Corporate Power Purchase Agreement: formulation of the related levelized cost of energy and its application to a real life case study

Luca Mendicino, Daniele Menniti, Anna Pinnarelli, Nicola Sorrentino
Department of Mechanical, Energy and Management Engineering
University of Calabria - Arcavacata, Rende, Cosenza, Italy
luca.mendicino@unical.it; daniele.menniti@unical.it; anna.pinnarelli@unical.it; nicola.sorrentino@unical.it

Abstract **- For corporate and industries the reducing of its environmental footprint is becoming more and more important, in order to improve the 'green and social brand' of their products and services. Many instruments may be used to this purpose but in recent years Corporate Power Purchase Agreement (CPPA) is the form of contract that is used more and more frequently. CPPA is a contract between an energy producer, from renewable sources and an end-user. Using CPPAs, the 'green brand' for a corporation and its product and services could be achieved. The main concern is related to the costs: still today, renewables are more expensive with respect to fossil fuels, therefore this results in higher prices for products and services, so a fair trade off between CPPA price and the gain of 'green brand' has to be determined. In this paper, the authors propose a method based on an opportune Levelized cost of energy formula able to support a stakeholder to define CPPA price and contractual length. A case study with significant results for a PV plant in the Italian real life application is provided. From the performed simulations emerges realistic ranges CPPA's contractual length and price convenient for involved stakeholder. In particular the length should be not less than 7 years and not more than 10 years while the price should be in the range between 75 €/MWh and 100 €/MWh.**

Index Terms **- Power Purchase Agreements, renewable energies, Levelized Cost of Energy, Life-Cycle Cost, contractual length, contractual price, corporate buyer, electricity market, new energy market models.**

I. Nomenclature

BEP	Break-even point
BMCPPA	Behind Meter Corporate Power Purchase Agreement
BSP	Balancing Service Provider
CAPEX	Capital expenditure
C&I	Corporate & Industrial users
CCT	Congestion Network Charges
CFD	Contract For Difference
COE	Cost of energy
DSO	Distribution System Operator
EMO	Electricity Market Operator
FPPA	PPA facilitator
LCOE	Levelized Cost of Electricity
NREL	National Renewable Energy Laboratory
PPA	Power Purchase Agreement
PV	Photovoltaic
RPS	Renewable Portfolio Standards
SAM	System Advisor Model
SCPPA	Sleeved Corporate Power Purchase Agreement
TCA	Tax & Customs agency
TLCC	Total Life-Cycle Cost
TSO	Transmission System Operator
VCPPA	Virtual Corporate Power Purchase Agreement

II. Introduction

New environmental policies for corporate and industrial users (C&I), increase the interest in using renewable energy for their needs in order to improve their green footprint. It is worth underlining that renewables have high initial investment costs which are determined by the power plant technology used, and the electricity market remains the subject of intense debates due to the electricity prices variability and political uncertainty around renewable energy targets and the convergence of these problems due to costs, technology, and type of user. Also, this results in the business sector sourcing electricity demand through special contracts with '*green*' generation facilities [1].

These contracts, named Power Purchase Agreements (PPAs), which are performance-based contracts that aim to create a "fair" and risk-controlled agreement for the purchase and sale of energy between an energy consumer (Buyer) and a Producer (Seller).

Recently in [2], a comparison from investors' perspective between feed in tariff, PPA and Renewable portfolio standard is performed, outlining the major benefit PPA in a grid parity framework, while in [3] PPAs are useful to mitigate the risk.
PPAs are quite new financial instruments so there is no theoretical statement in the literature to the knowledge of the authors and only some specific contractual statements in different countries are presented.

Moreover, PPAs are a suitable instrument to reduce risk for developers and financing parties and therefore can significantly help to increase the growth of renewables [4].
PPA is interesting way for the creation of renewable power plants that have a very high initial investment cost (Capex), like wind and solar photovoltaic (PV) power plants. Capex affects up to 90% on the total project value, while generally the operation and maintenance costs are very low.

PPAs have several parameters to define including the contractual length, practicable price, minimum and maximum energy deliveries, penalties and defaults, insurance, and many others variables. Optimizing these parameters will become ever more important as corporations look to determine whether it is economically profitable to enter into a PPA. At the same time, PPAs can have different structures such as fixed-price, fixed-indexed, or customized structures.
PPA contracts are also based on knowing *Levelized Cost of Energy* denoted with LCOE [5]. The LCOE determines the choice of the contract price that affects the payback time and the project profitability. An accurate LCOE evaluation is necessary to support investments in new power plants based on renewable energy sources.
While the LCOE represents the break-even cost to generate the energy, represented by the kWh cost and it generally is the calculation of the Total Life-Cycle Cost (TLCC) for each kWh unit of energy produced during the lifetime of a project, the *COE* is the cost to buy energy. According to this definition COE could be equal to LCOE (to balance generation costs) but often can be greater than LCOE to obtain a reasonable profit. However, for a project to be financially feasible, the nominal PPA price must be higher than the LCOE [6].
Since there is a link, the same parameters that affect the LCOE will affect the PPA price. Owing to the high volumes of energy involved but also to an immediate positive effect in the case of matching between generated energy and requested loads, one emerging market is the ***renewable energy corporate PPA market***, where C&I buyers purchase energy from a renewable power plant according to a Corporate Power Purchase Agreement (CPPA).

A. Corporate Power Purchase Agreement

The CPPA is a contract between a Buyer and a Seller that can be a Developer, an independent Power Producer or an Investor.
A Corporate Power Purchase Agreement (PPA) is a long-term contract under which a business agrees to purchase electricity directly from an energy generator. This differs from the traditional approach of simply buying electricity from licensed electricity suppliers, often known as utility PPAs [7].
The Buyer purchases renewable electricity at a pre-established price for a pre-agreed period of time. The agreement contains the commercial terms of the electricity sale*: contractual length*, *point of delivery*, *delivery date/times*, *volume* and *price*.

The electricity sold under a CPPA can be generated from existing renewable energy power plant/s as well as by a new power plant indicated to achieve as project. In the latter case, given the requirements to finance the project, the CPPA has stricter requirements - for example, a duration that covers at least the debt term of the project finance.

CPPAs use LCOE models to determine a fair price of energy similar to a standard retail energy contract. The importance of including all cost components in LCOE determination as well as that of understanding the effects of CPPA parameters and structures is becoming even more imperative as the CPPA market expands. The type of structure will influence the value of CPPAs.

CPPAs can be structured in several ways: the choice of most appropriate structure will require understanding of the corporate primary drivers, an analysis of the load profile and an evaluation of any other relevant considerations applicable to the corporate buyer. Proper financial analysis of the available alternatives, together with a risk identification, allocation and mitigation analysis is essential.

In this paper, attention is focused on challenges and solutions for CPPA concerning new projects development of particular photovoltaic plants but the results can be also applicable to wind projects [8].

B. State of the art

Nowadays, the majority of renewable energy PPAs are powered by wind farms that have extremely increased between 2012 and 2018, for example EMEA (European, Middle East and African) PPA market PPAs powered by wind exceed 80 % of the annual contracted capacity. In the last few years an important increase of solar PV plant developed under corporate PPAs has been observed and considering the EMEA PPA market annual volume data for the years from 2008 to 2018 is very likely that a further growth is expected [9]. As shown in *Fig.1* market data illustrate how global CPPAs have reached 35GW of installed power in 2018 and how top global companies are starting to procure energy by mean of PPAs (e.g. *Amazon*, *Google*, *Microsoft*, *Walmart* etc.). Companies that, first, started to focus on CPPAs to get as close as possible to the goal, have already achieved, in some cases, use of 100% green electricity.

CPPAs are commonly used in Europe [10]. In Germany thanks to government lenders, wind projects with PPAs totalled over 1.2 GW in capacity in 2013 [11]. Between 2008 and 2016, 650 MW of new capacity was signed in the U.S. and in 2015 the use of PPAs in the U.S. grew up to 1.6 GW [12]. Berkeley National Laboratory produced a dataset with a total of 34,558 MW of capacity in 387 signed or planned PPAs in the U.S. for 2016 – 2017 [13].

CPPAs differ by market, for instance, in California corporate buyers are not able to enter into PPAs for direct retail sale of power over the grid but rather can make use of virtual CPPAs (VCPPA) operated by the California Independent System Operator. In Texas, corporate buyers can acquire physical energy using "sleeved" transactions involving sales and purchases through third party retail electric providers [14]. The characteristic of this kind of contract are still under discussion and innovative solutions are suggested [15]. Within U.S. the PPAs have gained more interest where government laws as Renewable Portfolio Standards (RPS) mandate the level of renewable energy that a State is required to consume. Utilities must then purchase renewable energy at the levels required by the RPS. Because renewable energy is typically more expensive than gas or coal, utilities will utilize a maximum energy purchase limit, so they do not have to purchase more of the expensive renewable energy than required.

In other parts of the world, minimum energy purchase limits may be preferred to maximum limits due to energy policies, for example, in some Latin American countries where the Government policies shape the preferences by using energy purchase limitation in PPAs. Even within Europe regions new regulations about mandatory minimum quantity of renewable energy are emerging. Since each country has different energy or environmental policies, energy purchase limitation preferences vary. Unlike the U.S. or Europe, in Latin America the national governments typically award PPAs to energy generators. In 2014, the government of Peru awarded PPAs to projects with a total of 232 MW of capacity [8]. In Italy there was an increasing interest and recent regulation has placed PPA as an instrument to reach renewable 2030 targets [16]. The basic concept of a PPA however, does not change between countries.

C. Contribution of the paper

As CPPA is a quite new financial instrument and, to the knowledge of the authors, no general framework is present in the literature, and for this reason, this paper gives a comprehensive framework of the different CPPAs used in different countries sharing differences and peculiarities. Then a business model will be formulated to facilitate CPPA application. This results in a new LCOE formula, more complex with respect to the others presented in the literature, based on a PPA framework. This new formulation is helpful to evaluate the optimal CPPA price and contractual length. This may be very useful to establish contract form between different stakeholders in different renewable technologies, fuel cells [17]. The authors show, through some numerical applications for a solar photovoltaic plant of 20MW, LCOE sensitivity results that help to tune the CPPA price in order to take into account the several intrinsic uncertainties in the CPPA contracts. So, it represents a useful methodologies to support investors in renewable energy.

D. Structure of the paper

In the paper, firstly, the main differences between CPPA structures, recognized in the literature, have been outlined; then a proposed LCOE formula is described and finally a numerical application related to a CPPA for a 20MW PV power plant will be reported. Some sensitivity results help to tune the CPPA price in order to take into account the several intrinsic uncertainties characterizing CPPAs.

III. EXISTING CPPA STRUCTURES

At a general level, a PPA for corporate and industrial users has a framework structure as depicted in *Fig.2* where produced energy is exchanged to satisfy the energy needs of several corporate customers. Energy exchange is usually performed by mean of the national electrical grid.

A CPPA based on a new project is typically structured as long term agreement, usually as 10 years contract or more according to renewable power plant technology; otherwise it may not see a return on the capital costs and may not satisfy the requirements of lenders. The CPPA contractual length varies among sectors and jurisdictions. The pricing structure can be based on either a fixed price or a discount pegged to the wholesale market (spot market) price with a fixed floor, with many variations on both of these structures. Corporate buyers with lower energy demand and less experience of entering into CPPAs may want to join forces with other buyers through multiple buyer structures. Some approaches involve multiple CPPAs for a single project, where each CPPA is with a different buyer. Other approaches involve the development of a buying group, which will enter into a single CPPA for the benefit of all participating buyers. These risk-sharing solutions are increasingly attractive options for some corporate buyers. Potential termination rights and different accounting treatments are also leading corporate buyers towards using multiple buyer structures.

