POLITECNICO DI TORINO

Corso di Laurea Magistrale
in Ingegneria Energetica e Nucleare

Tesi di Laurea Magistrale

Large Scale Photovoltaic: Market Analysis in Italy

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Anno Accademico 2020/2021

Abstract

The environmental targets set by Europe of reaching a net zero carbon emission by 2050 and the European Green Deal have increased the environmental targets previously set. The Italian government managed to reach the targets set by 2020 in advance and started to work on the 2030 targets in 2017. Nevertheless, after the EU agreement on the Green Deal, the strategy has been revised and the Integrated National Energy and Climate Plan has been published with the aim of setting clear targets to reach by 2030 in compliance with the strategy of the European Union. The Italian strategy will strongly rely on solar and wind energy: the government intends reaching 51 GW of installed solar capacity from the 20.8 GW currently installed.

The cost-competitiveness of solar energy is well known, and it has already reached the grid parity stage in Italy. This study is aimed at giving in the first part an insight on the current status and future trends of photovoltaic technology. In the second part, the analysis has been focused on the Italian photovoltaic energy, market schemes and permitting phase. The biggest threats to the deployment of large scale photovoltaic are: the land procurement due to the national and regional/municipal constraints and the impossibility of knowing a priori the availability of connection capacity.

Lastly, a feasibility study has been performed on a site in the northern part of Italy. The scope was to assess which was the best design solution that maximized the IRR. Therefore, a technoeconomic optimization has been carried out on three different systems: the fixed mounting, the single axis tracking (astronomical) (SAT-A) and the single axis tracking with backtracking (SAT-B). For the economic analysis, a financial model has been built to account for taxation and the debt schedule.

The optimization showed that the backtracking system is a good trade-off between the system with the higher production (SAT-A) and the system with less land consumption (fixed mounting). For the optimization in the feasibility study also bifacial modules have been tested. Unfortunately, the cost figure found for the modules led to IRR lower with respect to the other systems. Nevertheless, all the systems have shown an economic and technical feasibility. As emerged from the sensitivity analysis, the continuous reduction in system cost will further benefit the system.

ACKNOWLEDGMENTS

It has been a long journey, but the end is right around the corner.

I have written this work during an internship at Eco Energy World, a developer of utility scale photovoltaic. My acknowledgments go to Svante Kumlin for giving me the opportunity to work firsthand with the solar development of large scale photovoltaic in Italy, and Giulia Castoldi who followed me directly during the work. Moreover, I would like to thank all the members of EEW for the support and advice received.

Secondly, I would like to express my gratitude to Rafael Guédez who got me passionate to the topic of project development during his lessons, and who has been my supervisor during the master thesis project.

I would like to express my gratitude to Politecnico di Torino who gave me the opportunity to participate to the double degree project at KTH allowing me not only to continue my formation, but also to experience the life in a country very different from Italy. A special thanks goes to ICHTus (Luca, Antonio and Giuseppe “Sax”) who has made days in Politecnico funnier, although the working load was extenuating. I would like to thank Luca who has always been a reference point and has joined me in Sweden for the Erasmus projects. Moreover, I am thankful to all the new friends I made in Sweden, in Björksätravägen, who gave a completely different rhythm to the Swedish daily life.

I am extremely thankful to Marion, the person I am sharing my life with since I arrived in Sweden. She, who has seen me working day and night to carry on the project regularly and who has always been there to give her support whenever I needed it. I cannot express in simple terms how much just some words can have strong impact.

Lastly, I want to express my gratitude to my family who has always been there for whatever I needed and always encouraged me in my studies and desires. There are no words to express how much I appreciate what you have done for me so far.

Federico

Monaco, February 2021

NOMENCLATURE

Here the Notations and abbreviation used in the thesis are described.

Notations

Symbol	***Description***
CP_A	Cost per unit power case A (€/kW)
CM_A	Cost per unit power and length case A (€/kW km)
CP_B	Cost per unit power case B (€/kW)
CM_B	Cost per unit power and length case B (€/kW km)
D_A	Distance from Low/Medium voltage substation (km)
D_B	Distance from High/Medium voltage substation (km)
D_{aer}	Connection distance realized in overhead line (km)
D_{cab}	Connection distance realized in cable line (km)
$STMD_{request}$	Request of the STMD fee (€)
P	Connection power (kW)
T_r	Reference tariff (€/MWh)
T_s	expected tariff (€/MWh)
$\%R_{off}$	Proposed reduction factor (-)
$\%R_n$	Additional reduction factor (-)
$\%R_1$	Delays reduction factor (-)
$\%R_2$	Change of ownership reduction factor (-)
P	Connection power (kW)
$WACC$	Weighted average cost of capital (-)
NPV	Net Present value (€)
$CAPEX$	Investment cost (€)
$OPEX$	Annual expenditure (€/yr)
$Revenues_t$	Revenues in year t (€)
$Taxes_t$	Taxes paid for year t (€)
d	Discount rate (-)
n_{cons}	Construction years (yr)
$LCOE$	Levelized cost of energy (€/MWh)
$EQUITY_{Share}$	Share of equity (-)
C_{Debt}	Loan interest rate (-)

$Debt_{Share}$	Share of debt (-)
C_{equity}	Cost of equity (-)
$Corporate_{tax-rate}$	Corporate tax rate (-)
CF	Capacity Factor (Adimensional)
$P_{installed}$	Installed power (MW)
E_{sold_t}	Energy sold year t (MWh)
PR	Performance ratio (-)
$POA\ Irradiation$	Plane of array Irradiation (MWh)
η_{module}	Module efficiency (-)
C_{EPC}	Engineering procurement and construction cost (€)
$C_{permitting}$	Permitting cost (€)
C_{PM}	Project margin (€)
$C_{Financing}$	Financing cost (€)
C_{syst}	System cost (€)
$C_{Eng\&Dev}$	Engineering and development cost (€)
C_{land}	Land cost (€)
C_{I-C}	Installation and construction cost (€)
$C_{grid-con}$	Grid connection cost (€)
$Contingency$	Contingency amount (€)
C_{PVSyst}	Photovoltaic system cost (€)
C_{module}	Module cost (€)
$C_{inverter}$	Inverter cost (€)
C_{BOS}	Electromechanical components, fence, CCTV… cost (€)
C_{struct}	Mounting structure cost (€)
$C_{LV\backslash MV-ESS}$	Low/medium voltage substation cost (€)
C_{MVLine}	Medium voltage line cost (€)
C_{HVLine}	High voltage line cost (€)
$C_{MV\backslash HV-ESS}$	Medium/high voltage substation cost (€)
D_{MV}	Medium voltage line distance (€)
D_{HV}	High voltage line distance (€)
C_{STMG}	Connection solution request cost (€)
C_{STMD}	detailed connection solution request cost (€)
$C_{AU\&other}$	Authorisation and/or other permitting cost/studies (€)
C_{TSO}	Transmission system operator connection cost (€)
C_{acq}	Land Acquisition cost (€)

C_{prep}	Land preparation cost (€)
$Financing_{fees}$	Financing fee amount (-)
G_{STC}	Standard condition irradiation (W/m^2)
A_{Land}	Land Area (m^2)
A_{mod}	Modules Area (m^2)

Abbreviations

YoY	Year over year
GIS	Geographic Information System
AC	Alternate current
TFEC	Total Final Energy Consumption
PV	Photovoltaic
DC	Direct current
EU	European union
IRENA	International Renewable Energy Agency
SAM	System Advisor Model
NREL	National Renewable Energy Laboratory
IEA	International Energy Agency
IEA PVPS	International Energy Agency Photovoltaic Power Systems Programme
CAGR	Compound Annual Growth Rate
CF	Capacity Factor
KPI	Key Performance Indicator
GHI	Global Horizontal irradiance
NDC	National Determined Contribution
TSO	Transmission System Operator
DSO	Distribution System Operator
EPC	Engineering Procurement and Construction
STC	Standard Test Condition
MPPT	Maximum Power Point Tracking
SCADA	Supervisory Control And Data Acquisition
USD	United States Dollars
LCOE	Levelized Cost Of Energy
PERC	Passivate Emitter Rear Cell
CIGS	Copper Indium Gallium Selenide
CdTe	Cadmium Telluride

HJT	Heterojunction - Technology
O&M	Operation and Maintenance
PV-T	Photovoltaic-Thermal
RO	Renewable Obligation
REC	Renewable Energy certificate
FiT	Feed in Tariff
FiP	Feed in Premium
CfD	Contract for Difference
JRC	Joint Research Centre of European commission
PPA	Power Purchase Agreement
Q1(2,3,4)	First (second, third, fourth) Quarter
HVDC	High Voltage Direct Current
GDP	Gross Domestic Product
TES	Total Energy Supply
TFC	Total Final Consumption
MGP	Day-ahead market - “Mercato del Giorno Prima”
PUN	National single price – “Prezzo Unico Nazionale”
INECP	Integrated National Energy and Climate Plan
PNIEC	“Piano Nazionale Integrato Energia e Clima”
RES	Renewable Energy Source
GHG	Greenhouse Gases
ETS	Emissions Trading System
CSP	Concentrated Solar Power
P	Power
DM	Ministerial decree - “Decreto Ministeriale”
D.Lgs/DLgs	Legislative decree – “Decreto Legislativo”
TICA	Testo Integrato Connessioni Attive
AU	Single authorisation – “Autorizzazione Unica”
PAS	Simplified Authorisation Procedure – “Procedura Abilitativa Semplificata”
RE	Renewable Energy
VIA	Environmental impact Assessment – “Valutazione di impatto ambientale”
VA	Eligibility to VIA assessment – “Verifica di Assoggettabilità”
PPR	Regional Landscape Plan – “Piano Paesaggistico regionale”
CdS	Authorities meeting – “Conferenza dei Servizi”
DOP, IGP, STG, DOC, DOCG	Certification of products
PAI	Hydrogeological plan – “Piano per l’Assetto Idrogeologico”

STMG	Minimal Technical Connection Solution
STMD	Detailed Technical Connection Solution
LV	Low Voltage
MV	Medium Voltage
HV	High Voltage
EHV	Extremely High Voltage
ESS	Electrical SubStation
GSE	Energy services Authority - “Gestore dei Servizi Energetici”
GO	Guarantee of Origin
IGO	Power plant who can emit GO
GME	Energy Market Authority – “Gestore dei Mercati Energetici”
SAT-A	Single axis tracking – astronomical
SAT-B	Single axis tracking with backtracking
IRR	Internal Rate of Return/hurdle rate
CAPEX	Capital expenditure
OPEX	Operation expenditure
GCR	Ground Coverage Ratio
NPV	Net Present Value
FVG	Friuli-Venezia Giulia
NTA	Construction regulation – “Norme Tecniche Attuative”
PRGC	Municipality regulatory plan – “Piano Regolatore Generale Comunale”
CCTV	Surveillance system
BOS	Balance Of System
SPV	Special Purpose Vehicle
IRES	Corporate tax
IMU	Municipal tax
IRAP	Production tax
EBITDA	Earnings Before Interest Taxes Depreciation and Amortisation
ROL	“Reddito Operativo lordo”
BAU	Business as usual scenario
DEC	Decentralised production scenario
CEN	Centralised production scenario
Poly-c	Polycrystalline modules
Mono-c	Monocrystalline modules
PVGIS	Photovoltaic Geographical Information System
TMY	Typical Meteorological Year

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1 INTRODUCTION

This chapter defines the background for the study. Moreover, it presents the study's delimitations, its purpose and the method employed.

1.1 Background

The fight against climate change sees all the world involved. The need of reducing the carbon emissions has forced the governments to change the energy mix of their countries in favour of cleaner sources of energy. In this context, investors are strongly influenced by technological and market barriers, and it is the connection between these two aspects that is the driver for the current engineering challenges in the energy sector.

Focusing on the electricity production, the strategy is to switch from the current centralized production of energy in fossil fuel plants to a combination of centralized and decentralized renewable energy production. Governments try to define policies and financing mechanisms to support this trend, especially for less mature technologies where the investment cost is high.

Indeed, renewable and sustainable energy sources are the key for the carbon emission reduction. Nevertheless, the technological development is necessary to guarantee their integration in the current power system: new infrastructure and new control strategy are needed for a safe integration of these sources in the current energy networks. Solar photovoltaic is one of the main renewable energy sources participating in the current energy challenges thanks the technological evolution and the cost reduction that has been faced in the past years.

Eco Energy World is a solar project developer involved in the development of utility scale solar projects with more than 1200 MW developed across Europe and Asia-Pacific and more than 3600 MW of a pipeline of projects in different countries. The company intends to reach 3300 MW of developed projects by 2023 and some of these will be in Italy [1]. This Master thesis has been performed in the form of an internship at Eco Energy World to study the development of utility-scale solar photovoltaic energy business and potential entry strategies in Italy.

1.2 Delimitations

The target of a business development analysis is to look for ideal sites where to assess the techno-economic feasibility of a project. This research is aimed at highlighting the possible business opportunity and the problems that may arise in the development of a large-scale photovoltaic project in Italy.

Italy benefits from an abundant solar resource. The country has strongly invested in the solar photovoltaic development and the current policies intend on further increasing the installed capacity in the country: the utility-scale solar photovoltaic installations are expected to increase in the upcoming years. The country has a good policy background for the integration and deployment of renewable energy. However, even if the availability of land is high, the site identification is not easy given the numerous constraints that must be respected. The study has thus been limited to a feasibility study of large-scale system (larger than 10 MW) in the northern part of the peninsula. No storage system has been considered.

The choice to settle the feasibility study in the northern part of the peninsula has been subject to data availability for the site identification and some electricity network's constraints that will be better explained in the feasibility study.

1.3 Purpose and method

The scope is to identify emerging trends, potential opportunities, and bottlenecks for the large scale solar photovoltaic development in Italy. The methodology used in the study is structured as follows: first, some knowledge on the current market and technological context is given. In the second part, the current trends and future scenarios for the Italian energy market are presented. Lastly, the feasibility study is developed in a location in the northern part of Italy. In the feasibility study different aspects of the technical and economic solutions are presented for the design of the optimal system.

In the first part, a general understanding of the worldwide solar photovoltaic energy, business models and support scheme's picture is given. Then, a focus on the technology and its evolution with the current commercial solution is presented. The current market drivers, the future policies and the national targets are the key indicators for the market evolution. Then, the techno-economic optimization of the design is carried out with the aim to assess which combination of system and modules is the optimal one. In particular, three different system configurations have been tested: fixed mounting, tracking astronomical and tracking with backtracking, to identify which one of the systems yields the best results. The study has been structured as follows:

- KPI definition
- Site identification
- Technoeconomic modeling
- Optimization process
- Results and sensitivity analysis

For the KPI definition, two technical and two economic KPI have been defined. For the optimization process the Internal rate of return has been used. The pre-feasibility study has been performed in a site identified with GIS software, such as QGIS and Google Earth, considering the constraints and the possible connection point. The technoeconomic modeling of the system has been done with System Advisor Model (SAM) and Excel. The optimization has been carried out using SAM, for the performances' simulation, and Excel for the economic analysis. Polycrystalline, monocrystalline, and bifacial modules have been tested in three different system configurations. The feasibility study has been concluded with a sensitivity analysis in order to assess the variables that had the stronger impact on the objective function.

In this section the process that led to the site selection is described.

2.1 PV energy overview

In 2019 the total installed renewable generation capacity increased by more than 200 GW (which is the largest YoY increase ever registered). Most of the installed capacity is in the electricity sector, but smaller shares can be found in the heating/cooling and the transport sector. In 2018, 11% of the total final energy consumption (TFEC) was estimated being supplied by renewables, a detailed breakdown can be seen in Figure 1. [2]

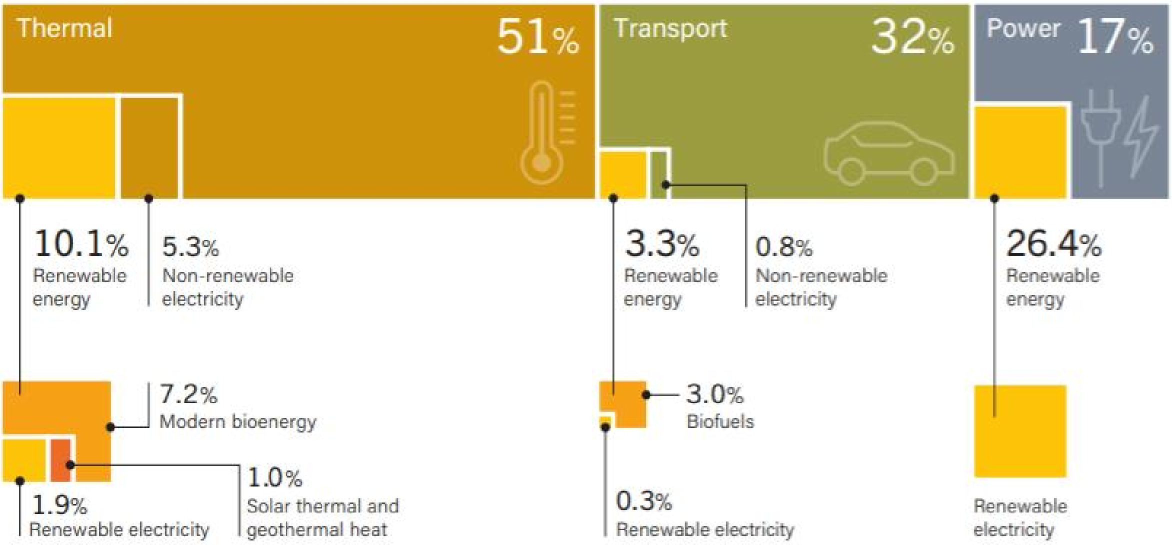

Figure 1 Renewable Share of Total Final Energy Consumption, by Final Energy Use [2]

2.1.1 PV energy in the world

Solar photovoltaic power added in 2019 was around 115 GW (DC) with an estimated increase of 12% compared to the previous year. PV power accounted for 57% of the total capacity installed in 2019, the other two larger contributors were wind power and hydropower with respectively 30% and 16% of the total capacity installed. The total installed PV capacity has reached 627 GW in 2019, Figure 2 shows the total installed capacity with the annual additions for the period 2009-2019 [2]

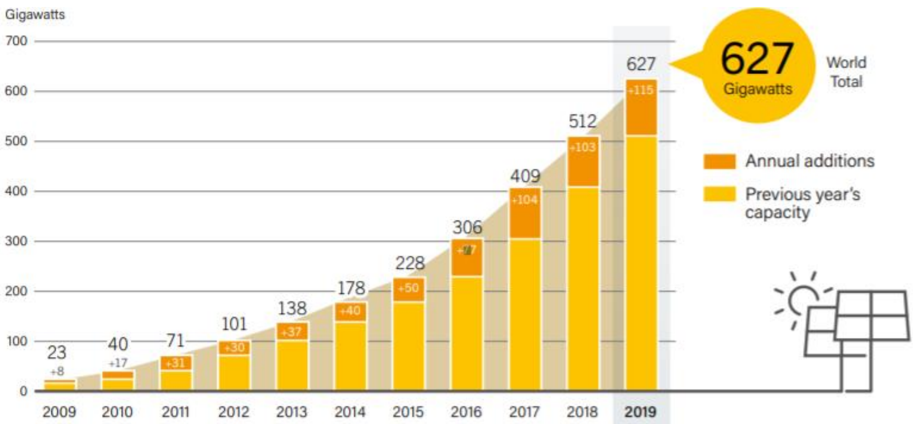

Figure 2 Solar PV Global installed capacity with annual additions (2009-2019) [2]

EU and USA solar-PV yearly installed capacity has increased and resulted in a compensation for the decrease of PV installations in China. [2] Figure 3 shows the installation trend of solar-PV in the years 2017-2019 for the largest contributor to the total installed capacity.

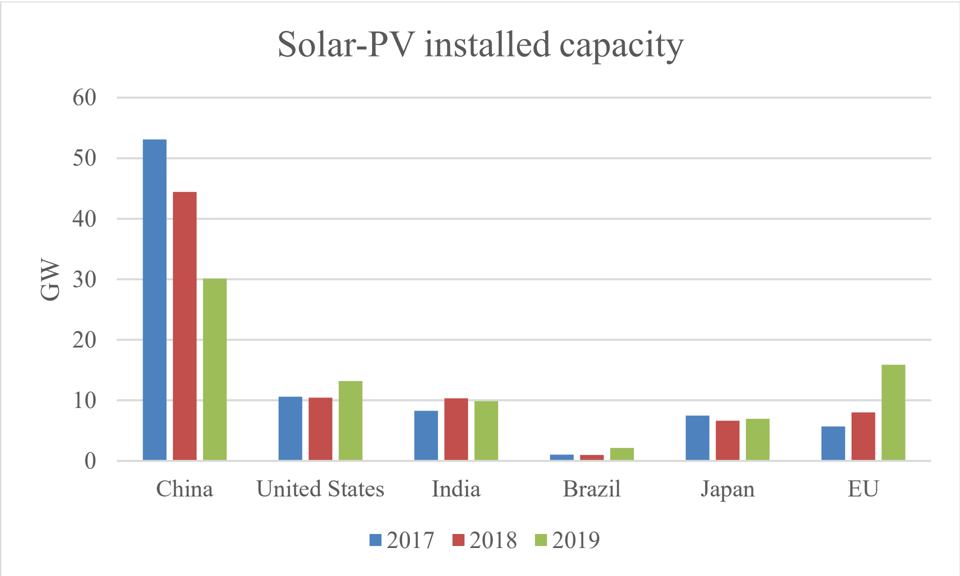

Figure 3 Installed capacity in main countries [3]

The five markets accounted for around 68% of the total installed capacity.

Worldwide, the total installed cost was around 995 $/kW. However, such cost is an average between small scale and Utility-scale projects. The cost of the latter is smaller than the former given the size factors. [4]

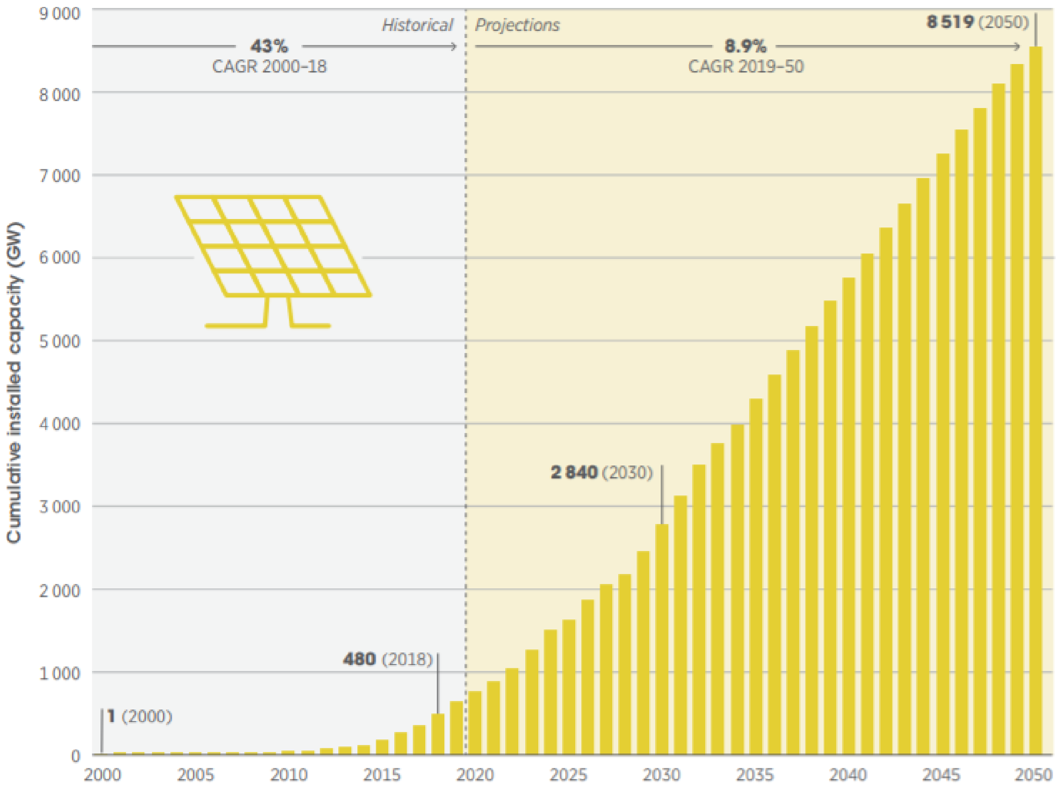

Figure 4 Projected Solar-PV installations

Considering the forecasted market trends of cost reduction of solar PV systems, the International renewable Energy Agency (IRENA) had forecasted the future solar-PV installations in 2018.

According to IRENA the installed capacity at the end of 2018 was 486 GW (the incongruence with the 512 GW of the IEA in Figure 2 might be related to difference in AC & DC rating of the systems) with a year-over-year (YoY) increase of 20% compared to 2017 (386 GW). This results into a compound annual growth rate (CAGR) of 43 % since 2000. Moreover, the cost competitiveness of solar-PV, the current policy and technological development will lead to a total installed capacity of 2840 GW in 2030 and 8519 GW in 2050 with a projected CAGR of 8.9% in the period 2019-2050. [5] The data is shown in Figure 4.

