of the river in a river stretch be concentrated to one point giving sufficient head for power generation. When a site has been identified as topographically suitable for hydropower, the first task is to investigate the availability of an adequate water supply [4].

2.2. Potential energy

The water flowing from point A to point B, with elevations ZA and ZB, loses potential energy corresponding to the drop in elevation. This loss of potential energy occurs regardless of the path along the watercourse or via an open canal, penstock and turbine. The potential energy lost can be converted to power lost according to the equation:

$$P = Q \cdot Hg \cdot \gamma \ [\mathrm{kW}] \qquad (1)$$

where:
P is the power in kW lost by the water
Q is the flow in m^3/s
Hg is the gross head in m, = ZA .– ZB,
and γ is the specific weight of water, (9.81 kN/m^3).

The water can follow the riverbed, losing power through friction and turbulence resulting in a marginal rise in the temperature of the water. Or it can flow from A to B through an artificial conveyance system with a turbine at its lower end. In this case the power will be used mainly for running a turbine, and a smaller part of the power is lost in friction in the conveyance system. In the latter case it is the power lost in pushing through the turbine that will be converted to mechanical energy and then, by rotating the generator, to produce electricity. The objective is to reduce construction costs while conserving the maximum amount of power available to rotate the generator. To estimate the water potential one needs to know the variation of the discharge throughout the year and how large the gross available head is. Then equation 1 becomes:

$$P = Q \cdot Hg \cdot \gamma \cdot \eta \ [\mathrm{kW}] \qquad (2)$$

2.3. Stream flow records

In Europe, stream flow records can be obtained from national hydrological institutes. These stream flow records can be of several different types, each useful for the evaluation of the generating potential of the considered site. These include:

- Measured stream flow data for a number of gauged sites
- Stream flow characteristics for these sites such as mean flow and flow duration curves (both expressed as actual flow and generalised as runoff per unit area of the catchment)
- Runoff maps, etc

There is a United Nations organisation, the .“World Meteorological Organisation.”, with a hydrologic information service (INFOHYDRO) whose objective is to provide information. [4]

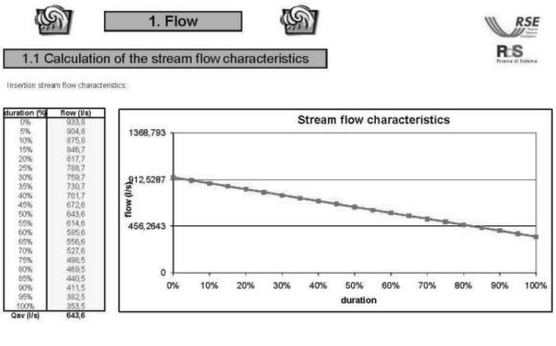
For the preparation of this article, the Water Service Corporation (Malta) has kindly provided me with the necessary data from the sewage treatment plant of Ta' Barkat for the dates 01/01/2012 to 30/06/2012 [5].

2.4. Stream Flow Characteristics

A programme of stream gauging, at a particular site over a period of years, will provide a table of discharges that has to be organised into a usable format [4].

2.4.1. Flow Duration Curves (FDC)

One way of organising discharge data is by plotting a flow duration curve (FDC) An FDC shows for a particular point on a river the proportion of time during which the discharge there equals or exceeds certain values. It can be obtained from the hydrograph, by organising the data by magnitude instead of chronologically. Most gauging stations (in the EU) are computerised, the easiest way to derive a FDC is to transpose the digital data to a spreadsheet, sorting them in descending order, and then by hand or by using a simple macro, classify the data as in Figure 1 below. Once done, the same spreadsheet, using its graphic building capability will draw the curve FDC. For the present case of Ta’ Barkat we have [4], [5]:



1. Flow

1.1 Calculation of the stream flow characteristics

Insertion stream flow characteristics

duration (%)	flow (l/s)
0%	933,8
5%	904,8
10%	875,8
15%	846,7
20%	817,7
25%	788,7
30%	759,7
35%	730,7
40%	701,7
45%	672,6
50%	643,6
55%	614,6
60%	585,6
65%	556,6
70%	527,6
75%	498,5
80%	469,5
85%	440,5
90%	411,5
95%	382,5
100%	353,5
Qav (l/s)	643,6

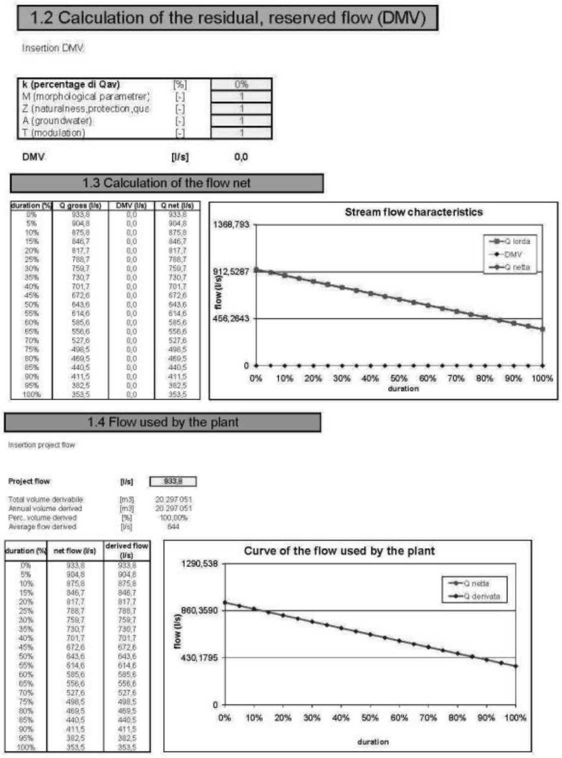
Figure 1: FDC for Ta’ Barkat for the year 2012 **[9].**