Considering the above general description of a CPPA the relation between Seller and Buyer is a WIN-WIN business relationship since it entails advantages for both involved parties where each partners create an environment that encourages continuous improvement, risk taking, a long-term perspective. In particular main advantages are:

- for **Sellers**:
- Risk mitigation, diversification of revenue streams and risk management on the energy off-take;
- Bankability, predictable and long-term income streams unlock finance and ease bankability with financial institutions;
- Business development, additional demand creation and development of standard terms and conditions (through establishing partnerships).

- for **Buyers**:
- Economics, long-term cost affordability and improved price visibility;
- Sustainability, reductions in carbon emissions and progress towards renewables targets;
- Brand and leadership, recognition for renewable electricity achievements and climate leadership.

In addition, the main concerns for corporate buyers entering into a CPPA are mainly related to *forecast wholesale price uncertainty, counterparty risk, change in law/regulations, power consumption and merchant risk* [18].

Corporates are concerned about **wholesale power prices** since they want to avoid unexpected costs but at the same time there is also the possibility that price may decline below the agreed CPPA price (*strike price*) for a sustained period of time.
Indeed, despite the technology cost and projects capex decrease, the CPPAs are generally long-term contracts so might be influenced by the market energy price uncertainty due to several factors such as the spread rate, fossil fuel costs, faults of essential power plants, weather conditions and so on [19]. For this reason, CPPAs should be thought of mainly as a hedge against rising prices and uncertainty, in the same way that corporations hedge interest rate risk.

The **counterparty risk** is flagged by the corporate buyers indicating the probability that an energy Seller may become insolvent and not be able to meet its obligations under the contract. It is worth noting that this risk may justify the presence of institutional operators or public regulators in the CPPA negotiations.

Corporate buyers and Sellers may be worried also about current energy policies and any possible **change in the law or regulation**, which may adversely affect a long-term agreement. It is increasingly common though, for some change in the law, and risks sharing between the Buyer and the Seller.

Some corporate buyers are concerned about the **power consumption risk** since the generation of the renewable power plants could not match the requested load in certain hours. Not all corporate buyers require loads with a flat demand profile. In this case, the corporate buyer may be subjected to **merchant risk** if the CPPA establishes the energy supply deficit must be purchased by the corporate buyer on the electricity market. This is a fundamental risk to be considered when entering into a CPPA and to this purpose the corporate buyers have to determine their energy procurement strategy with an understanding of their overall usage and load profile and how this may change over time [11].

There are many different types of CPPA structures. The right structure of a CPPA will be determined by the regulatory design of the relevant electricity market, the corporate buyer strategy and the capability of the corporate buyer. Starting from the general CPPA framework structure, evaluation of real cases leads to three possible different CPPA structures. One for on-site renewable power plants is the '*Behind the Meter CPPA*' structure.
For off-site renewable power plants the CPPAs are typically structured as long-term '*Sleeved CPPA' (SCPPAs)* and '*Virtual CPPA*' (VCPPAs) [20].

A. Behind Meter CPPA (BMCPPA)

The BMCPPA is so called because, as shown in *Fig.3* the renewable power plant is physically connected to the consumer 'behind the meter'. Examples include large rooftop or on-site solar or wind installations. This solution involves a direct contract between the Seller and the Buyer. The Seller may or may not be permitted (according to the regulatory framework) to sell any energy surplus with respect to the Buyer's load requirements to the network operator or to other buyers. Since the Buyer's load profile is unlikely to match exactly the production profile of the Seller, unless a storage solution is involved, this configuration does not generally allow the Buyer an off-grid configuration and bypasses the use of a retailer. For this reason, the Buyer still needs to pay connection charges, which form a large and rising component of the energy costs.

B. Sleeved Corporate PPA (SCPPA)

The SCPPA involves a connection to the grid but in this case, with respect to the BMCPPA, the power plant connection is off-site. The Seller sells all the generated power to the corporate buyer using a first contract (CPPA1). The corporate buyer immediately resells that power to a licensed supplier under a second contract (CPPA2). The licensed supplier then "sleeves" the power through the grid and sells power to the corporate buyer at its site. As depicted in *Fig.4* the Seller sells power directly to the Buyer and the licensed supplier then sleeves the power from the grid and supplies it to the Buyer's site.

The power flows from the power plant to the corporate buyer's site having been 'sleeved' over the grid by the licensed supplier who performs a balancing service under the CPPA2 (since renewable energy is intermittent) by topping up the renewable electricity with extra if needed (for example when the generator is not producing). The corporate buyer then repurchases the power at the CPPA2 price plus the network charges and fee (*sleeving fee*). In this case, the presence of the licensed supplier allows the corporate buyer to use the energy from a remote power plant exploiting an energy balancing service (BSP). A licensed supplier is necessary to manage billing, the energy mismatch of renewable generation (if necessary) and demand through market trading and ancillary services or simply because some regulatory frameworks require a retailer to put electricity into the grid. Producers may not have a retail licence and do not undertake many of these roles, thus requiring a licensed supplier or another entity to act as an intermediary.

C. Virtual Corporate PPA (VCPPA)

The VCPPA can be considered as a financial version of the SCPPA. A virtual approach replaces the physical CPPA model with a financial structure that creates a similar economic effect to a physical CPPA for both parties, avoiding the sleeving fees. The VCPPA structure is visible in *Fig.5*.

There are several variations on the VCPPA, according to the merchant risk appetite of each involved party. Under the VCPPAs signed to date, between major *Supplier* and *Producers*, have offered a fixed price for a certain term, accepting merchant risk during that term. The Seller "virtually" sells the energy that it produces to a corporate buyer for a fixed price.

The Seller sells energy to a licensed supplier under a standard power purchase agreement at a market price. The licensed supplier continues to sell energy to the corporate buyer under a standard electricity supply agreement at a market price.

At the same time as these conventional contracts the *Seller* and the *corporate buyer* sign a VCPPA contract for difference (CFD) in which they agree a fixed "strike" price for the renewable energy produced by the power plant.

In this way both Seller and corporate buyer are covered by the risk of market price fluctuations. Indeed, if the CFD, that is, the difference between the strike price and the market price, is positive the corporate buyer is committed to pay the difference to the Seller. Otherwise if it is negative the Seller is committed to paying the difference to the corporate buyer.

IV. THE PROPOSED LCOE FORMULA FOR A VCPPA

A. Brief review of LCOE models for CPPA in the literature

As mentioned, usually PPAs use an LCOE model to determine the fair price of energy like a standard retail energy contract. There are several parameters involved in a typical PPA including contractual length, price, delivery of energy (minimum/maximum), renewable energy credits, milestones and defaults, curtailment, interconnection and grid, liability & insurance, metering, credit, billing, decommissioning, taxes and so on (LCOE terms). In particular, the PPA price is the most important in determining whether the contract will be profitable for the seller, so it is necessary to consider how various LCOE terms may affect the price and so the payback period for a project. The LCOE is a useful metric to measure how feasible a power generation technology is for commercial implementation and indicates its competitiveness compared to other technologies [21]. For intermittent renewable sources, due to both generation variability and market price variability, LCOE becomes a stochastic variable. In [22] LCOE is estimated using

Monte Carlo simulation [22], as Monte Carlo approach is only slightly more complex than using point values, but provides more realistic information about risk and uncertainty and enables more useful analysis of potential investments in electricity generation. While in [23] traditional life-cycle cost calculation should is by a Co-Variation coefficient; It captures any synergies, or complementarities, between the time-varying patterns of electricity generation and pricing. The basic definition of the LCOE is represented by *Equation (1)*.

$$\text{LCOE} = \frac{\text{Total Lifetime Cost}}{\text{Total Lifetime Energy Production}} \qquad (1)$$

Although LCOE is a well-developed and standard technique in energy sector economics, several authors approach model construction in different ways to ensure the model matches research tasks and data availability according to the type of analysis. Several authors have reported several LCOEs models. There is great variability not only in the values but also in what the LCOEs include or do not include. For instance, the National Renewable Energy Laboratory (**NREL**) and others have developed and used several LCOE models. NREL uses SAM (System Advisor Model) to compute the LCOE using wind farm data for PPAs. *Equation (2)* is the LCOE formula used in SAM where *CPEi* is the cost of producing energy and *Ei* is the quantity of energy generated in the year i [24] . The difficulty in the analysis is what the *CPEi* has to consider.

$$\text{LCOE} = \frac{\sum_{i=0}^{n} \frac{CPE_i}{(1+r)^i}}{\sum_{i=0}^{n} \frac{E_i}{(1+r)^i}} \qquad (2)$$

CPEi = Cost to produce energy in year i
Ei = Energy generation in year i
r = Discount rate
n = End-of-life of the power plant

The LCOE equation can vary to accommodate necessary changes adopting a more detailed structure as represented in *Equation (3)* respect the general version represented in *Equation (2)* [25].

$$\text{LCOE} = \frac{\sum_{i=1}^{n} \frac{I_0 + Mi + Fi}{(1+r)^i}}{\sum_{i=1}^{n} \frac{Ei}{(1+r)^i}} \qquad (3)$$

I_0 = Investment expenditures in year 0 (including financing) defining year 0 as the year before the plant start-up year.
M_i = Operations and maintenance expenditures in year i
F_i = Fuel expenditures in year i
E_i = Energy generation in year i
r = Discount rate

These LCOE models consider all the capital costs and annual operational costs that are expected to be incurred in a project but do not include the effects of the energy delivery limits and their penalty costs imposed by the contract as well as market operators. The PPA contract limits, create penalties when the Seller does not fall within the energy delivery requirements affecting the actual LCOE. PPAs are used to share and reduce the risks of additional costs, however, in some cases the costs are not accounted for within LCOE models. The PPA contractual length is important because it creates costs that affect the actual LCOE. If the LCOE does not reflect the break-even cost, the Seller risks the project's failure and the Buyer risks a loss in profit from not providing enough energy to its use or its end-use consumers. A very accurate LCOE evaluation through a more appropriate formula could prevent the failure in financing a project and benefit the Seller, the Buyer and involved parties.

Some LCOE models [8] consider a more detailed break-down of parameters that explicitly includes the costs of fuel (F), production tax credit (PTC), depreciation (D), tax levy (T), and royalties (R) such as the represented in *Equation (4)*.

$$\text{LCOE} = \frac{\sum_{i=1}^{n} \frac{I_0 + OM_i + F_i - PTC_i - D_i - T_i + R_i}{(1+r)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1+r)^i}} \qquad (4)$$

I_0 = Investment expenditures in year 0 (including financing) defining year 0 as the year before the plant start-up year
OM_i = Operations and maintenance expenditures in year i
F_i = Fuel costs in year i
PTC_i = Production tax credit in year i
D_i = Depreciation in year i
T_i = Tax levy in year i
R_i = Royalties in year i
E_i = Energy generation in year i
r = Discount rate

PPAs typically consider tax credits as a part of LCOE as seen explicitly in *Equation (4)*. In the case of renewable energy technologies, tax credits reduce the LCOE by creating another source of revenue, thus allowing them to compete in the market against other energy sources such as conventional ones (gas, coal and oil). The extra revenue generated by tax credits is included in the LCOE equation and is then incorporated into the PPA price determination. However, it is necessary to consider that tax credits are a temporary situation that might not be present in future or in some countries, thus should not be taken into account.

