Hydropower potential from the drinking water systems of the Piemonte region (Italy)

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Abstract: In this study we focus on energy production by micro-hydro plants (MHPs) installed on pipe water supply systems, which convert the potential energy of a mass of drinking water flowing in the pipes with a certain head into hydropower at the lower end of the scheme. With an approach covering the drinking water systems we present a methodology aimed at estimating the potential and economic feasibility of the MHPs located in the Regione Piemonte (North-Western Italy), using Geographical Information System (GIS), Digital Terrain Models (DTM) and an existing database of the drinking water service facilities. Based on these indications, more detailed assessment of the hydropower potential can be pursued in the most promising mountain areas, that can also benefit of interesting opportunities for water system renovation.

Keywords: Micro-hydro, hydroelectric potential, water distribution systems, measure of financial performance.

1. Introduction

In the past ten years energy production from renewable sources has become a topic of considerable interest due to the increased cost of non-renewable resources, the greater sensitivity to environmental issues, and the opportunities produced by government renewable energy supports. In this context, the possibility of energy production from micro-hydro systems takes a role of main interest. In this paper we focus on electricity generation by micro-hydro plants integrated in water supply systems, which convert the potential energy of water flowing in pipes into electric power at the lower end of the pipes. While other European countries, such as Switzerland, have widely invested in this technology, Italy is still below its potential development level.

In the "run-of-river" category recent studies have analyzed the problem of the preliminary evaluation of small hydropower plants (SHPs) (e.g. [1]), the problem of designing the SHPs in terms of maximizing the economic benefits of the investment (e.g. [2]), the problem of determining the optimal installation capacity (e.g. [3]) and the techno-economic viability of SHPs of wide areas (e.g. [4]). However, to the authors' knowledge, no techno-economic studies are available for micro-hydro plants (MHPs) installed on water supply systems. In this paper, we systematically analyze a large number of drinking water supply schemes in the Regione Piemonte (North-Western Italy) to assess the potential of MHPs production. This evaluation is based on a number of simplifying hypotheses and produces a first glance of technical feasibility.

Once ascertained the technical feasibility, in most cases the energy production of this type of power plants is very small. In these cases an economic analysis may show that the installation and the operating costs are not negligible and that government incentives are necessary to financially support the works. Therefore, considering scale investment aimed at extending the use of micro-hydro, it is worthwhile estimating their economic feasibility. One of our aims is to find the minimum power level at which the investment can return an economic profit. With this purpose in mind, we take advantage of the joint use of economic and technical feasibility to estimate the energy generation potential at a regional scale.

We are conscious that the power generation from MHPs cannot be sufficient to solve the energetic problems of a certain region and that regulations which discipline this technology are changing due to emerging needs and knowledge. Here we show a methodology aimed at estimating the economic feasibility of MHPs on a large scale to encourage their diffusion. This methodology may help a swift and fair diffusion of the MHPs as well as stable and efficient regulations of this technology due to clearly identified advisable qualitative and quantitative economic incentives for the renewable resources.

The plan of the paper is as follows: in section 2 we present our methodology aimed at estimating the hydropower potential from water supply systems and in section 3 the estimation of revenues from small hydropower systems is shown. Section 4 is devoted to the discussion of the results obtained by applying our framework to a large scale case study and section 5 closes the paper.

2. A framework for estimating hydropower potential from water supply systems

In a water supply system using closed conduits the excessive pressure head has been always considered one of the major problems in mountainous regions. Several systems, such as pressure relief valves (PRVs) stations, can be adopted in order to reduce the overhead. The dissipated energy is often regarded as damaging the water distribution system; however, it could be considered wasted energy, that can be converted by installing suitable mini, micro, or small turbines [5].

SHPs can be implemented into a water supply system with several possible installation options, using tanks or distribution line hydropower plants. In the first case the hydropower plants are installed in the different sections of the transmission pipeline connecting the supply tank to the service or regulating tank. In the second case a power plant is installed in the pipeline just before its connection to the distribution system. It is worthwhile highlighting that in the last case, the hydropower plant is subject to wide diurnal and seasonal fluctuations. The possibility of the installation is therefore reliable only if the differential head between the service tank and the point of delivery of the distribution line is relatively high. Furthermore, any regulation of flow may cause technical hitches on the water supply schedule.

MHPs installed instead of PRV stations divert a fraction of the potential energy which would have been dissipated and help to reduce wear and tear caused by extra pressure. A turbine generally operates by the differential head available between the headrace and the tailrace. In order that a turbine may be installed, a minimum pre-specified residual pressure head at the delivery end of the water supply system must be ensured. In other words, if the sum of the minimum head requirement and the head losses in the delivery system is less than the available pressure head, a turbine installation may be feasible.

Based on these premises, a macro-scale estimation of the intrinsic potential of the water supply systems can be made in order to create energy-potential maps useful to identify the most interesting sites. Those sites will be subjected to further inspections to monitor the discharges in order to achieve technical feasibility assessment and to determine whether turbines installations could guarantee an annual economically convenient electricity production.

The need to define an intrinsic potential (Pni) of a pipe network stems from the requirement of estimating the achievable maximum theoretical energy potential. This can be done without knowing in advance the details of the components of the water system.

The Pni of a water supply system is the maximum theoretical energy potential that can be obtained from a MHP integrated in the water supply main pipe at the lowest point. Because the hydraulic head on the turbine (intrinsic head) is maximum, the power production that can be obtained is also maximum. In order to calculate the Pni, the knowledge of the seasonal demands, the elevation of the water sources and of the lowest point of the water supply system are required. When a turbine is installed in a water supply system, the hydraulic head necessary to the correct operation of the pipe network must be guaranteed. For this purpose, the lowest point of the water supply system is made coinciding with the lowest in-line water tank of the plant (A definition). However in most cases, especially for small mountain water supply system, the water tank coincides with the water sources. To overcome the problem of computing Pni, the lowest point of the water supply system is made coinciding with the lowest node of the system (B definition).

Following the definition of Pni given by [6], the intrinsic potential of a water supply system (A definition) is the sum of the potentials of every water source supplying the system. The single water source potential is evaluated using the source discharge q_i and the difference between the water source elevation and the lowest in-line water tank height as hydraulic head H (Fig.1).

