DOI: 10.1478/AAPP.97S2A31

AAPP | Atti della Accademia Peloritana dei Pericolanti
Classe di Scienze Fisiche, Matematiche e Naturali
ISSN 1825-1242

Vol. 97, No. S2, A31 (2019)

ENERGETIC AND ECONOMIC COMPARISON BETWEEN SYSTEMS FOR THE PRODUCTION OF ELECTRICITY FROM RENEWABLE ENERGY SOURCES (HYDROELECTRIC, WIND GENERATOR, PHOTOVOLTAIC)

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Abstract. The production of electricity from fossil fuels is one of the main causes of the emission of greenhouse gases into the atmosphere, which is currently causing far-reaching climate changes. The use of renewable energy sources (RES) in power plants instead of gas and oil derivatives is presented today as an essential intervention to try to limit the emission of carbon dioxide into the atmosphere in order to contain the worrying phenomena of global warming. In this context in the present work a comparison from an energetic and economic point of view among three different power generation plants (hydroelectric, eolic and photovoltaic), located in the water basin area of *Annunziata* stream in Reggio Calabria or in its immediate vicinity is presented. Energy productiveness and economic convenience are estimated during the useful life of the plants, together with their profitability. For the hydroelectric plant, made up of several elements, the preliminary sizing of the main components has also been carried out.

1. Introduction

Most energy demand is increasingly met with electrical energy and the demand at the planetary level is continuously growing. In the near future, a substantial part of the final energy demand in the automotive and industrial sectors will also shift to the electricity sector (Van Vliet *et al.* 2011; Mathiesen *et al.* 2012; Gattuso *et al.* 2016). The generation of electricity from fossil fuels, however, involves a massive production of CO_2 (Barbieri *et al.* 1995; Friedl and Getzner 2003; Ang 2007; Halicioglu 2009), with destabilizing effects on the Earth's climate, to be urgently reversed before the process becomes irreversible (Pretis and Roser 2017). The impact of climate change and the factors of vulnerability to nature, economy and health, varying in different territories and economic sectors, are a very worrying current evidence (McMichael *et al.* 2006; Giorgi and Lionello 2008): temperatures increase, precipitation regimes change, glaciers melt and the global average sea level is growing. It is expected that these changes will continue in the coming years and extreme weather events such as floods and droughts will become increasingly frequent and intense.

The changes in carbon dioxide concentration levels in the past were mainly due to large volcanic eruptions, but with the start of the industrial era, man seems to have become the main architect: according to what was established in 2013 by the latest IPCC report (*Intergovernmental Panel on Climate Change*) (Stocker *et al.* 2013) most of the warming that occurred since the mid-twentieth century is in fact due to the increase in anthropogenic emissions (Letcher 2009).

Deforestation has also increased the natural greenhouse effect, as forests, due to the reduced processes of photosynthesis, have consequently reduced the absorption of carbon dioxide from the atmosphere. All of these phenomena have accelerated terrestrial warming, with an increasingly evident trend over the last twenty years: recent data show indeed temperature increases comparable to those of the largest climatic variations on the Earth, which are nevertheless appearing at absolutely extraordinary speeds. Effects already underway are the extremes of precipitation (with an increase in the intensity of hurricanes in the Atlantic areas), more extensive fires, droughts, glaciers collapse, sea levels rising (with greater risks for nearby population centers of coastal areas), desertification and mass migrations. Climate change also creates significant pressure on ecosystems, leading to moves northwards of multiple plant and animal species, several of which will be compromised due to poor adaptability and only a very adaptable minority will not be at risk of extinction (Gilman *et al.* 2010). This will result in the loss of existing biodiversity and the establishment of new ones with the formation of new ecosystems. These changes could lead, if the current trends of socio-economic development and use of natural resources will not be changed, to profound and irreversible changes in both the environment and the society itself in the next 50-100 years (Wilby *et al.* 2002; Haines *et al.* 2006).

Currently the global temperature has increased of about 0.8 ºC in 150 years and it is estimated that an excess of 2° C compared to pre-industrial levels will make the changes for natural systems irreversible: the international objectives set by the *Kyoto Protocol* have not been in fact sufficient to protect the planet and it is necessary that the reduction of greenhouse gases is greater and affects all countries, both those more developed and, even more, those emerging that are currently the most responsible. The recent *Paris Agreement* of 2015 aims to achieve the goal of keeping the temperature rise below 2° C, to reach which global emissions of greenhouse gases should fall by 50% compared to 1990 levels by 2050. A leading role has been played for many years by *EU*, which has adopted policies and measures aimed at increasing the use of renewable energy, increasing energy efficiency and reducing carbon dioxide emissions, supporting the ambitious goal of reducing its emissions between 80 and 90% by 2050. The European Commission had already approved an ambitious 2020 plan for energy and climate change in 2008 to limit greenhouse gas emissions by 20% and to achieve a 20% renewable energy compared to the overall use of primary energy (EU Directive 2009/28/EC). In the future, therefore, various sectors such as transport (Briggs *et al.* 2017; Sinigaglia *et al.* 2017), construction (Apergis and Payne 2009; Arsalis *et al.* 2018) and agriculture in all Member States will be called upon to play their part, on the basis of their respective financial capacities, to help achieve these objectives.