B. CPPA Business Model related to the proposed LCOE formula

Recent literature has identified several costs that occur during the life of a renewable power plant project but are not represented in the above-illustrated standard LCOE models. In real CPPAs implementation, these costs regard mainly energy management, production uncertainty and the power mismatching between corporate buyer and Seller profiles of consumption and production respectively and operators' guarantees. There are several factors affecting CPPA resulting from geographical position between generation-consumption centres, site conditions or external factors that prevent on-site construction. Usually, the choice is the VCPPA structure as represented in *III.C*. This VCPPA structure will require special attention due to a greater number of contractual relations that implies the presence of a *facilitator* (PPA facilitator denoted with FPPA). This entity will act as a third part and it has a link function between the Seller, the corporate Buyer and all the involved market operators. FPPA takes the operational responsibility for the activities to be carried out, in particular the management of relations with market operators such as the national EMO (*Electricity Market Operator*), TSO (*Transmission System Operator*), DSO (*Distribution System Operator*) and the TCA (*Fiscal operator, Tax and Customs agency*). The above-described overview can be represented in *Fig.6*.

The application of a VCPPA configuration as described above implies a series of contractual relationships and costs, as shown in *Fig.7* . The emerging costs due to contractual relationship are illustrated in the following.

1) Market operators' guarantees – Gs

FPPA in order to operate in the electricity market has to present adequate financial guarantees towards the main electricity system operators, such as the TSO, DSO, EMO and TCA. The FPPA can act as a balancing responsible party (BRP) for the Seller and the corporate Buyer towards the TSO. In this role, it must provide a guarantee; the cost to deliver this guarantee is denoted with *GT*.

The FPPA is also an intermediary entity for corporate Buyer towards the DSO, therefore accountable for the energy transport charges and grid charges due to the DSO by the corporate Buyer. To this purpose, it must provide a guarantee; the cost to deliver this guarantee is denoted with *GD*.

In order to operate on the national electricity market, the FPPA provides to the EMO adequate financial guarantee according to the energy transaction scheduled; the cost of delivering this guarantee is denoted with *GM*.

Finally, regarding energy consumption, corporate Buyers must pay the *Excise duties* that FPPA has to collect and pay to the national Fiscal operator (TCA). To this purpose, it must provide a guarantee; the cost of delivering this guarantee is denoted with *GEx*.

The guarantee costs (GT, GD, GM, GEx) can be considered all deterministic and are usually expressed in an annual cost which is a percentage value of the total requested guarantee amount, Gs is considered a deterministic value.

2) Energy Mismatching costs - CM(p)

Owing to the unpredictability of the Seller production and the corporate Buyer randomness of the consumption, an energy deficit (*unp*) or surplus (*ovp*) can occur on an hourly basis. In this case, on an hourly basis, it is necessary to balance by selling on the market (if a surplus occurs) and purchasing from the market (if an energy deficit occurs) that implies a merchant risk as illustrated in *Fig. 8.* The corporate buyer has a number of options to mitigate this risk – it can choose to purchase balancing power for itself (e.g. by setting up a wholesale trading desk), or in this case of a VCPPA under analysis, through the FPPA.
A cost is related to the above merchant risk that is influenced by market conditions. It will be indicated with CM(p) where the p term denotes a stochastic cost.

3) Congestion Charges - CN(p)

Power exchanged with the grid and that virtually goes from the Seller to the corporate buyer's site flows through the electrical grid with all the congestions constraints that can occur and the corresponding fee due.
This fee is generally determined by the day ahead market results and by the operating status of the grid so it is influenced by market conditions. It is denoted with CN(p) where the p term denotes a stochastic cost.
Energy injected into the grid is generally sold at the market price in the area where the power plant is located (Pz, zonal price) while energy consumed by the corporate buyer is valued at the single national price (PUN). There is a gap between Pz and PUN which is the CCT cost that corresponds to the energy transportation cost [26, p. 52] [27].

4) Imbalances costs - CI(p)

For renewable generation assets, especially wind and PV, when the national electrical grid is involved, the challenge is that it becomes difficult to forecast and guarantee the production properly [28], owing to the variability of the weather conditions [29]. During the operation of the VCPPA, the FPPA bears imbalance costs due to the energy mismatching between the predicted power profile and the real power profile both for the Seller production and the corporate buyer consumption [30]. It is worth underlining how these costs do not correspond to the mismatching costs in *CM(p)* which is related to the lack of overlap between production and consumption. Moreover, these costs in some countries are determined by the electrical system as a whole, such as zonal or national imbalances. They are stochastic costs and are denoted with CI(p) where the p term denotes a stochastic cost.

5) Energy Management costs - EMC

The main task of the FPPA is to facilitate the energy exchange between Seller and corporate buyer, so it appears for the corporate buyer as a Supplier and for the Seller as an energy Trader, operating on his behalf in the liberalized electricity market; obviously this involves a fixed management cost to perform appropriate Energy Management activities, denoted with EMC.
To perform these activities a certain number of staff units are required. The use of full-time resources is necessary to provide the *Energy Management*, *Settlement* & *Invoicing*, *Logistics* & *Metering*, *Administration*, *Finance and Accounting* activities. Thus EMC are the costs incurred by the FPPA facilitator that include: personnel costs for the staff that manage end-users and register the energy schedule transactions; CRM system necessary for the billing process towards the end-users; facilities depreciation; general expenses.

6) Other costs

With reference to the model represented in *Fig. 7*, term *I* is the Capex to build the renewable power plant usually by mean of long-term debt provided by third parties or lenders. *O&M* term is: Operating cost, determined as the access cost to platform for the energy exchange between supplier and corporate buyer on the electricity market [31]; Maintenance cost generally correlated with the size in kW of the power plant. The remaining terms *DC*, *TMC* and *Taxes* are *pass-through charges* due from the corporate buyers to the market operators respectively for balancing service, transport-measurement services and VAT and Excise duties on electricity.

C. Proposed LCOE formula

The standard LCOE models as illustrated in the previous section do not consider several costs emerging from the operation of a FPPA in the VCPPA configuration as described above.
The aforementioned costs must be considered to determine the LCOE value and the related TLCC, therefore, a fair price of the VCPPA for the Seller and the corporate buyer. Considering a future market parity framework, the LCOE must be competitive with conventional energy price, thus tax credit is not taken into account since it may represent an additional revenue. The proposed LCOE formula for VCPPA is reported in (5).

$$LCOE_{VCRPPA} = \frac{\sum_{i=1}^{n} \frac{(I+GT_i+GD_i+GM_i+GEx_i+OM_i+EMC_i+CI(p)_i+CN(p)_i+CM(p)_i)}{(1+r)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1+r)^i}} \quad (5)$$

I = Investment cost
Guarantees' cost

- GT = TSO Guarantee costs
- GD = DSO Guarantee costs
- GM = Market Guarantee cost
- GEx = AdM Guarantee costs

OM = operation and maintenance costs
EMC = Energy Management Costs
CI(p) = Imbalance costs
CN(p) = Congestion Network charges
CM(p) = Mismatching costs
n = End-of-life of the power plant
r = actualization rate

It is quite evident as LCOE as valuated in *(5)* contains costs that depend on prices, electricity market variability, weather conditions, accuracy of the energy production and load forecast, as described in the previous subsection and denoted with (p) term highlighting the stochastic nature of LCOE.

V. Test case: A numerical application

The scope of this section is the use of the proposed LCOE formula to establish the optimal contractual length and price for a VCPPA aimed to the creation of a 20 MW capacity new PV power plant. A basic assumption refers to the power plant total forecasted production that balance the total energy needs of multiple corporate buyers. The estimated total energy production-consumption is 28 GWh per year. The production profile refers to the annual average profile for the PV plant located in Southern Italy while the consumption profile refers to a non-residential user considering for simplicity that all the n-users have the same load profile.

As mentioned, the proposed LCOE is a stochastic value, so to take any decision for the investment profitability and to establish the VCPPA contractual length and price, an LCOE sensitivity analysis is also performed.

A. LCOE evaluation

The following basic assumptions have been made for the analysis as indicated in *Table 1* and *Table 2:*

a) A PV power plant with a total capacity of 20 MW is considered;

b) The estimated annual production of the installed PV power plant, supposed located in Southern Italy, assuming a correct installation (azimuth:0° , tilt: 30°) was prudently set at 1,430 kWh/kWp;

c) The corporate buyer is composed of multiple users (about 1400) with an average annual energy consumption of about 20,000 kWh/year and contracted power of 10KW per each user;

d) The yearly energy produced by power plant is considered equal to the yearly energy consumption of the corporate buyer and estimated in 28 GWh;

e) The Seller exchanges the possible power plant energy surplus in the "wholesale market" (spot market in Italy), using the market Price (Pz Southern Italy) according to the current regulatory framework;

f) The power plant cost is set to 800 €/kWp;

g) A production decay of 0.3% per year is considered;

h) A time interval from 5 to 20 years (power plant End-of-life) is considered to evaluate which is the best VCPPA price;

i) The purchase and sale prices on the wholesale market are the average annual prices calculated during 2017;

j) An overlapping degree (energy matching) between Production and Consumption profile, of at least 50% is assumed ;

k) On the basis of point j):
50% of the corporate buyer consumption is purchased by the national electricity market at the market price and it determines mismatching costs CM(p) valuated considering the annual average PUN for the year 2017 of 53.94 €/MWh.

l) Operating cost including access to electricity platform (IPEX of 17,500 €/year for the first year and 10,228.21 € for the next years) and maintenance cost at 0,5% of the Investment cost;

m) Guarantee costs toward market operators have been evaluated considering the Italian regulatory framework;

n) EMC is evaluated considering the costs quoted by the Italian service providers;

o) CI(p) is evaluated considering 0.85 € per MWh produced and 0.50 € per MWh consumed;

p) CN(p) is evaluated considering the average CCT in the Italian electricity market in the year 2017;

q) Revenues are given:
50% of the Seller capacity sold to the corporate buyer considering a VCPPA price of 75 €/MWh;
50% of the Seller capacity sold on the national electricity market at the average zonal electricity market price (Pz Southern Italy);
A component (PCV) due to the energy Seller for its energy supply activity estimated at 116.50 € per user.

Starting from the above basic assumption the corresponding total costs and revenues have been calculated and reported in *Table 3* and *Table 4.*

While the related financial plan is reported in *Table 5.* The costs and revenues analysis with the NPV calculation leads to a payback period for the investment able to recover the total cost in a period between 9 and 10 years (BEP = 9.5), aligned with the contractual length of most CPPA signed in the global market. It can be noted also in *Table 5* how during the PV end-of-life, the LCOE value decreases up to the value of 73 €/MWh and therefore the basic VCPPA price considered in the simulation, of 75 €/MWh. A graphical representation is highlighted in
Graph 1 that underlines how, to reach a profit, the VCPPA must be higher than LCOE price as already pointed out in *II*.
In addition, it is worth noting how a different contract price determines the same LCOE curve but a different payback time due to different revenues in the financial plan simulation as shown in *Table 6,* where the VCPPA price has been set to 110 €/MWh.
Comparing the above two graphs, for the same VCPPA contractual length, for instance of the typical 10 years, only in the second case with a VCPPA price higher than LCOE value, is an adequate profit achieved (in this case, the BEP is 6.1 years). Varying the VCPPA contractual length the size of the profit-margin area varies naturally (see *Graph 2*).

