TECHNO-ECONOMIC ANALYSIS OF SIMPLE PRODUCTION AND CONSUMPTION SYSTEM FOR HYDRO POWER PLANTS: A CASE STUDY

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Overview

Over the past two decades, the European Union adopted a complex set of measures and actions aimed at promoting energy efficiency and the use of renewable energy sources (RES). The common goal of these measures is to lead the transition to a decarbonised and more sustainable energy system. With these directives, the EU has set binding targets in terms of reducing greenhouse gas emissions and increasing the share of renewable energy in the EU gross final energy consumption, combining these targets with tools, strategies, and economic sources aimed at achieving them. One of the most recent measures is the RePower EU, adopted in 2022 to react to the energy crisis caused by the Russian-Ukrainian conflict. The main goal of the RePower EU is the reduction of the Union's dependence on imports of external energy sources, through diversification of supplies and a strong acceleration in the development of renewable power plants. For this reason, RePowerEU has raised the renewable share target on EU gross final consumption to 42.5% by 2030, compared to the previous target of 32% set by the RED II Directive (Directive 2018/2001/EU), has allocated new financial sources to supporting investments in the renewable sector.
Already the first EU actions allocated economic sources to promote the use of renewable energy favouring the introduction, in each Member State, of incentive mechanisms designed to stimulate investments in renewable power plants. These state grants, being highly profitable, allowed a rapid growth of renewable installed capacity in Europe. Currently, around 47% of the electricity produced in EU comes from RES, mainly from photovoltaic and wind power plants. Also in Italy energy policies and incentive mechanisms led to a growth in renewable installed capacity. In particular, from 2009 to 2013, there was a rapid increase in RES installed capacity thanks to the introduction of advantageous and easily accessible support schemes, such as "Conto Energia", "Tariffa Omnicomprensiva" and "Certificati Verdi". In the following years, however, with the reducing of incentive mechanisms, due to the rationalization and optimization of the financial sources, the development of renewable power plants decreased and the growth of RES installed capacity slowed to a plateau.

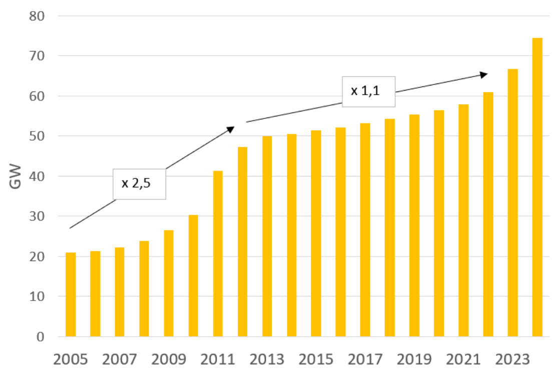

Figure 1 - Renewable energy installed capacity in Italy.