2.5. Residual, reserved or compensation flow

Uncontrolled abstraction of water from a watercourse (e.g. passing it through a turbine) even if it is returned to the stream close to the intake, could lead to sections of the watercourse being left almost dry with serious impacts on aquatic life. To avoid this happening, permission to divert water through a hydro turbine or a licence to abstract from a river or stream will almost always specify that a certain residual flow should remain. The residual flow is sometimes called other names, depending on the country, or authority responsible, e.g. "reserved flow", "prescribed flow" and "compensation flow" are terms commonly used. In Italy it is known as “Deflusso Minimo Vitale” “DMV”. This residual flow should be carefully evaluated since a flow that is too small would cause damage to aquatic life in the stream. On the other hand an unnecessarily large flow effects the power production and especially so in periods of low flow, thus reducing the benefits of the installation.

In our case, the DMV will be zero because all the water will either be thrown into the sea or used for agriculture [4].

Figure 2 below shows the calculations carried out for Ta’ Barkat sewage treatment plant [5].



1.2 Calculation of the residual, reserved flow (DMV)

Insertion DMV

k (percentage di Qav)	[%]	0%
M (morphological parametrer)	[-]	1
Z (naturalness,protection,qua	[-]	1
A (groundwater)	[-]	1
T (modulation)	[-]	1

DMV **[l/s]** **0,0**

1.3 Calculation of the flow net

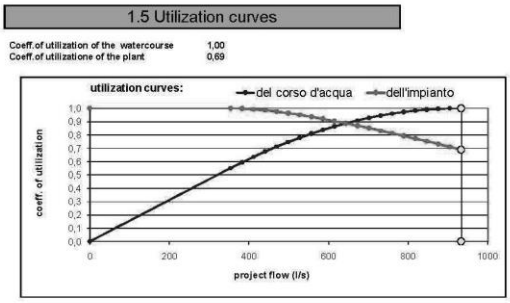
duration (%)	Q gross (l/s)	DMV (l/s)	Q net (l/s)
0%	933,8	0,0	933,8
5%	904,8	0,0	904,8
10%	875,8	0,0	875,8
15%	846,7	0,0	846,7
20%	817,7	0,0	817,7
25%	788,7	0,0	788,7
30%	759,7	0,0	759,7
35%	730,7	0,0	730,7
40%	701,7	0,0	701,7
45%	672,6	0,0	672,6
50%	643,6	0,0	643,6
55%	614,6	0,0	614,6
60%	585,6	0,0	585,6
65%	556,6	0,0	556,6
70%	527,6	0,0	527,6
75%	498,5	0,0	498,5
80%	469,5	0,0	469,5
85%	440,5	0,0	440,5
90%	411,5	0,0	411,5
95%	382,5	0,0	382,5
100%	353,5	0,0	353,5

1.4 Flow used by the plant

Insertion project flow

Project flow	**[l/s]**	933,8
Total volume derivabile	[m3]	20 297 051
Annual volume derived	[m3]	20 297 051
Perc. volume derived	[%]	100,00%
Average flow derived	[l/s]	644

duration (%)	net flow (l/s)	derived flow (l/s)
0%	933,8	933,8
5%	904,8	904,8
10%	875,8	875,8
15%	846,7	846,7
20%	817,7	817,7
25%	788,7	788,7
30%	759,7	759,7
35%	730,7	730,7
40%	701,7	701,7
45%	672,6	672,6
50%	643,6	643,6
55%	614,6	614,6
60%	585,6	585,6
65%	556,6	556,6
70%	527,6	527,6
75%	498,5	498,5
80%	469,5	469,5
85%	440,5	440,5
90%	411,5	411,5
95%	382,5	382,5
100%	353,5	353,5



1.5 Utilization curves

Coeff.of utilization of the watercourse 1,00
Coeff.of utilizatione of the plant 0,69

Figure 2: Calculations for Ta’ Barkat flow [5], [9].

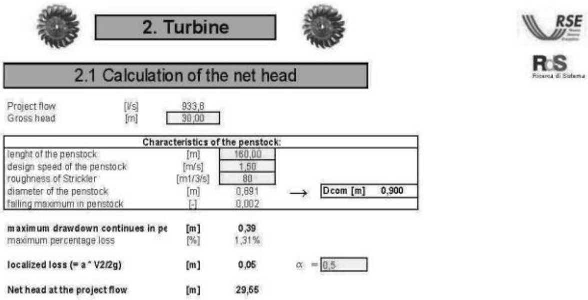
3. WATER PRESSURE OR “HEAD”.

3.1.Evaluation of gross head

The gross head is the vertical distance that the water falls through in giving up its potential energy (i.e. between the upper and lower water surface levels). Field measurements of gross head are usually carried out using surveying techniques. The precision required in the measurement will limit the methods that can be employed. In the past, the best way to measure gross head was by leveling with a surveyor’s level and staff, however this was a slow process. Accurate measurements were made by a tachometer or less accurately by a clinometer or Abney level. Nowadays with digital theodolites, electronic digital and laser levels and especially with the electronic total stations the job has been simplified. The modern electronic digital levels provide an automatic display of height and distance within about 4 seconds with a height measurement accuracy of 0.4 mm, and the internal memory that can store approximately 2,400 data points. Surveying by Global Positioning Systems (GSM) is now used widely and a handheld GPS receiver is ideal for field positioning, and rough mapping. In our example, it is estimated the gross head in 30 m [4], [5].