2. Renewable energy sources for electric energy production - Centralized and distributed production

The global energy framework concentrates electricity production in mega-power plants based on use of fossil and nuclear fuels; the electricity produced is fed into large high-voltage dorsals, from which the networks that go up to our cities, industries and homes depart. This complex and costly infrastructure, which significantly affects the final price of energy, has a certain rigidity: in fact, the flow of electricity travels in a unidirectional way, from the place of production to that of consumption. In this context, the end user plays the passive - and unaware - role of a simple energy consumer. The distributed generation, in which the current energy paradigm should be transformed, represents a different way of managing the electricity grid, based less and less on large power plants connected to large networks of pylons and increasingly on production units (wind, photovoltaic, central biomass, co-generators) of small-medium size, homogeneously distributed throughout the territory and connected directly to the users or in any case to low-voltage networks (Hvelplund 2006; Evans *et al.* 2009; Gonçalves da Silva 2010; Lund 2010) (see Figure 1) . Electric systems are evolving towards a growing integration of different sources of primary energy (both conventional and distributed generation), with increasing portions of non-programmable renewable energy, supported by a wider use of digital technologies (smart grids) (Gelazanskas and Gamage 2014; Siano 2014). Within this new scenario, the electricity grid completely changes its role and functions, gradually transforming itself from a passive network, where electricity simply flows from the place of production to that of consumption, to an active and intelligent network, capable of managing and regulating multiple electric flows that travel in a discontinuous and bidirectional manner. The reliability of the network is increased because the shutdown of a plant does not entail the interruption of supply, but is compensated by the presence of the other plants: this aspect is particularly important for plants based on renewable sources such as photovoltaic and wind power, which depend on unforeseeable weather factors and for the most part dispense energy in a discontinuous way. Moreover, since the energy flows generated by them vary continuously in voltage and frequency, subjecting the current networks to high levels of stress, the development of technologies such as network protection, interconnection and electrical load control devices allows to provide the network with an ever-increasing intelligence.

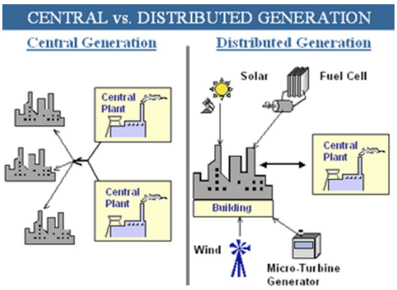

FIGURE 1. Centralized vs distributed energy generation.

One of the advantages of distributed generation is linked to the shorter length of electricity distribution and transmission networks. The long high-voltage networks lose about 7% of the transported electricity, and, in addition to entailing significant construction and maintenance costs, are at constant risk of interruptions and blackouts. On the other hand, distributed generation is protected from these risks by bringing the power plant (or rather, more interconnected power plants) closer to the final user. Moreover, since with the progressive diffusion of small plants with renewable sources the places of production and consumption of electricity tend not only to approach, but often to coincide, it is possible to use the waste heat of the combustion processes, differently from most of large thermoelectric power plants, where about 2/3 of the primary energy contained in the fuel is wasted and comes out of the chimney in the form of unused heat. Thanks to small biomass and micro-cogeneration plants spread throughout the territory, the ideal economic and technical conditions can be ensured for district heating and heat distribution systems over short distances, for residential, industrial and tertiary users (Rosen *et al.* 2005). The most evident critical issues in the use of distributed systems consist at the moment in aligning the variability of energy sources with that of loads: without an accumulation system, the generation of electricity must in fact instantly equalize its consumption. However, the use of energy storage systems for the support and optimization of the electricity grid is still a limited phenomenon on the globe, but has recently registered developments and interest, leaving a glimpse of a promising future for related technologies (Avril *et al.* 2010; Foley and Diaz Lobera 2013; Krajauc *et al.* 2013; Marino *et al.* 2013; Carbone 2015; Lorestani and Ardehali 2018).

3. Case study

In this paper a comparison is presented between three different RES plants for the production of electricity (hydroelectric, eolic and photovoltaic) (Katzenstein *et al.* 2010; Dursun and Gokcol 2011; Malara *et al.* 2016) for which the analysis of energy production, economic convenience and profitability in the course of plants life is carried out. The case study carries out, first of all, the sizing of the main elements of the hydroelectric plant, located in the hydrographic basin of the *Annunziata* stream of Reggio Calabria (Figure 2), in the area between the neighborhoods of Vito and Arasì. The wind and photovoltaic plants are located in the same area.