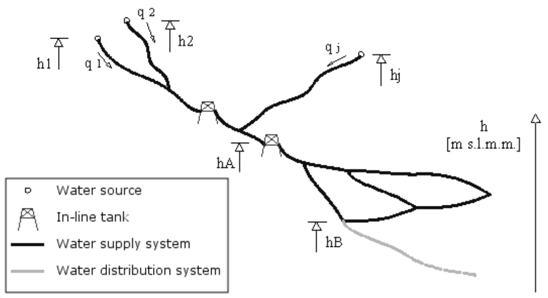

Figure 1: Theoretical scheme used for defining of the quantity necessary to evaluate the intrinsic potential.

The expression to estimate Pni_A is:

$$Pni_A = \sum_{j=1}^{n_s} \gamma \cdot q_j \cdot \left(h_j - h_A\right) = \gamma \cdot q_j \cdot H_A \quad (1)$$

where n_s is the total number of water sources of the system, γ is the water specific weight [kN/m^3], q_j is the jth source discharge [m^3/s], h_j is the elevation of the jth source of the system [m], and h_A is the height of the lowest water tank of the system [m].

H_A [m] is the intrinsic total head and it is defined as:

$$H_A = \sum_{j=1}^{n_s} \frac{q_j \cdot \left(h_j - h_A\right)}{Q} \quad (2)$$

The expression to estimate Pni_B is:

$$Pni_B = \sum_{j=1}^{n_s} \gamma \cdot q_j \cdot \left(h_j - h_B\right) = \gamma \cdot q_j \cdot H_B \qquad (3)$$

where h_B is the height of the lowest node of the system [m] and all other symbols preserve their previous meaning.

According to the previous B definition of intrinsic potential, the hydraulic head H_B is defined as the difference between the water source and the lowest node of the water supply system (Fig.1). It is defined as:

$$H_B = \sum_{j=1}^{n_s} \frac{q_j \cdot \left(h_j - h_B\right)}{Q} \qquad (4)$$

The B definition is useful because it leads to the estimation of the intrinsic potential in those cases where there isn't an in-line water tank or in cases where the A definition cannot be applied. If the Pni can be computed by Eq.(2), the Pni_B is:

$$Pni_B = Pni_A + \gamma \cdot Q \cdot \left(h_A - h_B\right) \qquad (5)$$

If the Pni of a water supply system is a useful information, even more interesting is the effective potential (Pne), defined as the difference between the intrinsic potential and the sum of head losses along the pipes. The head losses are function of the pipe diameters, of the pipe materials and of the discharge involved.

Computation of the above definitions of potential is intended to be made on a great number of water supply schemes simultaneously. In order to reduce the computational effort, a simplified scheme for the water supply system, shown in Fig.2, is adopted. In this scheme the water sources are connected to the lowest water tank with dummy pipes. The dummy pipes are characterized by a length equal to the plane distance between the jth source and the lowest tank or node of the scheme, and by a constant diameter.

Since every dummy pipe connects the jth source with the lowest tank or node of the system, the head losses would tend to be overestimated. To avoid this problem, we take advantage of the use of two definitions of the characteristic network diameter: the maximum diameter of the water supply main (d_{max}) and the weighted average diameter (d_{ave}), estimated as:

$$d_{ave} = \left(\frac{\sum_{i=1}^{n_c} d_i^{5.33} \cdot l_i}{\sum_{i=1}^{n_s} l_i} \right)^{\frac{1}{5.33}} \qquad (6)$$

where n_c is the number of pipes in the water supply system; d_i is the diameter of the ith pipe; l_i is the length of the ith pipe. Using d_{ave} that depends on $d^{5.33}$, losses are weighted linearly and d_{ave} can be effectively used to compute the total losses along the main pipe.

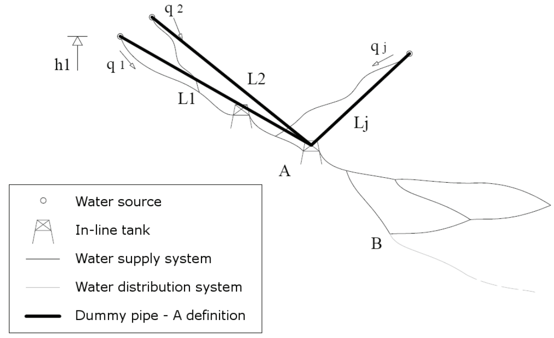

Figure 2: Theoretical scheme used for defining the dummy pipe necessary to evaluate the effective potential (A-definition).

The Pne can be computed as:

$$Pne = \sum_{j=1}^{n_s} \gamma \cdot q_j \cdot \left(h_j - h - \Delta y_j\right) \qquad (7)$$

where h [m] is the height of the lowest tank of the system (h_A) or of the lowest node of the scheme (h_B), Δy_j [m] is the term related to head losses and all other symbols preserve their previous meaning. The head losses are estimated as:

$$\Delta y_j = J_j \cdot L_j \qquad (8)$$

where J_j is head gradient of the jth dummy pipe, which links the jth source with the lowest tank or node, and L_j is the distance between the jth source and the lowest tank or node.

J_j of the jth dummy pipe is evaluated through the Strickler's formula:

$$J_j = \frac{10.29}{k_s^2} \cdot \frac{q_j^2}{d^{5.33}} \qquad (9)$$

Where k_s is the Strickler's coefficient of the dummy pipe [$m^{1/3}/s$]. As a measure of the roughness of the pipe, the Strickler's coefficient is a function of the material of the pipe. k_s is computed as the average of the Strickler's coefficients of the water supply system pipes. q_j is the average jth water source discharge [m^3/s], and d is the diameter of the pipe (d_{max} or d_{ave}).

Although greatly simplified, as it disregards the real configuration of the supply network, the method allows to establish, in a first approximation, if the overall features of the existing pipes make the system suitable for a micro hydro installation. Differences emerging between the intrinsic and the effective potentials highlight the role of the head losses in any specific system, that increases with the system service life.

Furthermore, the Eqs.(1), (3), and (7) can be systematically applied to estimate the hydropower potential of a wide region. This kind of application requires the availability of an extensive database of the water supply systems characteristics. The database need to have a well organized structure of the different classes of elements of the water supply systems and a reasonable amount of data related to the sources discharges.