The growth of distributed generation, characterized by small and medium sized renewable power plants connected directly to the distribution grids, contributed to improving the energy sector environmental performance and, more generally, it helped the spread of more aware and actively involved end users. However, distributed generation significantly changed the architecture of the power system, accelerating the transition from a centralized and unidirectional model to a decentralized and bidirectional model. This change introduced new critical issues and poses several technical challenges including: local congestion, reverse power flows in LV/MV cabins, and voltage regulation issues. These aspects must be adequately faced to ensure efficient and reliable management of distribution grids. The EU has progressively recognized the need to address the development of distributed generation through more selective support mechanisms based on the real needs of the grid. The aim is to avoid to promote the widespread development of new renewable power plants and projects that do not guarantee an adequate return in terms of benefits, but which on the contrary risk to accentuate the critical issues precedently discussed, especially on local distribution grids.
In this context, the RED II gives a central role to self-consumption and to energy self-sufficiency introducing the concepts of virtual self-consumption and renewable energy communities. Virtual self-consumption refers to a sharing model in which the energy produced by a plant is shared with one or more consumption units located remotely, but however within a specific grid perimeter. In this model the energy is virtually self-consumed thanks to the use of the public distribution grid. Unlike direct self-consumption, therefore, spatial coincidence between production unit and consumption point is not required, as well as the private connection between the power plant and the consumption unit.
In Italy, the RED II Directive was implemented mainly through two legislative decrees: Legislative Decree 199/21 and Legislative Decree 210/21, both of which are relevant to the evolution of the regulation related to self-consumption of electricity. Legislative Decree 199/21 defines the rules to regulate virtual self-consumption and identifies the eligible configurations admitted to support schemes, including Renewable Energy Communities (REC). The support mechanism assigns an economic incentive to virtually self-consumed energy that is produced by new renewable power plants inserted in the configuration. The mechanism promotes a better alignment between production and consumption, so it promotes local energy management and consequently it contributes to the reduction of congestion, reverse power flows and grid losses. Despite the excellent purposes, the spread of virtual self-consumption configurations today is still limited and the overall impact on the power system is still marginal. This is probably also due to the requirements that limit the access to citizens, entities, small and medium sized business, leaving out operators with large investment capital, such as the big power producer companies, reducing the potential contribution of large-scale initiatives.
However, Legislative Decree 210/2021, although less well-known, addresses the regulation of direct self-consumption by introducing a new definition of a Simple Production and Consumption System (SPCS). This new definition enables physical self-consumption without power limits and without the access restrictions that characterize the virtual self-consumption configurations, making SPCSs potentially relevant also for industrial operators and companies active in power generation.
Within this context, this work aims to illustrate the features and the potential of an SPCS. The aim is to understand if these systems could be a concrete opportunity to ensure the economic sustainability of investments in new renewable power plants and, at the same time, if they could offer an alternative remuneration method for plants reaching the end of the incentive period. For this purpose, the paper shows a techno-economic analysis of a specific case study, discussing the essential steps for assessing the viability of deploying a SPCS.

The new definition of SPCS:

The new definition of a Simple Production and Consumption System (SPCS) describes a configuration in which a private power line connects one or more production units, owned by a subject as producer, to a consumption unit owned by a single end-user. To realize the system, the areas where the power plant and the consumption unit are located must be owned by at least one of the subjects belonging to the system; however, the private power connection may also cross areas not owned by the subjects, such as roads, waterstreams, or interposed territories.
The general and wide description allow to include within SPCSs all the configurations previously related to to direct self-consumption, in this way there is no longer any difference between the different direct self-consumption configurations that can be implemented. The definition contained in Legislative Decree 210/2021 simplifies and promotes homogeneity in the self-consumption regulation, making these systems more competitive.

Based on the new definition, the essential elements of an SPCS can be divided into:

- A private power line
- One or more production units
- A consumption unit
- A power producer
- A single end-user

The power producer and the end-user may coincide in the same subject. In this case, it will be a prosumer and self-consumption on site will therefore be managed spontaneously by the subject. This case represents the simplest Simple Production and Consumption System scheme. More interesting, also in relation to the case study analyzed in this work, are the systems in which the power producer is different from the end-user. In this particular case, the energy supplied via the private connection by the power producer is used locally by the end-user, reducing his energy withdrawals from the public grid.

Current regulations allow the separated management of energy withdrawal and energy injection contracts: the end-user maintains the supply contract for the energy withdrawn from the grid, while the power producer manages the contract relating to the energy fed into the grid according to the applicable market schemes. In such a configuration, it is therefore needed to establish a private agreement between the two parties governing the share of energy supplied and self-consumed within the SPCS. In practice, the agreement between producer and end-user may take the form of an economic tariff for the energy supplied on site. This tariff is generally defined to be competitive with the overall cost of energy purchased from the grid, considering the avoided costs on the bill and the sharing of benefits between the parties. Unlike virtual self-consumption configurations, for which an explicit incentive related to shared energy is provided, the economic benefit of SPCSs depends mainly on the avoided costs associated with energy direct self-consumption.

The SPCS economic benefit comes from some avoided cost components, such as system charges and grid charges, applied to the energy share withdrawn from the grid, while self-consumptiom energy via a private connection is not subject to these charges and reduces grid energy withdrawals. It follows that, given the same energy consumption, an increase in the share of direct self-consumption is associated with an increase in overall economic savings for the end-user. In support of the analysis, Table 1 reports the main cost components applied to the energy withdrawn from the grid. The first column shows the macro-categories in which the different cost components are distinguished: Grid Charges, System Charges and Supplier commercial tariffs. In the second column we find all the different cost components. In the third column we find the entity who fixed the value to assign to the component, while in the fourth column we find the typical update frequency related to the specific component.