FIGURE 2. Territorial framework of Annunziata Stream.

The choice of the site was carried out based on:

- land availability (verification of properties or restrictions);
- accessibility of the site to the watercourse (the greater the accessibility, the lower the impact caused by possible interventions);
- absence of shading;
- wind characteristics.

3.1. Hydroelectric plant. In Reggio Calabria the *Annunziata* stream flows a short distance from the city center, near the port, and its terminal part is intubated for over 2 km, flowing under the *Liberty Avenue*, the *Liberty Square* and *Boccioni Avenue*. Its water catchment area is over 20 km^2, with a perimeter of about 40 km, a length of the main path of over 20 km, an average gradient of over 35% and an average altitude of about 650 m s.l.m. The hydroelectric plant adopted is of flowing water, a type that requires the construction of a barrier of the water course by means of a weir, with an intake structure immediately upstream of it. The main works and the elements constituting the system are shown in Figure 3.

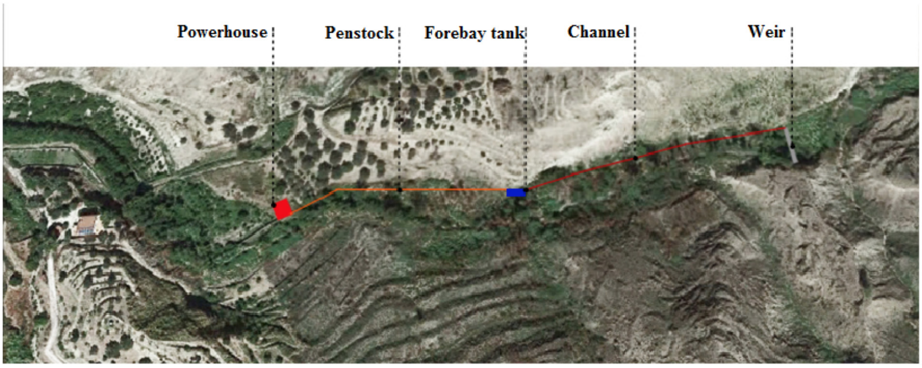

FIGURE 3. Hydroelectric power plant components.

They consist of:

- *weir*: raises the water height, favoring the derivation of water from the stream towards the power house within which the turbine is located
- *intake structure*: necessary to derive the water in a duct, with free surface or under pressure, and then convey it to the hydroelectric plant
- *derivation work*: conveys the water along a weak slope from the outlet to the starting point of the pipeline under pressure
- *forebay tank*: a small-capacity reservoir with a free surface that also acts as a sedimentation tank for suspended solid materials
- *penstock*: has the function of channeling the pressurized water from the loading basin to the turbine.

In order to establish the position of the loading tank and the powerhouse, *Google Earth* satellite images were analyzed and, through the related spatial analysis functions, the length L of the penstock and the level difference ΔH between free water in the tank and in the turbine were obtained:

$L = 200\, m \qquad\qquad \Delta H = 15\, m$

The design flow rate Q has been obtained by analyzing the flow duration curve, that shows, for a particular section of the watercourse, the period of time during which the flow rate is equal to or higher than a certain value. The curve of the basin in question was deduced from the average daily flow data recorded in the stream in the years 1953 - 1971 and available on the site of the *Arpacal Multi-risks Functional Center*. The average daily flow rates were then ordered in descending order, with an increasing index from 1 to 365 (Figure 4).

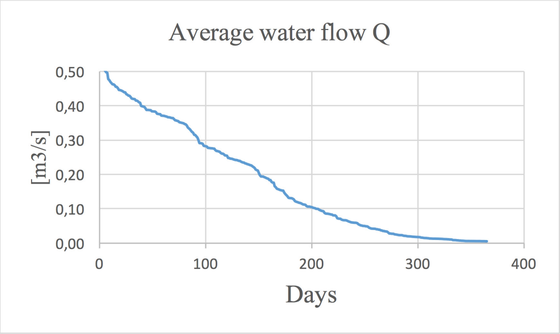

FIGURE 4. Flow duration curve.

The figure shows that to take advantage of the plant for 150 days a year, the project flow rate must be 0.20 m^3/s. The following step has been the sizing of the various works:

Weir

In order to dimension a fixed weir it is necessary to know the load h upstream of the outlet. Considering a non-regurgitated overflow, it is derived from the expression:

$$Q = m_0 L h \sqrt{2gh} \tag{1}$$

with:

- Q flow rate (0.20 $\mathrm{m^3/s}$)
- m_0 overflow coefficient - variable between 0.42 and 0.48
- L length of the weir (10 m)
- g acceleration of gravity (9.81 $\mathrm{m/s^2}$).

A load h equal to 0.55 m has been obtained.