3.2. Estimation of net head

Having established the gross head available, it is necessary to make allowances for the losses, from trash racks, pipe friction, bends and valves. In addition to these losses, certain types of turbines need to discharge their water to atmosphere, above the level of the tail water (the lower surface level). The gross head minus the sum of all the losses equals the net head, which is available to drive the turbine. Figure 3 shows these calculations [4].



2. Turbine

2.1 Calculation of the net head

Project flow [l/s] 933,8
Gross head [m] 30,00

Characteristics of the penstock:				
lenght of the penstock	[m]	160,00		
design speed of the penstock	[m/s]	1,50		
roughness of Strickler	[m1/3/s]	80		
diameter of the penstock	[m]	0,891	→	Dcom [m] 0,900
falling maximum in penstock	[-]	0,002		

maximum drawdown continues in pe	**[m]**	**0,39**	
maximum percentage loss	[%]	1,31%	
localized loss (= a * V2/2g)	**[m]**	**0,05**	α = 0,5
Net head at the project flow	**[m]**	**29,55**	

Figure 3: Calculation for the net head [5], [9].

4. HYDRAULIC TURBINES – TYPES AND CONFIGURATION

The purpose of a hydraulic turbine is to transform the water potential energy to mechanical rotational energy. The potential energy in water is converted into mechanical energy in the turbine, by one of two fundamental and basically different mechanisms:

- The water pressure can apply a force on the face of the runner blades, which decreases as it proceeds through the turbine. Turbines that operate in this way are called reaction turbines. The turbine casing, with the runner fully immersed in water, must be strong enough to withstand the operating pressure. Francis and Kaplan turbines belong to this category.
- The water pressure is converted into kinetic energy before entering the runner. The kinetic energy is in the form of a high-speed jet that strikes the buckets, mounted on the periphery of the runner. Turbines that operate in this way are called impulse turbines. The most usual impulse turbine is the Pelton [4].

4.1 Impulse turbines

4.1.1 Pelton turbines

Pelton turbines are impulse turbines where one or more jets impinge on a wheel carrying on its periphery a large number of buckets. Each jet issues water through a nozzle with a needle valve to control the flow. They are only used for high heads from 60 m to more than 1,000 m. The axes of the nozzles are in the plane of the runner. In case of an emergency stop of the turbine (e.g. in case of load rejection), the jet may be diverted by a deflector so that it does not impinge on the buckets and the runner cannot reach runaway speed. In this way the needle valve can be closed very slowly, so that overpressure surge in the pipeline is kept to an acceptable level (max 1.15 static pressure). As any kinetic energy leaving the runner is lost, the buckets are designed to keep exit velocities to a minimum. One or two jet Pelton turbines can have horizontal or vertical axis Three or more nozzles turbines have vertical axis. The maximum number of nozzles is 6 (not usual in small hydro). The turbine runner is usually directly coupled to the generator shaft and shall be above the downstream level. The turbine manufacturer can only give the clearance. The efficiency of a Pelton is good from 30% to 100% of the maximum discharge for a one-jet turbine and from 10% to 100% for a multi-jet one [4].

Figure 4: Pelton runner.

4.1.2. Turgo turbines

The Turgo turbine can operate under a head in the range of 50-250 m. Like the Pelton, it is an impulse turbine, however its buckets are shaped differently and the jet of water strikes the plane of its runner at an angle of 20º. Water enters the runner through one side of the runner disk and emerges from the other. It can operate between 20% and 100% of the maximal design flow. The efficiency is lower than for the Pelton and Francis turbines. Compared to the Pelton, a Turgo turbine has a higher rotational speed for the same flow and head. A Turgo can be an alternative to the Francis turbine, when the flow strongly varies or in case of long penstocks, as the deflector allows avoidance of runaway speed in the case of load rejection and the resulting water hammer that can occur with a Francis [4]. Figure 5 shows a schematic of the Turgo turbine.

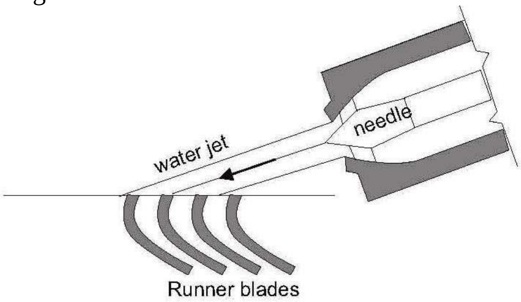


Figure 5: Turgo turbine.

4.1.3. Cross-flow turbines

This impulse turbine, also known as Banki-Michell is used for a wide range of heads overlapping those of Kaplan, Francis and Pelton. It can operate with heads between 5 and 200 m. As shown in Figure 6, water enters the turbine, directed by one or more guide-vanes located upstream of the runner and crosses it two times before leaving the turbine. This simple design makes it cheap and easy to repair in case of runner breaks due to the important mechanical stresses. The Cross-flow turbines have low efficiency compared to other turbines and the important loss of head due to the clearance between the runner and the downstream level should be taken into consideration when dealing with low and medium heads. Moreover, high head cross-flow runners may have some troubles with reliability due to high mechanical stress. It is an interesting alternative when one has enough water, defined power needs and low investment possibilities, such as for rural electrification programs [4].

4.2. Reaction turbines

4.2.1. Francis turbines.

Francis turbines are reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. In this turbine the admission is always radial but the outlet is axial. Figure 7 shows a horizontal axis Francis turbine. Their usual field of application is from 25 to 350 m head. As with Peltons, Francis turbines can have vertical or horizontal axis, this configuration being really common in small hydro.