	Bill charges	**Set by**	**Update frequency**
Grid Charges	Dispatching (PD)	ARERA	Quarterly
	Distribution (DS)	ARERA	Annual
	Transmission (TRAS)	ARERA	Annual
System Charges	UC3/UC6	ARERA	Quarterly
	System charge (Asos)	ARERA	Quarterly
	System charge (Arim)	ARERA	Quarterly
Supplier commercial tariffs	Capacity Market Charge (CMC)	Supplier	Variable
	Retailer's Spread	Supplier	Quarterly

Table 1 – Cost components applied on the bill

Methodology

In order to evaluate the feasibility of developing a SPCS, was used a methodology that can be divided into a series of steps:

1. Preliminary evaluation.
2. Energy flows analysis.
3. Estimation of avoided costs.
4. Definition of Economic Benefit parameter.
5. Definition of the economic tariff.
6. Estimation of overall economic benefit: end-user savings and additional producer margin.

Preliminary evaluation:

The case study analyzes the coupling between a hydropower plant owned by an Independent Power Producer and a consumer unit represented by a pumping station that operates a water distribution network in a region of central Italy. The production unit is a hydropower plant with a nominal power of 720 kW and an average annual production of approximately 2.5 GWh/y. The plant has reached the end of the incentive mechanism called “Tariffa Omnicomprensiva”, resulting in a reduction in its economic revenues; In this context, the implementation of an SSPC represents a possible solution to increase the value of the energy produced through direct on-site supply. The consumption unit, instead, consists of hydro pumps with a total nominal power of 605 kW, and an average annual consumption of approximately 4 GWh/y.

The distance between the two units is a key factor because the cost of the electrical connection depends on the length of the power line and significantly impacts the initial investment cost. Likely, in this case, the distance between the two units is less than 200 m, a condition that reduces the cost of the connection and promotes its feasibility. Moreover, since this configuration involves a power producer different from the end-user, the definition of a bilateral agreement and of a supply tariff for the energy self-consumed on site is required.

The preliminary evaluations highlight:

- comparable nominal powers;
- limited distance, therefore potentially limited initial investment;
- annual demand exceeding production, that is a favorable condition for maximizing self-consumption and fully valorizing the energy generated by the power plant.

Energy flows analysis:

To evaluate the suitability of the SSPC, it is necessary to assess the energy flows that characterize the SPCS. Specifically, it is necessary to estimate the share of energy self-consumption, the share of energy withdrawn from the grid, and the share of energy fed into the grid. These quantities are estimated by simulating the operation of the SPCS over a time interval of 1 year. For this purpose, it is necessary to have acces to the production and consumption data of the two units, in order to build the production and consumption curves, to overlay them and to estimate the energy shares. In this case study, the analysis is conducted using historical 2024 production and consumption data, recorded every 15 minutes. These measures are available on the Distribution System Operator (DSO) web portal or in Italy via the so called “Portale Consumi” provided by the Italian energy authority (ARERA). The adopted time resolution allows to compare the produced and consumed energy measures assuming instantaneous self-consumption with a negligible computational error.

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To evaluate energy shares, it is necessary to introduce some mathematical definitions:

- C_j is the amount of energy consumed by the end-user.
- P_j is the amount of energy produced by the hydro power plant.
- S_j is the amount of direct self-consumed energy within the SPCS.
- F_j is the amount of energy fed into the grid through the end-user's POD.
- W_j is the amount of energy withdrawn from the grid.
- j is an index that varies from 1 to 35040 and corresponds to the number of quarter-hour intervals contained in a year.

It is possible to determine the amount of energy self-consumption in the 15-minute interval j, as the minimum between the energy consumption and the energy production:

$$S_j = \min\ [C_j\ ;\ P_j]$$

(Eq. 1)

By summing over j we obtain the total amount of annual energy self-consumption (S_{tot}) :

$$S_{tot} = \sum_{j=1}^{35040} S_j$$

(Eq. 2)

To determine the amount of energy withdrawn from the grid, it must be considered that W_j is different from zero only if $C_j > P_j$. Indeed, the end-user user will withdraw energy from the grid only if the energy produced by the hydropower plant should be not sufficient to meet the required end-user's needs.