Intake structure

Also to size the intake structure it is necessary to know the load on the overflow h, which has been obtained using the expression:

$$Q = \mu b h \sqrt{2gh} \tag{2}$$

where

- Q flow rate
- μweir efflux coefficient (0.385)
- b overflow width
- h water height acting on the overflow
- g acceleration of gravity.

A rectangular overflow with a width of b = 5 m was assumed, obtaining a load h equal to 0.082 m.

Derivation work

For the determination of its geometric characteristics the expressions were used:

$$D_c = sqrt\frac{4A_c}{\pi} \tag{3}$$

$$A_c = \frac{Q}{v_c} \tag{4}$$

with

- D_c diameter
- A_c area of the duct section
- q flow rate
- v_c water speed inside.

Using a duct of circular cross section, for an average water speed of 1.5 m/s, a diameter of 0.41 m was obtained.

Forebay tank

In order to size the forebay tank it is necessary, first of all, to calculate the sedimentation speed v_0 with the *Stokes* expression:

$$v_0 = \frac{g}{18}\frac{(\rho_s - \rho)}{\mu}d^2 \tag{5}$$

with

- g acceleration of gravity
- ρ_s density of sedimentable particles (2’650 kg/m^3)
- ρ water density (1’000 kg/m^3)
- d diameter of sedimentable particles (0.0001m)
- μ water dynamic viscosity (0.001 kg/m s)

v_0 = 0.009 m/s was calculated. The minimum length of the tank L_v has therefore been calculated so that the sedimentation process takes place entirely inside it. Using expression (4):

$$L_v = \frac{Q}{v_0 B_v} \tag{6}$$

where

- Q flow rate
- v_0 particle sedimentation rate
- B_v width of the tank (2.5 m).

A value L_v=8.90 m has obtained. Adopting a value of 10 m and setting a height equal to 0.4 m, a volume of 10 m^3 is obtained.

Penstock

The diameter D of the penstock has been obtained using the expression of *Hazen-Williams* for the determination of the distributed load losses Δ:

$$\Delta = JL = \frac{10.675 Q^{1.852}}{C^{1.852} D^{4.8704}} \tag{7}$$

with

- Δ distributed load losses (0.75 m)
- J piezometric head (5% net height)
- L length of the penstock (200 m)
- Q flow rate
- C roughness coefficient (130 $\frac{m^{1/3}}{s}$)

A diameter of 400 mm has been obtained. Polyethylene pipelines were used.

Choice of the turbine

The choice of the turbine has been made by analyzing the diagram shown in Figure 5. Since the flow value is equal to 0.2 m^3/s and the net height is 15 m, a *Kaplan* turbine was chosen.

It consists of two basic parts, the impeller and the distributor. The impeller is made up of two or more parallel circular discs, joined together by a series of curved blades. The distributor has a rectangular section and unloads the water jet along the entire length of the impeller; the shape of the jet is rectangular, wide and not very deep. The liquid flow hits the blades placed on the upper edge of the wheel, flows above them and goes beyond them, entering the empty space between the upper and the lower blades; it then hits the lower blades from the inside, crosses them and exits the opposite side, after giving them its energy.

Plant power

The power of the hydroelectric plant has been obtained using the following relation:

$$P = Q \Delta H g \eta \tag{8}$$

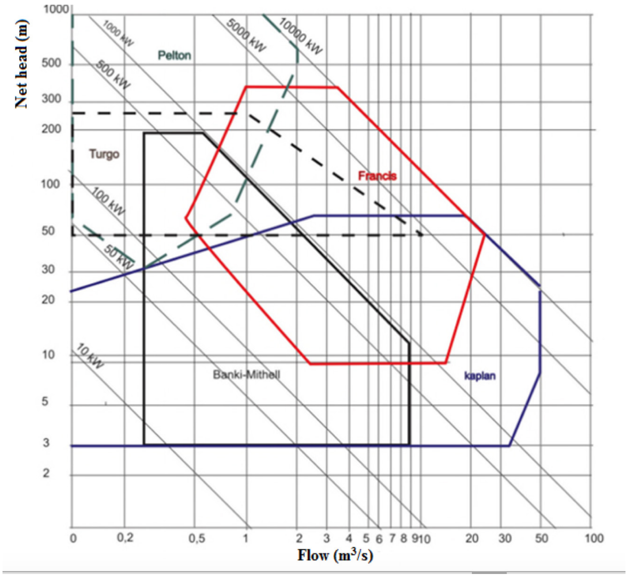

FIGURE 5. Operating ranges of the main hydraulic turbines.

where:

- Q design flow of the plant
- ΔH net height
- g acceleration of gravity
- η plant global efficiency (85%).

A power value of 25 kW has been obtained.