IRENA has forecasted that in 2050 around 60% of the installations will be made of Utility-scale PV systems, while 40% will be rooftop PV system. However, given the current policies and subsidies, a faster growth of the latter is expected in the short-term. [5]

2.1.2 PV energy in Europe

Europe has registered around 117 GWp of PV energy installed at the end of 2018, ten times higher than the 11.3 GW that were installed in 2008. [6]

The growth is also related to the European policies: the latest approved European Green Deal aims at reducing the emissions of 55% by 2030, compared to 1990 level. This target is more ambitious compared to the previous national determined contribution (NDC) of at least 40% emissions reduction, compared to 1990 emissions, by 2030 [7].

Of the 20.7 GW of capacity installed in 2018, 42 % (around 9 GW) were solar-PV while first was wind power with 9.7 GW the rest was 1.1 GW biomass, 0.4 GW hydro and 0.3 GW of natural-gas. With a total PV capacity of 117 GW, Europe contributes to 23% of the world PV market (well below the 66% share recorded in 2012) [6]. Three current future projections can be derived on the future installation of solar-PV systems that are shown in Figure 5.

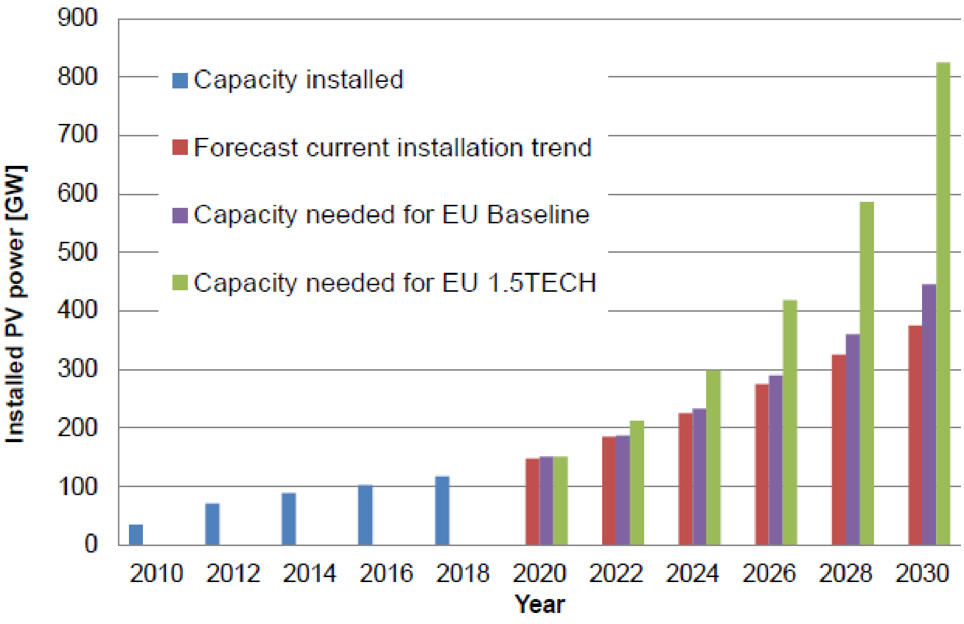

Figure 5 Actual and forecasted solar-PV installation according to 3 different scenarios. [6]

However, IRENA assessed that the additions in 2020 will be lower due to:

- the exceptionally high growth experienced in 2019,
- uncertainties in policy development in Spain and Germany (who are the largest contributors to the European PV market),
- the COVID-19 pandemic which led to delays in constructions
- COVID-19 impact on the market of unsubsidised and distributed PV

Overall in 2020 and 2021 the total expected capacity additions amount to 25 GW [8].

Moreover, the high penetration of renewable electricity in the market might be hindered by the capability of the electrical grids. Therefore, TSOs and DSOs have to remove transmission bottleneck among and within the Member States. [9]

2.2 PV technology

The solar-PV systems are categorised in 2 groups installation types which are: distributed-PV and utility scale PV. In both cases, the PV system is composed of several modules arranged in series to form a string and meet the required voltage level, then strings are connected in parallel to form an array which is connected to an inverter. Arrays are connected in parallel to meet the desired power output. The difference between the two is in the system size: Utility scales system has a power output larger than 1 MW, while distributed PV has a smaller size.

When developing a PV-systems, apart from assessing the solar resource in the area, additional constraints must be considered that will influence the size or other design parameters. When identifying a possible site, the most common constraints to consider are historical value of the area, hydrogeological risk as well as protected area and visual impact. A detailed list of constraints will be given for Italy in chapter *3.2.3 PV plants permitting process*.

2.2.1 Utility scale PV system description

The development of a solar-PV project is a complex procedure that requires different actors. In general, 7 different stages can be highlighted that are summarized in Figure 6.

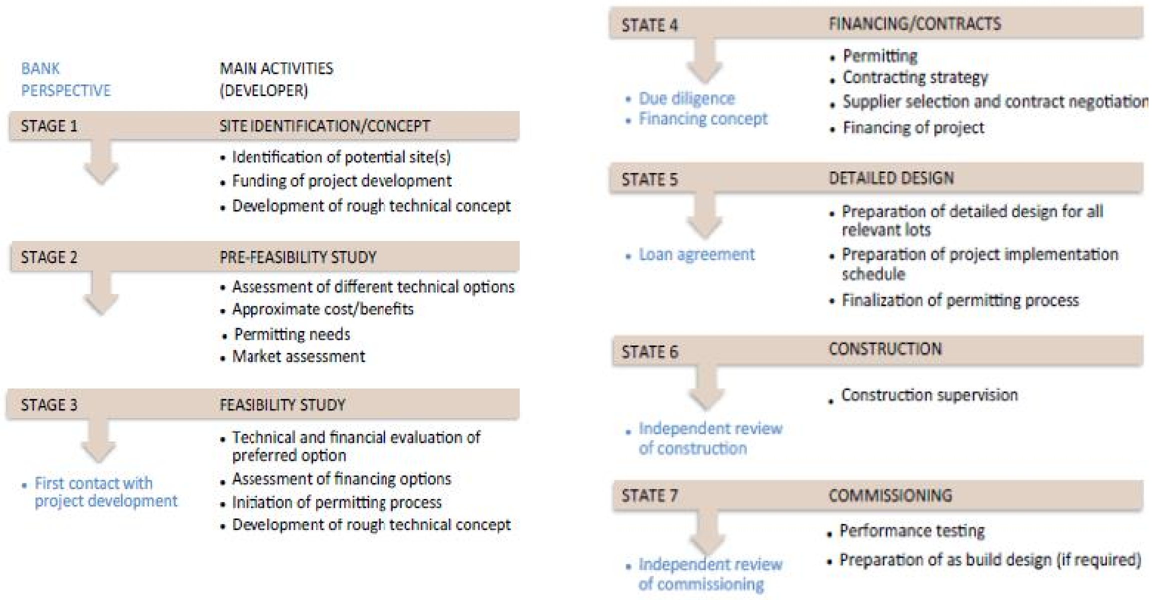

Figure 6 Project Development phases [10]

In the first stage, the site should be identified by assessing the solar resource, land availability, distance to the grid, roads, and other resources. A preliminary financial model should be developed and the market mechanism available must be analysed. A rough design of the system should also be considered.

In the second stage, the financial viability of the project is assessed by means of a pre-feasibility study. Usually, this phase is carried out as desktop study and the feasibility is assessed through a minimum financial hurdle rate.

In the third phase, an additional study will be conducted but, in this case, using data specific measurements and more specific financial parameters. In this phase the work should proceed with a limited number of sites.

In the fourth phase, financial permits must be obtained and the commercial contracts must be secured.

For the following phases, an EPC company is appointed for developing PV plants. The EPC contractor is required to confirm the solar energy resource, develop a detailed design of the PV plant with estimation of the energy yield, procure the equipment following the developer's directions, construct the PV plant, carry out the acceptance tests, and transfer the plant for commercial operation to its owner/operator. In this phase, the developer must oversee the implementation of the project while coordinating the activities. [10]

2.2.2 PV components

The solar energy is converted into electrical energy using the so called "PV-effect" in a P-N junction. A P-N junction is a junction of a same semiconductor material, for example Silicon, which has been doped in two different ways to increase the concentration of electrons. In case of Silicon, the N-type is usually doped with Phosphorus while the P-type is doped with Boron. In the P-N junctions, electrons from the n-type can jump to the p-type while holes from the p-type diffuse to the n-type if in the presence of energy (electric fields).

The photons emitted by the sun increase the energy of the electrons, allowing a "jump" from the valence band to the conduction one. These electrons are free to move and by applying an electric field the electron can be removed from the n-type to the p-type. The p-type semiconductor will be negatively charged while the n-type positively charged. A graphic idea is given in Figure 7.

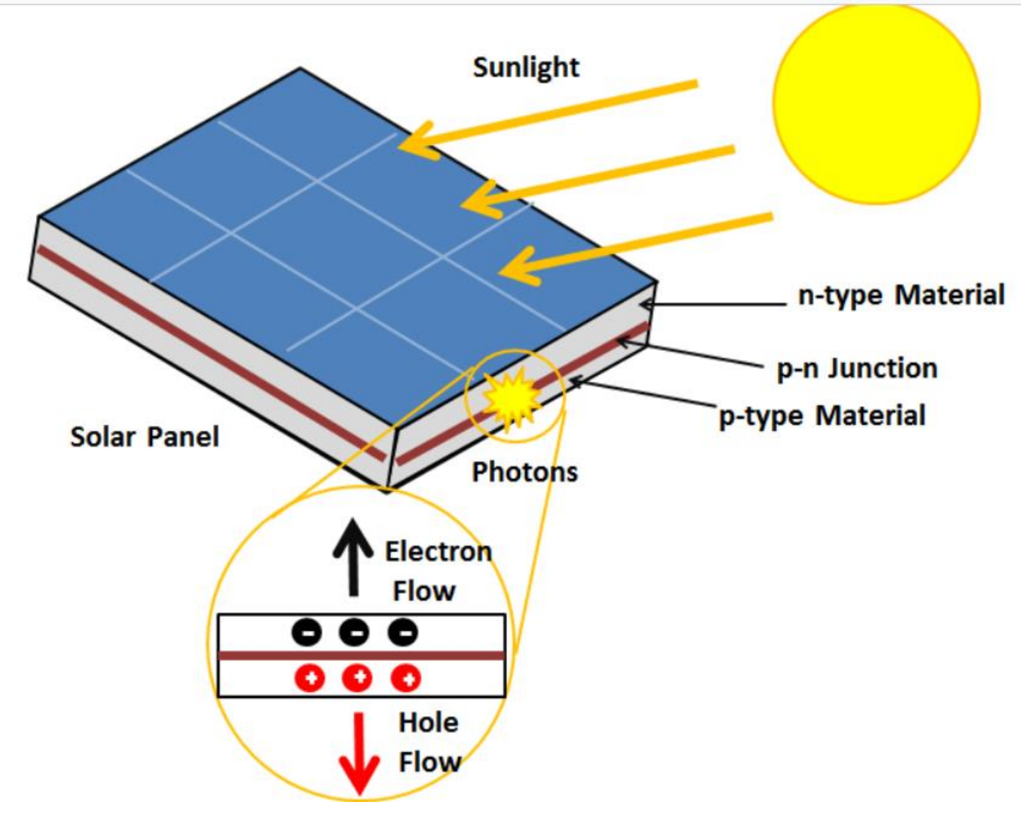

Figure 7 PV Effect [11]

The PV effect takes place in the PV-cells and the efficiency of conversion depends on the type of technology used. The National Renewable Energy Laboratory (NREL) shows the efficiency evolution for the different type of solar cells which is reported in Figure 8. These values are reached in laboratory condition and are consequently different from commercial cells efficiency values.

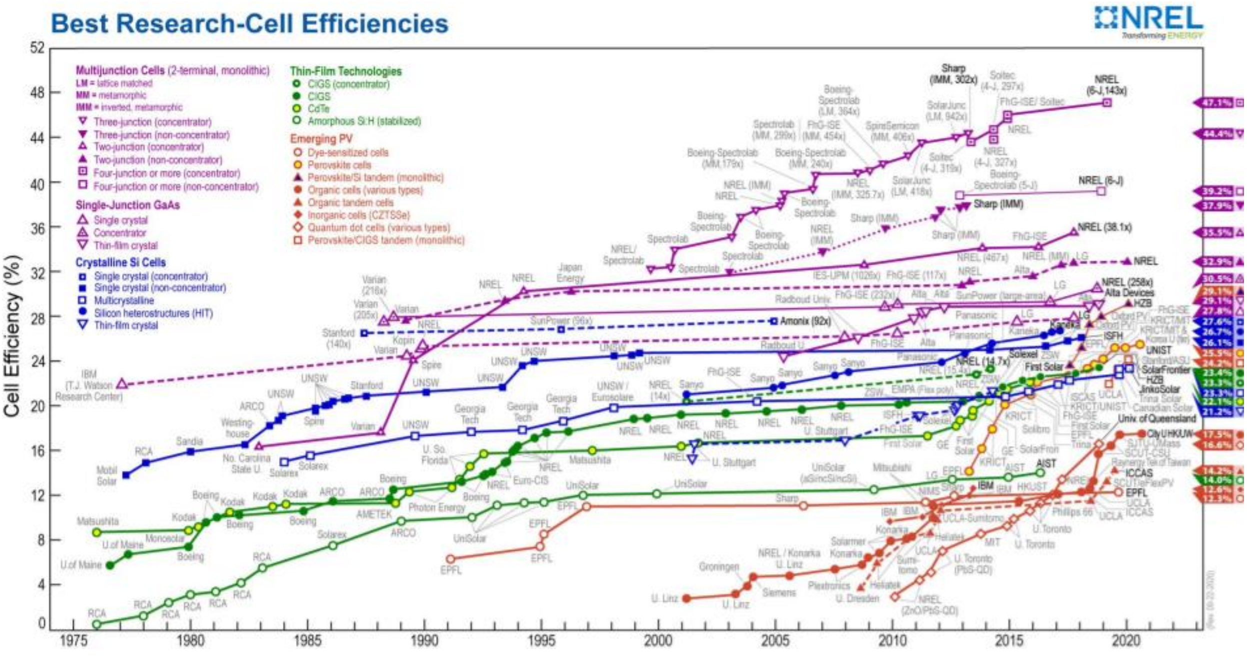

Figure 8 Best research Cell efficiency [12]

Nevertheless, PV cells are sold assembled into modules, with usually 72/144 or 60/120 cells per module. A solar cell is characterised by an I-V curve in STC, and a PV module can be represented in the same way because it is an assembly of solar cells. An example can be seen in Figure 9, where the influence of the irradiance level and the cell operative temperature is shown.

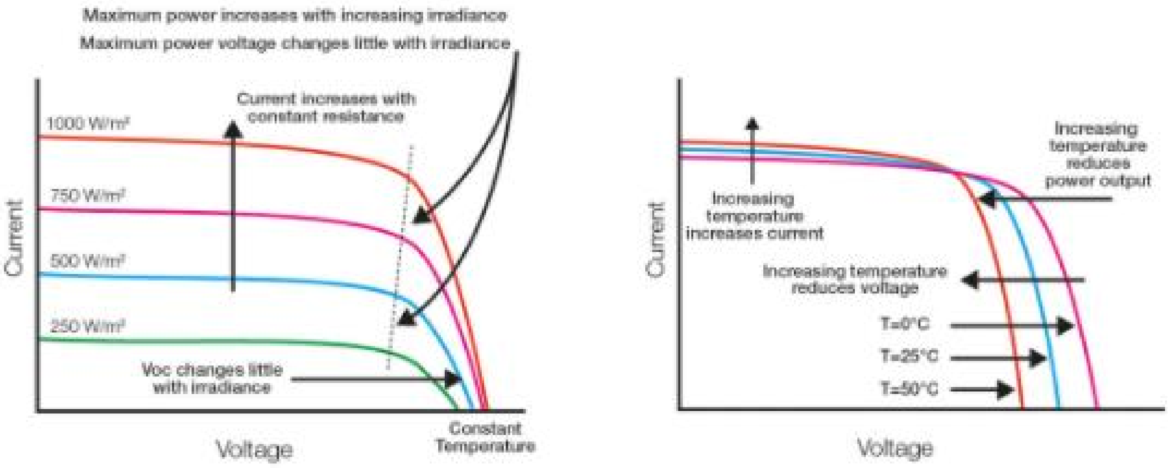

Figure 9 I-V curve of a PV module and Temperature/Irradiance effect [13]

To meet the desired Power output, the modules must be arranged into arrays which are characterised by the number of modules in series and in parallel.

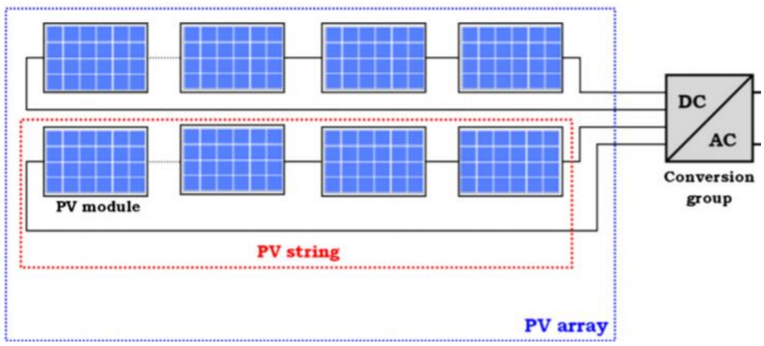

Figure 10 PV module, string and array [14]

The choice of number of modules in parallel and in series is dependent upon the design irradiance, the design temperatures, the inverter voltage and current limitations. Indeed, irradiance and temperature modify the module I-V curve as shown in Figure 9. The inverter converts the DC current into AC one. Moreover, the inverters are equipped with a MPPT device to adjust the voltage and to have the module working at the maximum power output for given temperature and irradiance conditions. A sketch of the DC side of the system and the inverter can be seen in Figure 10. For a utility scale system, additional components are required to connect the system to the national grid. These systems include transformers, power lines and protection switches. Moreover, SCADA systems are necessary to collect data for monitoring purposes.

2.2.3 Current status of technology and future trends

REDUCING COST

The solar PV industry aims at further reducing the costs and increasing the cell efficiencies. The increasing competition among manufacturers, and the entry of new companies in the manufacturing industry, led to a declining price of components. This was also reflected in tenders results where lower prices were bid by the competitors with respect to previous years. The average cost of modules has declined to 0.36 USD/W, but the value has strong variation in the different markets and countries [2].

In the EU market the cost of crystalline silicon modules has been falling during the years, reaching an average of 0.27 USD/W for the mainstream technology in December 2019 [4]. The historical trend is shown in Figure 11 for EU market.

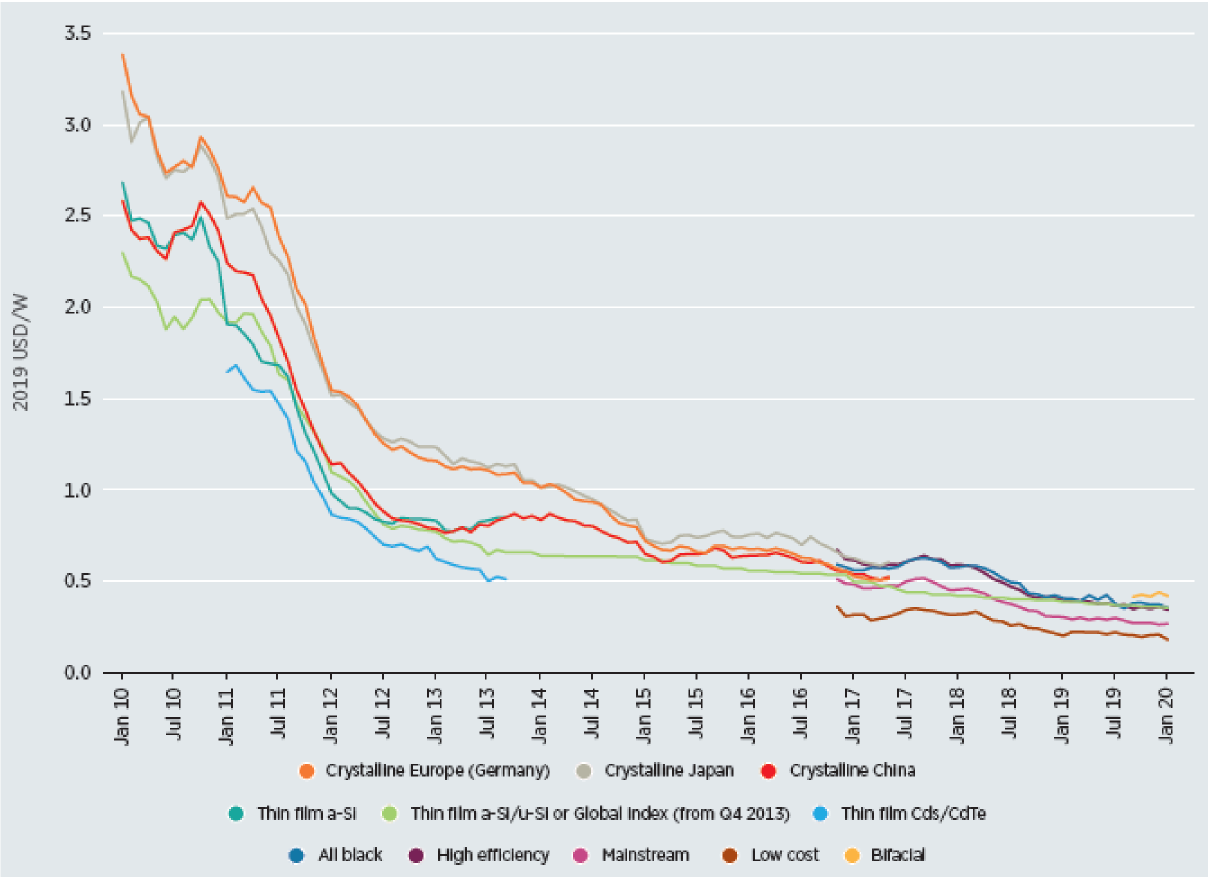

Figure 11 PV modules sold in Europe historical cost trend [4]

In 2018 the average LCOE for utility scale PV fell at 0.085 USD/kWh which was already competitive with fossil fuel LCOE. Nevertheless, the cost reduction trend is expected to continue and the forecasted average LCOE is expected to be in the range 0.014-0.05 USD/kWh.[5] The trend is shown in Figure 12.

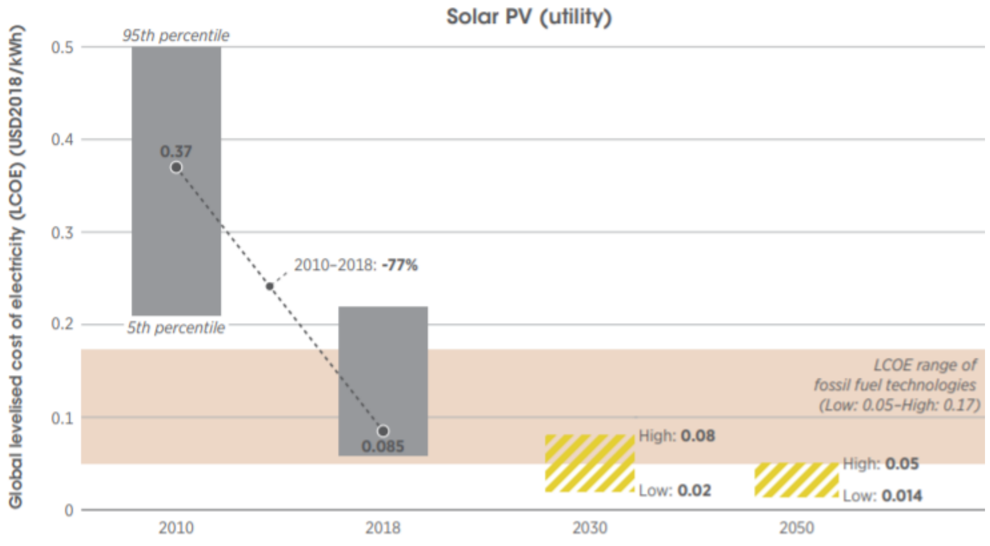

Figure 12 Utility-scale PV LCOE: Historical and projections [5]

The forecast for 2030 is derived from auctions and tenders results [5]. However, the average price of tenders in 2019 was already close to 0.030 USD/kWh, but in other markets it was even below 0.020 USD/kWh. In Portugal a price of 16.53 USD/MWh (14.76 €/MWh) was bid for 1.29 GW PV. [2]

PV MODULE TECHNOLOGY

PV module technology keeps on improving and research on higher efficiency modules is ongoing both for the mature and commercial technology such as crystalline silicon and thin film but also for new PV-cell materials[5]. Figure 13 gives an idea on the current Solar PV technology status.