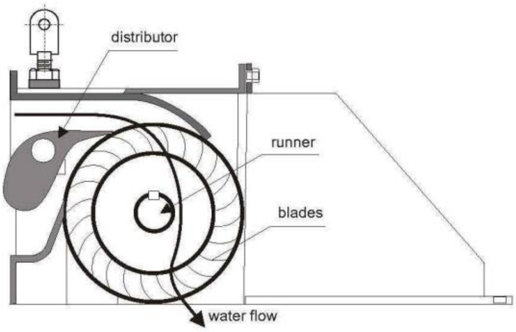


Figure 6: Principle of a Cross-flow turbine.

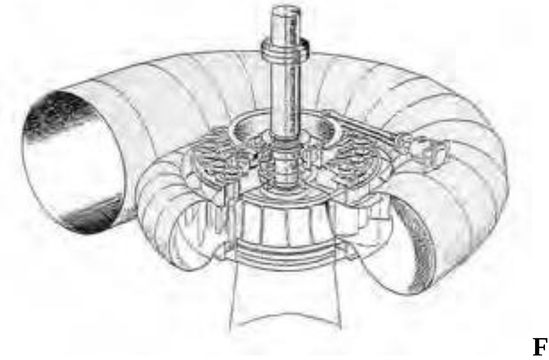


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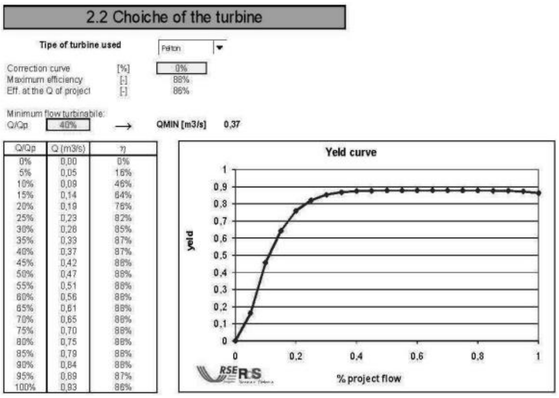
Figure 7: View of a Francis Turbine.

Francis turbines can be set in an open flume or attached to a penstock. They were commonly employed for small heads and power open flumes, however nowadays the Kaplan turbine provides a better technical and economical solution in such power plants. The water enters the turbine by the spiral case that is designed to keep its tangential velocity constant along the consecutive sections and to distribute it peripherally to the distributor. This one has mobile guide vanes, whose function is to control the discharge going into the runner and adapt the inlet angle of the flow to the runner blades angles. They rotate around their axes by connecting rods attached to a large ring that synchronise the movement off all vanes. They can be used to shut off the flow to the turbine in emergency situations, although their use does not preclude the installation of a butterfly valve at the entrance to the turbine.

The runner transforms the hydraulic energy to mechanical energy and returns it axially to the draft tube. Small hydro runners are usually made in stainless steel castings. Some manufacturers also use aluminium bronze casting or welded blades, which are generally directly coupled to the generator shaft.

The draft tube of a reaction turbine aims to recover the kinetic energy still remaining in the water leaving the runner. As this energy is proportional to the square of the velocity one of the draft tube objectives is to reduce the turbine outlet velocity. An efficient draft tube would have a conical section but the angle cannot be too large, otherwise flow separation will occur. The optimum angle is 7º but to reduce the draft tube length, and therefore its cost, sometimes angles are increased up to 15º. The lower head, the more important the draft tube is. As low head generally implies a high nominal discharge, the remaining water speed at the outlet of the runner is quite important. One can easily understand that for a fixed runner diameter, the speed will increase if the flow does.

Given the above analysis, it was concluded that the best turbine to match the conditions of flow at the waste treatment plant of Ta’ Barkat, is the Pelton turbine. Figure 8 shows the calculations.



2.2 Choiche of the turbine

Tipe of turbine used: Pelton

Correction curve [%] 0%
Maximum efficiency [-] 88%
Eff. at the Q of project [-] 86%

Minimum flow turbinabile:
Q/Qp 40% → QMIN [m3/s] 0,37

Q/Qp	Q (m3/s)	η
0%	0,00	0%
5%	0,05	16%
10%	0,09	46%
15%	0,14	64%
20%	0,19	76%
25%	0,23	82%
30%	0,28	85%
35%	0,33	87%
40%	0,37	87%
45%	0,42	88%
50%	0,47	88%
55%	0,51	88%
60%	0,56	88%
65%	0,61	88%
70%	0,65	88%
75%	0,70	88%
80%	0,75	88%
85%	0,79	88%
90%	0,84	88%
95%	0,89	87%
100%	0,93	86%

Figure 8: Choice of Pelton turbine.

5. ESTIMATION OF PLANT CAPACITY AND ENERGY OUTPUT

The FDC provides a means of selecting the right design discharge, and by taking into account the reserved flow and the minimum technical turbine flow, an estimate of the plant capacity and the average annual energy output. The design flow has to be identified through an optimisation process, studying a range of different flows, which normally gives an optimum design flow significantly larger than the difference between the mean annual flow and the reserved flow. Once the design flow is defined and the net head estimated, a suitable type of turbine must be identified. Every selected turbine has a minimum technical flow (with a lower discharge the turbine either cannot operate or has a very low efficiency) and its efficiency is a function of the operating discharge. The average annual energy production (E in kWh) is a function of:

$E = f_n (Q_{median}, H_n, \eta_{turbine}, \eta_{gearbox}, \eta_{transformer}, y, h)$

Where:

Q_{median} = flow in m3/s for incremental steps on the flow duration curve
H_n = specified net head
$\eta_{turbine}$ = turbine efficiency, a function of Qmedian
$\eta_{generator}$ = generator efficiency
$\eta_{gearbox}$ = gearbox efficiency
$\eta_{transformer}$ = transformer efficiency
y = specific weight of the water (9.81 KN/m3)
h = number of hours for which the specified flow occurs.