Energy production

The subsequent assessment of the energy yearly produced, considering 150 days of plant operation a year, provided:

$$E = Pt = 90'000 kWh/year \tag{9}$$

3.2. Wind generator.

Characterization of site wind velocity

Prior to the installation of a wind generator, the assessment of the site wind velocity is to be carried out, whose knowledge can be obtained by effecting anemometric measurement campaigns. The data collected were divided into speed classes and their frequency was calculated. By organizing the data into frequency classes, the frequency curve has been constructed, which indicates the percentage of time in which a certain speed has occurred (Figure 6). The site has an average speed of 2.88 m/s which is not particularly favorable for the installation of a wind generator.

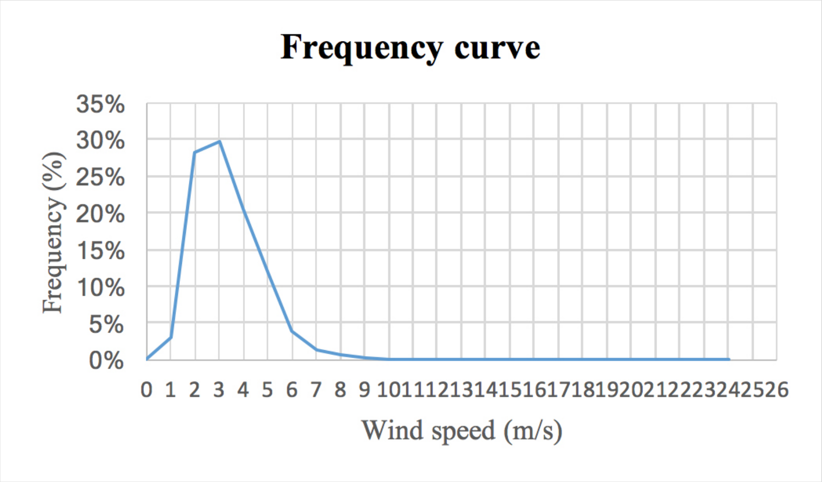

FIGURE 6. Frequency curve (%).

Wind generator

A three-axis wind generator with horizontal axis and nominal power equal to that of the hydroelectric plant (25 kW) has been installed. The generator is synchronous with permanent magnets, axial flow and direct connection to the hub; it uses wind inverters provided with maximum power point trackers (MPPT) to increase the amount of energy collected by the turbine. One of the strengths of this inverter is the very wide input voltage range, which guarantees a constant accumulation of energy, from the lighter breeze to the strongest wind.

Plant power

The electric power supplied by the turbine at the various wind speeds is given by the power curve shown in Figure 7, expressed by:

$$\begin{aligned} P(v) &= \frac{v^2 - v_{cut-in}^2}{v_{rated}^2 - v_{cut-in}^2} P_N \quad \text{per} \quad v_{cut-in} < v < v_{rated} \\ P(v) &= P_N \quad \text{per} \quad v_{rated} < v < v_{cut-off} \end{aligned} \tag{10}$$

The related characteristic parameters are shown in Table 1:

- $\mathbf{v}_{cut-in}$ ***cut in speed***, at which the generator starts to produce energy
- $\mathbf{v}_{rated}$ ***rated speed*** at which the nominal power is produced, corresponding to the maximum efficiency
- $\mathbf{v}_{cut-off}$ ***cut off speed***, at which safety mechanisms intervene to lock the rotor.
- $\mathbf{P}_N$ ***nominal power***.

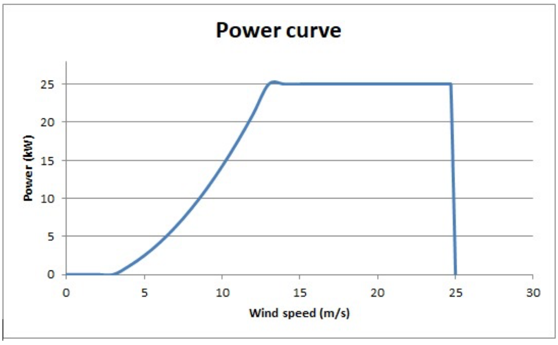

FIGURE 7. Wind generator power curve.

v_{cut-in}(m/s)	v_{rated}(m/s)	$v_{cut-off}$(m/s)	P_N(kW)
3	13	25	25

TABLE 1. Characteristic speeds of the wind generator power curve.

Energy production

The energy produced by the plant was determined by exploiting the speed distribution and the power curve (Figure 8). An energy production of 55’698 kWh/year has been obtained.

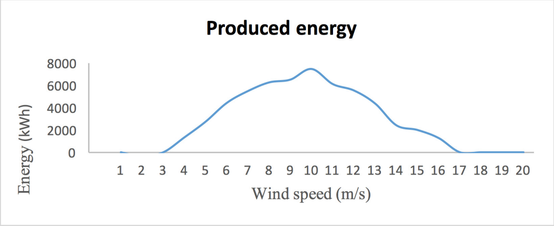

FIGURE 8. Energy produced by the wind generator.