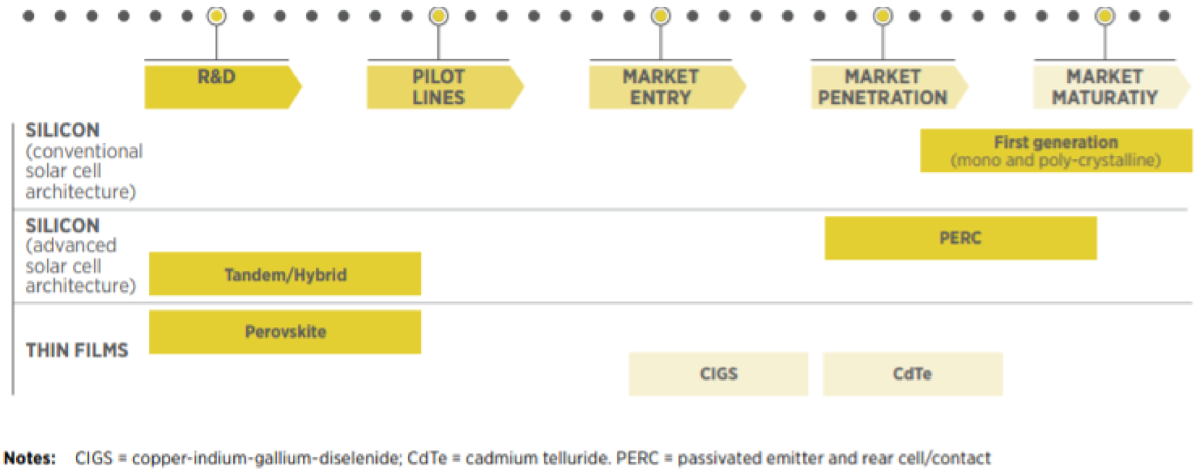

Figure 13 Solar PV technology status [5]

The polycrystalline and monocrystalline silicon modules have experienced a steady increase in efficiency reaching respectively 17% and 18% in 2017.[5] There are still scopes of improvement:

1) lowering the cost of c-Si modules for better profit margins
2) reducing metallic impurities, grain boundaries, and dislocations
3) mitigating environmental effects by reducing waste
4) yielding thinner wafers through improved material properties.

The PERC technology improved the conventional silicon technology with the addition of a passivation layer on the back of the cell improving the efficiency in three ways [5]:

1) Reducing recombination
2) Increasing light absorption
3) Enable high internal reflectivity.

Currently, also heterojunction (HJT) cells are being addressed. These cells combine advantages of common silicon cells with the good absorption of thin-film amorphous silicon cells. The advantage is the lower temperature of the production process and the higher efficiency of the cell [2].

Tandem/hybrid cells are cells of different materials stacked one on top of the other to convert specific energy bands of the sunlight. In Figure 8 they are named as multi-junction and are able to yield extremely high efficiencies, but unfortunately the production cost is too high [5].

Thin-film silicon technology is known as second generation PV cells. They have lower efficiencies compared to the crystalline silicon modules in STC. Among the non-silicon based, the Perovskites cells are being studied for a future market development. However, one of the problems is the durability: the crystals dissolve rapidly with humidity thus requiring encapsulation. Secondly, the high efficiency obtained for smaller sizes was not replicated for larger sizes of the cells [5].

CIGS cells have achieved 22.9% efficiency, but large scale production is hindered by the rarity of Indium, the complexity of the stoichiometry and multiple phases [5].

CdTe have an efficiency slightly lower than CIGS, but the flexibility of the production and its affordability affirmed it as the main thin-film technology [5]. FirstSolar is the main manufacturer of CdTe modules.

ADVANCED MODULE TECHNOLOGY

Bifacial modules are also starting to arise on the market scene. The advantage of using the irradiation impacting on the back of the module increases the module efficiency [5]. Currently, the registered cost for bifacial module is around 0.33 €/W while the high efficiencies modules PERC are 0.30 €/W [15].

Another innovation is the use of half cells where the PV cells are cut in half with laser technology, improving both durability and efficiencies. The implementation is easy because only the laser machine has to be added to the current production chain [5].

Multi-busbars cells present a higher number of busbar (metallic strips that conduct electricity). The increased number of busbars reduces the metal consumption for the front-facing metallisation, reduces the resistive losses between cells, and the optimisation of busbar width increases the cell efficiency. This is useful to increase bifaciality of modules [5].

Solar shingles requires PV modules designed to replace roofing materials. Costs are reduced through the removal of the ribbon and reduced fingers number and thickness (the fingers are metallic super-thin components placed perpendicular to the busbar. The fingers collect the generated DC current and deliver it to the busbars) [5].

O&M

The cost of O&M for a PV system is also expected to reduce with time. The use of remote maintenance and control technologies aim at reducing outages and costs. Drone technologies have the capability of monitoring large scale PV plants in less time than humans, while sending data directly to the cloud for analysis. The PV plant yield could be improved with a more accurate short-term forecasting of PV production and planification of the exchanges with the grid. However, there are different challenges on the communication between the different monitoring devices, which are subject to failings and have communication protocols that are not standardised [5].

Panels must be cleaned to maintain the system efficiency. The use of robotic cleaning for panels is becoming more common, the alternative is the use of a sprinkler system. New studies are carried out on coatings that will reduce the dirt deposited on panels [5].

Another topic that is relevant for the lifetime of PV modules is the temperature. Degradation could be reduced by means of modules cooling. PV-T technology are the most popular method for cooling PV panels. Other techniques include the use of water as well to cool the modules. Currently, the use of special coating aimed at re-emitting infrared radiation is under study as well as the possibility of using infrared reflection and radiative transfer to reduce the module temperature increasing the efficiency. The idea is to reflect the energy in the wavelength that cannot be used. The use of radiative transfer is also a great promise for increasing the cell efficiency [5].

2.3 Market mechanism

The targets and policies adopted by different countries have had a strong impact on renewable energy deployment. Different types of targets, pricing mechanism and policies have been adopted by countries [16]. The following chapter aims at giving a brief overview of the common targets and pricing mechanism available worldwide for the electricity sector.

2.3.1 Common market schemes

RENEWABLE ELECTRICITY CERTIFICATES

The Renewable Energy Quotas have been a common way for countries to set a target on renewable energy generation by a certain period (in UK it is known as Renewable Obligation (RO)). Quotas are supported in some countries using Renewable Energy Certificates (RECs). These certificates are awarded after the production of a certain amount of energy (typically 1 MWh) and they can be traded to meet the quotas. This is an additional financial support scheme for developers. In general, RECs are traded between utilities and generators to meet the renewable energy target or alternatively they can be bought by companies to meet their corporate renewable targets. More than 30 countries adopted this mechanism by 2017 [16].

FEED IN POLICIES

Feed-in policies are differentiated in Feed-In-Tariff (FiT) and Feed-in-Premium (FiP), where the energy produced, and sold, is remunerated at a fixed price in the first case and an increase of the market price is given in the second one. By 2017, these mechanisms were in use in more than 80 countries. [16].

The use of a Power Purchase agreement is usually seen as a FiT since a fixed price is given for the energy produced, while another common market mechanism, known as Contract for Difference (CfD) can be seen as a FiP mechanism [17].

The CfD mechanism is a long-term contract with an electricity producer. Whenever the wholesale market price is below the strike one, a premium is given to the energy producer to meet the strike price. However, in case the market price exceeds the strike one, the generator has to pay back the difference to the other party. [18]. A graphic representation of the CfD is given in Figure 14.

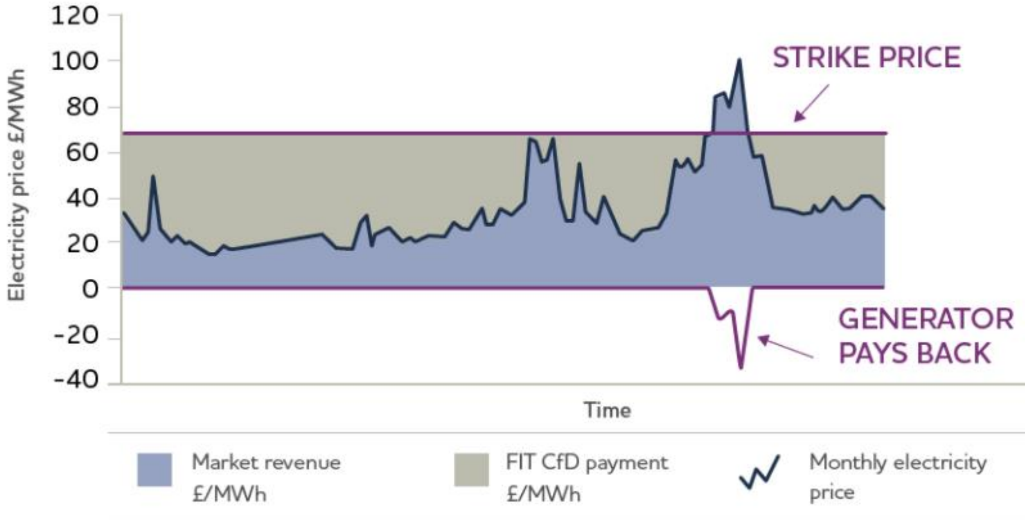

Figure 14 CfD example [18]

AUCTIONS

Auctions are gaining more and more relevance in plenty of countries. In an auction, the government, or a private actor, states the amount of power that intends installing. Different developers compete to propose the design that will have the lower cost of sold electricity to win the auction. A Power purchase agreement is usually signed in this case between the owner of the plant and the government/private for the selling of electricity [16].

According to IEA PVPS association, the tenders have not yet shown their full potential. Currently, they have been used only to develop photovoltaic capacity (or in general renewable capacity) just to meet specific targets of installations. However, they could be used in collaboration with the grid operator to develop specific renewable technology power in specific areas of the grid without threatening the reliability and the functioning of the electricity network or even helping to its safeguard [17].

OTHER SUBSIDIES

The deployment of renewables is also supported through financial and fiscal incentives. These are usually given in terms of tax incentives, risk mitigation and capital financing.

1) In the case of tax incentives, they are offered in the form of reductions in sales, energy, value-added or other taxes or in the form of investment tax credits, production tax credits or accelerated depreciation [16].
2) Capital grants can be used to target specific technologies or market sector. These are common in case of expensive technology, especially in the early stage of application. On the other hand, for small scale developers the government could facilitate the access to capital [16].
3) Risk mitigation is aimed at facilitating access to debt and equity investments by means of fixed conditions provided by the government [16].

In Europe different market schemes can be seen in the different member states as reported by JRC in a study conducted in 2017 [19]. Figure 15 provides a graphic representation of the different schemes available for solar PV.

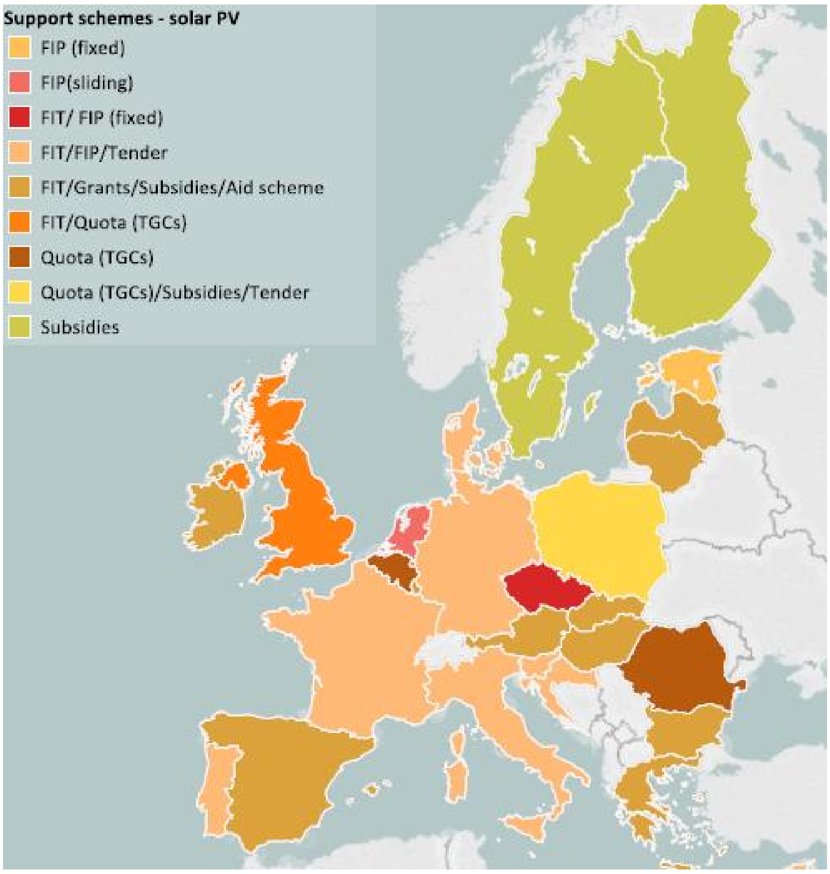

Figure 15 Solar PV support schemes in Europe [19]

2.3.2 Power Purchase Agreement

Utility-scale PV systems have experienced an increase in PPAs signed with private company and/or government authorities. As said before, when a PPA is in force between a government body and a generator, it can also be referred as FiT, while in case of a PPA signed with a company it is referred as “Corporate PPA”. The cost-competitiveness of renewables with conventional fossil fuels technology is pushing the market towards the removal of subsidies that were in force at the first stage of the technology, moving ahead to a PPA business model.

In a PPA business model, a generator of clean energy agrees with a buyer (off-taker) on the price at which a certain amount of electricity will be bought and the time-length of the PPA. The price might be fixed or linked with the inflation. This business model is benefitting for both the actors: the buyer can achieve its renewable targets or electricity bill reduction without owning a renewable system; on the other hand, the generator ensures a certain amount of revenues for a given period without being exposed to market prices fluctuations, thus increasing the bankability of the project. Moreover, PPAs are usually signed at a higher price than the wholesale one but at lower price of the retail one [20] [21].

Corporate PPA have been increasing during the years and in Q1/Q2 of 2020 8.9GW of Corporate PPAs were signed [22]. Figure 16 shows the volumes of Corporate PPAs.

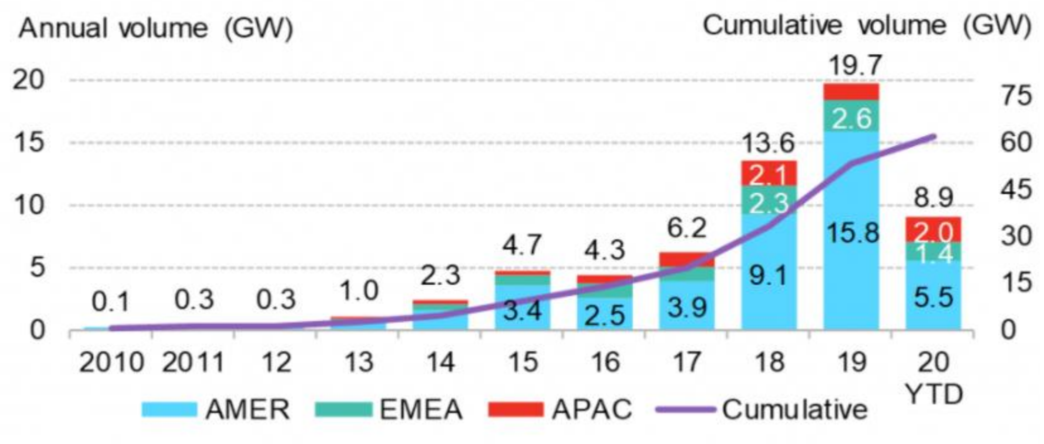

Figure 16 Corporate PPA volume by region [22]

2.3.3 Market limits and criticalities

Solar Photovoltaic energy is necessary to meet the climate goals. The technology is evolving, the cost is decreasing, and countries are implementing different policies to accelerate the deployment. However, renewable energy sources are affected by problems that may arise with the specific project, geographical contexts, or level of maturity. Among the different barriers that could threaten the development of solar photovoltaic there are the technological ones (grid interconnection, lack of skilled operators), the policy ones (lack of long-term targets and policy, complex regulations, lack of control), the market and economic barriers (carbon tax, low electricity prices, long payback periods) and regulatory and social barriers (lack of knowledge on solar competitiveness, lack of markets standards, lack of information) [5]. Figure 17 gives a more detailed description of the barriers.

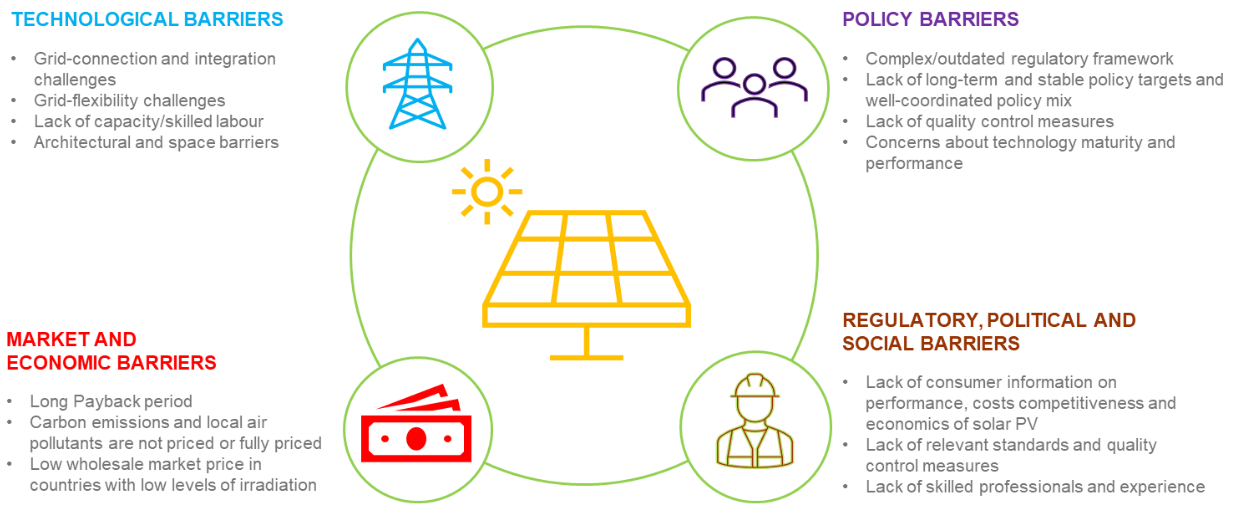

Figure 17 Barriers for solar PV future deployment [5]

Every country should strive to have a framework to develop renewables while reducing, in the meantime, the consumption and increasing the energy access. The policies required for the transition can be subdivided in three typologies: deployment policies, integration policies and enabling policies.

DEPLOYMENT POLICIES

Long term, well-defined and stable PV targets should be set to attract investments. A combination with long term support policies is necessary to increase the attractivity of the solar-PV market, moreover policies should be adapted to the market conditions. New business models should be supported by governments: for example, commonly shared and third party owned business models could open new opportunities for investors that have limited possibilities. In addition, corporate financing of projects for self-consumption or collaboration with electricity suppliers should be enabled and scaled up [5].

INTEGRATING POLICIES

Photovoltaic energy is a non-dispatchable energy source, its integration should be supported by an increase in flexibility from all the power sector: from a technological, market, business, and system operation perspective. This could result in a lower cost for the renewable system. Moreover, congestion of the electricity network should be avoided by building HVDC lines between regions. On the other hand, social integration policies are necessary to realise a fast growth of photovoltaic. Quality control on the PV installations and involvement of local communities into projects have higher possibilities of facilitating the acceptance by the different entities of the project on the territory [5].

ENABLING POLICIES

Photovoltaic development must be further promoted through co-ordination with the economic sector. Policies should push industries into competing for cost reduction of the system and creating new job opportunities. From a financial point of view, investment could experience an increased revenue streams due to the introduction of carbon pricing and/or other measures. Moreover, revenues could be used for strategic investments and budgets could be reallocated into other useful sectors. However, in order to avoid opposition from the fossil fuel industry, the workers could be reskilled for the renewable markets and university should promote technical education and training to provide new workforce with adequate skills [5].

3 ITALY STATUS

In this section the energy profile of Italy is described, and the current market and policy mechanisms available in the country are presented.

3.1 Country overview

Italy, officially referred as the Italian Republic, is a peninsula, located in the South-central Europe, delimited by the Alps, and surrounded by several islands in the Mediterranean Sea. Italy borders with France, Switzerland, Austria, Slovenia and the enclaved microstates of Vatican City and San Marino (see Figure 18). [23]

Figure 18 Italian Republic [23]

At the end of 2019, the total population in Italy was around 60.317 million. The total country surface is 301336 km^2 which leads to an average population density of 200 habitants per square kilometre [24]. The economy showed a positive trend in GDP growth with a value of 0.3 %, which is, however, lower with respect to the previous year's one [25]. The electricity consumption in the country has decreased compared to the previous year by 0.6%, reaching a total consumption of around 319.6 TWh [26]. The main data is summarized in Table 1.

Table 1 Country data source: IEA PVPS[24], Terna [26], Eurostat [25]

Population (million)	60.317
GDP growth	0.3 %
GDP per capita [k€]	26.9
Country Surface [km^2]	301336
Electricity Consumption [TWh]	319.6

3.1.1 Energy overview

PRIMARY ENERGY

The Italian energy production is strongly based on fossil fuel, in particular natural gas, which is the largest source employed for electricity and heat production; coal is on the other hand disappearing given the national target of carbon phase-out in 2025. The transport sector is still strongly relying on oil [27]. Figure 19 shows how the total energy supply (TES) by source has changed from 1990 to 2019.

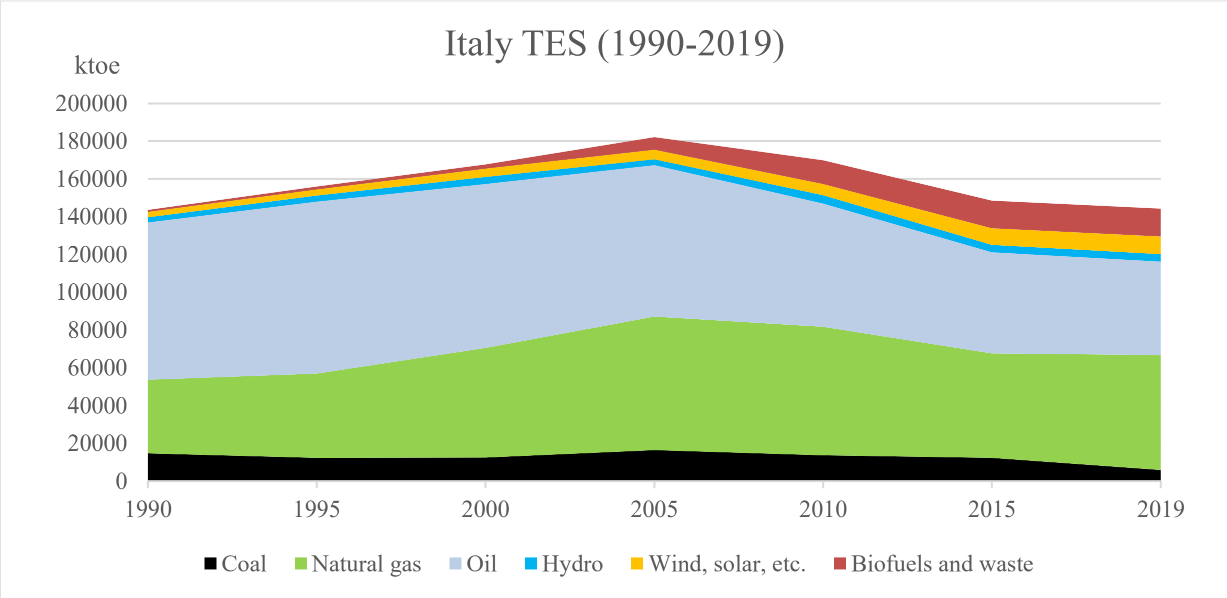

Figure 19 Italy TES by Source, IEA [27]

The energy supply mix has strongly changed across the years. The share of renewables in 1990's energy mix was around 4.6% while in 2019 a value of 19.4% has been registered [27].

The total final consumption (TFC) in 2018 is higher compared to 1990 levels, but since 2005 the trend has been decreasing. Figure 20 shows the evolution of the total final consumption by sector.

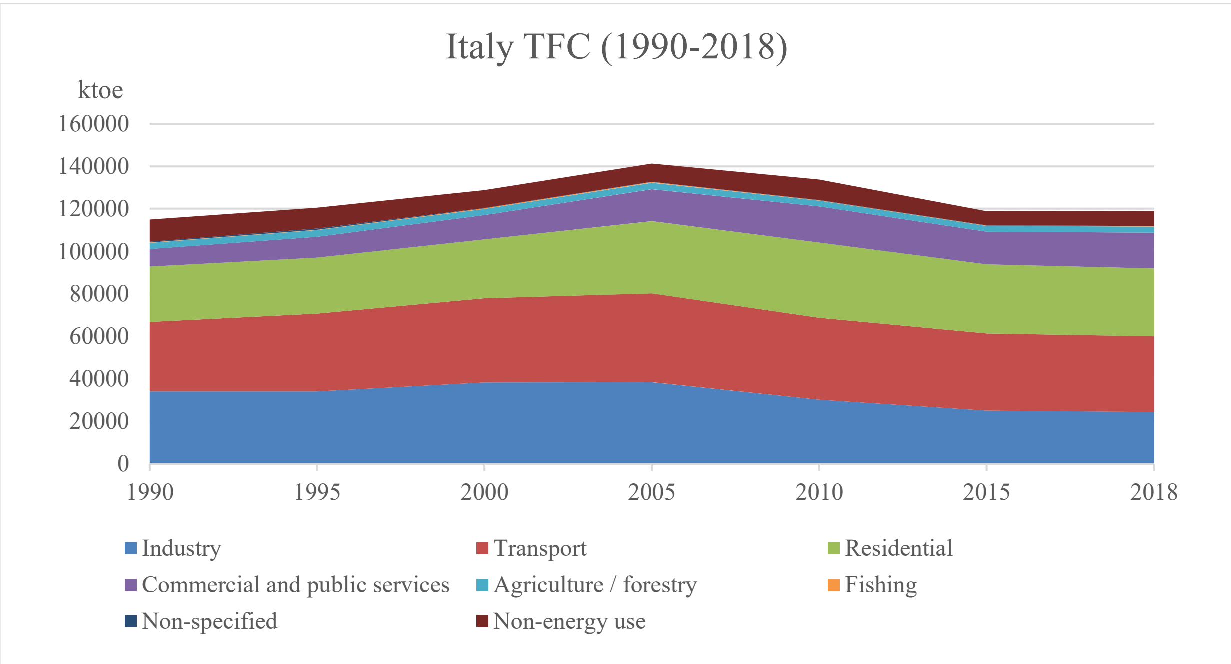

Figure 20 Italy TFC by sector, IEA [27]

All the sectors had shown an increased trend of energy demand across the years up to 2005. From this point onward, industry and transport have had a decreasing trend. The agricultural energy demand has been constant along the years, while residential and commercial sector have had an increasing demand. The consumption shares in 2018, of the different sectors, changed compared to 1990's one. Figure 21 shows the shares of the different sectors in the total consumption of 1990 compared to the ones in 2018.