B. LCOE Sensitivity Analysis

As mentioned several times, the VCPPA contractual length and price that allow the total costs to be recovered is affected by several parameters that are strongly determined by the assumptions and conditions under the VCPPA. To face the several intrinsic uncertainties in the VCPPA, a series of sensitivity simulations were carried out varying only some of the most important parameters:

- PV power plant Investment cost, I;
- VCPPA price;
- VCPPA contractual length;
- Imbalance costs, CI(p);
- Congestion Network Charges, CN(p);
- Actualization rate (r) taken as discount rate value in the LCOE formula;
- Overlapping degree (% of energy matching).

Sensitivity analysis 1: Investment Cost vs.VCPPA price

The scale for the VCCPA price ranges between 75-110 €/MWh, which are the most common prices on the electricity market, and mainly considering the results illustrated in previous section. The numerical results are reported in *Table 7.* This analysis gives the opportunity to evaluate a fair trade-off between the VCPPA contractual length and its price. As visible in *Table 7* it is possible to establish the VCPPA price that allows a profit to be reached considering a contractual length of the typical 10 years in combination with the Investment cost. For example, in case of an investment cost of 900 €/kWp the VCPPA price has to be higher than 80 €/MWh to reach a contractual length of less than 10 years. From a different perspective, it can be analysed how LCOE varies according to the PV power plant end-of-life and so it helps to determine the VCPPA price to achieve a profit.

The numerical results are reported in *Table 8.* It is possible to see how the situation improves as it moves towards the cases represented by the green area, in the upper-right part of the table that corresponds to the lowest cost of the power plant and at the same time the highest VCPPA contractual length that corresponds to the maximum PV power plant end-of-life.

Sensitivity analysis 2: Congestion Network Charges vs. Imbalance costs

The scale of values for the CN(p) ranges between 1-5 €/MWh while for the CI(p) between 0.5-5 €/MWh which represent the most possible values recently observed in the Italian electricity market [30] [32]. In *Table 9* the numerical results in terms of payback period are reported.

It has been observed how the increase in the VCPPA price from 75 to 110 €/MWh results in a payback period reduction of more than 30% since it reduces the payback from 9.0 to 5.9 years in the best case and from 10.5 to 6.5 years in the worst case as visible in *Table 10.* The same simulation is reported in *Table 11* but considering the LCOE price and as a consequence the VCPPA price, as numerical result.

Sensitivity analysis 3: nominal discount rate (r) vs. VCCPA price

As well known, an interest rate for Investment Ii different from discount rate (r) may be used. Interest rate depends on many factors such as borrower's credit worthiness, a risk associated with lending, Demand and in the economy. Clearly it is necessary to identify interest rate to follow a careful and not simple analysis that is out of the scope of this work, so in this analysis an interest rate equal to discount rate is used.

The third sensitivity analysis reported in *Table 12* evaluates the payback time to recover the investment, comparing the nominal discount rate with a scale ranging between 0-4.25% in combination with the VCPPA price variation between 75 and 110 €/MWh, without considering an inflation rate (consequently a real rate at the nominal rate). The inclusion in the procedure of an inflation rate would form a real rate different from the nominal rate that would affect negatively discounted cash flows, reducing them with a greater degree of complexity for the analysis.

Sensitivity analysis 4: Overlapping degree vs. VCPPA price

It is evident in *Table 13* how an increasing of the overlapping degree affects the payback period positively, which becomes smaller considering the same VCPPA price, thus a bigger profit area is obtained.

In *Table 14* the increasing of the overlapping degree effects the VCPPA price positively, which becomes considerably smaller with the extension of the power plant end-of-life and so of the contractual length.

This analysis allows determining a right compromise between VCPPA contractual length and price according to the different overlapping degree. From the technical perspective the case of 100% is particularly interesting, which could be achieved using an energy storage system on the producer or consumer side. This information may be used to evaluate the possible adoption of a storage system in order to synchronize production and consumption under a VCPPA contract [33], naturally it implies further economic analysis considering the investment and operation cost of the storage.

Sensitivity analysis 5: VCCPA contractual length vs VCPPA price

The last and perhaps most significant sensitivity analysis allows the achievable profit-margin to be defined considering the VCPPA price and the VCPPA contractual length. It is useful to observe the numerical results reported in *Table 15* identifying a realistic profit-margin area that gives the possibility of setting VCPPA conditions (contractual length and price).

Taking into consideration a benchmark analysis, it is possible to avoid particular situations considering a standard contractual length (for instance, not less than 7 years and not longer than 10 years).

Regarding VCPPA prices, at the same time, it is possible to avoid cases with prices over the limit fixed by the resulted LCOE value (75 €/MWh) and not higher than 100 €/MWh (considered that higher prices would be not competitive).

VI. Conclusions

In the last few years, owing to the lower cost of PV panels and wind turbines, the interest in Corporate Power Purchase Agreement to finance the development of renewable-source-based power plants increased also without feed-in tariffs. Indeed, these long-term contracts allow achieving market parity operation of new renewable-source-based power plants. In the literature, the Corporate Power Purchase Agreements (CPPA) can be classified in Behind the meter, Sleeved and Virtual PPA. Virtual CPPA (VCPPA) are the most-used ones as the power plant can be located elsewhere with respect to the corporate site and use the public electrical network to exchange power.

A VCPPA business model implies new costs, such as *Market operators' guarantees, Energy Mismatching, Congestion Charges, Imbalances, Energy Management and Operating and Maintenance costs* to be considered in the business plan for the evaluation of investment profitability. The paper presents an LCOE formula that takes into account such costs. Using this formula a deep economic analysis to realize a new project of a 20MW PV power plant in the Italian market framework was performed showing the parameters that influences the VCPPA profitability.

The proposed LCOE formula respect to the other ones considers the costs related to realization of a renewable power plant in a more realistic situation. The case study shows that best solution corresponds to the one with greater profitability obtained with the most competitive market price and the most acceptable contractual length (for the Italian case 100 €/MWh as market price and 10 years as contractual length) considering a standard production and load overlapping (50%). Despite this solution, many other profitable situations are possible in relation to a specific market case.

A particular emphasis was dedicated analyzing the impact of the power mismatching between the production and the load. This is important as both are stochastic variables and can sensibly affect the payback time and so the bankability of the investment. The 'what if' scenarios from the global sensitivity analysis reveals what outcomes might be more likely than others and it can help an analyst to decide which (if any) might be viable. Furthermore, the results from the global sensitivity analysis can also help to identify which one among the VCPPA variables influence more.

References

2019-05-14

[1] A. D. Smith and T. T. Tran, "Evaluation of renewable energy technologies and their potential for technical integration and cost-effective use within the U.S. energy sector," *Renewable and Sustainable Energy Reviews,* vol. 80, pp. 1372-1388, 2017.

[2] P. Friedemann, F. Eglib, B. Steffen and T. S. Schmidt, "How do policies mobilize private finance for renewable energy? - A systematic review with an investor perspective," *Applied Energy,* vol. 236, pp. 1249-1268, 15 February 2019.

[3] S. Yu, F. Fang, Y. Liu and J. Liu, "Uncertainties of virtual power plant: Problems and countermeasures," *Applied Energy,* vol. 239, pp. 454-470, 1 April 2019.

[4] WBCSD - World Business Council for Sustainable Development, "Action Plan 2020," WBCSD , [Online]. Available: https://www.luyol.com/wbcsd-world-business-council-for-sustainable-development/. [Accessed 2018].

[5] S. . B. Darling, F. You, T. Veselka and A. Velosa , "Assumptions and the levelized cost of energy for photovoltaics," *Energy & Environmental Science,* vol. 4 (9), pp. 3133-3139, 2011.

[6] L. Miller, R. Carriveau, S. Harper and S. Singh, "Evaluating the link between LCOE and PPA elements and structure for wind energy," *Energy Strategy Reviews,* vol. 16, pp. 33-42, 2017.

[7] DLA Piper, "Corporate Power Purchase Agreements (PPAs): What are they?," 06 2016. [Online]. Available: https://www.dlapiper.com/en/uk/insights/publications/2016/06/renewable-energy-global-paper/what-are-corporate-power-purchase-agreements-ppa/.

[8] M. Bruck, P. Sandborn and N. Goudarzi, "A Levelized Cost of Energy (LCOE) model for wind farms that include Power Purchase Agreements (PPAs)," *Renewable Energy,* vol. 122, pp. 131-139, 2018.

[9] K. Harrison, "Mid year PPA Update," October 2018. [Online]. Available: http://resource-platform.eu/files/knowledge/reports/BNEF-RESource-CorporatePPAs-Q32018.pdf.

[10] IRENA - International Renewable Energy Agency, "Corporate Sourcing of Renewables: Market and Industry Trends - Remade Index 2018," 2018. [Online]. Available: https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_Corporate_sourcing_2018.pdf. [Accessed 09 2018].

[11] European Wind Energy Association, "Where's the money coming from?," 2013. [Online]. Available: http://www.ewea.org/fileadmin/files/library/publications/reports/Financing_Offshore_Wind_Farms.pdf. [Accessed 2018].

[12] Baker & McKenzie, "The rise of corporate PPAs: A new driver for renewables," 2015. [Online]. Available: http://www.cleanenergypipeline.com/Resources/CE/ResearchReports/the-rise-of-corporate-ppas.pdf.

[13] Lawrence Berkeley National Laboratory - U.S. Department of Energy , "2017 Wind Technologies Market Report," 2017. [Online]. Available: https://emp.lbl.gov/sites/default/files/2017_wind_technologies_market_report.pdf.

[14] G. M. John, R. Sachdev, L. Sherman and D. Spielberg, "Corporate PPAs - Market Trends and Opportunities," 5 2016. [Online]. Available: http://s3.amazonaws.com/cdn.orrick.com/files/Corporate-PPAs-Market-Trends-and-Opportunities.pdf.

[15] World Business Council for Sustainable Development, "Innovation in POWER PURCHASE AGREEMENT STRUCTURES," 2018. [Online]. Available: https://www.wbcsd.org/Programs/Energy-Circular-Economy/Climate-Energy/REscale/Resources/Innovation-in-Power-Purchase-Agreement-Structures.

[16] Ministero dell'Ambiente, "Piano Energia e Clima 2018," 07 2018. [Online]. Available: ftp://ftp.minambiente.it/PNCE/Piano_Energia_Clima%20-%20Disegno%20e%20analisi%20(Bozza%20GSE%202018_07_02).pdf.

[17] H. Kanga, J. Honga, T. Honga, D. Hanb, S. Chinc and M. Leea, "Determining the optimal long-term service agreement period and cost considering the uncertain factors in the fuel cell: From the perspectives of the sellers and generators," *Applied Energy,* vol. 237, pp. 378-389, 1 March 2019.

[18] Pwc - PricewaterhouseCoopers, "Optimising Energy Procurement via corporate PPAs," p. 10, 2017.

[19] L. Hirth, "The market value of variable renewables: The effect of solar wind power variability on their relative price,," *Energy Economics - Science Direct,* vol. 38, pp. 218-236, 2013.

[20] Bird & Bird, "Corporate PPAs 2018: An international perspective," 2018. [Online]. Available: https://www.twobirds.com/en/news/articles/2018/global/bird-and-bird-and-corporate-ppas-an-international-perspective.

[21] T. . T. Tran and A. D. Smith, "Incorporating performance-based global sensitivity and uncertainty analysis into LCOE calculations for emerging renewable energy technologies," *Applied Energy,* vol. 216, pp. 157-171, 2018.