3.3. Photovoltaic plant.

Characterization of site solar radiation

To design a photovoltaic system, it is necessary to first analyze the irradiation characteristics of the installation site, verifying the absence of shading. The first step was therefore the determination of solar radiation at the site according to *UNI 10349* Parte 1 (2016), obtaining the monthly mean values of daily radiation on a horizontal surface (Figure 9) with a total annual value equal to 1751 kWh/(m^2 year).

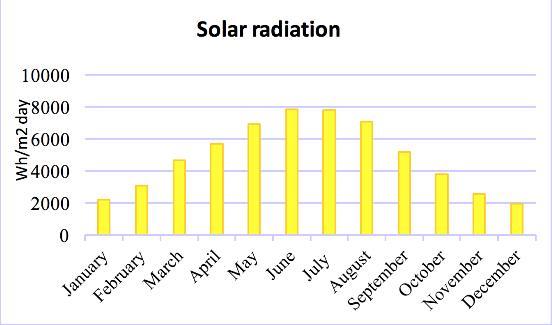

FIGURE 9. Solar radiation in the selected site.

Photovoltaic panels

Among the panels available on the market, multi-junction concentration ones were chosen, provided with a small motor for solar tracking to maximize energy production. Table 2 shows the characteristic parameters of the panels and of the generator.

Power (W_p)	$\eta_r(\%)$	NOCT (°C)	$\beta(\%/°C)$	Number of panels	Generator surface (m^2)
300	40	38.0	0.43	83	132.80

TABLE 2. Characteristics of the multi-junction concentration PV panel.

Plant power

As for the technologies previously analyzed,the generator power is of about 25 kWp.

Energy production

The electric energy E produced by the photovoltaic generator is given by:

$$E = S\eta I \tag{11}$$

with

- S panel surface (m^2)
- η panel efficiency
- I incident radiation on the panel (kWh/m^2)

Efficiency is a function of temperature:

$$\eta = \eta_r[1 - \beta(t_c - t_r)] \tag{12}$$

where

- η_r efficiency at the reference temperature t_r (25°C)
- β panel temperature coefficient

- t_c cell temperature, which can be estimated by means of the expression:

$$t_c = t_a + \frac{NOCT - 20}{800} G \tag{13}$$

with

- t_a outdoor air temperature (25°C)
- $NOCT$ Nominal Operating Cell Temperature (°C)
- G solar irradiance (W/m^2).

The analysis is carried out for every day of the year with a hourly step. Figure 10 shows the monthly trend of the produced energy; the total annual production value is 95’352 kWh.

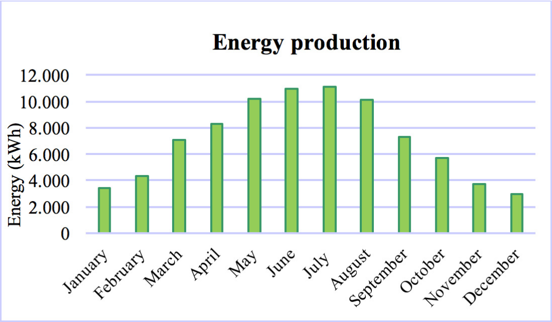

FIGURE 10. Electricity production of the photovoltaic generator.

4. Economic analysis

The analysis conducted is aimed at evaluating the economic advantage of the investment of each plant during its useful life. The study has been carried out calculating the *NPV (Net Present Value)* defined as:

$$NPV(€) = \sum_{i=1}^{N} \frac{(B_i - C_i)}{(1+r)^i} - I_0 \tag{14}$$

with:

- N number of years
- i single year
- B benefits (deriving from incentive and / or sale mechanisms)
- C costs (maintenance)
- r interest rate
- I_0 investment cost.

Economic benefits

For a plant that produces electricity from renewable sources derive from two cumulative mechanisms, the state incentives and the sale of the generated energy. The main government incentives, regulated by the *Electricity Services Operator* (GSE in Italy), apply to different extent for different renewable sources and plants with fixed powers; the most common are the **Energy Account** and **Energy Efficiency Certificates**, the latter most commonly known as *White Certificates*. The first mechanism, in its most recent issue, is established by *Ministerial Decree* 06/07/2012 [1], which regulates the incentive of energy produced by all the plants powered by RES connected to the electricity grid, other than photovoltaic ones, with power not less than 1 kW. It provides all-inclusive incentive prices for the sale of produced energy (only for the amount of energy fed into the grid), different for the type and power of the plant, for a duration equal to its conventional average useful life. The mechanism, initially applicable to all renewable sources, is currently in force only for hydroelectric and wind sources, while for photovoltaics it was replaced in 2014 by that of the on-site exchange, regulated by an *Integrated Text* issued by the *Electricity and Gas Authority* [2], and by income tax deduction, equal to 50% of the investment cost, distributed over the first ten years. The on-site exchange provides an indirect monetary compensation between energy input and withdrawn from the grid and can therefore only be used in the case of direct use of self-produced energy. The *Energy Efficiency Certificates* mechanism [3], created at European level to achieve the primary energy reduction targets and introduced by the EU Directive 2009/28 / EC (known as *Climate-Energy*) consists of negotiable securities that attest the energy savings and optimal use of energy, issued by the *Electricity Market Operator* (*GME* in Italy) on the basis of the certifications of the savings achieved by the Authority: a certificate is equivalent to the savings of 1 ton of oil equivalent (toe), conventional measurement unit used in energy balances, which takes into account the calorific value of energy sources. The contribution is about € 100/saved toe and has a five-year duration. The *Energy Efficiency Certificates* can not be combined with the other forms of incentive described. The sale of the energy produced can be a real invoiced sale, called *dedicated collection*, or, in the presence of a load, an *on-site exchange contract* (only for photovoltaics). The selling price of energy to the GSE is the *Pz* market price for the location of the plant: in the study conducted, the energy sales rate attributed to the plants is 0.07 €/ kWh.