3. Assessment of profitability from small hydropower systems

To install a small hydropower plant on the main supply of a drinking water system, some conditions must be satisfied. From a technical point of view, the manufacturing characteristics of the pipes must comply with the technical features of the MHP, in order to avoid the risk of too-high pressure values due to water hammer. If the technical feasibility is ascertained, it is also necessary to verify if the investment could be economic profitable. Assuming that the first two requirements are satisfied, the convenience of the installation only depends on the economic feasibility analysis results ([7], [8], and [9]).

In this section, we introduce the performance index we used to evaluate the economic feasibility of a MHP integrated in a drinking water system. The main aim of the analysis is to show the profitability of the MHPs of Piemonte as a function of the nominal power that can be installed, considering different economic and financial scenarios.

Since the evaluation of an investment in the design, construction and management of a MHP is equivalent to the analysis of its financial development, we consider as key parameters for the study the classical financial variables, namely “costs”, “proceeds”, and “time”.

The “costs" represent the capitals required for the achievement of the project and for its future management, necessary to guarantee the operational efficiency. They can be classified in “construction costs”, “trading and maintenance annual costs”, “administrative and management costs”, and “annual general costs and taxes”.

The “construction costs” represent the economic burden for the design and installation of the hydraulic, electric, and structural elements, for the achievement of the project and for other extra works. Since the aim of the study is to have an overall idea about the possible future development of MHPs, the possibility of a main supply replacement is not considered. The water system is always supposed to bear the static and dynamic stress due to high pressure values. Although this assumption can apparently lead to an extremely simplified scenario, it makes possible to evaluate the goodness of the investment referred only to the MHP integration in the water supply system. The main supply replacement is, indeed, a necessary choice in those cases of old age pipes, even if a MHP installation is not planned. Hence, the replacement burden are not a cost due to the small hydropower installation, unless an increase in the diameter value ensure remarkable reduction of the head losses.

The “trading and maintenance annual costs” are the costs related to the system management and to the costs of the ordinary and extraordinary periodical repairs.

The “administrative and management costs” are related to the cost that an energy producer has to pay to the electricity network manager to cover the administrative and management costs.

The “annual general costs and taxes” are related to the annual system management and to the tax treatment.

The “proceeds” are represented by the incomes due to the energy sale and the “time” is related to the physical, technical and commercial life of the goods that characterize the investment.

The economic feasibility of an investment can be evaluated through different approaches. In the present study, the proposed methodology take advantage of the definition of the Net Present Value (NPV), or Net Present Worth (NPW), based on the criterion of the cash flow update. In finance, NPV of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows. NPV is a central tool in discounted cash flow analysis, and is a standard method for using the time value of money to appraise long-term projects. It measures the excess or shortfall of cash flows, in terms of PV, once financing charges are met.

Each cash inflow/outflow is discounted back to its PV and then they are summed. Therefore NPV is,

$$NPV = \sum_{k=1}^{n} \frac{C_k}{\left(1+i\right)^k} \tag{10}$$

In the previous formula k is the time of the cash flow, i is the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk), and C_k is the net cash flow (the amount of cash inflow minus outflow) at time k.

The result of this formula, if multiplied with the annual net cash inflows and reduced by initial cash outlay, will be the present value. In case where the cash flows are not equal in amount then the previous formula will be used to determine the present value of each cash flow separately. Any cash flow within 12 months will not be discounted for NPV purpose.

NPV is an indicator of how much value an investment or project adds to the firm. With a particular project, if C_k is a positive value, the project is at the status of discounted cash inflow at the time k. If C_k is a negative value, the project is at the status of discounted cash outflow at the time k. Appropriately risked projects with a positive NPV could be accepted. This does not necessarily mean that they should be undertaken since NPV at the cost of capital may not account for opportunity cost, i.e. comparison with other available investments. In financial theory, if there is a choice between two mutually exclusive alternatives, the one yielding the higher NPV should be selected. If the NPV is equal to zero, we should be indifferent in the decision whether to accept or reject the project. This project adds no monetary value and the decision should be based on other criteria, e.g. strategic positioning or other factors not explicitly included in the calculation.

4. A large-scale case study (Regione Piemonte, Italy)

4.1 Regione Piemonte MHP energy potential estimation

Evaluating the feasibility and cost effectiveness of hydropower installations along a water supply network is the result of an analysis conducted in stages in which the detail of the investigation level is increasing. In a first phase, the analysis is aimed at estimating the macro-scale hydroelectric potential of each water supply system. At the next stage, the maps of potential can be useful to easily identify those potentially suitable sites for which further inspections and investigations are necessary. At the same time, monitoring the water source discharge is essential both to achieve an evaluation of the technical and economic feasibility and to determine if installation of one or more MHPs could be of economic interest.

With an approach covering more than 1000 drinking water systems in the region (Tab.1), we show a methodology aimed at estimating the potential and economic feasibility of the MHPs located in Piemonte.

The main data source for our study is represented by the census conducted by the Regione Piemonte, documented in the report "Infrastructures of the water supply systems in Piemonte" (May 2000). This study concerns the consistency of the waterworks on the basis of the surveys campaign conducted in 1997 and 1998. The georeferenced database (GIS), compiled by CSI Piemonte (Information System Consortium Piemonte - Italy), is organized into separate items for their class (eg penstocks, water sources, in-line tanks, etc.). For each class two types of information are available, the geographical references and the alphanumeric data. As the hydropower potential of a plant is a function of the head and water source discharge, as we showed in Section 2, the basic data necessary to estimate both the intrinsic and effective potential are catalogued in three particular infrastructure classes, i.e. "Sources", "Tank systems", and "Waterworks pipeline".

The first step of the analysis is aimed to checking the data consistency, focusing on water discharges, with regard to water source discharges and source elevations, and on water tanks with regard to heights. Penstocks are examined with regard for the availability of information on diameters, materials and year they have come into service. The presence of uncertainty and incongruity in the available data, especially with regard to the sources discharge and elevations, lead us to validate these data by means of different approaches. In particular we consider as the source discharge datum: (i) the average between the minimum and the maximum source discharge datum reported in the database (q_D); (ii) the estimated annual flow volume of the sources (q_A); (iii) the estimated annual volume of water flowing in the net (q_V); (iv) the estimated water annual demand based on the population datum (q_S). With regard to the source height data, we consider the values reported into the database (h_{DB}), the values extract from the 1:50 Digital Terrain Model (DTM) (h_{DTM50}) of Piemonte, and the values extract from a 1:250 Piemonte DTM (h_{DTM250}). Since the height of the lowest node of the water supply systems, necessary to apply the B definition of potential, is not reported into the database it is also extract from the 1:50 Piemonte DTM.