[22] H. Nathaniel, Courtney Smith and H. Eric, "A Monte Carlo approach to integrating uncertainty into the levelized cost of electricity," *The electricity Journal,* vol. 29, no. 3, pp. 21-30, 2016.

[23] R. Stefan and S. Ashuman, "Time of day pricing and the levelized cost of intermittent power generation," *Energy Economics,* vol. 48, pp. 97-108, 2015.

[24] NREL, "The System Advisor Model (SAM)," 2010. [Online]. Available: https://sam.nrel.gov/.

[25] J. Foster, L. D. Wagner and A. Bratanova, "LCOE models: A comparison of the theoretical frameworks and key assumptions," in *Energy Economics and Management Group Working Papers* , 2014.

[26] Gestore Mercati Energetici - GME, "REGOLAMENTO DELLA PIATTAFORMA DEI CONTI ENERGIA," [Online]. Available: https://www.mercatoelettrico.org/it/MenuBiblioteca/Documenti/20070212Regolamento_PCE.pdf.

[27] G. M. E. -. GME, "Disposizione tecnica di funzionamento n. 4 rev. 02 PCE," [Online]. Available: https://www.mercatoelettrico.org/it/MenuBiblioteca/Documenti/20161110_dtf-4rev2_PCE.pdf. [Accessed 03 2018].

[28] A. Ioannou, A. Angus and F. Brennan, "Stochastic Prediction of Offshore Wind Farm LCOE through an Integrated Cost Model," *Energy Procedia,* vol. 107, pp. 383-389, 2017.

[29] P. J. Spinney and C. G. Watkins, "Monte Carlo simulation techniques and electric utility resource decisions," *Energy Policy,* vol. 24, no. 2, pp. 155-163, 1996.

[30] G. Brusco, A. Burgio, D. Menniti, A. Pinnarelli, N. Sorrentino and P. Vizza, "Quantification of Forecast Error Costs of Photovoltaic Prosumers in Italy," *Energies,* vol. 10, no. 11, p. 1754, 2017.

[31] Gestore Mercati Energetici - GME, "Corrispettivi di accesso al mercato elettrico," [Online]. Available: http://www.mercatoelettrico.org/It/Mercati/MercatoElettrico/corrispettivi.aspx. [Accessed 12 03 2018].

[32] A. Gianfreda, L. Parisio and M. Pelagatti, "A review of balancing costs in Italy before and after RES introduction," *Renewable and Sustainable Energy Reviews, Elsevier,,* vol. 91(C), pp. 549-563, 2018.

[33] C. S. Lai and M. D. McCulloch, "Levelized cost of electricity for solar photovoltaic and electrical energy storage," *Applied Energy,* vol. 190, pp. 191-203, 2017.

[34] Norton Rose Fulbright, "Renewable energy in Latin America," 02 2017. [Online]. Available: http://www.nortonrosefulbright.com/files/renewable-energy-in-latin-america-134675.pdf.

[35] TERNA, "Allegato A.61 - Allegati al Codice di Trasmissione, Dispacciamento, Sviluppo e Sicurezza della Rete," 08 2016. [Online]. Available: http://download.terna.it/terna/0000/0105/77.PDF. [Accessed 09 03 2018].

[36] ARERA, "Allegato A - 111/06 - CONDIZIONI PER L'EROGAZIONE DEL PUBBLICO SERVIZIO DI DISPACCIAMENTO DELL'ENERGIA ELETTRICA SUL TERRITORIO NAZIONALE E PER L'APPROVVIGIONAMENTO DELLE RELATIVE RISORSE SU BASE DI MERITO ECONOMICO...," 2018. [Online]. Available: https://www.arera.it/allegati/docs/06/111-06allnew.pdf. [Accessed 09 03 2018].

[37] ARERA, "delibera 268/2015/R/EEL - Codice di rete per il servizio di trasporto dell'energia elettrica," [Online]. Available: https://www.arera.it/allegati/docs/15/268-15.pdf. [Accessed 13 03 2018].

[38] ARERA, "Tariffa per il servizio di trasmissione," [Online]. Available: https://www.arera.it/it/elettricita/trasmissione.htm. [Accessed 16 03 2018].

[39] ARERA, "Tariffe di distribuzione - elettricità," [Online]. Available: https://www.arera.it/it/elettricita/distr.htm. [Accessed 16 03 2018].

[40] ARERA, "Tariffa per il servizio di misura," [Online]. Available: https://www.arera.it/it/elettricita/mis.htm. [Accessed 16 03 2018].

[41] ARERA, "Oneri generali di sistema e ulteriori componenti," [Online]. Available: https://www.arera.it/it/elettricita/auc.htm. [Accessed 2018].

[42] Gestore Mercati Energetici - GME, "GME-Garanzie," 01 03 2018. [Online]. Available: https://www.mercatoelettrico.org/It/Mercati/MercatoElettrico/SistemaGaranzia.aspx.

[43] Gestore Mercati Energetici - GME, "Testo integrato della disciplina del mercato elettrico," [Online]. Available: https://www.mercatoelettrico.org/it/MenuBiblioteca/Documenti/20160720_testo_integrato_disciplina_mercato_elettrico.pdf. [Accessed 03 2018].

[44] *Decreto-legge del 02/03/2012 n. 16 Articolo 3*, 2012.

[45] MEF - Dipartimento delle Finanze, "Testo unico del 26/10/1995 n. 504 -," [Online]. Available: http://def.finanze.it/DocTribFrontend/getAttoNormativoDetail.do?id={2565B3F5-CD6B-448C-AC16-277DB90F3862}.

[46] Gestore Mercati Energetici - GME, "GME-Regolamento Operatori- Dati storici sui prezzi," [Online]. Available: http://www.mercatoelettrico.org/It/download/DatiStorici.aspx. [Accessed 01 03 2018].

[47] Gestore Mercati Energetici - GME, "GME-Dati 2016," 09 03 2018. [Online]. Available: https://www.mercatoelettrico.org/Newsletter/20170117newsletter.pdf.

[48] Gestore Mercati Energetici - GME, "GME-Dati 2017," 09 03 2018. [Online]. Available: https://www.mercatoelettrico.org/Newsletter/20180117Newsletter.pdf.

[49] G. -. C. d. a. a. Mercato. [Online]. Available: http://www.mercatoelettrico.org/It/Mercati/MercatoElettrico/corrispettivi.aspx.

FIGURES

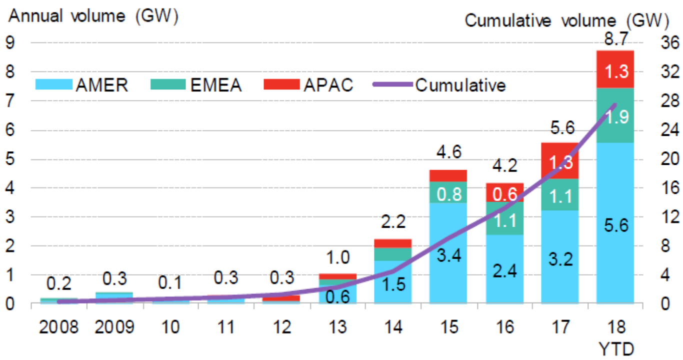

Fig. 1 - Global corporate PPAs distribution, by region - Source*: Bloomberg New Energy Finance - October 25th 2018*

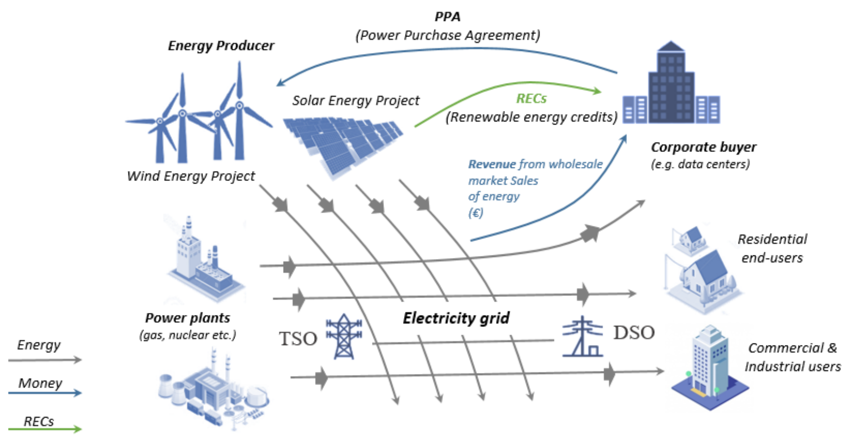

Fig. 2 - General CPPA framework structure with physical flows, energy flows and Renewable credts.