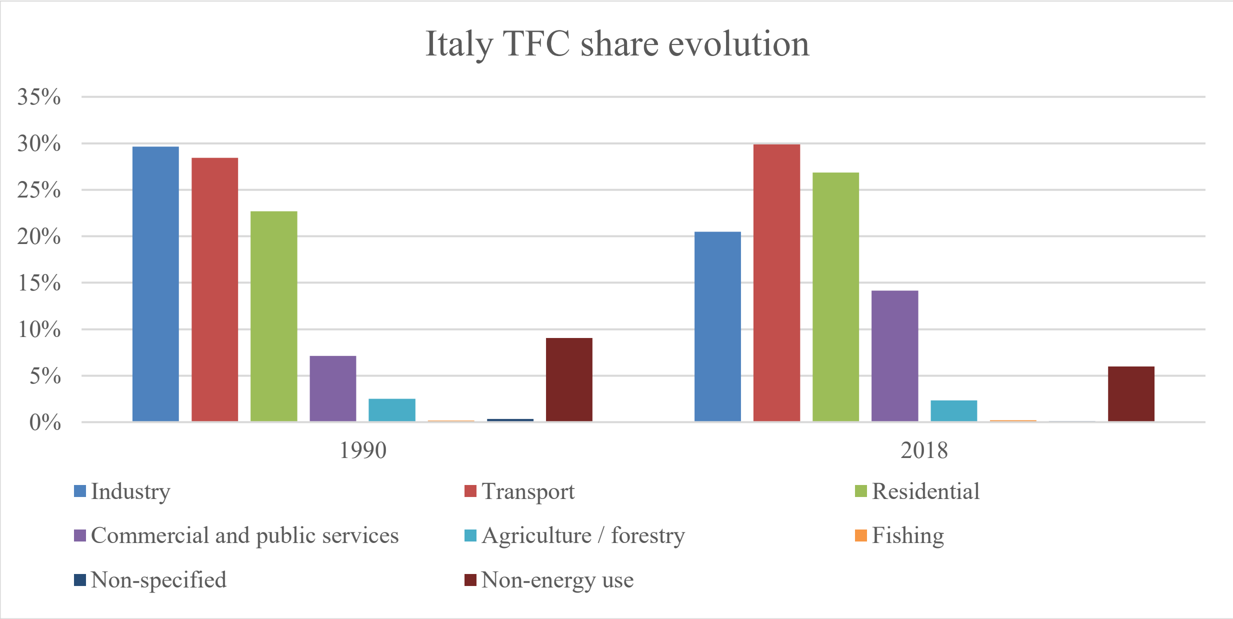

Figure 21 Italy TFC by sector: sector shares evolution 1990 vs 2018, IEA [27]

ELECTRICITY INSIGHTS

Figure 22 shows how the total electricity supply is differentiated by source. The environmental politics aimed at reducing the CO_2 emissions resulted in a reduction of the use of oil in the electricity production in favour of renewables and natural gas. Natural gas has the largest share in the electricity mix. Coal plants are being shut down to comply with the carbon phase-out by 2025.

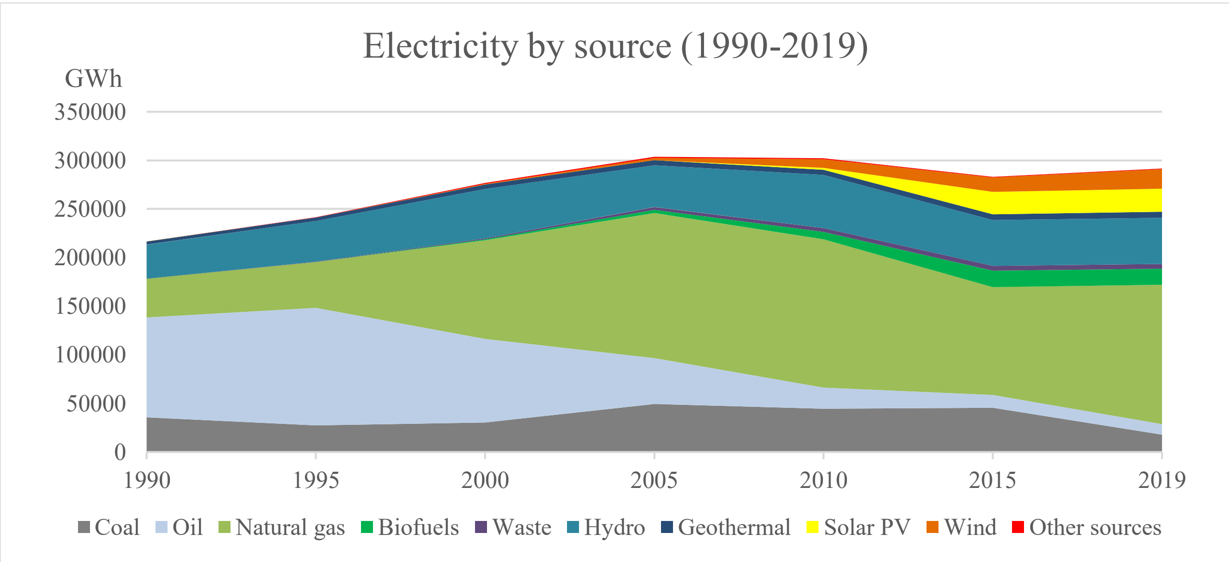

Figure 22 Italy Electricity supply by Source, IEA [26]

The total electricity production from renewables during 2019 was of 115.8 TWh of which 20.2 TWh from PV [28]. As presented in Table 1, the total electricity demand in Italy was 319.6 TWh in 2019 thus the total amount of electricity supplied by renewables was 36.2%. The sector that showed the largest increase in electricity consumption during the years is the commercial and public services sector. The historical trend can be seen in Figure 23, the electricity consumption data by sector is available up to 2018 (losses are not included).

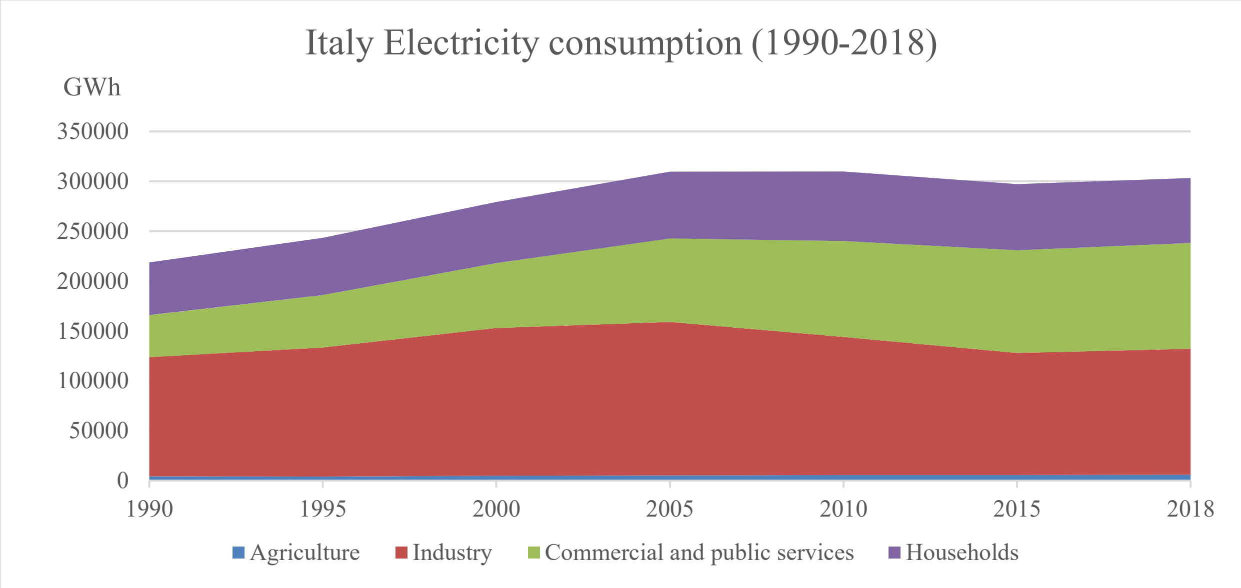

Figure 23 Electricity Final Consumption by sources, Terna [29]

3.1.2 Electricity market

In Italy, the GME ("Gestore dei mercati energetici") is the authority which manages all the energy markets. The Italian electricity market is subdivided into 6 zones with some additional nodes. The configuration of the zones and poles has changed during the year. From 2019 the independent poles FOGN ("Foggia") and BRNN ("Brindisi") were removed. From 2021 also ROSN ("Rossano") will be removed and the areal configuration of the zones will be changed, but the number of zones should increase to 7. The evolution can be seen in Figure 24.

Figure 24 Italian Market Zones evolution with regional boundaries[30]

MARKET OPERATION

In the Day-Ahead Market (MGP – "Mercato del Giorno Prima") hourly energy blocks are traded for the next day.

Participants submit bids/asks where they specify the quantity and the minimum/maximum price at which they are willing to sell/purchase. Offers of selling or acquiring are accepted after the closure of the market sitting, based on the economic merit-order criterion and considering transmission capacity limits between zones. The marginal price is determined, for each hour, by the intersection of the demand and supply curves and is differentiated from zone to zone when transmission capacity limits are saturated. The accepted demand bids pertaining to consumption units that belongs to Italian geographical zones are valued at the "Prezzo Unico Nazionale" (PUN – national single price); which is obtained as the weighted average of the zones' prices on the volumes traded in these zones.[31]

3.1.3 Energy policies and future scenarios

Italy has made strong advances in pursuing the objectives stated in the 2013 National energy Strategy, which included: reduction of energy costs, meet the environmental targets, strengthen security of energy supply, and promote a sustainable economic growth. Moreover, the improvement of electricity transmission between north and south and market liberalisation and market coupling have resulted in a wholesale price convergence across the country, trending towards the average European market price.[32]

The latest development on the European background with the approval of the Green Deal (that raised the environmental targets that had been set for 2030) has led to the publication of the Integrated National Energy and Climate Plan (INECP in English or PNIEC in Italian).

The strategy of the INECP is structured in 5 dimensions:

1) **Dimension decarbonisation:** the objective is to promote a higher penetration of renewables in the energy mix, while promoting the coal phase-out from the electricity generation. Hence, an electricity generation mix based on renewables and natural gas must be achieved [33]
2) **Dimension energy efficiency:** energy efficiency will be pursued using a mix of fiscal, economic, regulatory and policy instruments, primarily calibrated by sector of activity and type of target group. Moreover, an integration of energy efficiency aspects into other action whose main purpose was not the energy efficiency, will be incentivized to optimise the cost-benefit ratio of the actions: for example, in case of buildings in combination with actions of structural renovation or earthquake-proofing, energy saving measures could be implemented, in line with the strategy for energy renovation of the building stock by 2050. In case of buildings not being refurbished, solar heating, electric and gas heat pumps, and micro and mini high-efficiency cogeneration (HEC) technologies should be carefully considered, especially if fuelled by renewable gas [33]
3) **Dimension energy security:** the country should rely less on imports increasing the inland energy production for example with renewables and on the other hand diversify the source of supply (for example using natural gas, including liquefied natural gas (LNG), with infrastructure consistent with the scenario of deep decarbonisation by 2050). The energy infrastructure should become flexible enough to accommodate all the available resources without threatening the security of the system [33].
4) **Dimension internal market:** market integration is a key advantage for the entire EU. Electricity interconnections and market coupling with other states must be enhanced. The Italian reference for the electricity interconnections development is the TSO, Terna S.p.A., who publishes the network development plan [33]
5) **Dimension research, innovation and competitiveness:** resources must be used in order to support measures of use of renewables, energy efficiency and network technology. Moreover, synergy between systems and technologies must be pursued [33].

These 5 dimensions will lead Italy to achieve the objectives set for the country in compliance with the EU ones. In Table 2 the EU objectives and the Italian ones are presented. Considering the Renewables share in the final consumption, the national plan has set targets for the electricity, thermal and transport sector to achieve the 30% of renewable share. In the thermal sector 33.9% of the final energy use will be covered by renewables, in the transport sector this value should reach the 22.0% as presented in Table 2, while in the electricity sector 55.0% of the final consumption should be supplied by renewables [33].

Table 2 Summary of European and Italian targets 2020 and 2030 [33]

	2020 objectives		2030 objectives	
	EU	**ITALY**	**EU**	**ITALY (INECP)**
Renewable energies (RES)				
Share of energy from RES in the gross final consumption of energy	20%	17%	32%	30%
Share of energy from RES in the gross final consumption of energy in the transport sector	10%	10%	14%	22%
Share of energy from RES in the gross final consumption of energy for heating and cooling			+1.3% per year (indicative)	+1.3% per year (indicative)
Energy efficiency				
Reduction in primary energy consumption compared to the PRIMES 2007 scenario	-20%	-24%	-32.5% (indicative)	-43% (indicative)
Final consumption savings as a result of obligatory energy efficiency systems	-1.5% per year (without transport sector)	-1.5% per year (without transport sector)	-0.8% per year (with transport sector)	-0.8% per year (with transport sector)
Greenhouse gas emissions				
Reduction in GHG vs 2005 for all plants subject to ETS rules	-21%		-43%	
Reduction in GHG vs 2005 for all non-ETS sectors	-10%	-13%	-30%	-33%
Overall reduction in greenhouse gases compared to 1990 levels	-20%		-40%	
Electricity interconnectedness				
Level of electricity interconnectedness	10%	8%	15%	10%
Electricity interconnection capacity (MW)		9.285		14.375

Focusing on the electricity sector, a detailed forecast on the renewable energy deployment has been made by the Italian government. In Table 3 the forecast of the electricity demand and of the renewable production is shown.

Table 3 Electricity forecast renewable production and demand [33]

Source	2016	2017	2025	2030
Renewable production [TWh]	110.5	113.1	142.9	186.8
Hydro(effective) [TWh]	42.4	36.2		
Hydro (normalized) [TWh]	46.2	46	49	49.3
Wind(effective) [TWh]	17.7	17.7		
Wind(normalized) [TWh]	16.5	17.2	31	41.5
Geothermal [TWh]	6.3	6.2	6.9	7.1
Bioenergies [TWh]	19.4	19.3	16	15.7
Solar [TWh]	22.1	24.4	40.1	73.1
Total Gross electricity consumption [TWh]	325	331.8	334	339.5
RES share [TWh]	34.0%	34.1%	42.6%	55.0%

The electricity demand is expected to rise to 339.5 TWh by 2030 and almost 40% of the renewable production will come from solar energy. To achieve this production, Italy plans on installing renewable capacity according to the forecast presented in Table 4.

Table 4 Renewable capacity forecast [33]

Source	2016	2017	2025	2030
Hydro [MW]	18641	18863	19140	19200
Geothermal [MW]	815	813	920	950
Wind [MW]	9410	9766	15950	19300
of which offshore [MW]	0	0	300	900
Bioenergy [MW]	4124	4135	3570	3760
Solar [MW]	19269	19682	28550	52000
of which CSP [MW]	0	0	250	880
Total [MW]	52259	53259	68130	95210

Among the renewables employed for electricity production, solar is expected to reach 52 GW of installed capacity by 2030, of which only 880 MW of Concentrated solar power (CSP) and the rest of PV energy [33].

3.2 PV energy

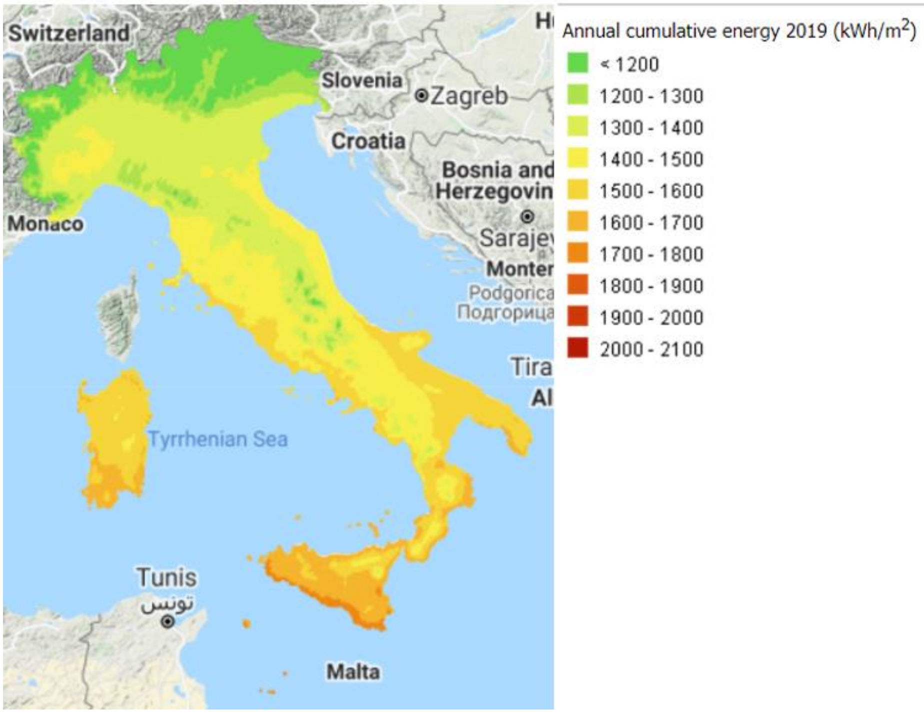

Figure 25 Solar irradiation map 2019, source sunRiSE[34]

Among all the European countries, Italy benefits of a strategic position to harvest solar energy due to its location. In Figure 25 the 2019 solar map is shown. The solar radiation has strong variation along the peninsula ranging from values around 1200-1300 kWh/m^2 in the north to values of 1800-1900 kWh/m^2 in the south parts of Italy (lower part of Sicily).

In next sections an insight into the installed PV capacity in Italy will be given.

3.2.1 Total installed capacity

At the end of 2019, the solar PV installed capacity had increased of 3.8%, reaching a total amount around 20865 MW, while the number of plants increased by 7.0% totalizing a number of 880090 plants distributed across Italy [35].

The data is summarized in Table 5 where a comparison between 2018 and 2019 registered data is presented.

Table 5 PV installed capacity 2018 & 2019 comparison [35]

	Installed by 31/12/2018		Installed by 31/12/2019		Variation YoY %	
Power group (kW)	**n°**	**MW**	**n°**	**MW**	**n°**	**MW**
1<=P<=3	279681	759.8	29741	803.6	6.3	5.8
3<P<=20	476396	3445.2	514162	3675.5	7.9	6.7
20<P<=200	54209	4244.0	56302	4403.3	3.9	3.8
200<P<=1000	10878	7413.2	11066	7504.4	1.7	1.2
1000<P<=5000	948	2328.2	953	2347.1	0.5	0.8

P>5000	189	1917.2	197	2131.5	4.2	11.2
Total	**822301**	**20107.6**	**880090**	**20865.3**	**7.0**	**3.8**

In Figure 26 the yearly evolution of the number of plants and the total install capacity can be seen.

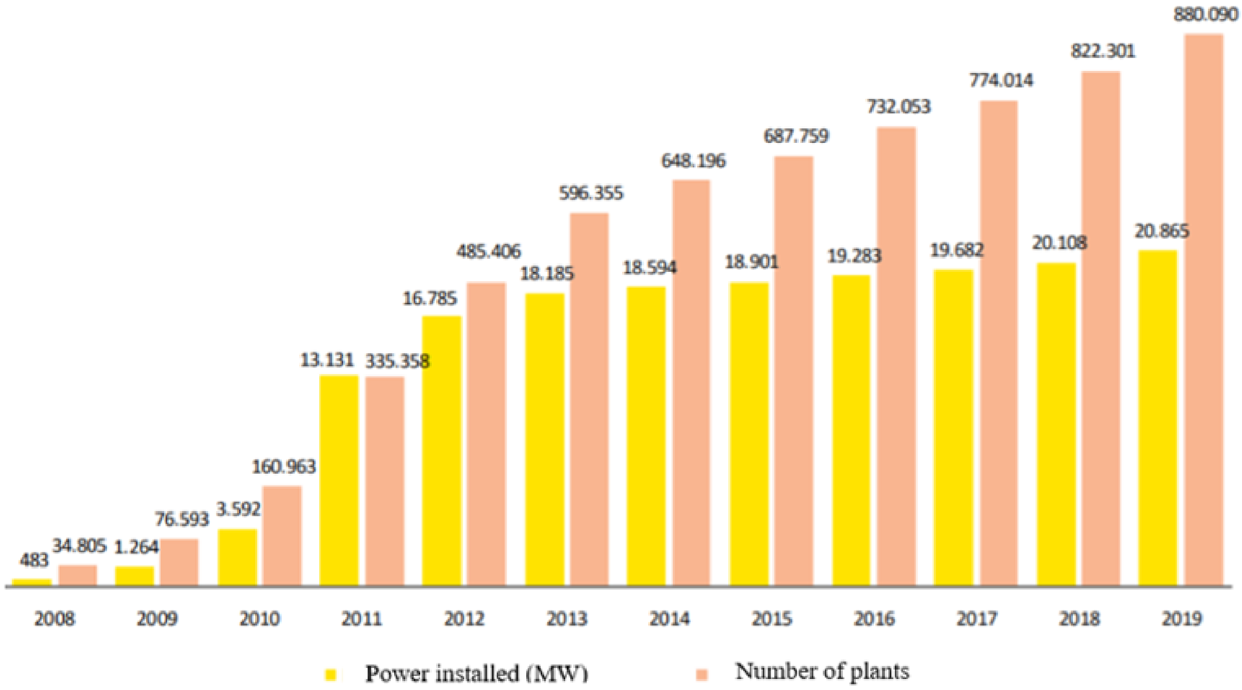

Figure 26 Yearly evolution of installed capacity and number of plants [35]

The average power of a plant at the end of 2019 was around 23.7 kW. The value has been decreasing since 2011 when the average was 38.7 kW. However, in 2019 the yearly installed average size was the highest value registered since 2013: 12.9 kW. All the data on the installed average size both yearly and cumulated can be found in Figure 27 [35].

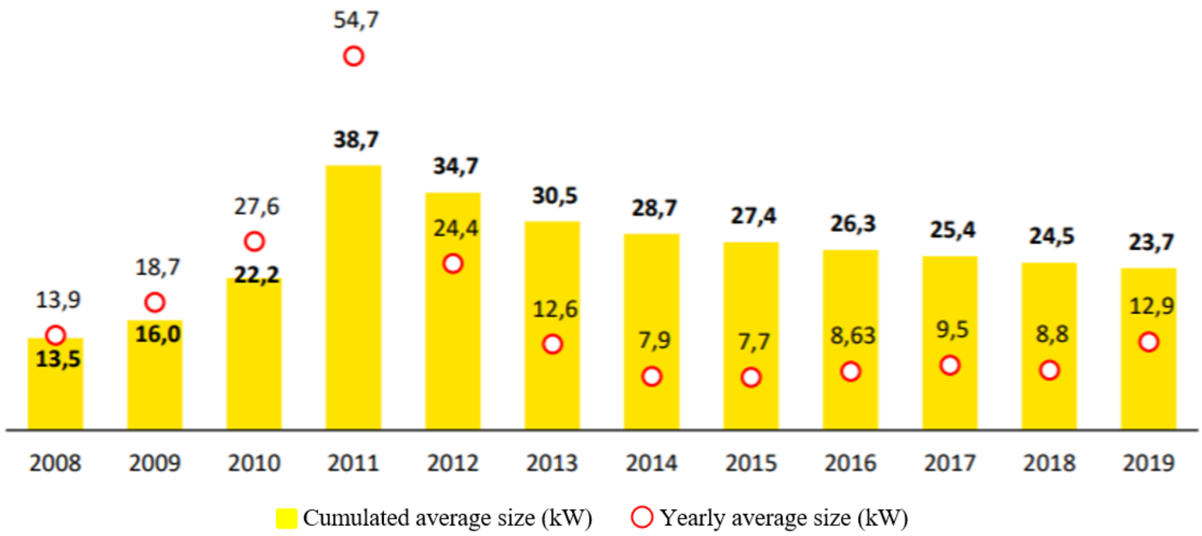

Figure 27 Installed average capacity yearly and cumulated - historical evolution [35]

Differently from what one would expect, the larger number of installations is not in the south of Italy where the solar resource is more abundant, but in the north of Italy. Around 47% of the installations can be found among Lombardia, Veneto, Piemonte and Emilia Romagna, while in the south (Molise, Campania, Puglia, Basilicata, Calabria, Sicilia and Sardegna) only 25 % of the total plants can be found. In Figure 28 a map of Italy with the plant distribution by region can be observed.