The macro-scale hydroelectric potential of Piemonte is then estimated both as intrinsic potential, through Eqs.(1) and (3), and as effective potential, through Eq.(7). Since for a certain number of water supply systems the A definition of potential cannot be applied because there is no in-line water tank in the plant, (or the water tank height is equal or lower than the source height), it is necessary to make use of the B definition. Although less realistic because it assume that a MHP can be installed in a node of the water supply system, it leads to overcome the above-mentioned problems and hence estimate the value of the macro-scale potential for every water supply system recorded in the database for which the data consistency was proved.

Regione Piemonte
Water Supply Systems

ATO	*Number of plant*	*Population*
1 – Novara, Verbania	176	501 723
2 – Vercelli, Biella	271	433 852
3 – Torino	288	2 135 488
4 – Cuneo	312	546 294
5 – Asti	175	233 852
6 – Alessandria	225	319 661
Total number of plants	1 447	4 170 870

Table 1. Regione Piemonte water supply system divided for Optimal Territorial Area (ATO).

The intrinsic head, H_A or H_B, as it can be seen from Eqs.(2) and (4), is a function of the difference between the upstream height where the pressure pipe starts and the downstream height where the MHP is installed. Since both A and B definitions assume that no upper reservoir is installed in the system plant, the head, H_i, is estimated as the average of the head, h_j, between the water source and the MHP heights, that is in correspondence of the in-line water tank (A definition) or of the lowest node of the scheme (B definition), weighted by the single water source discharge. In this way, the estimated Pni is equivalent to the maximum power that can be produced by an installed MHP. Although the so evaluated potential overestimates the effective energy production, the introduced simplifications are reasonable in a preliminary stage of the project planning. At this stage the main aim is indeed creating maps of the water supply systems suitable for a MHP which deserves in the future further consideration about the technical feasibility.

The Pne of the water supply systems of Piemonte is estimated through Eq.(7), as a function of the lowest tank of the scheme elevation and as a function of the average diameter (Pne_{Admed}) or the maximum diameter (Pne_{Admax}). It is also evaluated as a function of the minimum node of the scheme elevation and of the average diameter (Pne_{Bdmed}) or the maximum diameter (Pne_{Bdmax}). In Fig.3 the most interesting water supply system locations for micro-hydro purpose are shown.

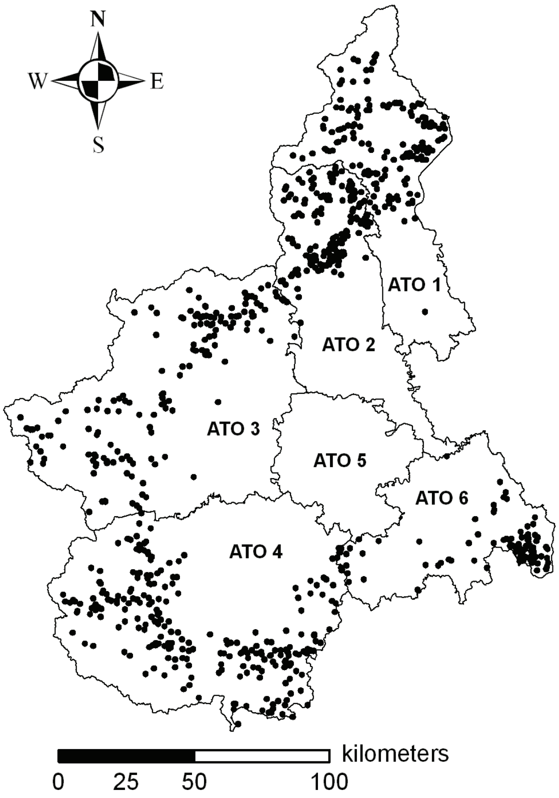

Figure 3: Water supply main locations of Regione Piemonte most interesting drinking water systems.

In Fig.4 and 5 the Pni_A and Pni_B distribution of the water supply system are shown in a logarithmic plane as a function of the discharge that can be swirl by a MHP and of the intrinsic head. It can be seen that most of the MHP with an intrinsic, or effective, potential greater than 200kW are located in ATO 1, ATO 3 and ATO 4. These three ATO also represent the areas that show the maximum hydroelectric potential in Piemonte. It can be explained looking at the morphological characteristics of the areas: ATO 1, ATO 3 and ATO 4 are indeed dominated by vast mountainous zone with huge differences in altitude and characterized by large water sources discharge rate. The communities living in these areas are organized in small villages and are served by a unique water supply system with several branches. Therefore, the water source flowing in the main supply pipe has to be sufficient to guarantee a proper service level for the furthest user.

From Fig.4 and 5 it is also possible to notice that more than 50% of the examined water supply systems falls in the region of potential below 20kW and more than half of them shows Pni values lying in the interval 3-10kW. It is worthwhile highlighting that in ATO 5 there are no results for the hydroelectric potential distribution. This means that the areas in ATO 5 are not interesting from the micro-hydro potential point of view due to their morphological configuration, mainly hilly with minor differences in altitude.

Fig.6 shows the Pni and Pne PDF of MHPs located in Piemonte. It can easily be seen that most of the global Pni of the area lies in the interval 21-31MW, whereas the variability range of the Pne is 14-26MW. Furthermore, it can be seen that the Pni estimated through Eq.(3) is larger than the Pni estimated through Eq.(1). It can be explained looking at the intrinsic head as defined in Eq.(3) and in Eq.(1). In Eq.(3) it is the difference between the water source elevation and the lowest node of the scheme height, whereas in Eq.(1) it is defined as the difference in height between the water source and the lowest water tank of the system. Since the lowest node of the scheme is usually lower than the lowest water tank, Pni_B is characterized by a higher intrinsic head than Pni_A. Furthermore, since it is always possible to identify the lowest node of the scheme, the number of plants for which the Pni_B can be computed is greater than the number of plants for which the presence of a system water tank is required in order to estimate the Pni_A. Moreover, as showed in Fig.4 and 5, there are many plants in Piemonte that give a modest contribution to the global hydroelectric potential amount.

In Piemonte there are several conventional hydropower with an installed potential around 30MW, for example, Ponte Morasco (29MW) or Ponte Vannino installation (32MW). Since just only one of the conventional hydropower located in the region can produce the equivalent power of the maximum estimated macro scale global potential of Piemonte (31MW), MHP could be thought as a modest contribution to the energy production market.