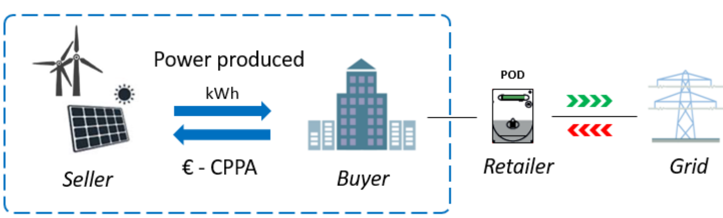

Fig. 3 - Behind the Meter CPPA configuration

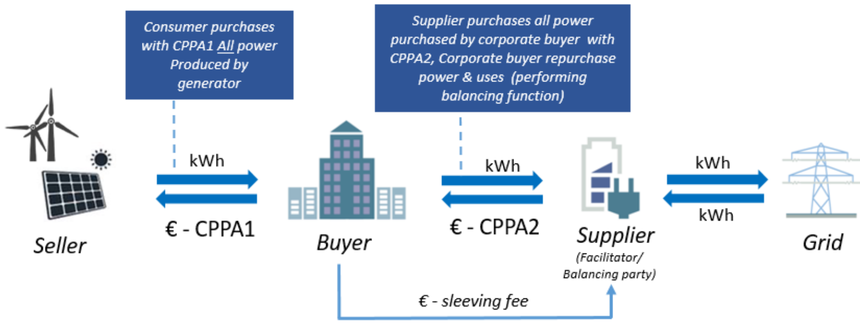

Fig. 4 - Sleeved CPPA configuration

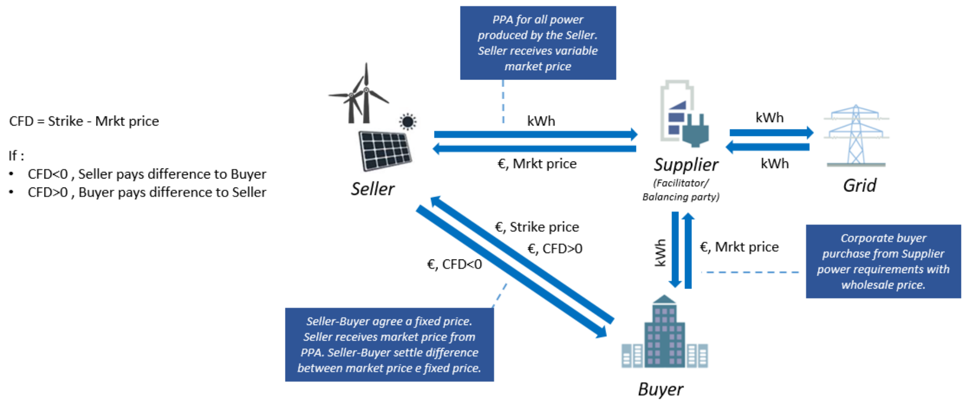

Fig. 5 - Virtual CPPA configuration

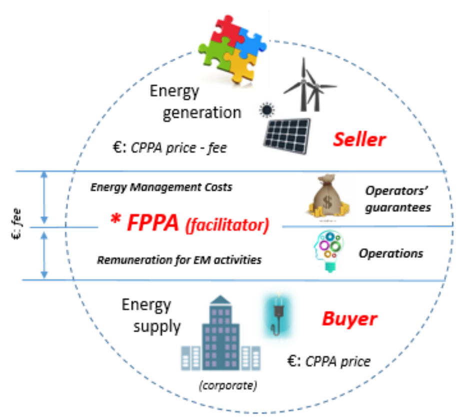

Fig. 6 - Involved parties in a VCPPA model

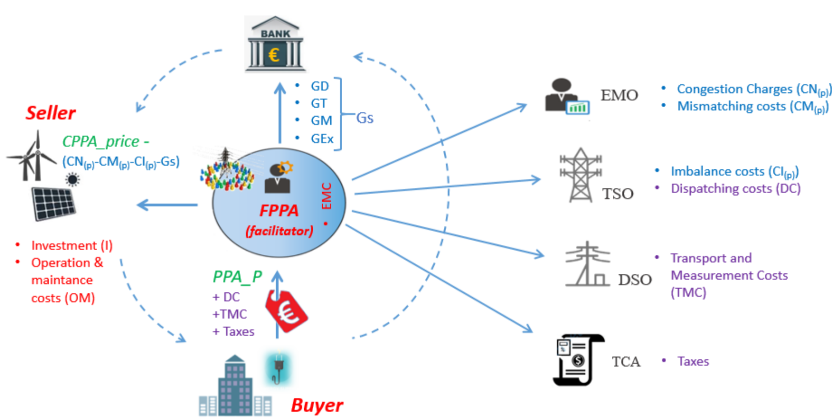

Fig. 7 - Contractual links within a VCPPA and related costs

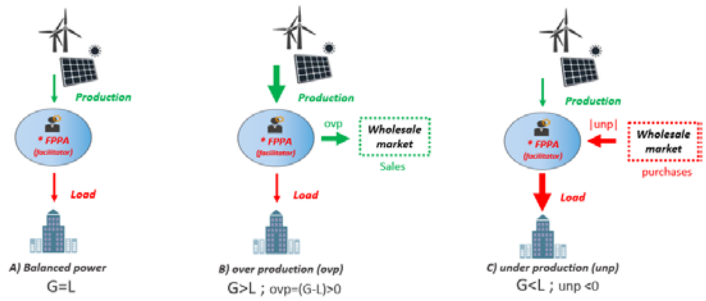

Fig. 8 - Energy mismatching concept

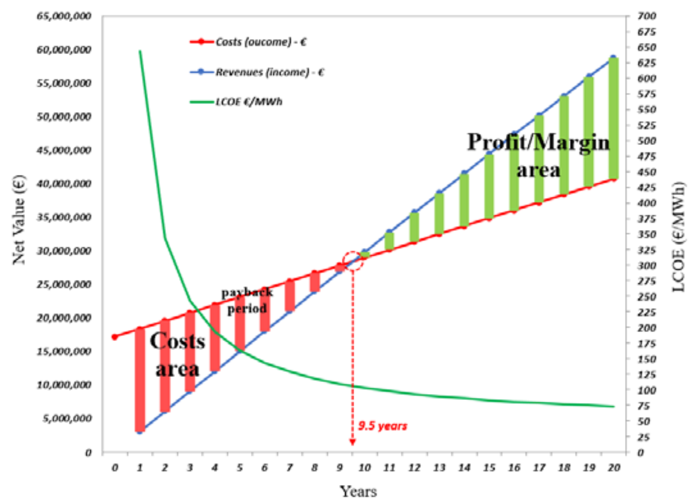

Fig. 9 - LCOE and Payback Period in VCPPA (contract price 75 €/MWh)

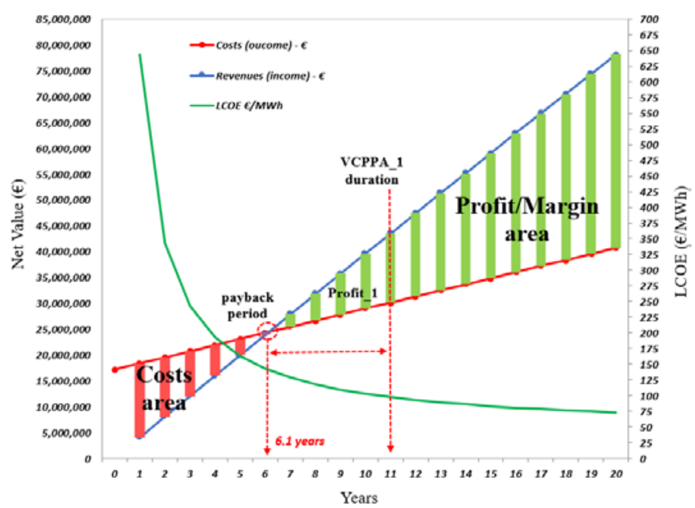

Fig. 10 - LCOE and Payback Period in VCPPA (contract price 110 €/MWh)

TABLES

Table 1 - hypothesis and data

Data and plant details	Year 0 -20	Details
PV power plant capacity - MWp	20	*Total installed power capacity*
Generation - MWh/MWp	1,426.34	*Energy generation. Data extracted by PVGIS referred to location in Southern Italy.*
Unit cost photovoltaic plant - €/kWp	800.00	*Basic price per installed kWp*
Annual energy production - MWh	28,526.80	*Peak power x Generation.*
generation decay - % year	0.3	*It is assumed that PV plant slightly decrease its production every year.*

Overlapping degree - %	50	*Quantity of generation that matches with load.*
Production in match with load - MWh	14,263.40	*Generated energy that satisfies the loads.*
Production fed into the grid - %	50	*% Energy sold within the market*
Production fed into the grid (market sell) - Mwh	14,263.40	*(Total generation) – (energy that matches with loads). Energy that does not matches with loads. Amount of energy sold on the market.*
Total energy load - MWh	28,519.94	*Total Energy needs.*
Corporate buyers – n°	1,426.00	*Number of considered end-users*
Energy purchased - MWh	14,256.54	*Energy that does not satisfies loads so purchased from the market.*

Table 2 - data prices

DATA PRICE		Details
PUN - €/MWh	53.94	*Average national electricity market price (2017)*
Pz_Southern Italy - €/MWh	50.19	*Average zonal electricity market price (2017)*
Basic VCPPA price - €/MWh	75.00	*Initial value set as VCPPA price*
Average energy imbalance (CI(p))	0.85	*Annual average cost*
Average CCT - (CN(p))	3.76	*Annual average cost*

Table 3 - economic analysis: costs

COST ITEMS - €	Year 0	Year 1-5	Year 6-20	Details
I - Investment Cost	16,000,000.00	-	-	*Cost of the photovoltaic plant*
O&M - Maintenance cost (0,5% of I)	-	80,000.00	80,000.00	*Maintenance costs (from second year)*
O&M - Operating cost	17,500.00	10,228.21	10,228.21	*Energy management costs*
TOTAL O&M	**17,500.00**	**90,228.21**	**90,228.21**	
GT - TSO guarantee	76,008.40	25,000.00	25,000.00	*Guarantee for Transmission system operator*
GD - DSO guarantee	7,256.63	7,256.63	7,256.63	*Guarantee for Distribution system operator*
GEx- TCA guarantee	3,565.00	3,565.00	3,565.00	*Guarantee for Fiscal operator*
GM - MRKT guarantee	2,920.67	2,920.67	2,920.67	*Guarantee for electricity market operator*
TOTAL Guarantees	**89,750.71**	**38,742.30**	**38,742.30**	*Guarantee for all the market operators*
EMC – Energy & Management Costs	**145,359.24**	**145,359.24**	**129,359.24**	*Costs related to the performed activities*
CI(p) - Imbalance costs	**39,078.15**	**39,078.15**	**39,078.15**	*Energy imbalances*
CN(p) – Congestion Network Charges (CCT)	**107,260.77**	**107,260.77**	**107,260.77**	*Costs for energy congestions*
CM(p) – Mismatching costs	**768,941.18**	**768,941.18**	**768,941.18**	*Costs for energy purchase on the market*
TOTAL COSTS	**17,167,890.05**	**1.189.609,86**	**1.173.609,31**	

Table 4 - economic analysis: revenues

REVENUE ITEMS - €	Year 0-20	
Energy sold to corporate buyers	2,138,955.55	*Energy remuneration by corporate buyers*
PCV component	166,132.14	*Component due to the Seller*
Energy surplus sold in the market	715,918.86	*Energy excess sold in the market*
TOTAL REVENUES	**3,021,046.55**	

Table 5 - Financial plan of a 20 MWp PV referred to the end-of-life (considering VCPPA price 75 €/MWh)

Year	Costs (oucome) - €			Revenues (income) - €			NPV	Generation					
	yearly total costs		Cumulated costs	yearly total revenues		Cumulated revenues		annual energy production (MWh)		cumulated production	LCOE €/MWh	LCOE €/kWh	LCOE c€/kWh
	Value	*Present Value*	*Present Value*	*Value*	*Present Value*	*Present Value*		*Value*	*Present Value*	*Present Value*			
0	17,167,890	17,167,890	17,167,890				-17,167,890						
1	1,189,610	1,189,610	18,357,500	3,021,047	3,021,047	3,021,047	-15,336,453	28,527	28,527	28,527	643.5	0.644	64.4
2	1,189,610	1,189,610	19,547,110	3,011,983	3,011,983	6,033,030	-13,514,080	28,441	28,441	56,968	343.1	0.343	34.3
3	1,189,610	1,189,610	20,736,720	3,002,947	3,002,947	9,035,977	-11,700,742	28,356	28,356	85,324	243.0	0.243	24.3
4	1,189,610	1,189,610	21,926,329	2,993,939	2,993,939	12,029,916	-9,896,413	28,271	28,271	113,595	193.0	0.193	19.3
5	1,189,610	1,189,610	23,115,939	2,984,957	2,984,957	15,014,873	-8,101,067	28,186	28,186	141,781	163.0	0.163	16.3
6	1,173,610	1,173,610	24,289,549	2,976,002	2,976,002	17,990,875	-6,298,674	28,101	28,101	169,882	143.0	0.143	14.3
7	1,173,610	1,173,610	25,463,159	2,967,074	2,967,074	20,957,949	-4,505,210	28,017	28,017	197,899	128.7	0.129	12.9
8	1,173,610	1,173,610	26,636,769	2,958,173	2,958,173	23,916,121	-2,720,648	27,933	27,933	225,832	117.9	0.118	11.8
9	1,173,610	1,173,610	27,810,379	2,949,298	2,949,298	26,865,420	-944,959	27,849	27,849	253,682	109.6	0.110	11.0
10	1,173,610	1,173,610	28,983,989	2,940,450	2,940,450	29,805,870	**821,881**	27,766	27,766	281,448	103.0	0.103	10.3
11	1,173,610	1,173,610	30,157,598	2,931,629	2,931,629	32,737,499	**2,579,900**	27,682	27,682	309,130	97.6	0.098	9.8
12	1,173,610	1,173,610	31,331,208	2,922,834	2,922,834	35,660,333	**4,329,125**	27,599	27,599	336,729	93.0	0.093	9.3
13	1,173,610	1,173,610	32,504,818	2,914,066	2,914,066	38,574,398	**6,069,580**	27,517	27,517	364,246	89.2	0.089	8.9
14	1,173,610	1,173,610	33,678,428	2,905,323	2,905,323	41,479,722	**7,801,294**	27,434	27,434	391,680	86.0	0.086	8.6
15	1,173,610	1,173,610	34,852,038	2,896,607	2,896,607	44,376,329	**9,524,291**	27,352	27,352	419,032	83.2	0.083	8.3
16	1,173,610	1,173,610	36,025,648	2,887,918	2,887,918	47,264,247	**11,238,599**	27,270	27,270	446,302	80.7	0.081	8.1
17	1,173,610	1,173,610	37,199,258	2,879,254	2,879,254	50,143,500	**12,944,243**	27,188	27,188	473,489	78.6	0.079	7.9
18	1,173,610	1,173,610	38,372,867	2,870,616	2,870,616	53,014,117	**14,641,249**	27,106	27,106	500,596	76.7	0.077	7.7
19	1,173,610	1,173,610	39,546,477	2,862,004	2,862,004	55,876,121	**16,329,643**	27,025	27,025	527,621	75.0	0.075	7.5
20	1,173,610	1,173,610	40,720,087	2,853,418	2,853,418	58,729,539	**18,009,452**	26,944	26,944	554,565	**73.4**	**0.1**	**7.3**