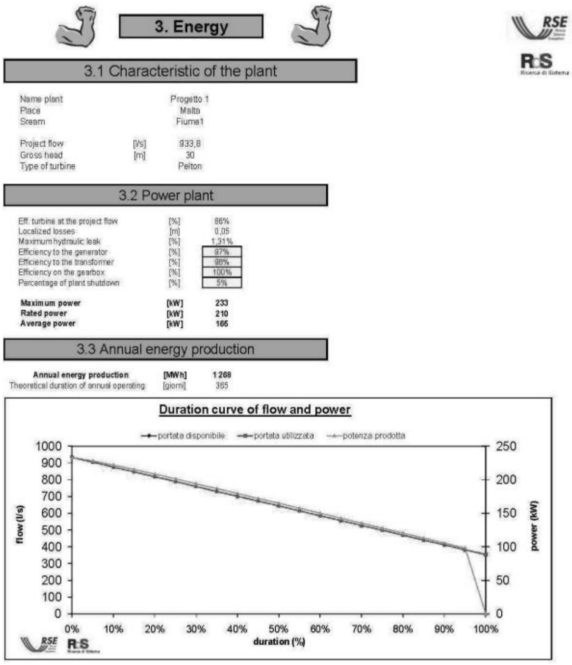
The energy production can be calculated by dividing the useable area into vertical 5% incremental strips starting from the origin. The final strip will intersect the FDC at Q_{min} or $Q_{reserved}$ which ever is larger. For each strip Q_{median} is calculated, the corresponding $h_{turbine}$ value is defined for the corresponding efficiency curve, and the energy contribution of the strip is calculated using the equation:

$$E = W \times Q_{median} \times H \times \eta_{turbine} \times \eta_{generator} \times \eta_{gearbox} \times \eta_{transformer} \times y \times h$$

where:

W = strip width = 0.05 for all strips except the last one that should be calculated
h = number of hours in a year
y = specific weight of the water (9.81 KN/m3)

The average annual energy production is then the sum of the energy contribution for each strip. The capacity of each turbine (kW) will be given by the product of their design flow (m3/s), net head (m), turbine efficiency (%), and specific weight of the water (kNm-3). In our case, the production of energy will be as hown in Figure 9.



3. Energy

3.1 Characteristic of the plant

Name plant		Progetto 1
Place		Malta
Sream		Fiume1
Project flow	[l/s]	933,8
Gross head	[m]	30
Type of turbine		Pelton

3.2 Power plant

Eff. turbine at the project flow	[%]	86%
Localized losses	[m]	0,05
Maximum hydraulic leak	[%]	1,31%
Efficiency to the generator	[%]	97%
Efficiency to the transformer	[%]	98%
Efficiency on the gearbox	[%]	100%
Percentage of plant shutdown	[%]	5%
Maximum power	**[kW]**	**233**
Rated power	**[kW]**	**210**
Average power	**[kW]**	**165**

3.3 Annual energy production

Annual energy production	**[MWh]**	**1 268**
Theoretical duration of annual operating	[giorni]	365

Figure 9: Results of energy production [9].

5. ECONOMIC ANALYSIS

5.1. Introduction

An investment in a small hydropower scheme entails a certain number of expenses, extended over the project life, and procures some revenues also distributed over the same period. The expenses include a fixed component - the capital cost, insurance, taxes other than the income taxes, etc- and a variable component - operation and maintenance expenses-. At the end of the project, in general limited by the authorisation period, the residual value will usually be positive, although some administrative authorisations demand the abandonment of all the facilities that revert to the State.

The economic analysis compares the different possible alternatives to allow the choice of the most advantageous or to abandon the project. From an economic viewpoint, a hydropower plant differs from a conventional thermal plant, because its initial investment cost per kW is much higher but the operating costs are extremely low, since there is no need to pay for fuel. If there are reasons to believe that certain factors will evolve at a different rate from inflation, these must be treated with the differential inflation rate. For instance, if we assume that due to the electricity tariffs will grow two points less than inflation, while the remaining factors stay constant in value, the electricity price should decrease by 2% every year.

Figure 10 shows the specific cost of installed capacity in Europe.

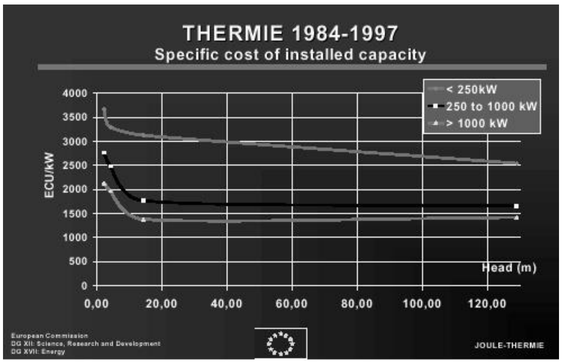
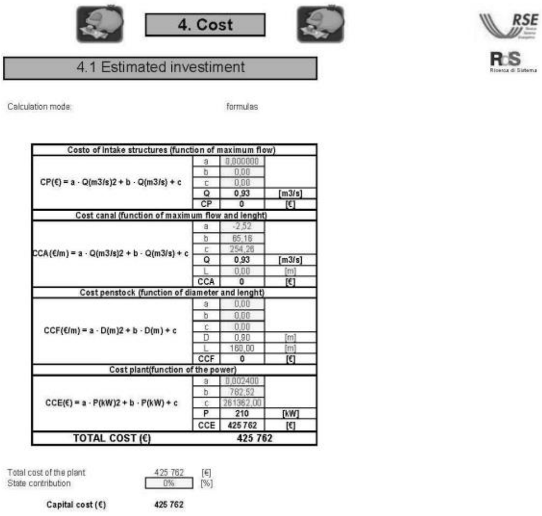


Figure 10: Specific cost of installed capacity.