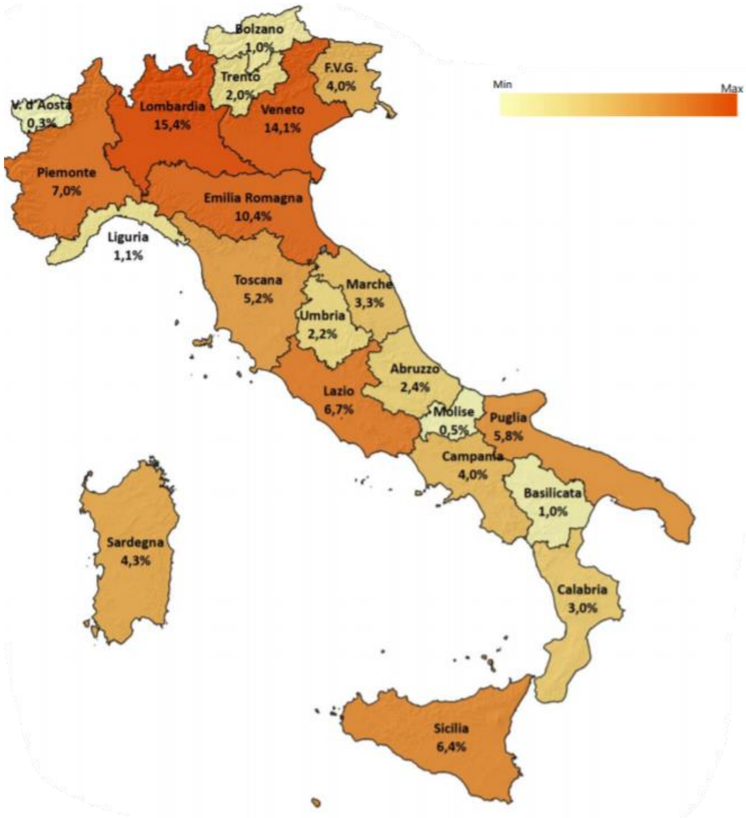

Figure 28 Regional distribution of PV installation at the end of 2019 (Number of total plants: 880090) [35]

However, considering the regional power distribution in Figure 29, the region with the higher installed capacity is Puglia, which was identified in the South block before.

Figure 29 Regional Power distribution share at the end of 2019 [35]

Therefore, the installations in Puglia have a larger average size compared to the one in Lombadia, Veneto or Emilia Romagna. In particular, the ratio between the share in Figure 29 over the one in Figure 28 also gives the share of the average installed power in that region over the national average of 23.7 kW.

The type of solar PV systems installed at the end of 2019 were for 42% ground-mounted systems. However, Lombardia had only 14% of ground mounted installations, while a completely different situation can be seen in Puglia where 75% of the installations are ground mounted. Analysing the regional data in Figure 30 it could be said that ground mounted installations are preferred in the south compared to the north. Nevertheless, the comparison does not apply to every case.

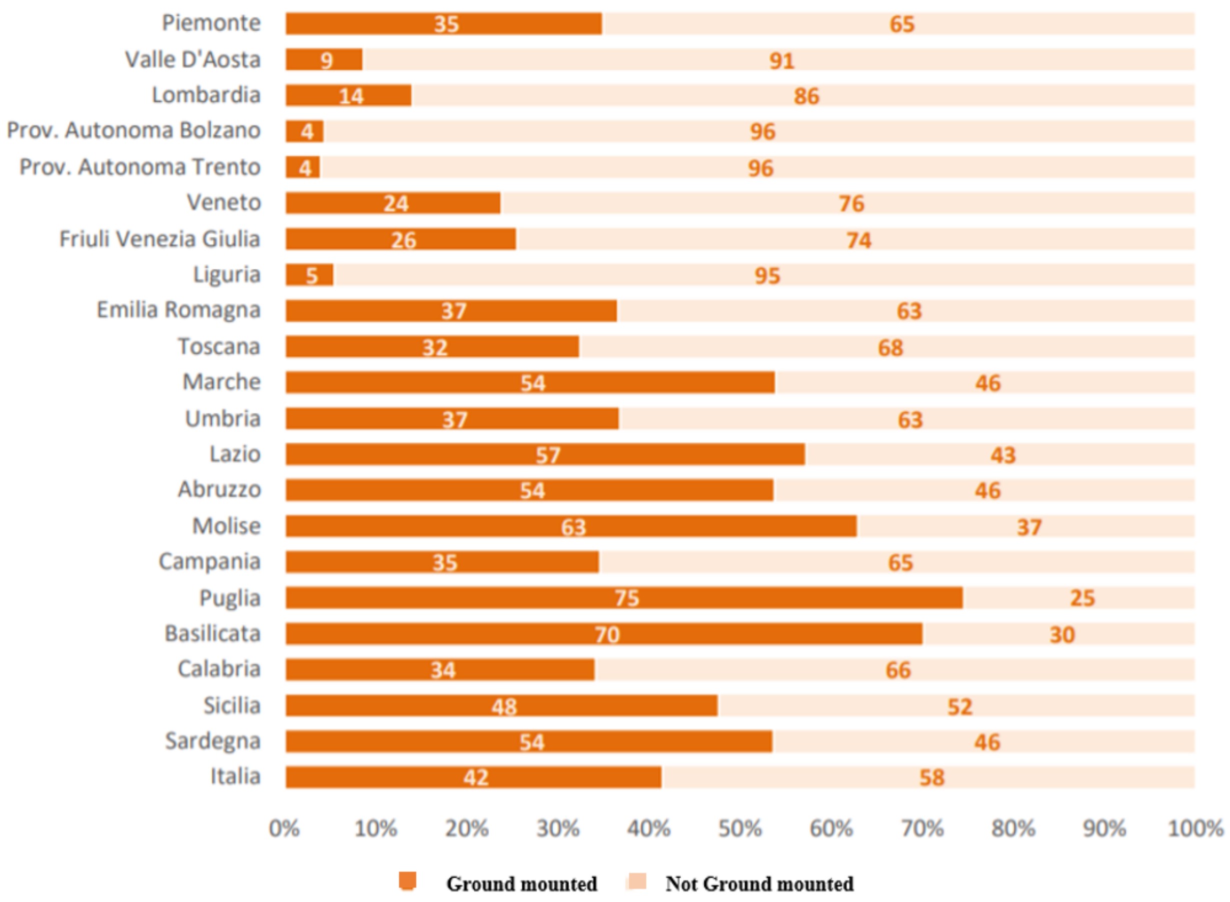

Figure 30 Ground-mounted vs Not Ground-mounted installation share by region [35]

Analysing the technology used for PV panels, around 73% of the power installed is supplied by polycrystalline silicon modules. These modules have always been the less expensive compared to others, and especially in the early deployment of the technology were the more cost-effective solution. Monocrystalline modules supply 22% of the power while the rest is covered by thin film, amorphous silicon and other technology, respectively with a share of 3%, 1% and 2%.

In Figure 31 a technology differentiation by region is given. The region with the largest share of thin-film is Sicily, probably because even if thin-film technology has lower nominal efficiency compared to silicon modules, the temperature power loss coefficient is lower; hence the solution might result in higher performances in locations with high outdoor temperature. Nevertheless, the choice of technology is affected by several drivers: module cost, performances, land availability, power constraints, etc… that vary from project to project.

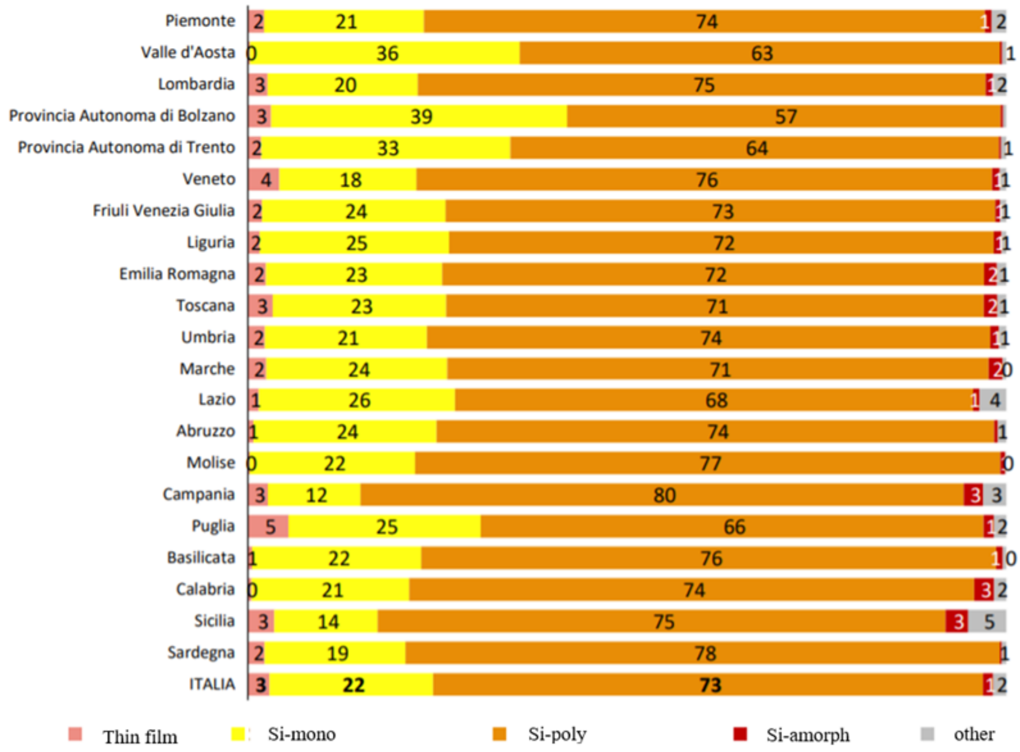

Figure 31 Share of power supplied by different PV technology - regional variations [35]

3.2.2 PV energy future trends

The INECP is the current plan adopted by Italy. According to the power forecast in Table 4, PV capacity should increase from 20865 MW to 28300 MW by 2025 and to 51120 MW by 2030.

The expected cost reduction of the technology is a positive driver towards its deployment. Moreover, Italy plans on supporting deployment of photovoltaic: on buildings, roofs, car parks, services areas, etc. However, the forecasted target cannot be reached promoting only rooftop installations: Italy is aware that large ground-mounted installations are necessary. Nevertheless, the environmental impact of these installations is higher, but priority should be given to already contaminated sites, former artificial areas, and waste disposal areas. In this way, areas that were in an abandoned state can be recovered and used to reach the environmental targets [33].

3.2.3 PV plants permitting process

When considering the construction of a Large-scale renewable plant the Legislative Decree 387/2003 (D.Lgs 387/2003), the Legislative Decree 152/2006 (D.Lgs 152/2006) and the Ministerial Decree 10/09/2010 (DM 10/09/2010) have to be considered. These Decrees have been updated during the years, with the aim of updating the regulation according to the evolution of the market. Moreover, given that a grid connection is required, the "Testo Integrato per le Connessioni Attive" (Italian initials TICA) must be considered. The topics of authorisation, environmental impact, unsuitable areas, and grid connection are addressed in the following sections.

<u>AUTHORISATION</u>

To construct and operate a renewable energy power plant it is necessary to receive an authorisation. The D.Lgs 387/2003 implements the EU directive 2001/77/EC on the promotion of renewable energy in the electricity market and regulates the authorisation procedure for renewable energy plants [36]. For large-scale system (size larger than 1 MW) the "Autorizzazione Unica" (Italian initials A.U.), which literally means "Single authorisation", must be obtained. For plants below a certain threshold, conventionally 20 kW but it can vary in every region up to 1 MW, it possible to request a simplified authorisation procedure: "Procedure Abilitativa Semplificata" (Italian initials P.A.S.) [37]. The Authorisation procedure is regulated by article 12 of D.Lgs 387/2003. It is released by the Region or province of competence in most of the cases, by the ministry of economic development for plants with a thermal power larger than 300 MW or by the ministry of transport in case of offshore systems [38]. In particular, the authorisation is released after the "Conferenza dei Servizi" (Italian initials C.d.S.), a procedure to collect all the needed Authorities' approvals. The main highlights of the decree are:

- Art. 12.1 defines authorized RE plants and related works as *public utility*, *urgent and undeferrable* [38]
- Art. 12.3 states that after receiving the A.U. request the authority has 30 days to convene the C.d.S. and start the authorisation procedure which must be concluded in no more than 180 days [38]
- Art. 12.4 is the entitlement to build and operate the RE plant with the obligation to restore the site after the operation period [38].

In the context of authorisation, the DM 10/09/2010

- gives the list of documents that must be presented for the AU (art. 13)
- adds information on the timeline in case of VIA and on compensation measures (art.14)

The documents to be presented for the authorisation procedure are given in art. 13 and they are summarized in Table 6.

Table 6 Single authorisation procedure minimal documentation DM 10/09/2010 [39]

Content	Details	Reference
Final project	Must be included: • The interconnection work details • the other necessary infrastructures • the plant decommissioning plan • the site restore plan	Art. 13.1 a)
Technical report	Including: • Proposer general data and certificate of incorporation • Description of renewable source and the expected production • Description of the works (construction, decommissioning, and site recovery) and their execution • Estimate of decommissioning and site recovery costs • Social impact assessment	Art. 13.1 b)
Other relevant documentation	Public utility declaration with cadastral details	Art. 13.1 d)
	Connection estimate accepted by the developer with necessary document for the authorization	Art. 13.1 f)
	Urban destination certificate and relation with Regional landscape plan ("Piano Paesaggistico Regionale" Italian initials P.P.R.)	Art. 13.1 g)

	Environmental Impact analysis ("Valutazione di impatto ambientale" Italian initials V.I.A) or eligibility to V.I.A./screening ("Verifica di assoggettabilità" Italian initials V.A.)	Art. 13.1 h)
	Authorization request cost payment proof	Art. 13.1 i)
	Commitment to deposit, at the beginning of the construction, the decommissioning and site recovery costs	Art. 13.1 j)
	Superintendence communication	Art. 13.1 i)
Other specific documentation	Other specific documentation is listed in the Annex 1 of the decree, as stated in art. 13.2	Art. 13.2

The art. 14.7 b) of DM 10/09/2010 states that renewable plants with power larger than 1 MW must undergo the procedure of V.A. [39].

Article 14.11 of DM 10/09/2010 states that all the administration involved in the CdS can request integrative documents within 90 days from the beginning of the procedure. The proposer has 30 days (with possible extension to 60 days) to provide the requested documents from the date the request has been issued [39].

According to article 14.13 of DM 10/09/2010 the authorisation procedure can be suspended until the V.A. is finished [39].

Article 14.15 of DM 10/09/2010 states that during the CdS the compensation for the municipality involved in the project is determined [39].

ENIVIRONMENTAL IMPACT ANALYSIS – V.A. / V.I.A.

As said previously, the solar photovoltaic plants with power higher than 1 MWp are subject to the eligibility to environmental impact analysis (V.A.) while in some region the regulation might be different and they are subject directly to the environmental impact assessment [40].

The V.A. and V.I.A. are regulated by D.Lgs 152/2006, some changes were applied to this decree after the "Decreto Semplificationi" Law n° 120 of 2020 (L.120/2020). The timeline for the two procedures is described in art. 19, 23, 24 and 25 of the D.Lgs 125/2006 and reported in Table 7.

Table 7 V.A. / V.I.A. procedures timeline [41][42]

Procedure	Timeline	Reference
V.A.	1) The authority can request integration in 5 days after receiving the documentation, the proposer will have 15 days to provide them 2) In no more than 45 days from the publication of the complete documentation, observation by affected people/authority can be presented 3) After the authority verifies eventual additional environmental impacts 4) In no more than 45 days after the additional observation the result of the V.A. is given: the RE plants should undergo or not to a V.I.A.	Art. 19

V.I.A.	1) The proposer can have a preliminary meeting with the authorities to verify the level of detail of the study 2) The authority can request integration in no more than 15 days after receiving the documentation, the proposer will provide information before 30 days have passed from the request 3) In no more than 60 days, from the publication of the complete documentation, feedbacks by affected people/authority can be presented 4) In no more than 30 days, the proposer can present observations on the feedbacks 5) The proposer has a limit of 30 days to adequate the documentation, with integrations, etc… a suspension of maximum 180 days can be obtained from the proposer in specific cases 6) In no more than 30 days, observations on the integrations are collected and the previous point is repeated. 7) In no more than 60 days, after the closure of the previous steps, the scheme of the measure of V.I.A. is given to the environment and land protection ministry, a prolongation of 30 days can be requested by the authority 8) In no more than 30 days the ministry of the cultural patrimony must give the approval. In no more than 60 days the environment and land protection ministry gives its approval 9) After this approval, the V.I.A. is submitted to the cabinet for final approval which takes place in no more than 30 days	Art.23-24-25

In case of V.A. the necessary documentation is the preliminary environmental study which is conform to the guidelines in Annex IV-bis of the Part II of D.Lgs 152/2006 and it consists of:

- Project description: physical characteristic, location, demolition works (if any)
- Description of the environmental components affected by the project
- Description of the possible effect on the environment: emission, waste production, use of natural resources

Moreover, the Annex V gives detailed aspects to consider when assessing the previous points that are listed in Table 8.

Table 8 Annex V Part 2 D.Lgs 152/2006 [41]

Aspect	Considerations
Project characteristics	a) the size and design of the project as a whole b) cumulation with other existing and / or approved projects c) the use of natural resources, in particular soil, territory, water and biodiversity d) the production of waste e) pollution and environmental disturbances f) the risks of serious accidents and / or disasters related to the project in question, including those due to climate change, based on scientific knowledge g) risks to human health such as, by way of example but not limited to, those due to water contamination or air pollution.

Project location	a) the use of the existing and approved land b) the relative wealth, availability, quality and regeneration capacity of the area's natural resources (including soil, territory, water and biodiversity) and its subsoil c) the carrying capacity of the natural environment, with particular attention to the following areas c1) wetlands, riparian areas, river mouths c2) coastal areas and marine environment c3) mountainous and forest areas c4) reserves and natural parks c5) areas classified or protected by national legislation; the sites of the Natura 2000 network c6) areas in which the failure to comply with the environmental quality standards relevant to the project established by Union legislation has already occurred, or in which it is believed that it may occur c7) areas with high demographic density c8) areas of landscape, historical, cultural or archaeological importance c9) territories with agricultural production of particular quality and typicality referred to in Article 21 of Legislative Decree 18 May 2001, n. 228.
Type and characteristics of the potential impact	a) the extent and extension of the impact such as, by way of example but not limited to, geographic area and density of the potentially affected population b) the nature of the impact c) the cross-border nature of the impact d) the intensity and complexity of the impact e) the probability of impact f) the expected onset, duration, frequency and reversibility of the impact g) the cumulation between the impact of the project in question and the impact of other existing and / or approved projects h) the possibility of reducing the impact effectively.

In case of V.I.A. the documentation required is presented in D.Lgs 152/2006 art. 23 and consist of:

- The project's technoeconomic study
- The environmental impact study
- The non-technical summary
- Transboundary impacts' analysis if any
- Public notice
- Payment proof
- Results of public project preview if any

UNSUITABLE AREAS

The DM 10/09/2010 also defines the areas deemed unsuitable for the realization of RE plants. This definition is necessary to protect the historical, cultural, and environmental patrimony of Italy and to safeguard biodiversity and agricultural tradition.

The criteria to identify unsuitable areas are described in art. 17.1 and listed in annex 3 of the decree. Regions were appointed with the duty of defining which areas were unsuitable for each technology giving a differentiation by plant size [39]. Table 9 summarizes the areas deemed unsuitable.

Table 9 Unsuitable Areas DM 10/09/2010 [40]

	Content	Regulation reference
1	Areas linked to environmental protection	Art.142 D.Lgs 42/2004
2	UNESCO areas, areas of great public interest	Part 2 of D.Lgs 42 2004 art.136 D.Lgs 42 2004
3	Visual cone [..]	D.Lgs 42 2004
4	Archaeological areas and proximities	Art. 142 DLgs 42/2004
5	Natural protected areas	Art.12 394/1991
6	Ramsar area	Ramsar convention
7	Natura network 2000 areas	92/43/CEE and 79/409/CEE
8	Important Birds Areas (I.B.A.)	
9	Areas not included in the one listed in the previous point that have a key role in preservation of biodiversity	International conventions (Berna, Bonn,Paris,Washington,Barcellona) 92/43/CEE and 79/409/CEE
10	DOP, IGP, STG, DOC, DOCG areas and/or areas of great value with respect to landscape-cultural contest; areas with a strong agricultural production in coherence with Art. 12 c7 D.Lgs 387/2003	
11	Hydrogeological risks area	Hydrogeological asset plan "Piano Assetto Idrogeologico" (P.A.I.) as per D.L. 180/1998
12	Specific areas	Art.142 D.Lgs 42/2004

According to article 17.3 of DM 10/09/2010, it is the region's duty to identify the unsuitable areas on their territory according to the national guidelines. In some cases, the municipalities might have more strict constraints according to which areas are eligible for PV installations, and in some cases, they add size constraint.

GRID CONNECTION

The Grid connection solution is part of the required documentation for the A.U. and TICA ("Testo Integrato delle Connessioni Attive") is the relevant regulation.

Art.6 of TICA refers to the connection requests procedures [43]. The relevant authority, to which the connection request must be submitted, is defined in art. 6.1 and depends on the plant capacity:

- Plants below 10 MW refer to the local DSO
- Plants above or equal to 10 MW refer to the Transmission system operator (TSO) Terna.

The list of information/documents that must be provided during the connection request can be found in Art. 6.3. For large scale systems, the cost that must be paid for the connection estimate is defined in art. 6.6 and it is equal to 2500 €, to which VAT of 22% must be added. The timeline for the connection process is given in Part III and Part IV of the TICA respectively in case of LV/MV-connection or HV/EHV-connection. [43]

Title I of Part III gives the main details in terms of the steps to be concluded for the connection, some of them are listed in Table 10

Table 10 Main steps in the LV/MV connection[43]

Phase	LV/MV
Connection estimate elaboration	60 days
Acceptance of the estimate	45 days from the receiving of the estimate
Minimum work for connection	The proposer starts the minimum works required for the connection after the acceptance of the estimate
Starting of A.U. process	90 days from the acceptance of the estimate
Authorization documents from the network operator	30 days from acceptance of the estimate
Connection works	30 days (simple works) 90 days + 15 days/km per every km in excess to the first (complex works)
Operation Contract	20 days from acceptance of the estimate 20 days before finishing of the works
Activation of the connection	5 days after testing the first parallel with the electricity network

The connection estimate is also known as Minimum Technical Connection Solution (Italian initials - STMG).

Title II gives the economic details on the connection cost, in particular article 12 defines the calculation procedure for such a cost [43]. The amount is calculated in two ways according to the type of electricity line to build:

1) Only aerial line or cable line: the connection cost is the minimum between A and B [43] as per eqn. (1)

$$min\begin{cases} A = CP_A \cdot P + CM_A \cdot P \cdot D_A + 100 \\ B = CP_B \cdot P + CM_B \cdot P \cdot D_B + 6000 \end{cases} \quad (1)$$

Where:

$CP_A = 35\ €/kW$

$CM_A = 90\ €/(kW\ km)$

$CP_B = 4\ €/kW$

$CP_A = 7.5\ €/(kW\ km)$

$P = power\ for\ connection\ in\ kW$

$D_A = aerial\ distance\ from\ the\ closer\ LV/MV\ cabin\ in\ excerise\ since\ 5\ years;$

$D_B = aerial\ distance\ from\ the\ closer\ HV/MV\ cabin\ in\ excerise\ since\ 5\ years;$

In case of cable connection, the values of CM is doubled [43].

2) Mixed cable line and aerial line: the connection cost is the minimum between A and B [43] as per eqn. (2)

$$min \begin{cases} A = CP_A \cdot P + CM_A \cdot P \cdot D_A \cdot (\frac{D_{aer} + 2 \cdot D_{cab}}{D_{aer} + D_{cab}}) + 100 \\ B = CP_B \cdot P + CM_B \cdot P \cdot D_B \cdot (\frac{D_{aer} + 2 \cdot D_{cab}}{D_{aer} + D_{cab}}) + 6000 \end{cases} \quad (2)$$

Where:

$D_{aer} = distance\ realized\ in\ overhead\ line$

$D_{cab} = distance\ realized\ in\ cable\ line$

The connection cost is given to the operator in two payments: 30 % is given at the acceptance of the STMG and 70% is given when the minimum works required for the connection are completed by the proposer.