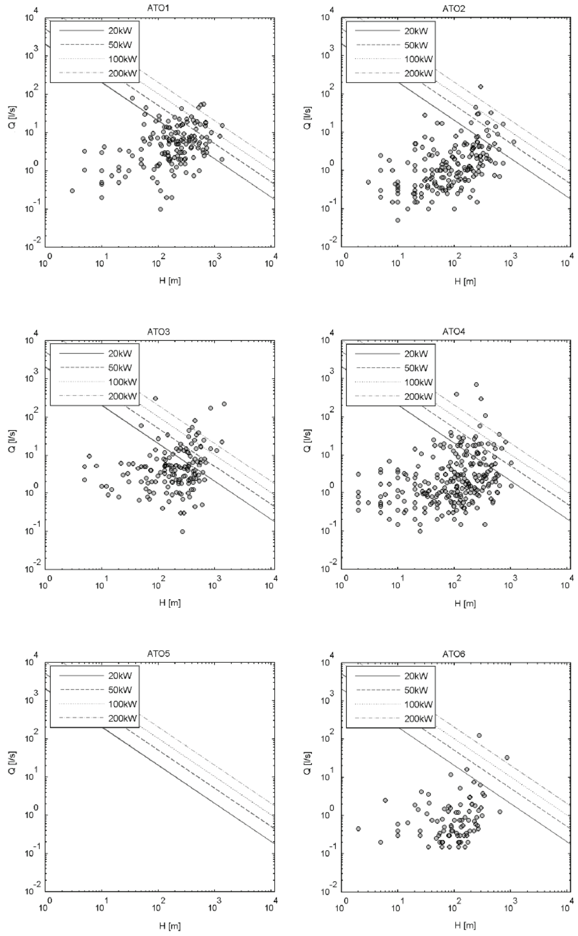

Figure 4: Pni evaluated considering the water supply system demand and the height of the lowest tank reported into the database.

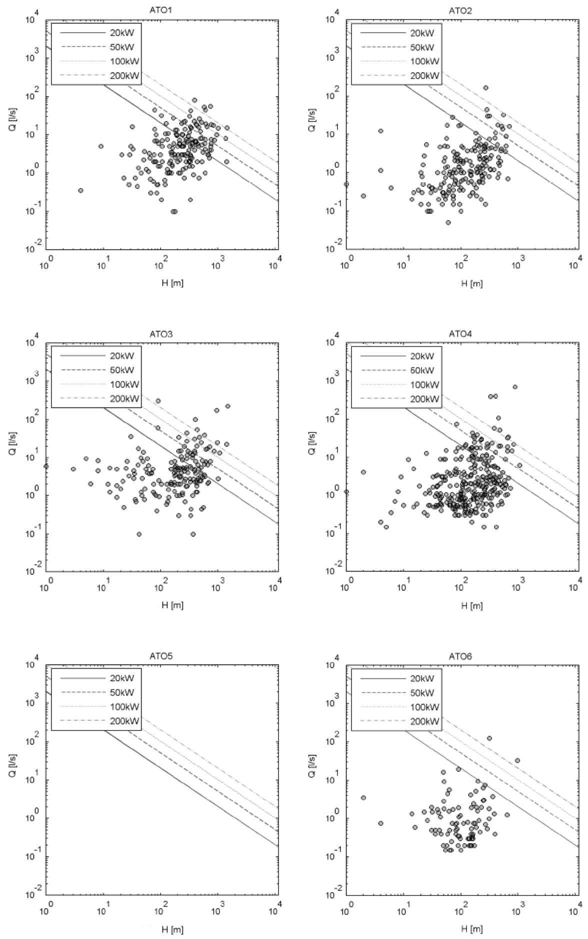

Figure 5: Pni evaluated through the water supply system demand reported in the database and considering the height of the lowest node of the net evaluated by a 1:250 DTM.

Although the energy contribution by MHPs integrated in the water supply systems is not quantitatively significant, these installations have several extremely interesting advantages. Indeed, frequently conflicting background for new conventional hydroelectric plants or for upgrading the existing are created by the imperatives of the aquatic ecosystems conservation and by the competition between the different uses of the water resources. On the other hand, MHPs don't imply strong impacts on the water resources system, but guarantee the conservation and the multiple uses of the water resources. In addition, MHPs highly characterize the mountain and piedmont regional development. The incentive of the water multiple use (drinkable and hydroelectric) can also lead to a reorganization and rationalization of the existing mountain water supply systems and to a reduction of the drinkable water prizes due to the income risen from energy sale.

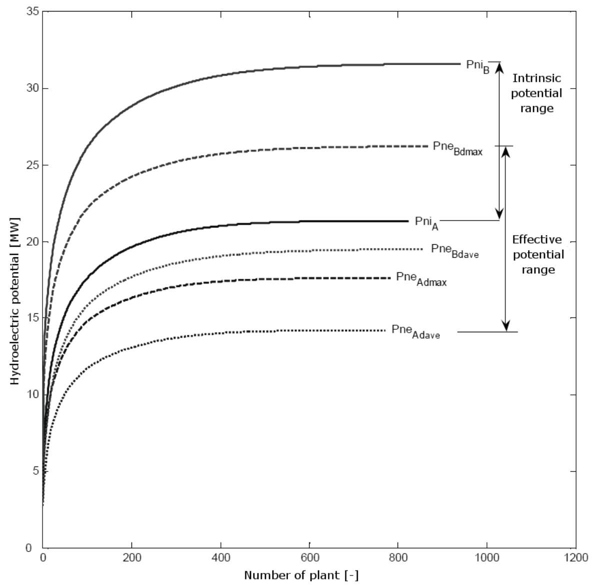

Figure 6: Total intrinsic and effective potential of Piemonte water supply.

4.2 Regione Piemonte MHPs economic potential estimation

With a view to a wide diffusion of MHPs, the economic feasibility of large scale investment can give an idea of the potential range for which a yield is probable. On the basis of the obtained results about micro-hydro energy potential, we applied the methodology shown in Section 3 to estimating the economic potential of the MHPs located in Piemonte.