So if $C_j > P_j$, we can express the amount of energy withdrawn from the grid with the following equation:

$$W_j = (C_j - P_j)$$

(Eq. 3)

By summing over j we obtain the amount of annual withdrawn energy (W_{tot}) :

$$W_{tot} = \sum_{j=1}^{35040} (C_j - P_j)\ ,\ if\ C_j > P_j$$

(Eq. 4)

In the same way, to estimate the energy fed into the grid, it must be considered that F_j is different from zero only if the energy produced by the hydropower plant is greater than the needs required by the end- user.

So, if $C_j < P_j$ we can quantify the amount of energy fed into the grid with the following equation:

$$F_j = (P_j - C_j)$$

(Eq. 5)

By summing over j we obtain the amount of annual injected energy (F_{tot}) :

$$F_{tot} = \sum_{j=1}^{35040} (P_j - C_j)\ ,\ if\ C_j < P_j$$

(Eq. 6)

Once all the energy flows have been estimated, it is possible to define two important indexes, useful for providing an evaluation of the expected performance of the system: the Self-Consumption index and the Self-Sufficiency index.

The Self-Consumption index (SC_i) is the ratio between the total energy self-consumption and the total energy produced by the hydropower plant:

$$SC_i = \frac{S_{tot}}{P_{tot}}$$

(Eq. 7)

While the Self-Sufficiency index (SC_i) is the ratio between total the total energy self-consumption and the overall end-user's energy needs:

$$SS_i = \frac{S_{tot}}{C_{tot}}$$

(Eq. 8)

In *Figure 2*, it is possible to observe the graphic representation of the overlaying of the consumption and production curves related to 2024. As can be seen, the production curve is almost always below the consumption curve and furthermore both curves are characterised by a flat trend during the year. These two features, easily observable from the graphical representation, already demonstrate the excellent coupling that can be achieved between these two units.

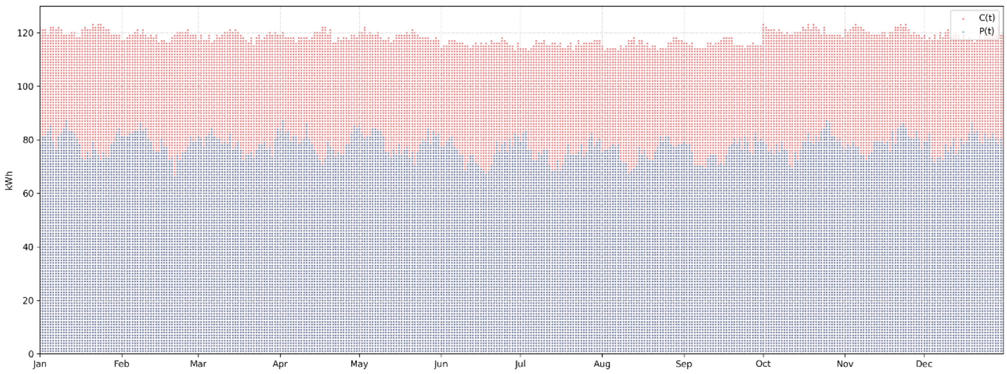

Figure 2 - Quarter-hourly Production (P(j)) and Consumption (C(j)) over the entire year.

Table 2 instead shows the results obtained by applying the equations previously illustrated and the annual values related to the hydropower plant overall energy production and the overall end-user's energy needs. All data are related to 2024.

	HYDROPOWER PLANT P2024	**CONSUMPTION UNIT (C_{2024})**	**SELF-CONSUMPTION (ENERGY)**	**INJECTED ENERGY F_{2024}**	**WITHDRAWN ENERGY W_{2024}**	**SELF-SUFFICIENCY SS_i**	**SELF-CONSUMPTION SC_i**
	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]	%	%
ANNUAL AMOUNT	2.637	3.948	2.636	1	1.312	66,8%	99%

Table 2 – SPCS annual energy flows and indexes (reference year: 2024)

Now it is necessary to associate an economic value to the energy flows in order to calculate the economic revenues related to the SPCS.