4.1. Hydroelectric plant. For the construction of the micro hydroelectric plant it is necessary to bear the investment and maintenance costs shown in Table 3, for a total initial cost of € 82'345.

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[1] MISE; DM 6 luglio 2012, Attuazione dell'art. 24 del decreto legislativo 3 marzo 2011, n. 28, recante incentivazione della produzione di energia elettrica da impianti a fonti rinnovabili diversi dai fotovoltaici, Gazzetta Ufficiale Serie Generale n.159 del 10-07-2012 - Suppl. Ordinario n. 143

[2] Deliberazione dell'Autorità per l'energia elettrica e il gas ARG/elt 74/08, Testo Integrato per lo Scambio sul Posto, 26/07/2012

[3] MISE, Decreto 10/05/2018, Modifica e aggiornamento del decreto 11 gennaio 2017, concernente la determinazione degli obiettivi quantitativi nazionali di risparmio energetico che devono essere perseguiti dalle imprese di distribuzione dell'energia elettrica e il gas per gli anni dal 2017 al 2020 e per l'approvazione delle nuove Linee Guida per la preparazione, l'esecuzione e la valutazione dei progetti di efficienza energetica, Gazzetta Ufficiale, Serie Generale n.158 del 10/07/2018.

Cost/benefit item	*Cost/benefit(€)*
Turbine, generator, electric components	50'031
Powerhouse construction, tubes laying	5'126
Polyethylene tubes	27'188
Yearly maintenance	200
Yearly incentivized benefit	19'722 from 1^{st} to 20^{th} year 6'304 from 21^{st} to 25^{th} year

TABLE 3. Costs and benefits of the hydroelectric plant.

The incentives for the energy produced by hydroelectric plants connected to the electricity grid, established by *Ministerial Decree* July 6, 2012 envisage, for the flowing water plant type and power of 25 kW (power classes between 20 and 200 kW), an all-inclusive tariff equal to € 0.219 / kWh for the first 20 years of operation. As the annual energy production is 90'000 kWh, an annual revenue of 19'722 € is obtained. From 21^{st} to 25^{st} year energy is sold at the unit price established by the Authority (not incentivized) for the dedicated withdrawal (€ 0.07 / kWh), obtaining a total of 6'304 €/year (Table 3). The NPV calculated for a period of 25 years (which coincides with the useful life of the plant) amounted to € 325'200. The investment cash flow shows a return on investment of 5 years.

4.2. Wind generator. The cost of a wind generator includes its supply and substructure; for the estimation of the latter an important factor is the accessibility to the site area, for the handling of large enough pieces. In our case, the area subject to intervention is accessible without particular restrictions on the dimensions of the transported elements, so that the price of the generator and its installation amounts to € 60'000. Maintenance costs amount to around € 200/year. With regard to incentives, the *Ministerial Decree*of 6 July 2012, for plants with a capacity between 20 and 200 kW, provides an all-inclusive tariff of 0.268 € / kWh for the first 20 years of operation: as the annual production is 55'698 kWh, a annual revenue of € 14'927 (Table 4). From 21^{st} to 25^{th} year energy is sold at the unit price established by the Authority (not incentivized) for the dedicated withdrawal (€ 0.07 / kWh). Investment *NPV* for a period of 25 years, coinciding with the useful life of the plant, is equal to 242'010 €. Cash flow shows a pay back time of the investment of 5 years.

Cost/benefit item	*Cost/benefit(€)*
Wind generator	55'000
Substructure and laying	5'000
Yearly maintenance	200
Yearly incentivized benefit	14'927 from 1^{st} to 20^{th} year 3'899 from 21^{st} to 25^{th} year

TABLE 4. Costs and benefits of the wind generator.