In case of HV/EHV connection, the reference for the timeline and the economic details is Part IV of the TICA. However, in case of connection to the HV/EHV network, the grid operator is the TSO: Terna S.p.A. Therefore, for the connection with Terna, the main document that regulates the connection is the Grid code.

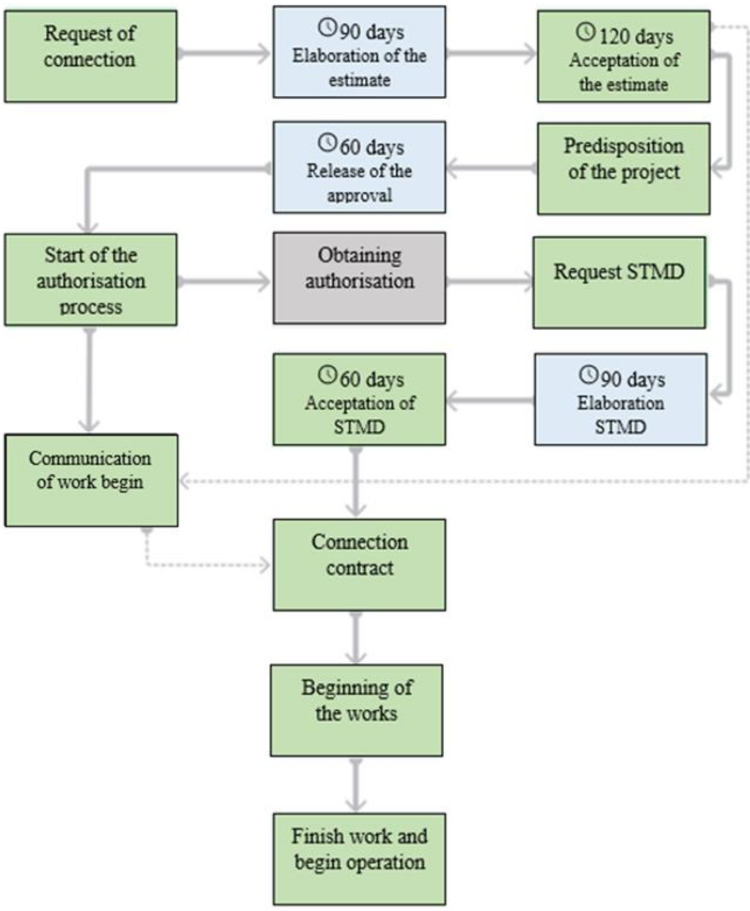

Figure 32 HV/EHV connection timeline [44]

The timeline of the connection procedure is described in section 1A of the Grid Code [45] and a diagram is published by Terna on its website and presented in Figure 32.

After receiving demand of connection, Terna will process the request and elaborate on an estimate (STMG) for the connection trying to comply with the user request. In case the requested injected power is not acceptable by the grid in that point: Terna gives information about the power that can be injected or proposes a possible solution to the developer to satisfy his request. Terna will provide an estimate only for the grid-plant for connection (STMG), the costs of the user plant for connection are afforded by the applicant himself. The developer can accept the estimate with a maximum term of 120 days [44].

Once the estimate is accepted the project is predisposed, the user can decide to carry on this phase on his own following Terna standards, and Terna will have 60 days to approve the predisposition of the project [44].

After obtaining the TSO approval, the authorisation process can start. Art. 21.3 of TICA states that within120 days (for HV connections) from the date of STMG acceptance, the developer has to start the A.U. process, including the interconnection project, validated by the grid operator. Simultaneous with the A.U. application, the developer has to notify the grid operator about the permitting process start with the relevant details [43].

Once the authorisation is obtained, the TSO will elaborate the Minimum Technical Detailed Solution (Italian initials STMD) which is the technical references for the works. Once the STMD has been accepted, the connection contract is signed, and the construction can start [44].

The cost that must be paid by the developer are given in art. 26 of the TICA. In case of renewables, the STMD request fee is calculated as per eqn. (3):

$$STMD_{request} = min\begin{cases}1250\text{ €} + 0.25\text{ €}/kW \cdot P \\ 25000\text{ €}\end{cases} \quad (3)$$

Where: P is the power for connection purposes expressed in kW.

The connection fee, which is given with the STMG, is the maximum between zero and the difference between the TSO cost and a threshold value (eqn. (4)). The result is then multiplied by the power utilisation factor, which is the ratio between the power for connection purposes and the maximum power that can be connected at the voltage level [43].

$$treshold\ value = (100000\text{ €}/km \cdot \frac{D_{cab}}{D_{aer} + D_{cab}} + 40000\text{ €}/km \cdot \frac{D_{aer}}{D_{aer} + D_{cab}}) \cdot D_{tot} \quad (4)$$

Where: D_{tot} is the total distance from the connection point which can be at the most equal to 1 km, D_{aer} is the distance in overhead line, while D_{cab} is the cable line distance. In case of distances larger than 1 km, D_{tot} is put equal to 1 km while the two shares will assume the values for the specific case [43].

The TSO value depends on the specific connection solution, which depends on the size of the plant to be connected. Table 11 has been extracted from Annex A2 of the Grid connection code and it shows the solution that is chosen according to the user size [46]. The connection schemes can be found in the same document. The average cost of HV/EHV components/facilities is reported in Terna's average cost of connection solution document, a copy of the table has been added in Annex 1 [47].

Table 11 TSO production units connection solutions Annex A2 of the Grid connection code [46]

User size	Voltage nominal	Standard solution

		"antenna" ()	"entra-esce" (in-out)	
6 - 10 MW	MV-150 kV	Solution to find with the DSO		
10 - 100 MW	120-150 kV	Yes	Yes	"entra esce in sbarra semplice"
100 - 250 MW	120-150 kV	Yes	No	
200 – 350 MW	220-380 kV	Yes	Yes	"entra esce in sbarra semplice + bypass"
200 – 350 MW (with more production groups)	220-380 kV	Yes	Yes	"entra esce in doppia sbarra"
>350 MW	380 kV	yes	yes	"entra esce in doppia sbarra"

The maximum utilisation power of the lines depends on the voltage level and is reported in Table 12

Table 12 Power limit for the different voltage level

Voltage [kV]	132	150	220	380
Max operating power [MW]	286	325	476	1777

3.3 Market schemes

When it comes to renewables and energy efficiency, the main authority in charge of monitoring and giving information on the possible market solution/subsidies is the GSE: "Gestore dei servizi energitici".

3.3.1 Current financial mechanism

REVERSE AUCTIONS – DM 4/07/2019

For large scale photovoltaic systems (P > 1 MW), there is only one subsidy scheme available that was introduced with Ministerial Decree of 4th July 2019 (D.M. 04/07/2019), which consists of a reverse auction system whose remuneration is based on a CfD mechanism (previously discussed in *FEED IN POLICIES*).

Seven periods for these auctions were defined and all the renewable energy sources can compete in four different groups to win the available capacity for the subsidies. Ground mounted PV systems compete in group A against wind plants [48]. Table 13 summarizes the periods' time slots and the available capacities that will be subsidized for group A.

Table 13 Reverse auction DM 4/07/2019 time slots and capacities [48]

Period	Starting date	Closing date	Power [MW]
1	30/09/2019	30/10/2019	500
2	31/01/2020	1/03/2020	500

3	31/05/2020	30/06/2020	700
4	30/09/2020	30/10/2020	700
5	31/01/2021	2/03/2021	700
6	31/05/2021	30/06/2021	800
7	30/09/2021	30/10/2021	1600

The incentive is paid for 20 years and the strike price is calculated according to eqn. (5):

$$T_s = T_r(1 - \%R_{off})(1 - \sum_n \%R_n) \tag{5}$$

Where: T_r is the reference tariff, which is equal to 70 €/MWh and it will be lowered to 66.5 €/MWh starting from 01/01/2021, and $\%R_{off}$ is the reduction factor applied by the proposer which must be in the range 2%-70%.

$\sum_n \%R_n$ is composed of:

- %R1: all the system whose 1st operation day is after 15 months, even if compatible with the deadline, receive a 1% reduction per year
- %R2: 50% reduction if the system is transferred to a 3rd party before the signing of the contract [49].

Art. 14 of the DM 4/07/2019 [49] gives the ranking criteria for the offers, which is based in order on:

1) Higher $\%R_{off}$
2) Higher legality rating
3) Plants that will be built on waste dumps, expired caves or land that was recovered
4) Faster to close the application procedure.

GUARANTEE OF ORIGIN - GO

Another possible mechanism of revenues for renewable power plants is the (GO) Guarantee of Origin's trading. GO is a certificate awarded to plants that have been recognized by the GSE through an application process and have been thus classified as IGO-plants. Every 1 MWh of energy generated, the GSE emits 1 GO on the account of the producer, at the cost of 0.033 €/GO [50].

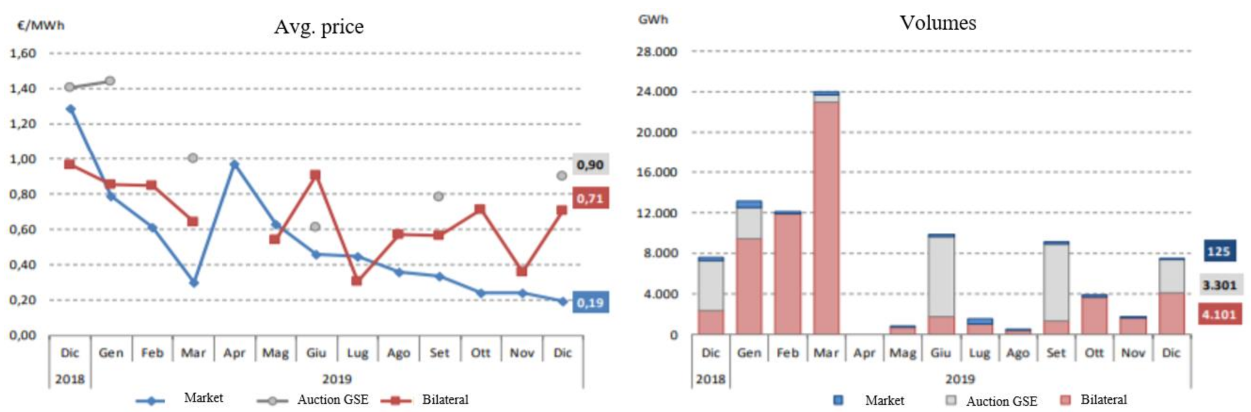

Figure 33 GO: monthly average prices and volumes traded by market in 2019 [51]

The producer can trade the GOs obtained on the trading platform of the GME. The GO can be traded in bilateral exchanges or sold on the market platform of the GSE. A fee of 0.003 €/GO has to be given to the GME for every GO traded [52]. The average selling price and the volumes traded monthly in 2019 are reported in Figure 33.

3.3.2 Future financial schemes

COMPETITIVE TENDERS

The mechanism of tenders, with a contract for difference scheme (same as DM 04/07/2019), will be employed also in the future by the Italian government, given the possibility of planning the renewables' installations and because it gives the developers certainty regarding revenues. The DM 04/07/2019 will yield results that will be necessary for the improvement and revision of the mechanism [33].

LONG-TERM CONTRACTS (PPA)

Italy intends to promote the use of PPAs in combination with regulations that encourage investors and purchasers to enter into this kind of agreement. The Ministerial Decree of 4 July 2019 provides that a regulatory framework for the creation of a market platform for long-term trading be set up within 180 days of its entry into force. The study is aimed at defining the necessary nomenclature to identify all the possible types of PPAs and the requirements that must be fulfilled to enter into these contracts [33].

The objective is to define a scheme that does not involve charges for the State or for the consumers. Italy plans on providing an initial push to the mechanism using pilot projects that are part of National Action Plan for Green Public Procurement and procurement procedures, using the State-owned company Consip to run tenders [33].

As mentioned above, the Ministerial Decree of 4 July 2019 will contribute to the development of PPAs. The Decree stipulates, in fact, that GME must create a market platform for long-term trading. The aim is to promote the trading of production from newly constructed renewable energy plants, either entirely reconstructed or reactivated, upgraded or refurbished, which started operating after 1 January 2017 and have not benefitted from energy production incentives. On a preliminary basis, PPAs are expected to contribute to at least an additional 0.5 TWh each year of renewable energy [33].

SHARING OBJECTIVES WITH REGIONS AND IDENTIFYING SUITABLE AREAS

The renewables targets, especially in the electricity sector, will be met chiefly through wind and photovoltaic energy. Regions themselves will be able to identify the areas that are suitable for installing renewable energy plants and those which are not, considering the protection of agricultural and forested areas, cultural and landscape assets, and the quality of air and bodies of water. It will be easier to plan the installations and the production of renewables, but it will also be necessary to simplify the authorisation procedures [33].

STRENGTHENING GUARANTEE OF ORIGIN FRAMEWORK

The aim is to strengthen the Guarantee of Origin framework by promoting its use for PPAs and evaluating the recognition of such guarantees for all energy produced [33].

3.3.3 Key actors

The Italian solar energy market is a fragmented one without a limited number of major players. In first place, most of the solar PV systems are rooftop systems, probably owned by the owner of the building even if developed by a photovoltaic development company. According to MordorIntelligence, some of the larger operators are: Gruppo STG Srl, Sonnedix Power Holdings Ltd, Enel SpA, EF solare Italia SpA and SunPower Corporation [53].

According to an article from the Italian newspaper "LaRepublica", Sonnedix has a total amount of 234 MW of non-subsidized photovoltaic energy. However, according to the same article, Canadian Solar Inc. has secured 55.8 milion dollars from the Italian bank Intesa San Paolo for the development of 151 MWp of PV energy [54].

The oil company Eni plans on reaching 220 MW of photovoltaic capacity by 2022 from the 58 MW [55].

Another example of new developer is the Spanish group Powertis, which plans on developing 500 MW of solar photovoltaic with the intentions of reaching 1 GW of ready to invest assets by 2023 [56].

The Italian photovoltaic market, after reaching the photovoltaic grid parity, has become extremely active with different investors and companies willing to invest. Moreover, the publishing of the INECP gives security on the policy aspect of the solar development, stating that the government is willing to promote photovoltaic installations.

3.3.4 Main Barriers

The Italian government has tried with the DM 10/09/2010 and the DLgs152/06 to make the permitting process faster for the developers. However, even if the areas have been identified by the regions, permitting processes are still slow.

Firstly, the authorisation process for utility-scale systems could be delayed due to the VIA procedure. Indeed, even if the AU process should last up to 180 days (6 months), it is suspended in case of VIA of which the duration has strong variability according to the different cases.

Secondly, the land procurement is a threat to the project. To apply for the grid connection it is necessary to have the land rights on the surface where the PV system will be built. Although the regions have identified the unsuitable areas, it can be difficult to find a suitable site which is outside the constrained areas and that respects the municipal laws in terms of construction constraints (distances, height,…) or land destination of use.

In some cases, regions have also extended the power limits or size constraint for the installation (for example: every site can be of maximum 2 ha and 300 m away from another site [57],..).

Lastly, there is the grid connection process. As said, it is necessary to identify a suitable piece of land, obtain the rights and then it is possible to apply for the connection process. However, the Italian TSO or DSO do not publish any data concerning the grid capacity in any point of the network. Therefore, in several cases there are queues of request for connections, or after spending resources on trying to find a suitable area, the connection capacity could be lower than what was planned to be developed.

4 FEASIBILITY STUDY

In this chapter the feasibility study is carried out. The methodology used in the analysis, as well as the main KPIs used in the optimization process, are presented. Lastly, the results are presented and discussed.

4.1 Objective & Methodology

4.1.1 Objective

The PV installations have reached the stage of grid parity according to the LCOE value. This feasibility study will propose a non-subsidized PV plant design, in a site which is suitable with respect to the constraints set by the national guidelines and the specific region/municipal guidelines. The objective is to compare three different type of systems: Fixed mounting, single axis tracker (SAT-A) and single axis tracker with backtracking (SAT-B), to identify which one of the designs yields the highest IRR.

4.1.2 Methodology

The feasibility study has been structured in three main phases: the first one consists of the selection of a site, the second one of the technoeconomic optimization of the PV installation and the last one is the comparison of the results with a sensitivity analysis. The first phase can be furtherly divided in two steps: the site selection in terms of region and municipality constraints, and the grid connection solution. In the second phase, three main sections can be identified: the financial modeling, the technical modeling and the optimization phase.

In the site selection phase, the software QGIS and Google Earth have been used to analyse the electricity grid map and the constraints to choose a suitable location that has a favourable location and is not hindered by any constraint related to DM 10/09/2010 or regional/municipal legislation.

The financial modeling of the system has been performed with Excel, the choice has been mainly related to the tax accounting. The CAPEX, the OPEX, the tax accounting and the revenues have been clearly defined with the relative assumptions. The technical modeling of the system to evaluate the performances has been carried out using the software System Advisor Model (SAM). The different technical parameters are described, and the necessary assumptions are given. Successively, the optimization process has been performed on the following variables: the module type, the DC/AC ratio, the Power installed, the ground coverage ratio (GCR), the tilt angle (in case of fixed mounting), the inverter type. The step-by-step procedure is explained in the following parts.

Lastly, the results have been compared and a sensitivity analysis has been performed on the best of the three, to assess the impact of different variables.

4.1.3 KPIs

The main KPI used in the design process is the project IRR. The project IRR gives an idea of the risk of the project and it is usually one of the indicators used to quickly assess which project should be pushed forward among a group of projects. Nevertheless, other indicators will be considered to draw additional comments: the levelized cost of energy LCOE, the performance ratio PR, the capacity factor CF.

IRR

As said before, the main indicator used in the analysis to optimize the system design is the Internal Rate of Return (IRR), which is an economic indicator. The internal rate of return is the discount rate that brings the net present value of a cash flow to zero. The formula of the NPV is presented in equation (6):

$$NPV = -\sum_{t=0}^{n_{cons}-1} \frac{CAPEX}{n_{cons}(1+d)^t} + \sum_{t=n_{cons}}^{n_{cons}+lifetime-1} \frac{Revenues_t - OPEX - Taxes_t}{(1+d)^t} \tag{6}$$

Where: n_{cons} is the expected construction period, $Revenues_t$ are the revenues generated during year t, $CAPEX$ is the total capital expenditure, $OPEX$ are the operational expenditures, $Taxes_t$ are the taxes paid in year t, d is the discount rate and t is the generic year of the analysis.

The IRR is the value of d that sets at end of the lifetime the NPV to 0 and can thus found solving the equation (7):

$$NPV = -\sum_{t=0}^{n_{cons}-1} \frac{CAPEX}{n_{cons}(1+IRR)^t} + \sum_{t=n_{cons}}^{n_{cons}+lifetime-1} \frac{Revenues_t - OPEX - Taxes_t}{(1+IRR)^t} = 0 \tag{7}$$

The higher is the value of the IRR, the lower is the risk of the project and thus it is easier to attract investors.

LCOE

The Levelized Cost Of Energy (LCOE) represents at which price the energy should be sold through the project lifetime in order to have an NPV equal 0. It can be evaluated using eqn. (8)

$$LCOE = \frac{\sum_{t=0}^{n_{cons}-1} \frac{CAPEX}{n_{cons}(1+WACC)^t} + \sum_{t=n_{cons}}^{n_{cons}+30} \frac{OPEX + Taxes}{(1+WACC)^t}}{\sum_{t=n_{cons}}^{n_{cons}+30} \frac{E_{sold_t}}{(1+WACC)^t}} \tag{8}$$

Where: E_{sold_t} is the total energy sold in the year t, and $WACC$ is the weighted average cost of capital. The WACC is calculated as per eqn. (9):

$$WACC = Debt_{Share} \cdot C_{debt} \cdot (1 - Corporate_{tax-rate}) + Equity_{share} \cdot C_{equity} \tag{9}$$

Where: $Debt_{Share}$ is the share of debt considered in the project, C_{debt} is the cost of debt (interest on the loan), $Corporate_{tax-rate}$ is the rate applied for the corporate tax in the country (interest at as tax shield), $Equity_{share}$ is the share of equity in the project (the sum of the debt and the equity share is 1) and C_{equity} is the cost of equity, also known as equity IRR (it is the minimum IRR accepted by the equity investor).

For this study, the LCOE has been calculated accounting for taxes, and not accounting for them.

CF

The technical performances can be expressed using the total energy production. However, the capacity factor, defined by eqn. (10), can be used as well to give an idea of the system production in relation to the installed capacity. It represents the amount of time at which the plant has operated at full capacity in a year.

$$CF = \frac{E_{sold_{t=1}}}{P_{installed} \cdot 8760} \tag{10}$$

$P_{installed}$ represents the nameplate DC capacity of the system.

PR

To assess the quality of the solar system design, the performance ratio is a relevant parameter. For a well-designed system, the yearly value is usually around 82% with monthly variations (higher in winter, lower in summer). The indicator is presented in eqn. (11):

$$PR = \frac{E_{sold_{t=1}}}{POA\ Irradiation \cdot \eta_{module} \cdot A_{mod}} \tag{11}$$

The term $POA\ Irradiation$ in the equation stands for the Plane of Array Irradiation which is the irradiance arriving on the module surface, η_{module} stands for the module efficiency and A_{mod} is the total modules area. The PR could exceed 100 % for bifacial modules because A_{mod} and η_{module} are defined for the main face of the module and do not account for the rear face.

4.2 Technoeconomic optimization modeling

4.2.1 Site selection

The analysis has been conducted in the north of Italy. The irradiation in the north of Italy is lower compared to the rest of Italy. However, the irradiation is not the only driver that affects the site selection. The grid capacity availability has also a strong impact on the project feasibility, because in case the grid connection is denied by the TSO, the project cannot be built. Indeed, most of projects tend to be developed in the south of Italy. Moreover, renewable energy plants that have accepted the STMG will have already the connection capacity reserved for them, even if the process of authorisation could end up in a refusal. Among the region belonging to the north, the Friuli Venezia-Giulia region has been chosen.

Friuli Venezia-Giulia (FVG) had, at the end of 2019, only 2.8% of the total power installed in Italy. In particular, the planning decisions on how much and where to develop renewable energy plants are left to the different municipalities. Nevertheless, even if municipalities oversee the identification of suitable areas, the authority in charge of the authorisation process, AU, is the region [58].

CONSTRAINTS

The FVG region has integrated all the datasets related to the areas deemed unsuitable by DM 10/09/2010 on the IRDAT portal [59], which is directly accessible from QGIS to download the data and build a regional map of the unsuitable areas. From Figure 34 to Figure 38 a map of most of the constraints can be seen. The missing one is the hydrogeological constraint, which can be verified by municipality.