Estimation of avoided costs:

As already said, the economic advantage related to a SPCS is in the avoided costs on the bill. In particular, the energy self-consumption within the SPCS is not subject to grid charges, system charges and other charges set by the energy supplier. Therefore, the final consumer, who no longer withdraws all the energy from the grid, benefits from economic savings equal to the avoided charges do not apply to the self-consumption energy. In this case, economic savings are quantified by taking into account especially grid and system charges. In fact, eletrical energy price will still have to be paid by the end-user to the power producer and so it is a costant if it is assumed that the supplier and the power producer apply the same price without further price spreads.

The value of the grid and system charges on the bill, applied to the energy withdrawals, are related to the unit consumption type and power. In order to assign an accurate value to each one of the cost components, the characteristics and type of the end-user were considered and all the values assumed by the components during 2024 were collected. Components data are shown in *Table 3* where the last line shows the average annual value assumed by each component.

Quarter (2024)	**Dispatching (PD)**	**Distribution (DS)**	**Transmission (TRAS)**	**UC3**	**System charge (Asos)**	**System charge (Arim)**	**Capacity Market Charge (CMC)**	**Supplier's Spread**
	[€/MWh]	[€/MWh]	[€/MWh]	[€/MWh]	[€/MWh]	[€/MWh]	[€/MWh]	[€/MWh]
Q1	7,5	0,48	9,89	6,3	35,34	4,086	2,5	4,54
Q2	6,87	0,48	9,89	6,3	41,13	4,77	2,5	4,54
Q3	6,38	0,48	9,89	6,3	41,13	4,77	2,5	4,54
Q4	8,22	0,48	9,89	6,3	41,13	4,77	2,5	4,54
AVERAGE	7,2	0,48	9,89	6,	39,68	4,6	2,5	4,54

Table 3 – Grid and System charge componentson the bill in 2024 (€/MWh)
and their corresponding annual average

Definition of Economic Benefit parameter:

In order to assign an economic value (€/MWh) to self-consumed energy, it was chosen to define a parameter called Economic Benefit (EB). EB is the sum of all avoided grid and system charges and therefore it is expressed by the equation:

$$EB = PD + DS + TRAS + UC3 + CMC + A_{SOS} + A_{RIM} \quad \text{(Eq. 9)}$$

The Economic Benefit parameter for 2024 can be estimated using a mathematical formulation similar to the previous one, but related to the average values assumed in 2024:

$$\overline{EB}_{2024} = \overline{PD}_{2024} + \overline{DS}_{2024} + \overline{TRAS}_{2024} + \overline{UC3}_{2024} + \overline{CMC}_{2024} + \overline{A_{SOS}}_{2024} + \overline{A_{RIM}}_{2024} \quad \text{(Eq. 10)}$$

EB is a key parameter because it represents the end-user 's economic savings per unit of self-consumed energy. Whereas, for the power producer it can be seen as an implicit form of incentive, indeed if the end-user paid to the power producer the same price as he pays on the bill he would receive an additional revenue to the mere sale of energy. As will be seen later the EB will be shared between producer and end-user in such a way that both can enjoy the economic advantage generated by the implementation of the SPCS.Using the average value of the 2024 charges, shown in Table 2, in the equation *(Eq. 4)* it is possible to estimate the EB parameter in about 75 €/MWh.

Definition of the economic tariff:

As already shown, a direct supply of energy from the power plant to the end-user is realized within the SPCS. When the power producer is different from the end-user, the first will apply a price to the energy supplied and self-consumed under the SPCS. It is therefore necessary to set a private agreement between the parties and define an economic tariff to regulate only the energy self-consumption.