In our study we analyze the economic feasibility of the MHPs that display Pni_A values up to 400kW, considering different possible scenario. The examined scenario are characterized by some initial hypothesis about both the efficiency of the installation (η) and the weighted average cost of capital (WACC). The installation efficiency account for the seasonal and daily water demand fluctuations, for the period in which the plant is not working to allow maintenance works and for the time when the maximum potential is not available. In this study we assume as installation efficiency values η=50% and η =30%, that respectively corresponds to 6100 and 3100 equivalent hours. For what it concerns the WACC, we consider WACC=8% and WACC=14%. Beyond the η and the WACC, there are other parameters that can influence the analysis (e.g. the discount rate *i*). Since we are looking at the MHPs feasibility of a region and not of a single specific site, considering this parameters as constant can be reasonable. Another important parameter to account for is represented by the support for Renewable Energy Sources (RES) in conformity with the laws in force. The Italian laws, in details, provides that RES producers may apply for Green Certificates (RECs) or the all-inclusive feed-in tariff, as shown in Appendix A.

In this study the results of the economic potential of the MHPs either in the case that they have been commissioned before December 31st 2007 or in the case that they have been commissioned after December 31st 2007 are shown. The case of the 40 years return period of the investment is analyzed.

In the case that plant have been commissioned before December 31st 2007 the results of our study are shown in Figs.7, 8, and 9. The MHPs that have been commissioned before December 31st 2007 are eligible for the net metering service only if their capacity is up to 20kW, otherwise, MHPs of more capacity can apply for the sale of energy at guaranteed prices. Fig.7 shows the NPV analysis results under the hypothesis of net metering service and WACC=8%. An economic profit is possible in those cases in which a plant capacity of at least 6kW can be installed and if η is over 50%, otherwise, whether the η is lower, for instance 30%, an economic profit is possible only if a plant of 9kW capacity is installed.

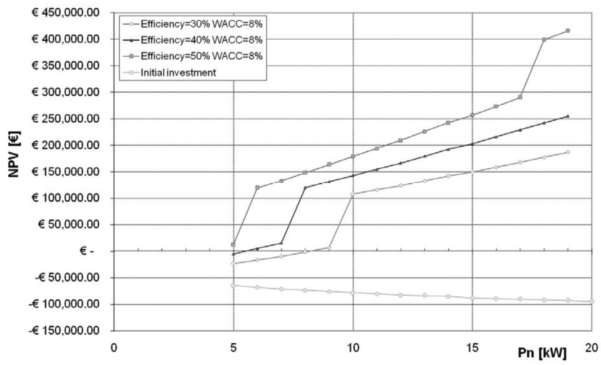

Figure 7: NPV estimation in the case of return period of 40 years, WACC=8% and energy sale as net metering service. The MHP is supposed to have been commissioned before December 31st 2007.

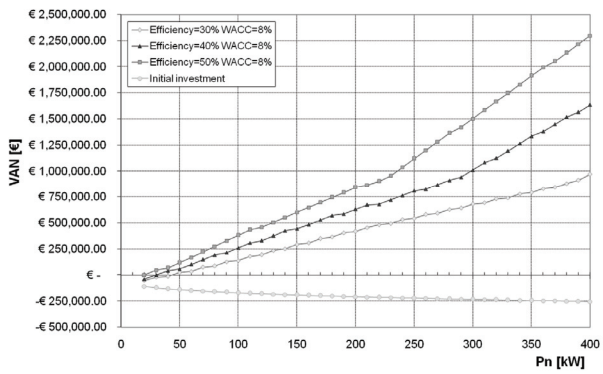

Figure 8: NPV estimation in the case of return period of 40 years, WACC=8% and energy sale as guaranteed prices. The MHP is supposed to have been commissioned before December 31st 2007.

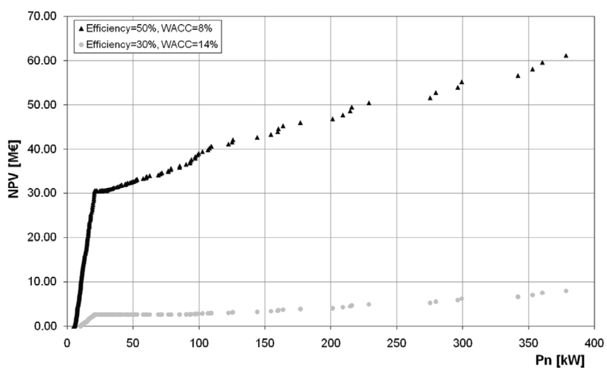

Figure 9: NPV PDF of Regione Piemonte MHPs in the case of return period of 40 years, under the hypothesis that they have been commissioned before December 31st 2007.

In the case of guaranteed prices (Fig.8), the NPV is positive for installed capacity of more than 20kW with η=50%. If the η decreases to 30%, the NPV is positive only if it is possible to install a plant of 50kW capacity. The necessity of a high power capacity plant in the case of low η is similar to the one shown for plant capacity up to 20kW. As the η decreases, higher power capacity plant are indeed needed to produce the quantity of energy the sale of which can level the high building cost.

Fig.9 shows the NPV PDF of Piemonte potential MHPs in both the case of η=50% and WACC=8% and η=30% and WACC=14%. It can be seen that the global NPV in the first case is about 60M€, whereas in the last case it is less than 10M€.

In the case that plant have been commissioned after December 31st 2007 the results of our study are shown in Figs.10, 11, and 12. Fig.10 shows the NPV analysis results under the hypothesis of net metering service and WACC=8%. An economic profit is possible in that cases in which a plant capacity of at least 6kW can be installed and if η is over 50%, otherwise, whether the η is lower, for instance 30%, an economic profit is possible only if a plant of 9kW capacity is installed. In the case of guaranteed prices (Fig.8), the NPV is positive for installed capacity of more than 20kW with η=50%. If the η decreases to 30%, the NPV is positive only if it is possible to install a plant of 50kW capacity. The necessity of a high power capacity plant in the case of low η is similar to the one shown for plant capacity up to 20kW. As η decreases, higher power capacity plant are indeed needed to produce the quantity of energy the sale of which can level the high building cost.