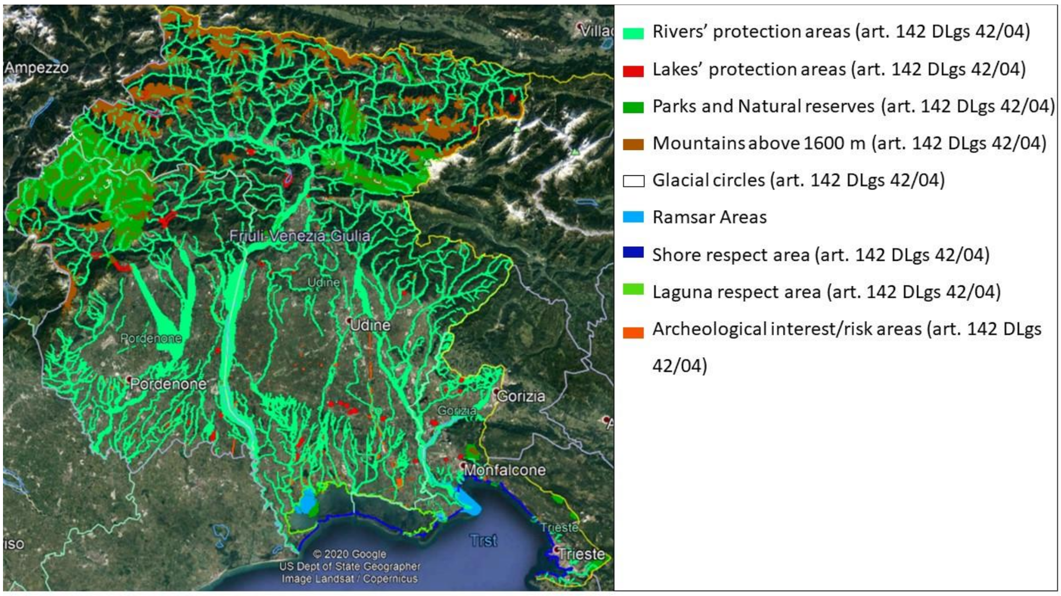

Figure 34 DM 10/09/2010 Constraints FVG - part 1 [59]

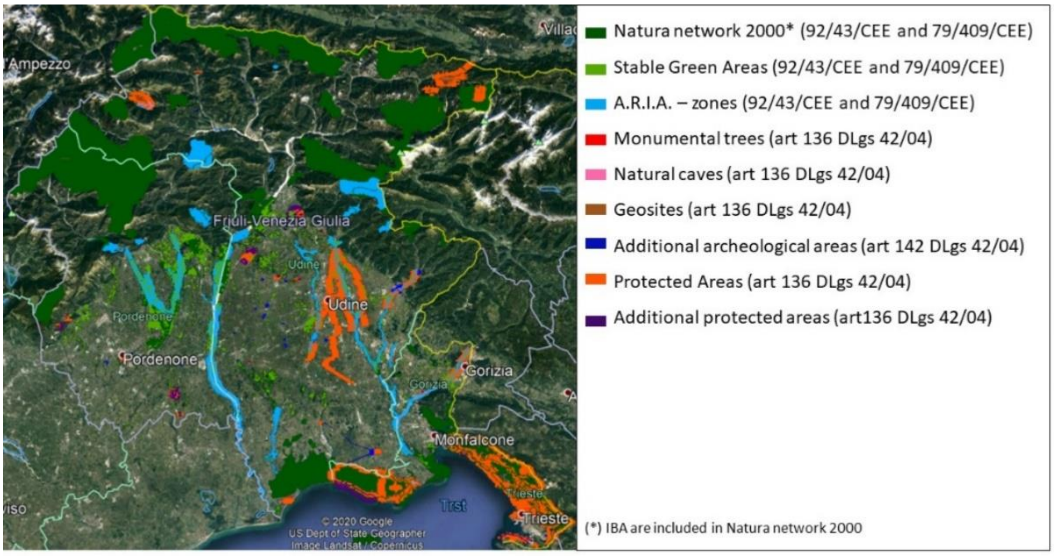

Figure 35 DM 10/09/2010 Constraints FVG – part 2 [59]

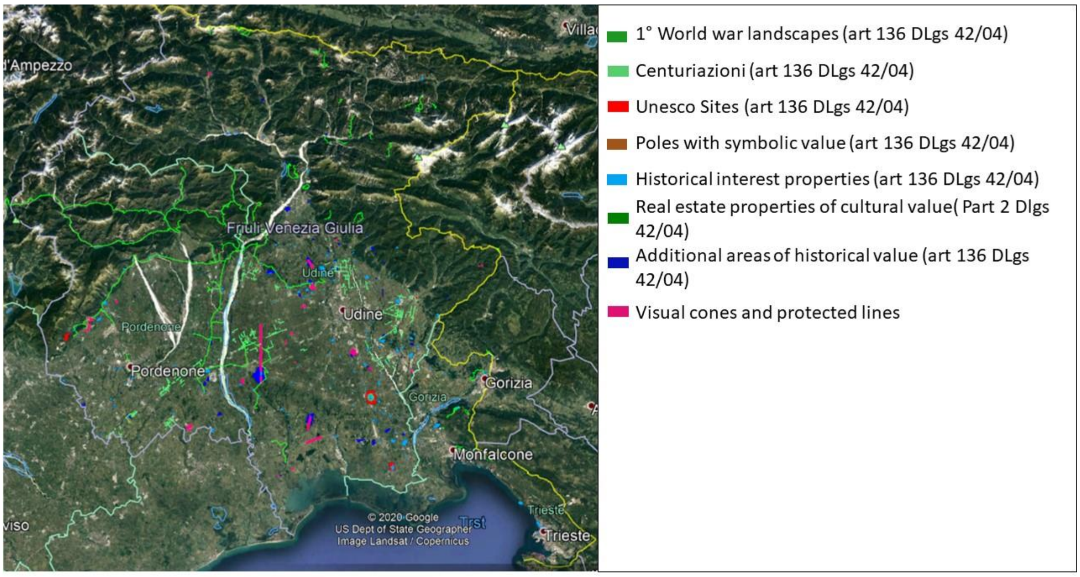

Figure 36 DM 10/09/2010 Constraints FVG - part 3 [59]

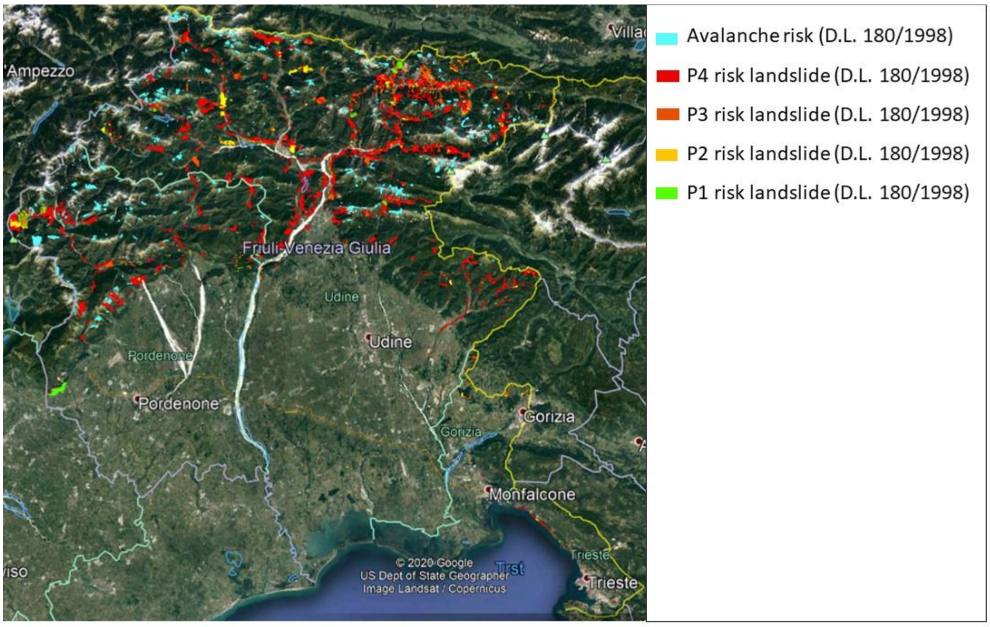

Figure 37 DM 10/09/2010 Constraints FVG - part 4 [59]

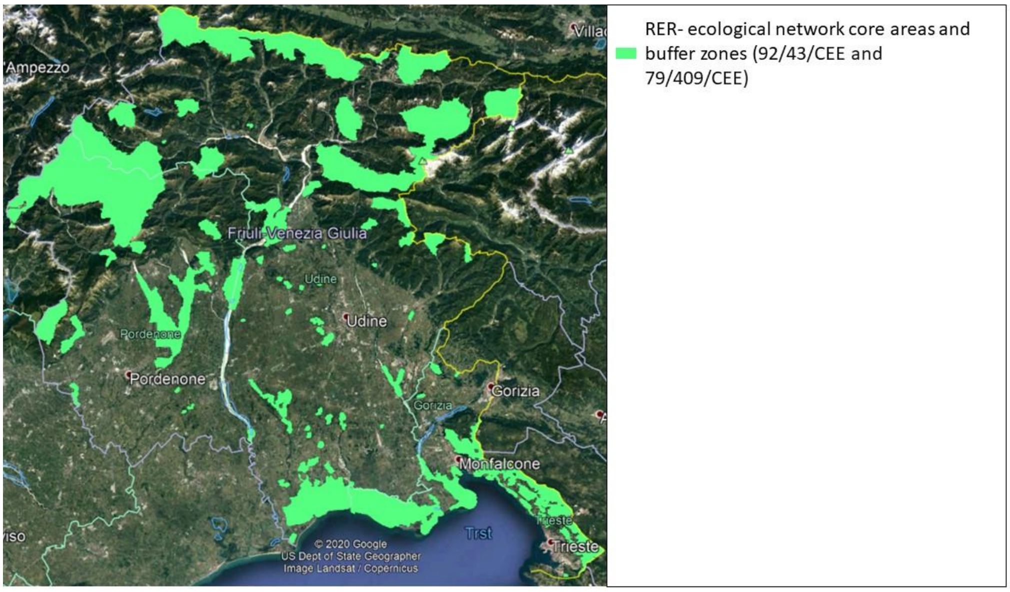

Figure 38 DM 10/09/2010 Constraints FVG - part 5 [59]

The municipality chosen for the study is Premariacco, it is located east of Udine, which is a big consumption centre. The municipality of Premariacco allows in its territory the installation of PV systems with no specific constraint. As said in the “Norme tecniche attuative” (NTA) which are the construction direction/limitations of the “Piano Regolatore Generale Comunale” (PRGC), which is the municipality regulatory plan, the photovoltaic systems are allowed in zone E5 and E6 [60].

SITE & GRID CONNECTION

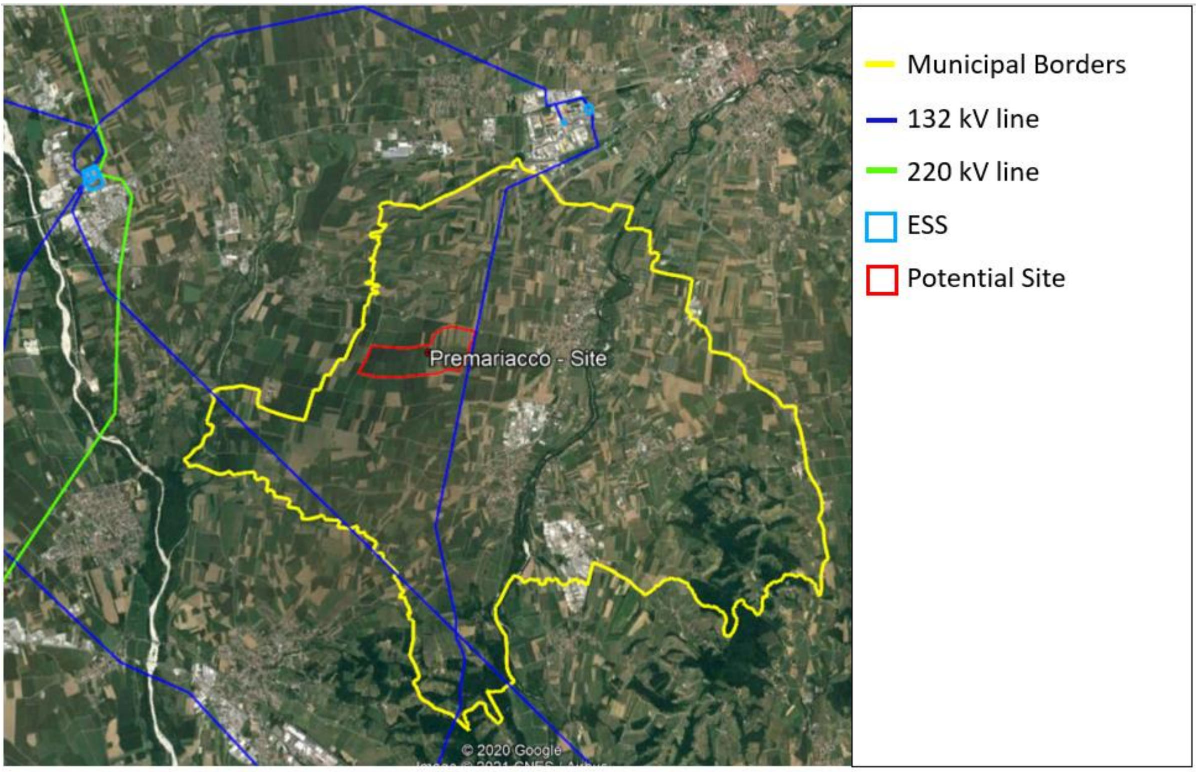

Figure 39 Premariacco site and electricity grid

The proposed site in Figure 39 is in zones E5 and E6 of the PRGC. The slope of the area is slightly irregular in the E-W direction (Figure 40) and almost flat on the N-S direction (Figure 41).

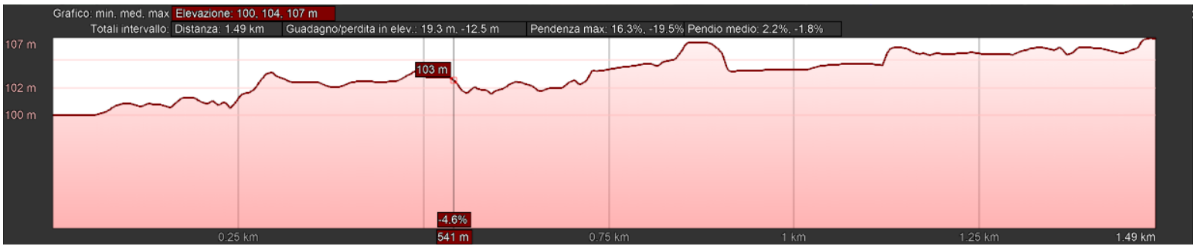

Figure 40 Slope profile E-W direction

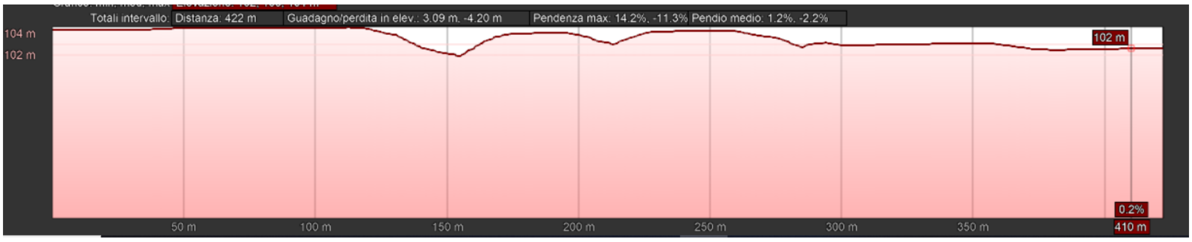

Figure 41 Slope profile N-S direction

The potential area identified has a surface of 76 ha. However, for the study only 70 ha have been considered as effectively usable by the PV system to account for the space that has to be left from the borders and the internal space for roads, inverters and LV/MV substation. The annual global horizontal irradiation is 1327 kWh/m^2. The possible connection point is the MV/HV ESS “Cividale” located at about 4 km from the site. The site is not affected by any constraints as shown in Figure 42. No hydrogeological constraint is present in the area [61].

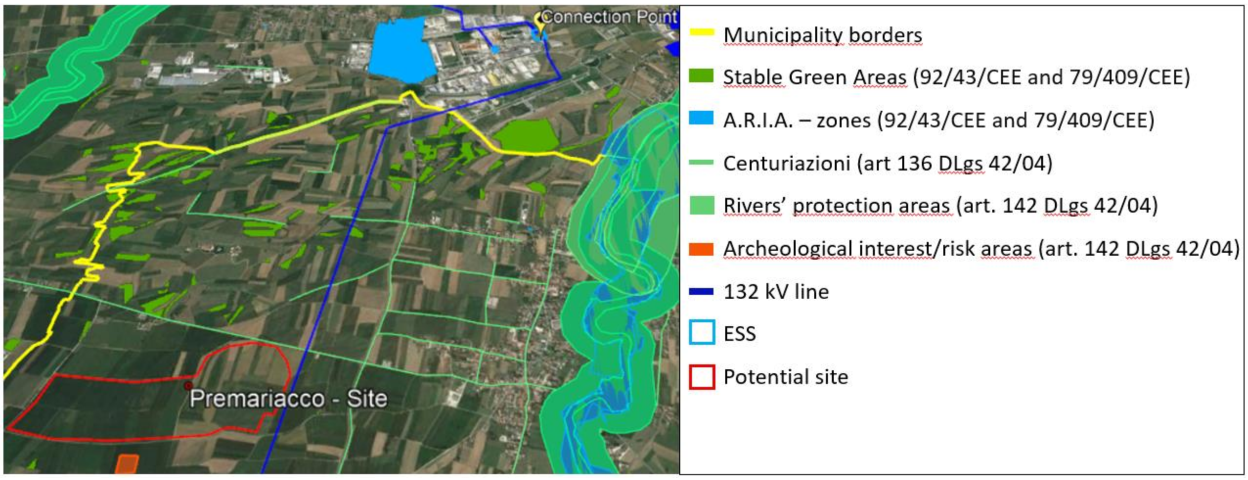

Figure 42 Potential site and connection point

For the connection cost estimation, it has been assumed to have the possibility to connect at the Connection point highlighted on the map using an MV cable line for about 3.8 km and locating the user MV/HV ESS closer to the Connection point and using an HV cable line for about 0.2 km.

4.2.2 Financial modeling

CAPEX & OPEX BREAKDOWN

A CAPEX and OPEX model have been built to evaluate the capital and operational expenditure of the system for the technoeconomic optimization.

Among the expenses that concur in the OPEX expenditure, three components have been identified: the system O&M, the replacement, the insurance expenses, and the land rent. According to IRENA, the total OPEX for a PV system located in Germany was around 10 USD/kW [4]. Considering the breakdown proposed from Lawrence Berkeley National Laboratory [62], a cost of 6.5 €/(kW yr) has been assumed for the system O&M (accounting also for the extraordinary maintenance). The insurance fee has been assumed equal to 0.3% of the total CAPEX, while the land rent has been assumed equal to 0.3 €/m^2 in accordance with online references [63].

The CAPEX of the system has been estimated using the following structure eqn(12) to eqn. (19):

$$\begin{cases} CAPEX = C_{EPC} + C_{permitting} + C_{PM} + C_{Financing} & (12) \\ C_{EPC} = C_{syst} + C_{Eng\&Dev} & (13) \\ Csyst = C_{PVsyst} + C_{grid-con} + C_{I-C} + C_{land} + Contingency & (14) \\ C_{PVsyst} = C_{module} + C_{inverter} + C_{BOS} + C_{struct} + C_{LV\backslash MV-ESS} & (15) \\ C_{grid-con} = C_{MVLine} \cdot D_{MV} + C_{HVLine} \cdot D_{HV} + C_{MV\backslash HV-ESS} + C_{TSO} & (16) \\ C_{permiting} = C_{STMG} + C_{STMD} + C_{AU\&other} & (17) \\ C_{land} = C_{acq} + C_{prep} & (18) \\ C_{Financing} = \dfrac{(C_{syst} + C_{Eng\&Dev} + C_{permitting} + C_{PM}) \cdot Debt_{Share} \cdot Financing_{Fees}}{1 - Debt_{Share} \cdot Financing_{Fees}} & (19) \end{cases}$$

Where: C_{module} is the cost of the PV module, $C_{inverter}$ is the cost of the inverter, C_{BOS} is the Balance of System cost, $C_{construction}$ is the construction cost, $Contingency$ are the contingencies accounted in the system cost, $C_{LV\backslash MV-ESS}$ is the cost of the LV/MV field substation, C_{MVLine} is the cost of the MV line per unit of length, D_{MV} is the distance of the MV line, C_{HVLine} is the cost of the HV line per unit of length, D_{HV} is the is the distance of the HV line, $C_{MV\backslash HV-ESS}$ is the cost of the user MV/HV electric substation, C_{TSO} is the cost given by the transmission system operator (see section *3.2.3 - GRID CONNECTION*), C_{STMG} is the cost for the STMG request, C_{STMD} is the cost for the STMD request, $C_{AU\&other}$ is the cost for the AU request and all the reports/study that must be conducted to achieve the authorisation, $C_{Eng\&Dev}$ is the cost for Engineering and development, C_{PM} is the project margin, C_{acq} is the land acquisition cost, C_{prep} is the land preparation cost and $Financing_{Fees}$ is the rate of fee for the debt request (debt issuance and transaction fees).

For the modules, C_{module}, a cost reference of 0.22 €/Wp and 0.25 €/Wp has been found for polycrystalline and monocrystalline silicon modules from the projects of Remanzacco [64] and Premariacco [65], both located in FVG. For bifacial modules, the price reported on the PVxchange platform was of 0.33 €/Wp [66].

For the inverter, $C_{inverter}$, two configurations are commonly used in large scale systems: central or string inverter. For the string inverter a price of 0.035 €/WAC has been found for the project of Comacchio (which is in Emilia Romagna) [67] and a price 70% lower (0.025 €/W_{AC}) has been assumed for the central inverter based on the data reported by the IEA PVPS report [24], the ISE report [68] and the Q2/Q3 Solar Industry Update [69].

The BOS is usually given as a sum of cabling, construction, installation, and other costs (fence, CCTV, SCADA…). It has been preferred to separate components' cost from construction and installation works. For the calculation, C_{BOS}, has been assumed equal to 0.07 €/Wp. The construction and installation cost, C_{I-C} , has been assumed equal to 0.05 €/Wp (which is close to the value from IEA PVPS report [24]). The project of Remanzacco had a total value of 0.120 €/Wp [64].

The mounting structure of the system has always been given as a separate cost in most of Italian projects. The project of Remanzacco had a fixed mounting structure with a cost of 75 €/kWp [64]. The project of Premariacco had a tracking structure with a cost of 100 €/kWp [65]. Therefore, C_{Struct} has been assumed equal to these two values in the two different systems considered.

The MV/HV ESS cost has been taken from ENEL price list and depends on the power of the transformers. The values are reported in Table 14.

Table 14 MV/HV ESS prices[70]

Power [MVA]	Price [k€/n]
32	1530
50	1630
80	1730
126	2450

The cost of an MV Line has been assumed from a project in the municipality of Premariacco called "Premariacco Sud", the value was of 40000 €/km for 10 MW AC power. Considering that the power is linked to the cable section and that the cost of cables decreases with size, a size factor of 0.6 has been assumed to scale the cost. The cost references of the two project can be found on the Friuli Venezia Giulia's VIA web portal [71] [65].

The cost of the LV/MV ESS has been assumed from Remanzacco [64]and Comacchio [67]. The two projects had respectively a cost of around 35 €/kVA_{AC} and 45 €/kVA_{AC}. Therefore, a value of 40 €/kVA_{AC} has been considered for the analysis.

The cost of the HV line has been assumed from ENEL price list. For a 120-150 kV Aluminium cable a cost of 1000 k€/km [70] is given and the power that can be carried is of 250 MVA [47], a size factor of 0.6 has been used in this case as well to scale the costs.

The connection cost of the TSO, C_{TSO}, varies in case of connection to a new ESS or an existing one. According to the different voltage level the components' price to consider is reported in Table 15

Table 15 C_{TSO} reference cost [47]

voltage	Power limit	Station AIS ss	Stallo ST ss
132	286	1780	439
150	325	1780	439
220	476	1736	637
380	1777	1891	958

In case of an existing substation, the cost given for the connection is equal to the cost of one "Stallo". In case of new ESS, the cost is equal to three "Stallo" plus a "Station AIS". The C_{TSO} is then calculated by applying the threshold value and the power coefficient (see section *3.2.3 - GRID CONNECTION*).

The land preparation work cost has been assumed equal to 0.5 €/m^2. The Land acquisition cost has been assumed equal to 3.5 €/m^2 as an average of the agricultural land cost in Friuli Venezia-Giulia [72].

For the permitting cost, a value of 10 €/kW has been used for $C_{AU\&other}$. The other two costs have been already discussed in section *3.2.3 - GRID CONNECTION.*

The other costs have been assumed as follow: $C_{Eng\&Dev}$ equal to 4% of the C_{EPC}, $Contingency$ equal to 2% of C_{syst}, C_{PM}has been set to 5 % of the total CAPEX without $C_{Financing}$, the $Financing_{Fees}$ have been set to 2%. The CAPEX calculation tab has been added in Annex 2.

<u>TAXES</u>

In the PV market, it is a common choice to build a Special Purpose Vehicle (SPV) to develop the project. The SPV will be responsible for all the developing, the construction and the beginning of operation. The SPV could also decide to operate the plant or to leave it to another company. The SPV will be subject to the corporate tax (IRES), the production tax (IRAP) and the municipal tax (IMU). The IRES has a rate of 24 %, the IRAP has a base rate of 3.9% and can be varied by region in a range of ±0.92%(Friuli Venezia Giulia uses 3.9% [73]). The municipal tax (IMU) is calculated from a quantity obtained from the PV plant's cadastral value, on which is then applied a municipal rate that can vary between 0.76% and 1.06 % (the municipality of Premariacco applies a value of 0.86 % [74]).

The tax base for the IRAP is the value of the production minus the cost of the production, which according to art. 2425 of the Italian civil code corresponds to the English acronym EBIT.[75]

The IMU is applied on the cadastral value of the PV plant with some manipulations. In 2016 the cadastral value of a 1MW was of 5000 €/MW [76]. This cadastral value has to be increased by 5% and multiplied by a coefficient of 65 because PV plant are classified as D/1 – D/10 systems

[77]. The amount to pay as IMU is obtained by applying the municipal tax rate on the previous value.

The corporate tax is applied on the quantity known as EBT. The IRAP is not deductible for the IRES calculation, while IMU can be deducted. The IMU paid on the same year can be deducted in the percentage of

- 60% in 2020 and 2021
- 70% in 2022
- 100 % from 2023[78] .

As seen from the taxable bases used for these taxes, the amortisation acts as a financial shield. Neglecting the depreciation, the amortisation can be subtracted from the EBITDA to obtain the EBIT. However, in case of the acquisition of the land for a successive construction of the PV system, the cost of the land cannot be included in the amortisation. The value not to include is given as the maximum between the land acquisition price and 30 % of the PV plant cost (without the land); any work of demolition or bonification is included in the land price [79]. The rate of amortisation for large scale PV system is 4 %, thus 25 years are needed for the amortisation [80].

The interests paid by an SPV act as a tax shield for the corporate tax calculation. According to Italian legislation, if the passive interests are in absolute value higher than the active ones, and if their difference is lower or equal to 30% of the ROL ("Reddito Operativo Lordo"), the difference can be subtracted from the EBIT to calculate the EBT. For a PV system the ROL is equal to the EBIT plus the amortisation and thus the ROL will be coinciding with the EBITDA in the analysed case [81], [82].

The explanation of the tax application is a simplification of the general rule given by the Italian Legislation. Moreover, the terms of the Italian accounting system have been converted to the English one. However, according to the different type of company, different rules on the amortisation/interest/tax rate/tax deductibility must be considered.