In this case study, the price (TP) applied to energy supplied by the power producer and self-consumed by the end-user is set by the following economic tariff:

$$TP = \left[\frac{Q_{\mathrm{F1}} \cdot PUN_{\mathrm{F1}} + Q_{\mathrm{F2}} \cdot PUN_{\mathrm{F2}} + Q_{\mathrm{F3}} \cdot PUN_{\mathrm{F3}}}{Q} \cdot (1 + F_{LOSS}) \right] + [(EB \cdot R_{\%}]$$

(Eq. 11)

In which:

- $\mathrm{Q_{Fi}}$ is the amount of energy consumed in the corresponding band (F1, F2, F3)
- Q is the overall energy consumed
- $\mathrm{PUN_{Fi}}$ is the energy price on spot energy markets
- $\mathrm{F_{LOSS}}$ is the power loss factor
- EB is the economic benefit
- $\mathrm{R_{\%}}$ is a coefficient that depends on the price of energy on spot markets

For this case study a specific economic tariff was chosen to allow to allocate the Economic Benefit between the power producer and the end-user. The sharing of the EC is carried out through the $R_{\%}$ coefficient, defining the portion of the economic savings that will be attributed to the producer ($EB \cdot R_{\%}$).

The $R_{\%}$ coefficient is very important, because it does not assume a constant value but varies depending on energy price on the spot markets. The relationship between $R_{\%}$ and the energy price is inversely proportional. When the price of energy on the markets increases $R_{\%}$ decreases, while if the price of energy decreases $R_{\%}$ increases. Linking the $R_{\%}$ parameter to energy price on spot markets allows us to create a sort of insurance scheme:

- the producer is protected when energy prices are low
- the end-user is protected when energy prices are high

Observing equation 3 *(Eq. 3)*, when energy prices $PUN_{\mathrm{F}i}$ are low, and thus the producer's investment is put at risk, he can benefit from a larger share of the EB. On the other hand, the end-user, who is already enjoying a low energy price, can easier waive the economic savings generated by the SPCS.
Otherwise, when energy prices are high and the producer already earns good revenues from the energy supply, he can easier waive the economic savings, protecting the end end-user that is exposed to high energy costs.

Estimation of economic benefit:

We now have all the elements to evaluate revenues and savings generated in 2024 by the SPCS under examination. First of all, it is necessary to indicate the relationship between $R_{\%}$ and the energy price on the spot markets. To simplify the analysis, in this study we chose to use a stepwise trend for $R_{\%}$, with $R_{\%}$ constant for each PUN variation of 20 €/MWh, starting from $R_{\%}$ = 1 for $PUN \leq 50$.

Now it is possible to calculate for each range of the PUN the part of EB that remains with the power producer and the corresponding ((EB · (1- $R_{\%}$)) which instead represents the part of economic benefit that remains with the end-user in the form of economic savings. Based on the end-user's unit savings ((EB · (1- $R_{\%}$)), it is possible to calculate the difference between the price he would pay with his energy supplier, and the price he would pay for the energy supply within the SPCS.
Finally, we can obtain the annual savings of the end-user that is calculated as the product between the unit economic savings ((EB · (1- $R_{\%}$)) and the annual energy self-consumption (S_{tot}).

Instead, the product between the producer's share of EB and the annual energy self-consumption energy (S tot) represents the additional revenues for the power producer.
The results obtained for each PUN Range are reported in *Table 4.*

PUN annual average	$R_{\%}$	*Power Producer's benefit share ($EB \cdot R_{\%}$)*	*End-user's benefit share (EB · (1- $R_{\%}$))*	*Tariff Price (TP)*	Supplier' tariff	Δ price	End-user annual savings	Power producer additional revenue
PUNm < 50	100%	75,0 €	0 €	< 127 €	< 127 €	0 €	0 €	< 197.700€
50,01 < PUNm < 70	90%	67,5 €	7,5 €	≃ 130 €	≃ 137 €	7,5 €	19.770 €	≃ 177.930 €
70,01 < PUNm < 90	80%	60,0 €	15,0 €	≃ 143 €	≃ 158 €	≃ 15,0 €	≃ 39.540 €	≃ 158.160 €
90,01 < PUNm < 110	70%	52,5 €	22,5 €	≃ 156 €	≃ 179 €	≃ 22,5 €	≃ 59.310 €	≃ 138.390 €
110,01 < PUNm < 140	60%	45,0 €	30,0 €	≃ 170 €	≃ 200 €	≃ 30,0 €	≃ 79.080 €	≃ 118.620 €
140,01 < PUNm < 150	50%	37,5 €	37,5 €	≃ 183 €	≃ 220 €	≃ 37,5 €	≃ 98.850 €	≃ 98.850 €
150,01 < PUNm < 170	40%	30,0 €	45,0 €	≃ 196 €	≃ 241 €	≃ 45,0 €	≃ 118.620 €	≃ 79.080 €
170,01 < PUNm < 190	30%	22,5 €	52,5 €	≃ 209 €	≃ 262 €	≃ 52,5 €	≃ 138.390 €	≃ 59.310 €
190,01 < PUNm < 210	20%	15,0 €	60,0 €	≃ 223 €	≃ 283 €	≃ 60,0 €	≃ 158.160 €	≃ 39.540 €
210,01 < PUNm < 220	10%	7,5 €	67,5 €	≃ 236 €	≃ 303 €	≃ 67,5 €	≃ 177.930 €	≃ 19.770 €
PUNm > 220,01	0%	0 €	75 €	≃ 239 €	≃ 314 €	≃ 75,0 €	≃ 197.700 €	= 0 €