The estimated costs for such an installation are tabulated below, together with the projected profits. Two scenarios for revenue have been considered, one with the rate of €0.07/kWh and the other with €0.144/kWh [7]. Figures 11 and 12 show the results obtained.



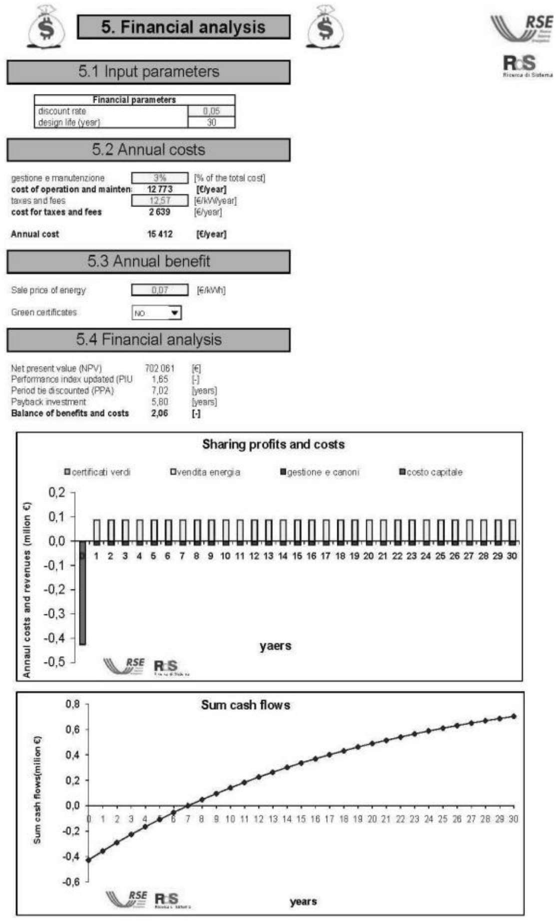
4. Cost

4.1 Estimated investiment

Calculation mode: formulas

Costo of intake structures (function of maximum flow)			
CP(€) = a · Q(m3/s)2 + b · Q(m3/s) + c	a	0,000000	
	b	0,00	
	c	0,00	
	Q	0,93	[m3/s]
	CP	0	[€]
Cost canal (function of maximum flow and lenght)			
CCA(€/m) = a · Q(m3/s)2 + b · Q(m3/s) + c	a	-2,52	
	b	65,16	
	c	254,26	
	Q	0,93	[m3/s]
	L	0,00	[m]
	CCA	0	[€]
Cost penstock (function of diameter and lenght)			
CCF(€/m) = a · D(m)2 + b · D(m) + c	a	0,00	
	b	0,00	
	c	0,00	
	D	0,90	[m]
	L	160,00	[m]
	CCF	0	[€]
Cost plant(function of the power)			
CCE(€) = a · P(kW)2 + b · P(kW) + c	a	0,002400	
	b	782,52	
	c	261362,00	
	P	210	[kW]
	CCE	425 762	[€]
TOTAL COST (€)		**425 762**	

Total cost of the plant	425 762	[€]
State contribution	0%	[%]
Capital cost (€)	**425 762**	



5.1 Input parameters

Financial parameters	
discount rate	0,05
design life (year)	30

5.2 Annual costs

gestione e manutenzione	3%	[% of the total cost]
cost of operation and mainten	**12 773**	**[€/year]**
taxes and fees	12,57	[€/kW/year]
cost for taxes and fees	**2 639**	[€/year]
Annual cost	**15 412**	**[€/year]**

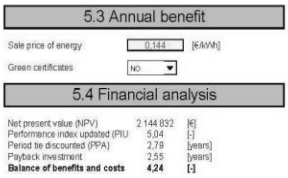
5.3 Annual benefit

Sale price of energy 0,07 [€/kWh]
Green certificates NO

5.4 Financial analysis

Net present value (NPV)	702 061	[€]
Performance index updated (PIU	1,65	[-]
Period tie discounted (PPA)	7,02	[years]
Payback investment	5,80	[years]
Balance of benefits and costs	**2,06**	**[-]**

Figure 11: Scenario for the feed-in tariff of €0.07/kWh fed into the grid [9].



5.3 Annual benefit

Sale price of energy 0,144 [€/kWh]
Green certificates NO

5.4 Financial analysis

Net present value (NPV)	2 144 832	[€]
Performance index updated (PIU	5,04	[-]
Period tie discounted (PPA)	2,79	[years]
Payback investment	2,55	[years]
Balance of benefits and costs	**4,24**	**[-]**

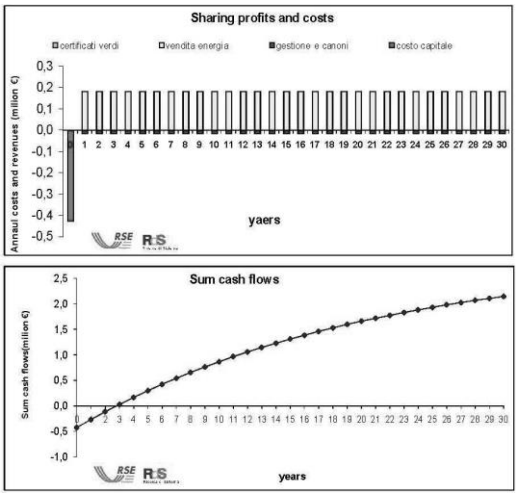
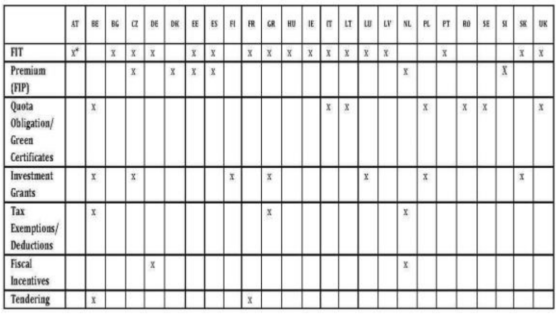


Figure 12: Scenario for the feed-in tariff of €0.144/kWh fed into the grid. Non-Residential (kWh) [7], [9].