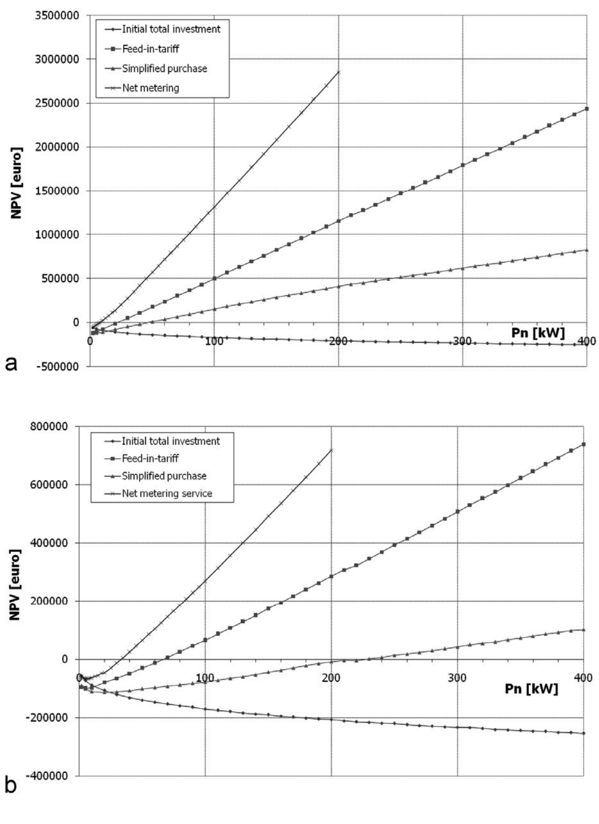

Figure 10: NPV estimation in the case of return period of 40 years; (a) η=50% and WACC=8%; (b) η=30% and WACC=14%. The MHP is supposed to have been commissioned after December 31st 2007.

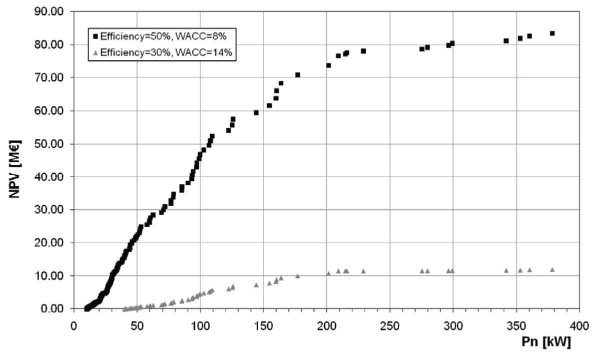

Figure 11: NPV PDF of Piemonte MHPs in the case of return period of 40 years, under the hypothesis that they have been commissioned after December 31st 2007 and that energy is sold as net metering service for MHPs up to 200kW and simplified purchase and resale arrangements for MHPs over 200kW.

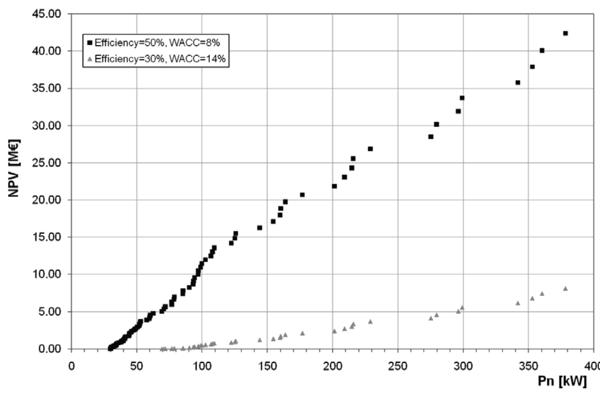

Figure 12: NPV PDF of Piemonte MHPs in the case of return period of 40 years, under the hypothesis that they have been commissioned after December 31st 2007 and that energy is sold following the feed-in-tariff mechanism.

The results shown in Fig.10 highlight that for MHPs up to 200kW the net metering service is the most profitable choice for the producers although for plant up to 20kW it is possible to see a marked worsening. For example, let us consider a MHP with an installed capacity of 20kW, the WACC=8% and η=50%. As shown in Fig.7, the MHP supposed to have been commissioned before December 31st 2007 displays NPV=416000,00€, while the MHP supposed to have been commissioned after December 31st 2007, shown in Fig.10-a, displays NPV=133000,00€. However, in the second case a credit balance is shown only for installed power capacity higher than 9kW (Fig.10-a), whereas in the first case a credit balance is possible for installed power capacity of 6kW (Fig.7), the supports benefit also those plant with an installed power capacity in the range 20-50kW which in conformity with the previous support scenario cannot guarantee the return of the initial investment. Furthermore, if from a strictly economic point of view low capacity MHPs are not attractive, they can guarantee that only the MHPs that assure high performances would be built and can avoid a scattershot diffusion of the MHPs.

In Figs.11 and 12 the NPV PDF of Piemonte MHPs economic potential is shown. Fig.11 shows the economic potential in terms of NPV of 40 years return period investment either in the case of η=50% and WACC=8% or η=30% and WACC=14%, considering that the produced energy is sold as net metering service for MHPs up to 200kW and as simplified purchase and resale arrangements for MHPs with an installed capacity over 200kW. It can be seen that, following the most profitable hypothesis (η=50% and WACC=8%), the maximum NPV is about 80 million euro that correspond to a global intrinsic potential of 21MW. However, following the less profitable hypothesis (η=30% and WACC=14%), the corresponding maximum NPV is about 12 million euro. Furthermore, if we consider the hypothesis of energy sold following the feed-in-tariff mechanism, the maximum NPV decreases respectively to 42 and 8 million euro.

The results of our analysis highlight that the mechanism of support plays a central role in the macro scale analysis of the MHPs integrated in the water supply systems. If we simultaneously consider all the potential MHPs of a region, simplifying assumptions about the variables "cost" and "continuity of services" can be done to focus our attention on the impact that the economical supports have on the diffusion of MHPs. It is shown that the number of plants that can present a credit balance drastically changes as a function of the different mechanism of support in conformity with the laws in force.

5. Conclusions

Hydropower, large and small, remains by far the most important of the "renewables" for electrical power production worldwide, providing 19% of the planet's electricity. Small-scale hydro is in most cases "run-of-river", with no dam or water storage, and is one of the most cost-effective and environmentally benign energy technologies to be considered both for rural electrification in less developed countries and further hydro developments in Europe. In this paper we focus on electricity generation by MHPs installed on pipe networks. In most cases, even if the technical feasibility is possible, the energy production is so small that the economic analysis in terms of NPV can shows negative results.

With an approach covering the drinking water systems in Piemonte we show a methodology aimed at estimating the first-approximation potential and economic feasibility of MHPs, using GIS, DTM and an existing database of the drinking water service facilities. Based on these indications, more detailed assessment of the hydropower potential are pursued in the most promising mountain areas, that can also benefit of interesting opportunities for water system renovation.