Table 6 - Financial plan of a 20 MWp PV referred to the end-of-life (considering VCPPA price 110 €/MWh)

Year	Costs (oucome) - €			Revenues (income) - €			NPV	Generation					
	yearly total costs		Cumulated costs	yearly total revenues		Cumulated revenues		annual energy production (MWh)		cumulated production	LCOE €/MWh	LCOE €/kWh	LCOE c€/kWh
	Value	Present Value	Present Value	Value	Present Value	Present Value		Value	Present Value	Present Value			
0	17,167,890	17,167,890	17,167,890				-17,167,890						
1	1,189,610	1,189,610	18,357,500	4,019,244	4,019,244	4,019,244	-14,338,255	28,527	28,527	28,527	643.5	0.644	64.4
2	1,189,610	1,189,610	19,547,110	4,007,187	4,007,187	8,026,431	-11,520,679	28,441	28,441	56,968	343.1	0.343	34.3
3	1,189,610	1,189,610	20,736,720	3,995,165	3,995,165	12,021,596	-8,715,123	28,356	28,356	85,324	243.0	0.243	24.3
4	1,189,610	1,189,610	21,926,329	3,983,180	3,983,180	16,004,776	-5,921,553	28,271	28,271	113,595	193.0	0.193	19.3
5	1,189,610	1,189,610	23,115,939	3,971,230	3,971,230	19,976,006	-3,139,933	28,186	28,186	141,781	163.0	0.163	16.3
6	1,173,610	1,173,610	24,289,549	3,959,316	3,959,316	23,935,323	-354,227	28,101	28,101	169,882	143.0	0.143	14.3
7	1,173,610	1,173,610	25,463,159	3,947,439	3,947,439	27,882,761	2,419,602	28,017	28,017	197,899	128.7	0.129	12.9
8	1,173,610	1,173,610	26,636,769	3,935,596	3,935,596	31,818,357	5,181,588	27,933	27,933	225,832	117.9	0.118	11.8
9	1,173,610	1,173,610	27,810,379	3,923,789	3,923,789	35,742,147	7,931,768	27,849	27,849	253,682	109.6	0.110	11.0
10	1,173,610	1,173,610	28,983,989	3,912,018	3,912,018	39,654,165	10,670,176	27,766	27,766	281,448	103.0	0.103	10.3
11	1,173,610	1,173,610	30,157,598	3,900,282	3,900,282	43,554,447	13,396,848	27,682	27,682	309,130	97.6	0.098	9.8
12	1,173,610	1,173,610	31,331,208	3,888,581	3,888,581	47,443,028	16,111,820	27,599	27,599	336,729	93.0	0.093	9.3
13	1,173,610	1,173,610	32,504,818	3,876,915	3,876,915	51,319,943	18,815,125	27,517	27,517	364,246	89.2	0.089	8.9
14	1,173,610	1,173,610	33,678,428	3,865,285	3,865,285	55,185,228	21,506,800	27,434	27,434	391,680	86.0	0.086	8.6
15	1,173,610	1,173,610	34,852,038	3,853,689	3,853,689	59,038,917	24,186,879	27,352	27,352	419,032	83.2	0.083	8.3
16	1,173,610	1,173,610	36,025,648	3,842,128	3,842,128	62,881,044	26,855,397	27,270	27,270	446,302	80.7	0.081	8.1
17	1,173,610	1,173,610	37,199,258	3,830,601	3,830,601	66,711,646	29,512,388	27,188	27,188	473,489	78.6	0.079	7.9
18	1,173,610	1,173,610	38,372,867	3,819,110	3,819,110	70,530,755	32,157,888	27,106	27,106	500,596	76.7	0.077	7.7
19	1,173,610	1,173,610	39,546,477	3,807,652	3,807,652	74,338,408	34,791,930	27,025	27,025	527,621	75.0	0.075	7.5
20	1,173,610	1,173,610	40,720,087	3,796,229	3,796,229	78,134,637	37,414,550	26,944	26,944	554,565	73.4	0.1	7.3

Table 7 - Plant Cost vs Contract Price, contractual length Sensitivity

Result: Payback period

I - Investment cost (€/kWp) \ VCPPA price (€/MWh)	75	80	85	90	95	100	105	110
700	8.4	7.7	7.2	6.8	6.4	6.0	5.7	5.4
725	8.7	8.0	7.5	7.0	6.6	6.2	5.9	5.6
750	8.9	8.3	7.7	7.2	6.8	6.4	6.1	5.8
775	9.2	8.6	8.0	7.5	7.0	6.6	6.3	5.9
800	**9.5**	8.8	8.2	7.7	7.2	6.8	6.5	6.1
825	9.8	9.1	8.5	7.9	7.5	7.0	6.7	6.3
850	10.1	9.4	8.7	8.2	7.7	7.2	6.8	6.5
875	10.4	9.7	9.0	8.4	7.9	7.4	7.0	6.7
900	10.7	9.9	9.2	8.6	8.1	7.7	7.2	6.9
925	11.0	10.2	9.5	8.9	8.3	7.9	7.4	7.1
950	11.3	10.5	9.8	9.1	8.6	8.1	7.6	7.2
975	11.6	10.8	10.0	9.4	8.8	8.3	7.8	7.4
1,000	11.9	11.1	10.3	9.6	9.0	8.5	8.0	7.6

Table 8 - Plant Cost vs Contractual length, price Sensitivity

Result: LCOE

I - Investment cost (€/kWp) \ Power plant end-of-life (years)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
700	148.6	130.9	118.2	108.7	101.4	95.5	90.7	86.7	83.4	80.5	78.0	75.9	74.0	72.3	70.8	69.5
725	152.2	133.9	120.8	111.0	103.4	97.4	92.4	88.3	84.9	81.9	79.3	77.1	75.1	73.4	71.8	70.5
750	155.8	136.9	123.4	113.3	105.5	99.3	94.1	89.9	86.3	83.3	80.6	78.3	76.3	74.5	72.9	71.4
775	159.4	139.9	126.1	115.6	107.6	101.1	95.8	91.5	87.8	84.6	81.9	79.5	77.4	75.6	73.9	72.4
800	163.0	143.0	128.7	117.9	109.6	103.0	97.6	93.0	89.2	86.0	83.2	80.7	78.6	76.7	75.0	**73.4**
825	166.7	146.0	131.3	120.3	111.7	104.8	99.3	94.6	90.7	87.4	84.5	81.9	79.7	77.7	76.0	74.4
850	170.3	149.0	133.9	122.6	113.7	106.7	101.0	96.2	92.2	88.7	85.7	83.1	80.9	78.8	77.0	75.4
875	173.9	152.1	136.5	124.9	115.8	108.6	102.7	97.8	93.6	90.1	87.0	84.4	82.0	79.9	78.1	76.4
900	177.5	155.1	139.1	127.2	117.9	110.4	104.4	99.3	95.1	91.4	88.3	85.6	83.1	81.0	79.1	77.4
925	181.1	158.1	141.7	129.5	119.9	112.3	106.1	100.9	96.5	92.8	89.6	86.8	84.3	82.1	80.1	78.4
950	184.7	161.2	144.4	131.8	122.0	114.2	107.8	102.5	98.0	94.2	90.9	88.0	85.4	83.2	81.2	79.4
975	188.3	164.2	147.0	134.1	124.0	116.0	109.5	104.1	99.5	95.5	92.2	89.2	86.6	84.3	82.2	80.4
1,000	192.0	167.2	149.6	136.4	126.1	117.9	111.2	105.6	100.9	96.9	93.4	90.4	87.7	85.4	83.3	81.4

Table 9 - Congestion Network Charges vs Imbalance costs, contractual length Sensitivity (considering VCPPA price 75 €/MWp)

Result: Payback period

CN(p) - (€/MWh) \ CI(p) - (€/MWh)	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
1.00	9.0	9.1	9.2	9.3	9.3	9.4	9.5	9.6	9.7	9.8
1.25	9.1	9.1	9.2	9.3	9.4	9.5	9.6	9.6	9.7	9.8
1.50	9.1	9.2	9.3	9.3	9.4	9.5	9.6	9.7	9.8	9.9
1.75	9.1	9.2	9.3	9.4	9.5	9.6	9.6	9.7	9.8	9.9
2.00	9.2	9.3	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0
2.25	9.2	9.3	9.4	9.5	9.6	9.6	9.7	9.8	9.9	10.0
2.50	9.3	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.0
2.75	9.3	9.4	9.5	9.6	9.6	9.7	9.8	9.9	10.0	10.1
3.00	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.1
3.25	9.4	9.5	9.6	9.6	9.7	9.8	9.9	10.0	10.1	10.2
3.50	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.1	10.2
3.75	**9.5**	**9.6**	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3
4.00	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.1	10.2	10.3
4.25	9.6	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4
4.50	9.6	9.7	9.8	9.9	10.0	10.1	10.1	10.2	10.3	10.4
4.75	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5
5.00	9.7	9.8	9.9	10.0	10.1	10.1	10.2	10.3	10.4	10.5

Table 10 - Congestion Network Charges vs Imbalance costs, contractual length Sensitivity (considering VCPPA price 110 €/MWp)

Result: Payback period

CN(p) - (€/MWh) \ CI(p) - (€/MWh)	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
1.00	5.9	5.9	6.0	6.0	6.0	6.1	6.1	6.2	6.2	6.2
1.25	5.9	6.0	6.0	6.0	6.1	6.1	6.1	6.2	6.2	6.2
1.50	5.9	6.0	6.0	6.0	6.1	6.1	6.2	6.2	6.2	6.3
1.75	6.0	6.0	6.0	6.1	6.1	6.1	6.2	6.2	6.2	6.3
2.00	6.0	6.0	6.0	6.1	6.1	6.2	6.2	6.2	6.3	6.3
2.25	6.0	6.0	6.1	6.1	6.1	6.2	6.2	6.2	6.3	6.3
2.50	6.0	6.0	6.1	6.1	6.2	6.2	6.2	6.3	6.3	6.3
2.75	6.0	6.1	6.1	6.1	6.2	6.2	6.2	6.3	6.3	6.4
3.00	6.0	6.1	6.1	6.2	6.2	6.2	6.3	6.3	6.3	6.4
3.25	6.1	6.1	6.1	6.2	6.2	6.2	6.3	6.3	6.4	6.4
3.50	6.1	6.1	6.2	6.2	6.2	6.3	6.3	6.3	6.4	6.4
3.75	**6.1**	**6.1**	6.2	6.2	6.2	6.3	6.3	6.4	6.4	6.4
4.00	6.1	6.2	6.2	6.2	6.3	6.3	6.3	6.4	6.4	6.5
4.25	6.1	6.2	6.2	6.3	6.3	6.3	6.4	6.4	6.4	6.5
4.50	6.2	6.2	6.2	6.3	6.3	6.3	6.4	6.4	6.5	6.5
4.75	6.2	6.2	6.3	6.3	6.3	6.4	6.4	6.4	6.5	6.5
5.00	6.2	6.2	6.3	6.3	6.3	6.4	6.4	6.5	6.5	6.5