5.2 Incentive policies

The main types of support existing in the Member States for small hydropower are: investment aid, tax (fiscal) incentives (deductions), green certificates or certificates for renewable electricity production, green bonus, net-metering, market based support systems. Existence of combined systems such as FIT and Premium are possible in certain countries. Table 1 shows the summary of the support scheme available in the EU [6].

Table 1: Resume of the support schemes for SHP in the EU.



	AT	BE	BG	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE	IT	LT	LU	LV	NL	PL	PT	RO	SE	SI	SK	UK
FIT	x*		x	x	x		x	x		x	x	x	x	x	x	x	x			x				x	x
Premium (FIP)				x		x	x	x										x					X		
Quota Obligation/ Green Certificates		x												x	x				x		x	x			x
Investment Grants		x		x					x		x					x			x					x	
Tax Exemptions/ Deductions		x									x							x							
Fiscal Incentives					x													x							
Tendering		x								x															

5.2.1. Price-based instruments

Feed-in Tariff (FIT): AT, BG, CZ, EE, GR, HU, IE, LT ,LU, LV, SK, UK, FR, PT, ES, IT, DE give guaranteed price per kWh to the generator of renewable. The tariff is set over a long period of time, usually 20 years. This system gives very long term visibility for investors (except in case of retroactive decisions that should be avoided). But FIT are disconnected from market needs and could create competition distortions [6].

Feed-in premium (FIP):

CZ, DK, EE, SI, NL,ES offer feed in premiums above the average spot electricity market price. Variable (e.g. based on the LCOE (levelized cost of electricity)) in BE or contract for difference in UK): Feed in Premium will vary according to market price. As the market price increases, the premium amount can be designed to decline (and vice versa). The risk is for the budget of the State [6].

Fixed: With a constant premium on top of the spot market price (the bonus remains unresponsive to changes over time and continues to be offered even if electricity prices increase (but the State can introduce caps and floors). The risk is for the investor. This system gives long term visibility for investors and with FIP; the operators shall react to market signals. Also, FIP must be encouraged as they give an incentive to producers to be connected to the market price [6].

5.2.2. Quantity based market instruments

Green certificates/Quota obligations:

In LT, SE, IT, BE, PL, RO, UK, suppliers are obliged to show that a certain amount of electricity delivered to the end consumers stems from RES. Producers of electricity from renewable energy sources receive an electricity certificate, a so called green certificate, for every MWh of green electricity produced. However, in some cases it is also possible to put in place a banding mechanism, which facilitates the State to assign more or less than one certificate per unit of energy according to the production technology. By selling these green certificates, the producer receives an extra income in addition to the sale of electricity. Green Certificates schemes usually include a penalty (or buyout price) that the entities under the obligation, have to pay if they fail to get or buy enough certificates by the end of the year. In this way, the system is connected to the market and the price is based on supply and demand. This approach gives investors a better perspective on better technologies to develop. But as designed today, the lack of European integration, in addition to States' interventions, disturb the system. However to avoid a system's collapse such as in Austria, or disturbance in wood industry as, for instance. In Poland, a need of careful supervision of the system by always keeping demand higher than the supply and avoiding unwanted effects resulting out of energy market distortion is inevitable [6].

Investment grants:

One main task of the investment support is not to improve energy production, but technologies as such. The state makes grants available for research and investment projects that involve the generation of renewable energy or the application of RES technologies. Among other costs, the preparation and planning costs and the cost of materials can be eligible for subsidies. In FI, LU, GR, BE, CZ, PL, SK, support is granted on a certain percentage rate of the investment, based on the planned investment of the application, not on the original investment, meaning that rising costs during project conduction are not eligible. In Finland, costs for feasibility studies, licensing acquisition of ownership are not included in the term investment. Nevertheless, demands set by others than energy authorities, such as water authorities or museum officials are accounted as energy investment.

Support of SHP has been applied to the full sector <10MW. The investment grant has proven to be non sufficient for small plants with high unit investment costs (Euro/kW) and common technologies. The grant is sufficiently in use by the larger SHP sector (1-10 MW) or project serving direct use of the produced energy by the owner of the SHP plant. In Belgium, investment grants are reserved for small and middle sized companies, and limited to a certain number of sectors. With its range of eligible companies and investments (from 25.000€ upwards, with a limit of up to 1, 5 million€ in 4 years), it excludes a number of companies being eligible to this form of support, creating some distortion in the market. Due to demands from other administrations (fish passes), extra investment costs are not eligible to this support.

Poland, the Czech Republic and Slovakia, use both, own resources and the Structural (Cohesion) Funds. In Poland, there are "Innovative economy" and "Infrastructure and environment" funds. Similar funds exist also in two other countries. Grants from the Environmental Protection and Water Management Funds are generally available for environmentally oriented infrastructure (mainly fish paths and fish ladders) [6].