The Piemonte water supply systems show a global intrinsic potential that can vary in the range 21-31MW, whereas the variability range of the effective potential is 14-26MW. Although in Piemonte there are several conventional hydropower with an installed potential around 30MW, MHPs could be thought as a modest contribution to the energy production market. However the energy contribution by MHPs distributed installations on the water supply systems has several extremely interesting advantages, like the aquatic ecosystems conservation, no impacts on the water resources system and the incentive of the water multiple use, drinkable and hydroelectric. The MHPs integrated in the water supply systems can also lead to a reorganization and rationalization of the existing mountain drinking water systems and to a reduction of the drinkable water prizes due to the income risen from energy sale.

The economic viability of the MHPs projects is critically dependent on the state incentives and supports. A NPV analysis of the micro-hydro potential plant of Piemonte indicates that the minimum capacity at which an investment in MHPs can return an economic profit can vary in the range 9-35kW and that the maximum NPV value can vary in the range 8-80 million euro as a function of the incentives. In our opinion, for providing the requisite motivation to all the stake-holders for harnessing MHPs in mountain and piedmont water supply systems, stable and suitable incentives and strategies are required.

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Appendix A. Green Certificates and all-inclusive feed-in-tariff mechanism.

Green Certificates, also known as Renewable Energy Certificates (RECs), represents the environmental value of renewable energy and is a tradable commodity proving that certain electricity is generated using renewable energy sources. One certificate represents generation of 1 MWh of electricity and can be traded separately from the energy producer tradable certificates giving evidence of RES generation. They provide a benefit to their holders, who can use them to comply with their obligation to inject a certain quota of RES into the power grid. Several countries use RECs as a mean to make the support of green electricity generation closer to a market economy. Such national trading schemes are in use in e.g. Poland, Sweden, the UK, Italy, and some US states.

The all-inclusive feed-in tariff (i.e. including the support and the revenue from the sale of electricity) is applied, at the request of the operator, to the net electricity generated and concurrently injected into the grid. To be eligible for the all-inclusive tariff, plants must fulfil some requirements like: commissioning after December 31st 2007, yearly average nominal capacity not exceeding 1MW, and, only for wind plants, electrical capacity not exceeding 0.2MW. To benefit from the support, producers must ask GSE (Energy Service Manager) to qualify their plants as RES-E plants. Eligible plants include new, upgraded/repowered, totally/partially renovated and reactivated plants that have been commissioned after April 1st 1999, co-firing plants that have been commissioned before April 1st 1999 and have operated as hybrid plants after such date. Parties producing RES-E in plants commissioned after December 31st 2007 (yearly average nominal capacity of less than 1MW and of 0.2MW for wind plants) and feeding it into the grid may apply for an all-inclusive feed-in tariff over a period of 15 years. The tariff, which is an alternative to RECs, is differentiated by source as shown in Tab.2. The all-inclusive feed-in tariff may be revised every three years by a Decree of the Minister of Economic Development, taking into account the need for ensuring an adequate remuneration of the investment in RES-E generation.

All-inclusive feed-in-tariff

Source	*All-inclusive feed in rate (€cent/kWh)*
Wind (P < 200 kW)	30
Geothermal	20
Waves and tides	34
Hydro (other than the one indicated in the previous point)	22
Biomass, biogases and bioliquids when complying with EU Regulation 73/2009	30
Landfill gas, sewage treatment plant gas, biogases and bioliquids	18

Table 2. All-inclusive feed-in-rate differentiated by renewable energy source (GSE).

GSE qualifies plants as RES-E ("IAFR") plants in view of subsequently issuing RECs in respect of their electricity generation (subject to specific conditions); or granting the all-inclusive feed-in tariff for the electricity generated and injected into the grid.

The plants that GSE has qualified as RES-E plants receive a number of RECs equal to the product between their supportable net electricity generation and the multiplicative factors differentiated by source as shown in the Tab.3. A plant can be eligible for RECs for different period, under art.10, para. 1 of the Ministerial Decree of December 18th 2008. For instance, a MHPs which has been commissioned after December 31st 2007 is eligible for RECs for 15 years while a MHP which has been commissioned until December 31st 2007 is eligible for RECs for 12 years.

An alternative to the market (bilateral transactions and power exchange) for the sale of electricity generated and injected into the grid is represented by the simplified purchase and resale arrangements with small producers. An agreement is entered between the producer and GSE, whereby GSE purchases and resells the electricity to be fed into the grid at the zonal price or at a minimum guaranteed price and, on behalf of the producer, transfers the fees for the use of the grid, like dispatch and transmission fees, to distributors and to the Transmission System Operator (TSO). To benefit from the simplified arrangements the RSE plants have to honour some requirements, like having a nominal apparent power of less than 10MVA, using RES as wind, solar, geothermal, waves, tides, hydro (run-of-river only), having a nominal apparent power greater than or equal to 10MVA (plants using RES other than wind, solar, geothermal, waves, tides and hydro (run-of-river only), provided that they are owned by a self-producer.

The parties operating or owning one or more plants commissioned before December 31st 2007 which use RES and have a capacity of up to 20 kW, or plants commissioned after December 31st 2007 which use RES and have a capacity of up to 200kW, or high-efficiency cogeneration plants having a capacity of up to 200kW can apply for the net metering service.

Under the net metering service, producers/users may feed into the grid the electricity that they generate on site but do not consume immediately and take in from the grid part or all of the electricity that they need at a different time. The service provided by GSE entitles the applicant to get a yearly net metering contribution that is expressed in euro. This contribution refunds the producer/user for part of the costs incurred for withdrawing electricity from the grid.

RECs multiplicative factors

Source	*Multiplicative factor*
Wind (P > 200 kW)	1.00
Off-shore wind	1.50
Geothermal	0.90
Waves and tides	1.80
Hydro (other than the one indicated in the previous point)	1.00
Biodegradable waste and biomass (other than the one indicated in the following point)	1.30
Biomass and biogases obtained from agriculture, animal husbandry and forestry on a short supply-line basis	1.80
Landfill gas, sewage treatment plant gas and biogases (other than the ones indicated in the previous point)	0.80

Table 3. Green Certificates multiplicative factor differentiated by renewable energy source (GSE).