Table 11 - Congestion Network Charges vs Imbalance costs, VCPPA price Sensitivity

Result: LCOE

CN(p) - (€/MWh) \ CI(p) - (€/MWh)	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
1.00	70.1	70.6	71.1	71.7	72.2	72.8	73.3	73.8	74.4	74.9
1.25	70.3	70.9	71.4	71.9	72.5	73.0	73.6	74.1	74.6	75.2
1.50	70.6	71.1	71.7	72.2	72.8	73.3	73.8	74.4	74.9	75.5
1.75	70.9	71.4	72.0	72.5	73.0	73.6	74.1	74.7	75.2	75.7
2.00	71.1	71.7	72.2	72.8	73.3	73.8	74.4	74.9	75.5	76.0
2.25	71.4	72.0	72.5	73.0	73.6	74.1	74.7	75.2	75.7	76.3
2.50	71.7	72.2	72.8	73.3	73.8	74.4	74.9	75.5	76.0	76.5
2.75	72.0	72.5	73.0	73.6	74.1	74.7	75.2	75.7	76.3	76.8
3.00	72.2	72.8	73.3	73.8	74.4	74.9	75.5	76.0	76.5	77.1
3.25	72.5	73.0	73.6	74.1	74.7	75.2	75.7	76.3	76.8	77.4
3.50	72.8	73.3	73.8	74.4	74.9	75.5	76.0	76.5	77.1	77.6
3.75	**73.0**	**73.6**	74.1	74.7	75.2	75.7	76.3	76.8	77.4	77.9
4.00	73.3	73.8	74.4	74.9	75.5	76.0	76.5	77.1	77.6	78.2
4.25	73.6	74.1	74.7	75.2	75.7	76.3	76.8	77.4	77.9	78.4
4.50	73.9	74.4	74.9	75.5	76.0	76.6	77.1	77.6	78.2	78.7
4.75	74.1	74.7	75.2	75.7	76.3	76.8	77.4	77.9	78.4	79.0
5.00	74.4	74.9	75.5	76.0	76.6	77.1	77.6	78.2	78.7	79.3

Table 12 - Discount rate vs Contract Price, contractual length Sensitivity

Result: Payback period

r - nominal discount rate (%) \ VCPPA price (€/MWh)	75	80	85	90	95	100	105	110
0.00%	**9.5**	8.8	8.2	7.7	7.2	6.8	6.5	6.1
0.25%	9.7	8.9	8.3	7.8	7.3	6.9	6.5	6.2
0.50%	9.8	9.1	8.4	7.9	7.4	7.0	6.6	6.2
0.75%	9.9	9.2	8.5	8.0	7.5	7.0	6.6	6.3
1.00%	10.1	9.3	8.6	8.1	7.6	7.1	6.7	6.4
1.25%	10.2	9.4	8.7	8.1	7.6	7.2	6.8	6.4
1.50%	10.4	9.6	8.9	8.2	7.7	7.3	6.8	6.5
1.75%	10.5	9.7	9.0	8.3	7.8	7.3	6.9	6.5
2.00%	10.7	9.8	9.1	8.5	7.9	7.4	7.0	6.6
2.25%	10.9	10.0	9.2	8.6	8.0	7.5	7.1	6.7
2.50%	11.1	10.1	9.3	8.7	8.1	7.6	7.1	6.7
2.75%	11.2	10.3	9.5	8.8	8.2	7.7	7.2	6.8
3.00%	11.4	10.4	9.6	8.9	8.3	7.8	7.3	6.9
3.25%	11.6	10.6	9.8	9.0	8.4	7.9	7.4	7.0
3.50%	11.9	10.8	9.9	9.1	8.5	7.9	7.5	7.0
3.75%	12.1	11.0	10.0	9.3	8.6	8.0	7.5	7.1
4.00%	12.3	11.2	10.2	9.4	8.7	8.1	7.6	7.2
4.25%	12.6	11.4	10.4	9.6	8.8	8.2	7.7	7.3

Table 13 - Overlapping degree vs VCPPA price, contractual length Sensitivity

Result: Payback period

CM(p) - overlapping degree (%) \ VCPPA price (€/MWh)	75	80	85	90	95	100	105	110
30%	9.9	9.1	8.5	7.9	7.4	7.0	6.6	6.3
35%	9.8	9.0	8.4	7.9	7.4	7.0	6.6	6.3
40%	9.7	9.0	8.4	7.8	7.3	6.9	6.5	6.2
45%	9.6	8.9	8.3	7.8	7.3	6.9	6.5	6.2
50%	**9.5**	8.8	8.2	7.7	7.2	6.8	6.5	6.1
55%	9.5	8.8	8.2	7.6	7.2	6.8	6.4	6.1
60%	9.4	8.7	8.1	7.6	7.1	6.7	6.4	6.0
65%	9.3	8.6	8.0	7.5	7.1	6.7	6.3	6.0
70%	9.2	8.6	8.0	7.5	7.0	6.6	6.3	6.0
75%	9.1	8.5	7.9	7.4	7.0	6.6	6.2	5.9
80%	9.1	8.4	7.9	7.4	6.9	6.5	6.2	5.9
85%	9.0	8.4	7.8	7.3	6.9	6.5	6.2	5.8
90%	8.9	8.3	7.7	7.3	6.8	6.4	6.1	5.8
95%	8.9	8.2	7.7	7.2	6.8	6.4	6.1	5.8
100%	8.8	8.2	7.6	7.1	6.7	6.4	6.0	5.7

Table 14 - Overlapping degree vs VCPPA price, VCCPA price Sensitivity

Result: LCOE — Power plant end-of-life (years); rows: CM(p) - overlapping degree (%)

CM(p) - overlapping degree (%)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
30%	176.1	155.7	141.1	130.3	121.8	115.0	109.5	105.0	101.1	97.8	95.0	92.5	90.3	88.4	86.7	85.1
35%	172.8	152.5	138.0	127.2	118.8	112.0	106.5	102.0	98.1	94.9	92.0	89.5	87.4	85.4	83.7	82.2
40%	169.6	149.3	134.9	124.1	115.7	109.0	103.5	99.0	95.2	91.9	89.1	86.6	84.4	82.5	80.8	79.3
45%	166.3	146.2	131.8	121.0	112.7	106.0	100.6	96.0	92.2	88.9	86.1	83.7	81.5	79.6	77.9	76.4
50%	163.0	143.0	128.7	117.9	**109.6**	**103.0**	97.6	93.0	89.2	86.0	83.2	80.7	78.6	76.7	75.0	**73.4**
55%	159.8	139.8	125.5	114.9	106.6	100.0	94.6	90.1	86.3	83.0	80.2	77.8	75.6	73.7	72.0	70.5
60%	156.5	136.6	122.4	111.8	103.5	96.9	91.6	87.1	83.3	80.1	77.3	74.8	72.7	70.8	69.1	67.6
65%	153.2	133.4	119.3	108.7	100.5	93.9	88.6	84.1	80.3	77.1	74.3	71.9	69.8	67.9	66.2	64.7
70%	150.0	130.3	116.2	105.6	97.5	90.9	85.6	81.1	77.4	74.2	71.4	69.0	66.8	64.9	63.2	61.7
75%	146.7	127.1	113.1	102.6	94.4	87.9	82.6	78.1	74.4	71.2	68.4	66.0	63.9	62.0	60.3	58.8
80%	143.4	123.9	109.9	99.5	91.4	84.9	79.6	75.2	71.4	68.2	65.5	63.1	61.0	59.1	57.4	55.9
85%	140.2	120.7	106.8	96.4	88.3	81.9	76.6	72.2	68.5	65.3	62.5	60.1	58.0	56.1	54.5	53.0
90%	136.9	117.5	103.7	93.3	85.3	78.8	73.6	69.2	65.5	62.3	59.6	57.2	55.1	53.2	51.5	50.0
95%	133.6	114.4	100.6	90.3	82.2	75.8	70.6	66.2	62.5	59.4	56.6	54.3	52.2	50.3	48.6	47.1
100%	130.4	111.2	97.5	87.2	79.2	72.8	67.6	63.2	59.6	56.4	53.7	51.3	49.2	47.4	45.7	44.2

Table 15 - Contractual length vs contract price, profit-margin sensitivity

Result: Profit-Margin (k€) — VCPPA price (€/MWh); rows: VCPPA contractual length (years)

VCPPA contractual length (years)	75	80	85	90	95	100	~~105~~	~~110~~
~~5~~	-8,101.1	-7,392.3	-6,683.6	-5,974.9	-5,266.1	-4,557.4	-3,848.7	-3,139.9
~~6~~	-6,298.7	-5,449.5	-4,600.3	-3,751.1	-2,901.8	-2,052.6	-1,203.4	-354.2
~~7~~	-4,505.2	-3,516.0	-2,526.7	-1,537.4	-548.2	**441.1**	1,430.3	2,419.6
~~8~~	-2,720.6	-1,591.8	-462.9	**666.0**	**1,794.9**	**2,923.8**	4,052.7	5,181.6
~~9~~	-945.0	**323.1**	**1,591.2**	**2,859.4**	**4,127.5**	**5,395.6**	6,663.7	7,931.8
10	**821.9**	**2,228.8**	**3,635.7**	**5,042.6**	**6,449.5**	**7,856.4**	9,263.3	10,670.2
~~11~~	2,579.9	4,125.2	5,670.5	7,215.7	8,761.0	10,306.3	11,851.6	13,396.8
~~12~~	4,329.1	6,012.4	7,695.6	9,378.9	11,062.1	12,745.3	14,428.6	16,111.8
~~13~~	6,069.6	7,890.4	9,711.2	11,532.0	13,352.7	15,173.5	16,994.3	18,815.1
~~14~~	7,801.3	9,759.2	11,717.2	13,675.1	15,633.0	17,590.9	19,548.9	21,506.8
~~15~~	9,524.3	11,618.9	13,713.6	15,808.3	17,902.9	19,997.6	22,092.2	24,186.9
~~16~~	11,238.6	13,469.6	15,700.5	17,931.5	20,162.5	22,393.5	24,624.4	26,855.4
~~17~~	12,944.2	15,311.1	17,678.0	20,044.9	22,411.8	24,778.6	27,145.5	29,512.4
~~18~~	14,641.2	17,143.6	19,646.0	22,148.4	24,650.8	27,153.1	29,655.5	32,157.9
~~19~~	16,329.6	18,967.1	21,604.6	24,242.1	26,879.5	29,517.0	32,154.5	34,791.9
~~20~~	18,009.5	20,781.6	23,553.8	26,325.9	29,098.1	31,870.2	34,642.4	37,414.5