Tax exemptions/deductions/Fiscal Incentives:

The Energy Investment Deduction is a tax scheme offered by the State in BE, GR and NL. In addition to the normal write off, a certain percentage rate of the investment costs can be deducted from the taxable profits. The income tax is therefore reduced [6].

Tendering:

In FR, BE, IT, the regulatory authority announces that it wishes to install a determined capacity of a given technology or suite of technologies. Project developers then apply to build the project and name the price at which they are willing to develop the project. Tenders commonly contain specific requirements (e.g. shares of local manufacturing, details of technological specifications, maximum price per unit of energy). The bidder with the lowest offer is selected and can go ahead with the project.

Usually the parties sign a long term contract (power purchasing agreement).

In Belgium, a tendering procedure is foreseen for some navigable waterways under public ownership. The system is equivalent to the French system: the developer who is able to develop the best project, and hence bid the higher price for a fee/kWh gets the concession. In this business plan, the developer takes all the financial incentives (listed above) into account that he has the right to. This system is a good way for governments to avoid windfall profits and to give enough security to investors. It seems to be the best system for mature technologies but is more appropriate for large installations. For both main financial instruments that were identified above, fiscal incentives, tax exemptions or tax reductions are applicable as well.

In general, these mechanisms exempt producers of renewable energy from certain taxes in order to incentivize the deployment of new and highly efficient technologies. The applicable tax rate in each Member State will influence on the effectiveness of such fiscal incentives [6].

5.3 Commons remarks

Need for stabilisation of the incentive schemes. An incentive system should be clearly set out and all changes should be scheduled and timed, so that producers can plan properly their investments. Hydropower developers need to know the rules at an early stage, for instance how and under which conditions their projects will be sustained.

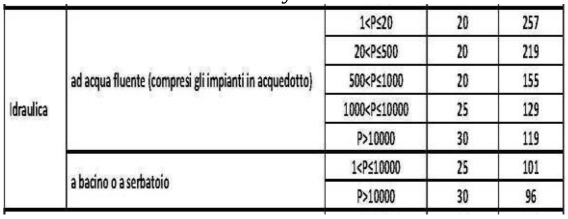
In the last months, a very strong barrier has been raised in some Member States: the regulatory risk, related to the latest legislative changes in the remuneration rules of the Special regime, the so called "moratorium" for new RES power plants, which includes even retroactive measures. Banks have some difficulties financing plants. All the uncertainty is leading to a greater difficulty on achieving financial support for new projects. Need for suitable incentive support for the rehabilitation and upgrading of old plants, to avoid in the future to loss the present energy production and, in many cases, to get the chance to increase it improving the schemes performances also from the environmental point of view. Special need for the following issues:

- Regulatory stability and governmental support to help achieving financing for developing new projects;
- Adequacy of the FIT and the concession period in relation with the specificities of the country;
- Decrease the investment insecurity by stabilizing the prices within the support system on a long term period and take care of the relatively low buy back rate;
- Reducing the extremely bureaucratic licensing environment [6].

5.4. Incentive policies in Italy

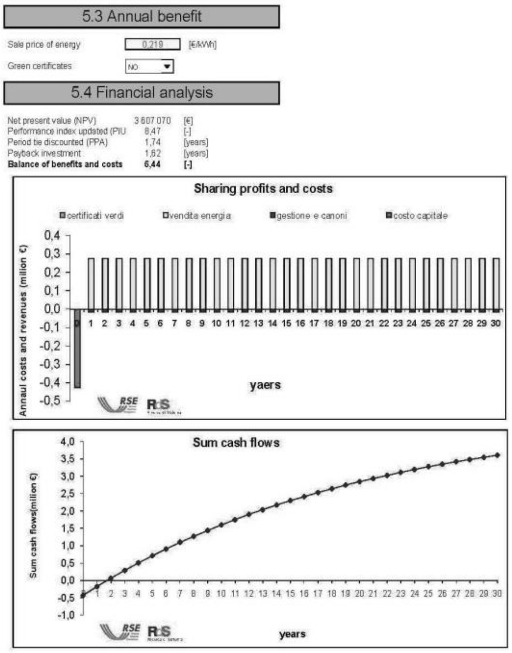
Table 2 summarises the fiscal incentives in Italy.

Table 2: Incentives in Italy



Idraulica	ad acqua fluente (compresi gli impianti in acquedotto)	1<P≤20	20	257
		20<P≤500	20	219
		500<P≤1000	20	155
		1000<P≤10000	25	129
		P>10000	30	119
	a bacino o a serbatoio	1<P≤10000	25	101
		P>10000	30	96

For the type of plant examined in the article, the reference rate is equal to €219/MWh for a period of 20 years. Figure 13 details the results [8].



5.3 Annual benefit

Sale price of energy 0,219 [€/kWh]

Green certificates NO

5.4 Financial analysis

Net present value (NPV) 3 607 070 [€]
Performance index updated (PIU 8,47 [-]
Period be discounted (PPA) 1,74 [years]
Payback investment 1,62 [years]
Balance of benefits and costs 6,44 [-]

Figure 13: Scenario of revenues for the proposed system with an annual production of €219/MWh [8], [9].

6. CONCLUSION

From research done to compile the following article, it is noted that Malta has no incentive policies for hydropower. The case study shows that there is a potential for exploiting the down flow of the water head at the treatment plant of Ta ' Barkat.. The payback period for installing pelton turbines at the site, would be 5.8 years with a FIT of €0.07/kWh and 2.55 years for a FIT of €0.144/kWh.

Hydropower is now a mature technology and every opportunity to harvest energy from it would contribute to the renewable energy target and should be seriously considered.

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