4.3. Photovoltaic plant. A concentrated solar panel has a lower base cost compared to a traditional silicon panel, but its overall price increases for the presence of the solar tracker:

Cost/benefit item	*Cost/benefit(€)*
Photovoltaic generator	57’500
Installation	5’000
Yearly maintenance	150
Yearly incentivized benefit	9’800 from 1st to 10th year 6’675 from 11st to 25th year

TABLE 5. Costs and benefits of the photovoltaic plant.

in the analysed case the cost of the two components amounted to € 57’500 (Table 5). The installation cost, considering the anchorage of the mobile structure, is equal to € 5’000, while maintenance one is lower than that of the other two plants and equal to € 150 / year (Table 5).

With regard to incentives, the *Energy Account* ceased in 2013 for photovoltaic plants, so that the main mechanisms in force are the *White Certificates*, applicable for the first 5 years of plant life (amounting to € 8’220) and the income tax deduction, equal to 50% of the initial investment cost (€ 31’250), distributed over the first 10 years. However, the two incentives are not cumulative, so that, considering the respective amount, the second was preferred. Throughout the life of the plant (25 years), energy is sold at the unit price established by the Authority (not incentivized) for the dedicated withdrawal (€ 0.07 / kWh) and provides € 6’675 / year. Table 5 shows the values of the benefits resulting from the different mechanisms. *NPV* was € 128’350 and the investment is already re-paid after the fifth year.

4.4. Economic comparison. For the three plants Table 6 shows a comparison between investment costs, benefits (linked to incentive mechanisms and sale of energy yearly produced) and *NPV*. It is possible to notice that the investment is greater for the hydroelectric plant (which also has the greatest land occupation), lower for wind and photovoltaic plants; energy production is higher for hydroelectric and photovoltaic plants, lower for the wind generator. In particular, it is observed that photovoltaic production, slightly higher than hydroelectric one, is obtained with a 25% lower investment cost.

The benefits, resulting from different incentive mechanisms and tariffs for the various plants (*Energy Account* for hydroelectric and wind power, income tax deduction for photovoltaic systems) plus the sale of produced energy are greater (and consequently *NPVs*) for the hydroelectric plants, lower for the photovoltaic generator, notwithstanding the similar energy production. The high values of *NPV* for the hydroelectric plant, despite of its highest investment cost, are due to the high energy production together with a high incentivizing tariff. In all three cases there is a considerable economic return over the useful life of the plants, which repays the investment cost extensively and in a short time (maximum 4-5 years).

5. Conclusions

Energy availability affects the economic and social progress of a country, but the way in which energy is obtained can negatively affect the ecosystem and consequently the quality

Plant typology	*Energy production (kWh/year)*	*Investment cost (€)*	*Benefits (€year)*	*NPV(€)*
Hydroelectric	90’055	82’345	19’722 from 1^{st} to 20^{th} year 6’304 from 21^{st} to 25^{th} year	325’200
Eolic	55’698	60’000	14’927 from 1^{st} to 20^{th} year 3’899 from 21^{st} to 25^{th} year	242’010
Photovoltaic	95’352	62’500	9’800 from 1^{st} to 10^{th} year 6’675 from 11^{st} to 25^{th} year	128’350

TABLE 6. Economic comparison between the three plants.

of life. Currently a worrying climate change is in course, to cope with it is urgent to reduce the dependence on traditional fossil energy sources. To this end, the world community, and in particular the European Union, have actively engaged on the issue of energy sustainability, even if the steps taken towards the establishment of a new energy paradigm based mainly on renewable sources, although addressed to the right direction, appear rather fearful. From this point of view, in this work an energetic and economic comparison has been effected among three different renewable-source plants (hydroelectric, wind and photovoltaic) located in the area of the stream basin of the *Reggio Calabria’s Annunziata* torrent. The annual energy production of the respective generators has been compared, estimating the related investment costs and the benefits deriving from the state incentives and the sale of energy. The economic comparison has been conducted estimating the *NPV* indicator by performing a cost-benefit analysis. It was possible to observe the highest investment cost in the case of the hydroelectric plant, which generates a high energy production, the smallest one in the case of the wind farm, whose production is the lowest, while the photovoltaic plant shows costs comparable to those of the wind generator, but ensuring the greatest energy production among the three plants. The benefits derive from different incentive mechanisms and tariffs (*Energy Account* for hydroelectric and wind power, income tax deduction for photovoltaics) plus the sale of generated energy and are highest for hydroelectric plant, lowest for the photovoltaic generator, due to the absence of highly remunerating tariffs. All the plants show a substantial economic return (*NPV*) over their useful life, and succeed in short time to repay the cost of the investment (4-5 years). *NPV* is greater for hydroelectric plant due to its high energy production and its greatest benefits enjoyed, despite of the highest investment cost, and lowest for photovoltaics, due to lowest tariffs, despite of its low investment cost and high production.

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Paper contributed to the international workshop entitled “New approaches to study complex systems“,
which was held in Messina, Italy (27–28 november 2017), under the patronage of the *Accademia Peloritana dei Pericolanti*
Manuscript received 04 September 2018; published online 20 December 2019