Table 4 – SPCS annual economic outcomes across different PUN ranges under the proposed supply tariff structure

Results

Based on the analysis conducted, a Self-Consumption Index (SC_i) of 99% can be observed, which means that approximately all the energy generated by the hydroelectric plant will be self-consumed on site and therefore valued through the economic tariff of supply to the end-user. While the Self – Sufficiency index is 66%, this means that much more than half of the overall annual energy demand required by end-user users can be satisfied on-site thanks to the the SPCS, the remaining demand will have to be withdrawn from the grid as already happens. Finally, it can be observed that approximately 1 MWh of energy produced by the hydro power plant will be fed into the grid and can be economically exploited through market sales.

In the analysis a complex economic tariff was implemented, but capable of guaranteeing benefits to both entities that constitute the SPCS. The results vary with the price of energy on the wholesale market (PUN) and on the charges applied on the bill; however, in the scenario analyzed, the configuration is economically viable for both parties.

The use of historical production and consumption data, with a 15-minute resolution allows a highly accurate estimate of the energy flows, reducing the error associated with the results.

Assuming the values of the tariff components recorded in 2024 and a scenario with an average annual PUN of 110 €/MWh (a value compatible with recent price scenarios) and applying the EB parameter previously presented, the following annual economic results are obtained:

- expected revenues for the power producer equal to 138.390 €, additional to the revenues associated with the sale of energy.
- End-user annual savings equal to 59.310 €.

Finally, the cost difference between energy purchased through a supplier and the cost of energy supplied in the SPCS is positive and tends to increase as the PUN increases, highlighting the convenience of the configuration, particularly in high-price scenarios.

Conclusions

In conclusion, the analysis shows how SPCSs can represent an effective solution for both power producers and end-users, as they allow to increase the economic value of the energy produced through direct self-consumption and the sharing of economic benefits between the parties through dedicated contractual agreements. The most recent regulatory framework has helped to simplify the qualification and the deployment of such configurations, making them a concrete alternative to explicit support mechanisms that, in many cases, require technical and stringent requirements. SPCSs are particularly attractive for renewable power plants that have completed their incentive period and no longer benefit from direct subsidies. This scenario is expected to become frequent, due to the numerous power plants that entered into operation in the early stages of RES installed capacity expansion and now are reaching the end of incentive schemes. In this context, the implementation of an SPCS can constitute an alternative strategy compared to revamping or repowering interventions, contributing to improving the economic performance of the power plants.

The results presented in this work also demonstrate the importance of conducting an accurate techno-economic analysis in the preliminary design phase. In the absence of favorable conditions, such as poor matching between curves or high connection costs, it may be appropriate to evaluate virtual self-consumption configurations or other alternative solutions. Moreover, we were able to examine how SPCSs can ensure significant economic performance and how they can be useful in mitigating the impact of energy price volatility in energy markets.

Although it was not explored in detail in this work, it is also worth underlining that local self-consumption associated with SPCSs can also generate benefits to the power distribution grids, reducing congestion and grid losses, limiting reverse power flows, and helping to contain the need upgrades in distribution grids. In general, we can say that the development of these systems can help to make the management of distribution grids more reliable, secure and efficient.

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