Important to remind that all taxes are in general paid the year after the one to which they refer. Nevertheless, IRAP and IRES are paid in advance and a correction is applied in the following year in case of overestimation or underestimation [83].

<u>REVENUES</u>

For the revenues three different sources have been considered: firstly, the wholesale electricity market revenues, secondly, the selling of the GO and lastly, the signing of a Corporate-PPA.

Given that the signing of a corporate PPA corresponds to the selling of energy to a company, it has been assumed that the GO revenues cannot be cumulated since the energy sold through the PPA is already certified as "green". For the GO revenues a price of 0.19 €/MWh has been assumed for the 30 years of operation to which 0.033 €/MWh and 0.003 €/MWh must be subtracted (see section *3.3.1 Current financial mechanism*).

The PPA can be signed for the full energy produced or for just a share of it, it has a certain duration and a given price. For the purpose, a PPA at a fixed price of 45 €/MWh [84]for 60 % of the energy sold and with a duration of 10 years [84] has been assumed.

The wholesale price of the electricity sold varies in the different areas as explained in section *3.1.2 Electricity market.* The TSO, Terna SpA, has drafted some scenarios on the wholesale price evolution in the different market areas [85]. The scenario description proposes a forecast of the electricity wholesale price for three different target years: 2025, 2030, 2040, and for four different scenarios: BAU, PNIEC, DEC & CEN. Considering that Italian energy policies will follow the PNIEC scenario, the prices forecasted for such scenario have been considered for 2025 and 2035. For 2040 an average between the CEN and DEC has been considered (CEN stands for centralised production, DEC stands for decentralised production, while BAU means

Business As Usual). The energy prices are summarized in Table 16, (see section *3.1.2 Electricity market* for a graphic localisation of the market zones).

Table 16 Electricity Price forecast - TSO scenarios [77]

Year	Market Zone	Scenario TSO			
		BAU [€/MWh]	PNIEC [€/MWh]	CEN [€/MWh]	DEC [€/MWh]
2025	NORD	63	63	57	55
	CNOR	63	62	57	55
	CSUD	52	60	56	54
	SUD	52	60	56	54
	SICI	53	60	56	54
	SARD	53	60	56	54
2030	NORD	56	69	64	62
	CNOR	56	67	63	62
	CSUD	55	65	62	61
	SUD	54	64	62	60
	SICI	55	64	62	60
	SARD	55	64	62	60
2040	NORD	70		77	75
	CNOR	67		75	72
	CSUD	65		72	63
	SUD	64		70	62
	SICI	65		71	63
	SARD	65		71	62

The 2019 and 2020 data can be downloaded from the GME historical data. The values are presented in Table 17.

Table 17 Electricity price 2019 and 2020 – GME [86]

Market zone	2019 Price	2020 Price
NORD	53.3	39.94
CNOR	53.7	40.19

CSUD	55.4	43.48
SUD	51.4	39.14
SICI	64.1	47.67
SARD	51.9	39.32

For the years for which data was not available, a linear interpolation has been used, while from 2040 onward, a flat price has been considered.

The revenues calculation has been simplified assuming a single price value for the energy even if the PV production and the market price profiles have hourly variations.

OTHER ECONOMIC ASSUMPTION

For the project, 2 years of construction and 30 years of lifetime have been considered. The CAPEX has been assumed to be evenly distributed among the construction years. Single debt and single equity repayment have been considered. No inflation on the OPEX and no escalation on the revenues has been considered: the land rent has been assumed fixed by contract, the PPA has been assumed at a fixed price (sometimes escalation might be included in the PPA contract) and the electricity price provided by the TSO has been assumed that it already accounts for escalation. A ratio Debt/Equity of 80/20 and a debt term of 20 years have been assumed. Moreover, the Equity IRR has been set to 8 % for the LCOE calculation. The cost of debt has been assumed equal to 2% has suggested by IEA PVPS report [24].

4.2.3 Technical modeling

DESIGN VARIABLES

Different modules have different efficiency and temperature behaviour. Three different types of PV panel have been tested: Bifacial mono-crystalline, Monofacial poly-crystalline and Monofacial mono-crystalline. The commercial modules chosen are respectively: LONGi Solar LR4-HBD-455M, Bluesun Solar BSM355P-72, Talesun Bistar TP6F72M-405 which are also available in SAM database. The datasheets can be found in Annex 3.

The DC/AC ratio is the ratio between the DC nameplate capacity and the Inverter AC one. The oversizing of the DC side is necessary to compensate for the irradiation, which is only in some days and some hours at the STC conditions. However, a too high DC/AC ratio could lead to high values of clipping losses.

The power installed (DC) and the GCR are two proportional variables. The GCR expresses the ratio of module area over the total land area. In general, the power varies according to the land area and GCR value. However, for this study the value of the land area will be constrained by the site land availability and the values of GCR and power are linked by eqn. (20)

$$P_{installed} = \eta_{module} \cdot G_{STC} \cdot A_{Land} \cdot GCR \tag{20}$$

Where: G_{STC} is the STC irradiation (1 kW/m^2), A_{Land} is the land area, GCR is the ground coverage ratio and η_{module} is the module efficiency in STC irradiation.

In a fixed system the tilt angle must be optimised as well to maximize the production.

The inverter used in large scale systems is usually of two types: string inverter or central inverter. The string inverter has a lower size and is usually connected to a limited number of strings to reduce the mismatch losses. The central inverter is connected to a larger number of strings and it has higher losses. However, the central inverter cost is lower than the string one and thus an optimum must be found.

OTHER TECHNICAL ASSUMPTIONS

- This being a prefeasibility study with a final aim of screen different systems to choose the best one, that will have to be further refined in the following step of the development, the sizing of the system is done in SAM using the option "Estimate subarray configuration". In this way it is possible to give as inputs the desired DC/AC ratio and the desired DC power and the software will automatically choose the number of modules in series and parallel.
- For bifacial module, the bifaciality factor has been assumed equal to 70%, the transmission factor has been set as default (0.013) and the ground clearance height has been assumed 1m.
- For the modeling in SAM, Huawei technologies SUN2000-100KTL-USH0 has been used for the string inverter, assuming mismatch losses of 1%. The central inverter has been simulated assuming simply a higher value of mismatch losses (2.5 %). The string inverter allows the possibility of changing the DC/AC ratio easily compared to a larger inverter, the chosen inverter has an AC power of 100 kW.
- The yearly degradation has been assumed equal to 0.5%/yr (average between Switzerland 0.2% and Spain 0.8%) [87]. The soiling losses have been assumed equal to 2% constant during the years. The diodes and connections' losses have been set at 0.5 % (default value in SAM).
- The DC wiring losses have been assumed equal to 1.5 %.
- Availability losses have been neglected.
- On the AC side, the losses from the inverter to the field ESS have been assumed equal to 1 %. The transformer's no-load losses have been set to 0.2 % while the load losses have been assumed equal to 0.8 %. The losses on the transmission line have been assumed equal to 1 %.
- The ground albedo has been assumed equal to 0.2 and the sky model used is the Perez one. The weather data has been downloaded from PVGIS for the coordinates 46.056 N 13.360 W. The TMY file 2005-2014 has been used.[88]
- The economic analysis is run on the annual production without an hourly profile; thus the azimuth has been kept for all the system at 180° (south).
- The tracking rotation limit has been assumed equal to 55°.

4.3 Optimization process

The optimization process has been done for the three different system and the three types of module separately, optimising the post-tax project IRR. The Powell conjugated direction method has been used, approximating with a second order polynomial function for the single variable steps.

In case of fixed mounting, all the variables must be optimized. The optimisation has been performed firstly on GCR, tilt and DC/AC ratio. The iterations were stopped when the objective function had no relevant change. After that, the central inverter was tested, using a search space in the vicinity of the optimum previously obtained.

For the single axis tracker systems: astronomical and backtracking, the number of variables to optimise was reduced by one, given the absence of the tilt angle. The procedure has been repeated like the fixed mounting system.

The land has been considered as leased in the optimization process.

4.3.1 Optimization Fixed Mounting

Figure 43 shows the convergence plot for the optimization process. The stop criteria used for the iterations was to have a flat profile for the target function. The number of steps performed is reported on the x-axis, each of the steps has been divided in 3 sub-steps to apply the Powell method: tilt optimization, GCR optimization and DC/AC ratio optimization.

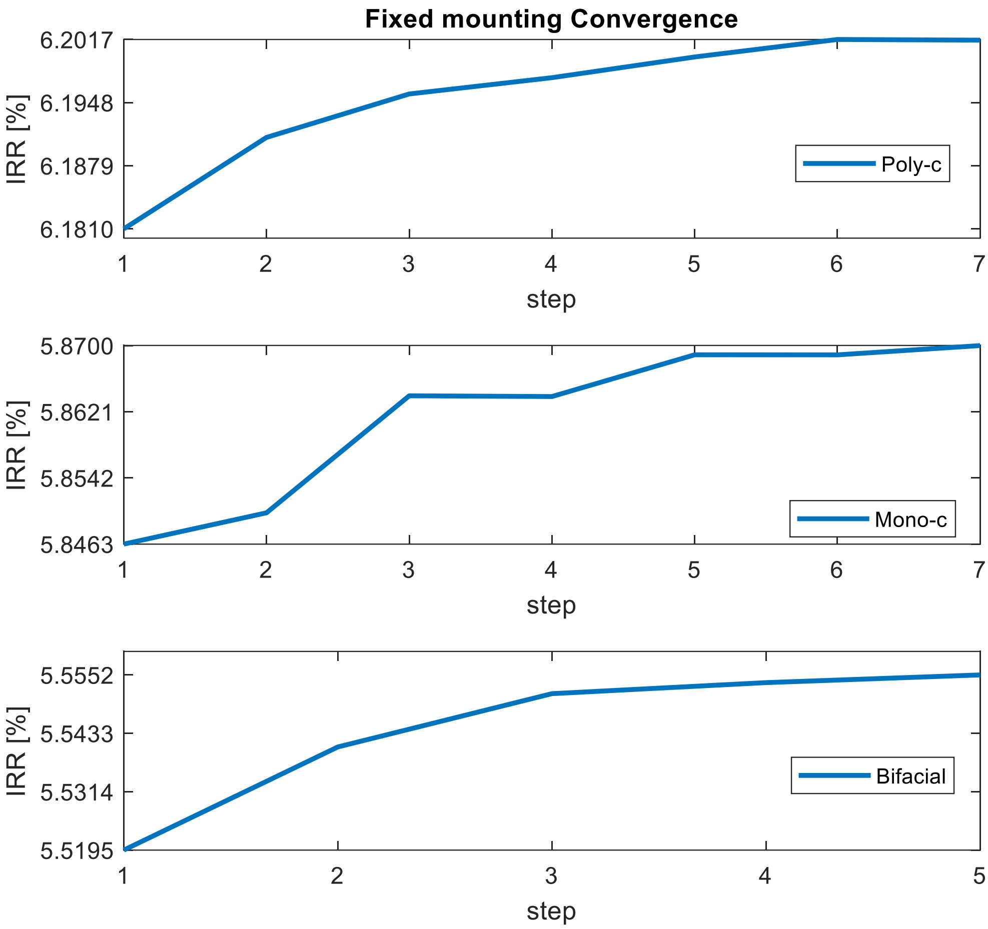

Figure 43 Convergence plot fixed mounting

The optimal variables' values, for every module are presented in Table 18.

Table 18 Fixed tilt optimal values (String inverter)

	Poly-c	Mono-c	Bi-facial
Power [kWp]	56493.5	57760.6	57443.5
DC/AC ratio	1.17	1.16	1.05
GCR	0.441	0.409	0.381
Tilt [°]	24.7	27.6	30.5
CF [%]	13.9%	14.0%	15.2%
Yield [kWh/kWp]	1221	1227	1329
PR [%]	80.4%	80.1%	86.2%

Post-tax IRR [%]	6.20%	5.87%	5.56%
LCOE [€/MWh]	50.54	51.64	52.60

As explained in the previous paragraph, the central inverter has been simulated only increasing the mismatch losses. It has been assumed that the optimum of the layout with the string inverter was close to the optimum with the central one. Therefore, a search space in the vicinity of the optimum points previously found has been used (3 points for each of the variable). The values obtained are plotted in Figure 44.

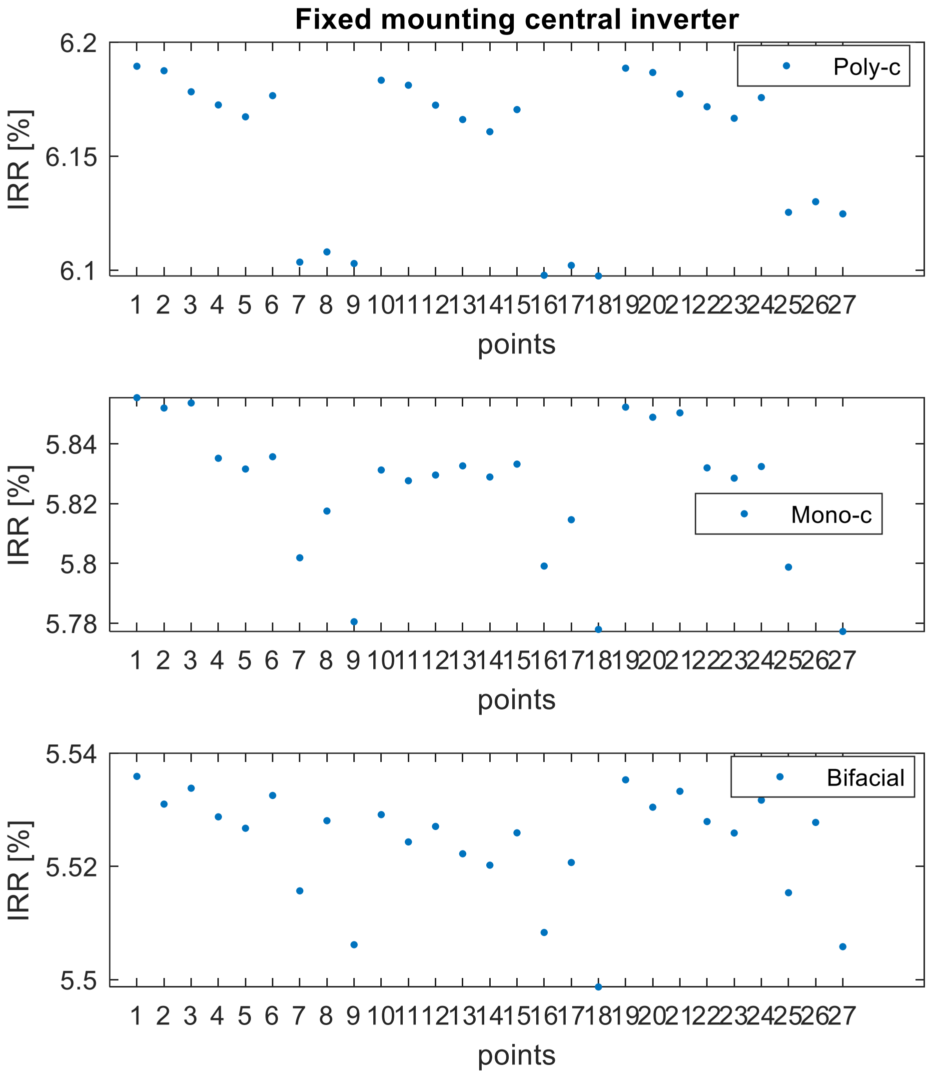

Figure 44 Fixed mounting - String inverter: IRR at tested points.

The optimal points for every configuration are presented in Table 19

Table 19 Fixed mounting optimal values (Central inverter)

	Poly-c	Mono-c	Bi-facial
Power [kWp]	56493.5	57760.6	57443.5
DC/AC ratio	1.17	1.16	1.05
GCR	0.441	0.409	0.381

Tilt [°]	24.7	27.6	30.5
CF [%]	13.7%	13.8%	15.0%
Yield [kWh/kWp]	1204	1210	1310
PR [%]	79.3%	79.0%	85.0%
Post-tax IRR [%]	6.19%	5.86%	5.54%
LCOE [€/MWh]	50.62	51.72	52.70

The central inverter layouts have, for every combination tested, a lower value of IRR. The systems with the central inverter have lower energy production (due to increased losses) and a lower CAPEX. Nevertheless, the reduction of performances had a stronger impact compared to the savings on the CAPEX.

4.3.2 Optimization SAT – A

The same optimization strategy has been applied for the SAT-A system. The number of variables, in this case, has been reduced by one because there is no tilt input in such system. The convergence plot for the three different modules is shown in Figure 45. For the mono-c module the iterations have been stopped at 7 because, although the 5th iteration showed an oscillation, the values of the 6th and 7th are in line with the one of the 4th iteration.

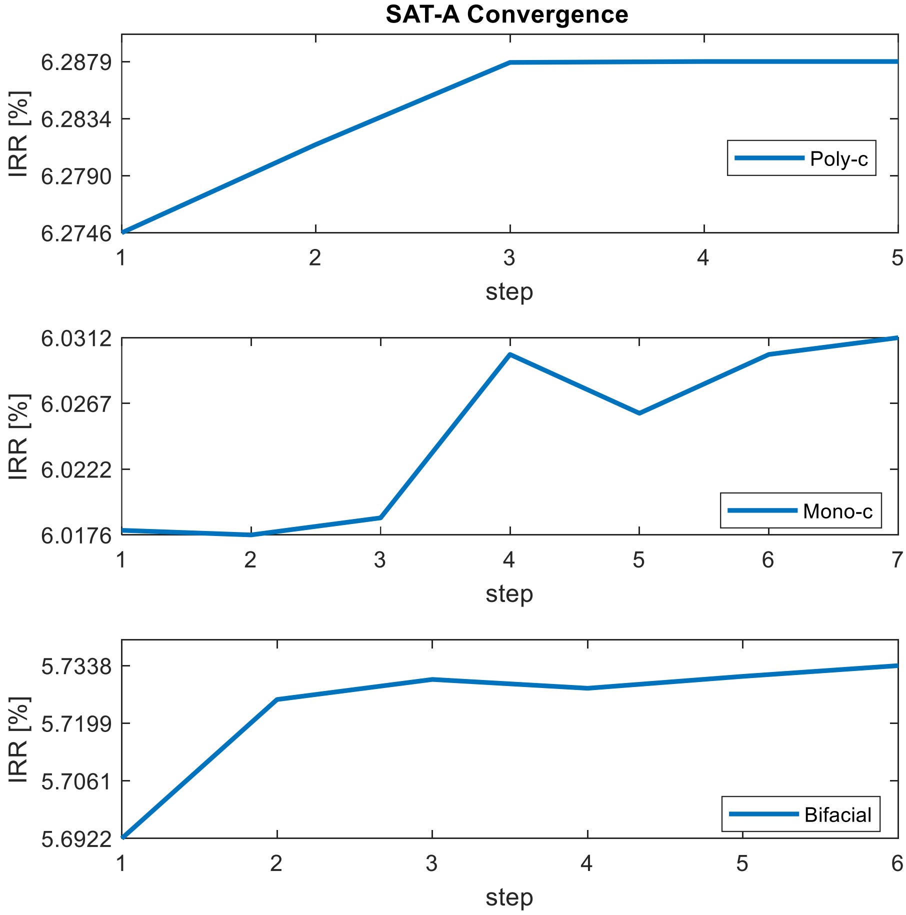

Figure 45 Convergence plot SAT-A

The layouts' optimal variables are shown in Table 20.

Table 20 SAT-A optimal values (String inverter)

	Poly-c	Mono-c	Bi-facial
Power [kWp]	34192.5	36211.1	39667.0
DC/AC ratio	1.16	1.14	1.05
GCR	0.267	0.257	0.263
CF [%]	15.5%	15.6%	16.6%
Yield [kWh/kWp]	1359	1365	1451
PR [%]	76.1%	76.4%	81.3%
Post-tax IRR [%]	6.29%	6.03%	5.73%
LCOE [€/MWh]	50.44	51.20	52.00

As per the fixed mounting, also in this case the central inverter optimum has been searched in the vicinity of the string inverter's values. The optimal results are presented in Table 21.

Table 21 SAT-A optimal values (Central inverter)

	Poly-c	Mono-c	Bi-facial
Power [kWp]	34192.5	36211.1	39667.0
DC/AC ratio	1.16	1.14	1.05
GCR	0.267	0.257	0.263
CF [%]	15.3%	15.4%	16.3%
Yield [kWh/kWp]	1340	1346	1431
PR [%]	75.0%	75.3%	80.1%
Post-tax IRR [%]	6.26%	6.00%	5.71%
LCOE [€/MWh]	50.56	51.33	52.13

Like the previous system, the optimal values of the central inverter designs have lower CAPEX and lower performances. However, the overall effect has resulted into a reduction of the IRR. The values of the objective function for the tested points are shown in Figure 46. Three values for each of the two variables have been used.

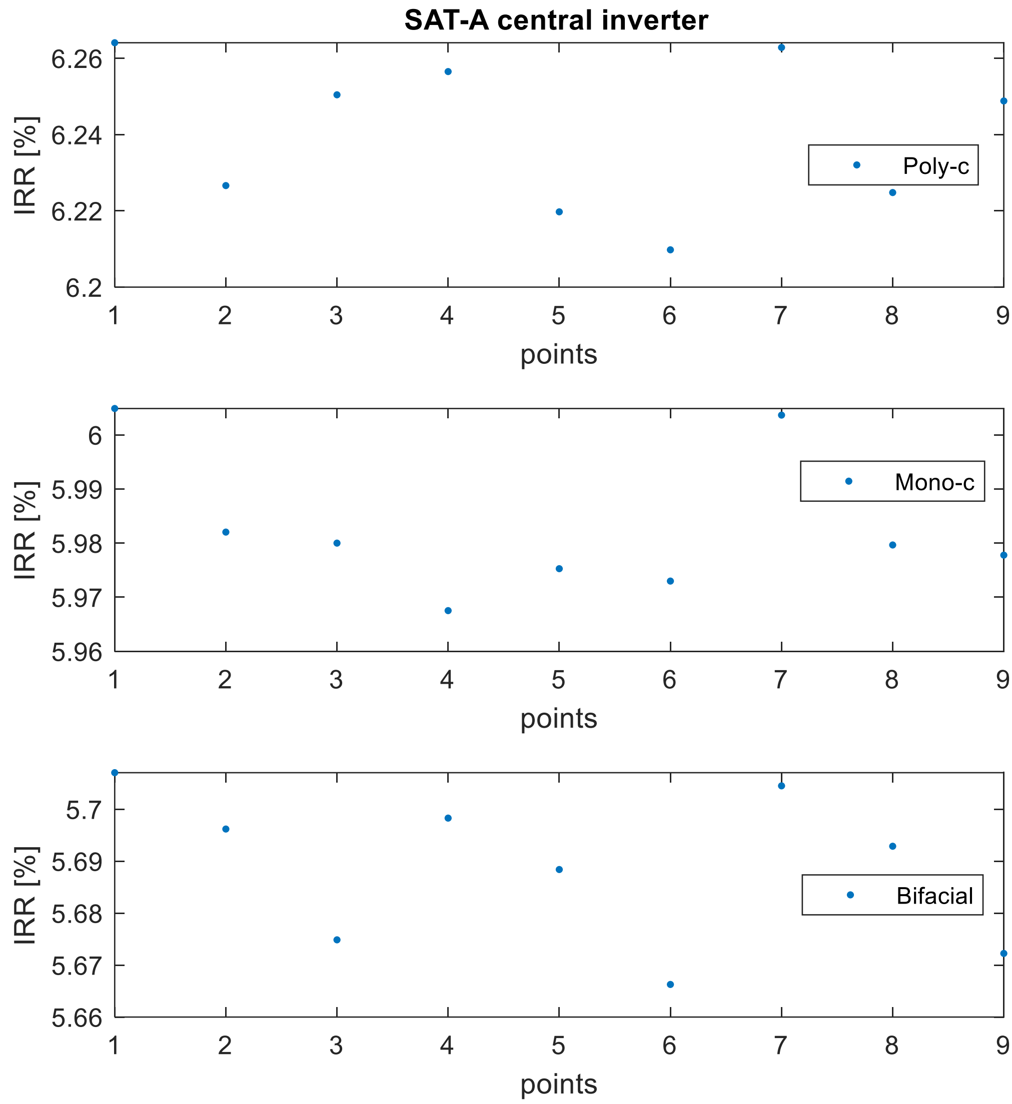

Figure 46 SAT-A - Central inverter: IRR at tested points

4.3.3 Optimization SAT - B

Lastly, the procedure has been repeated for the SAT-B system. The optimal design variables for the three configurations are listed in Table 22. As in the previous systems, the polycrystalline modules have the highest IRR.

Table 22 SAT-B optimal values (String inverter)

	Poly-c	Mono-c	Bi-facial
Power [kWp]	48950.4	51086.6	48877.1
DC/AC ratio	1.17	1.14	1.05
GCR	0.382	0.362	0.324
CF [%]	15.4%	15.5%	16.7%
Yield [kWh/kWp]	1351	1359	1459
PR [%]	80.7%	80.8%	86.0%

Post-tax IRR [%]	6.65%	6.35%	5.99%
LCOE [€/MWh]	48.95	49.83	50.92

The convergence plots are shown in Figure 47.

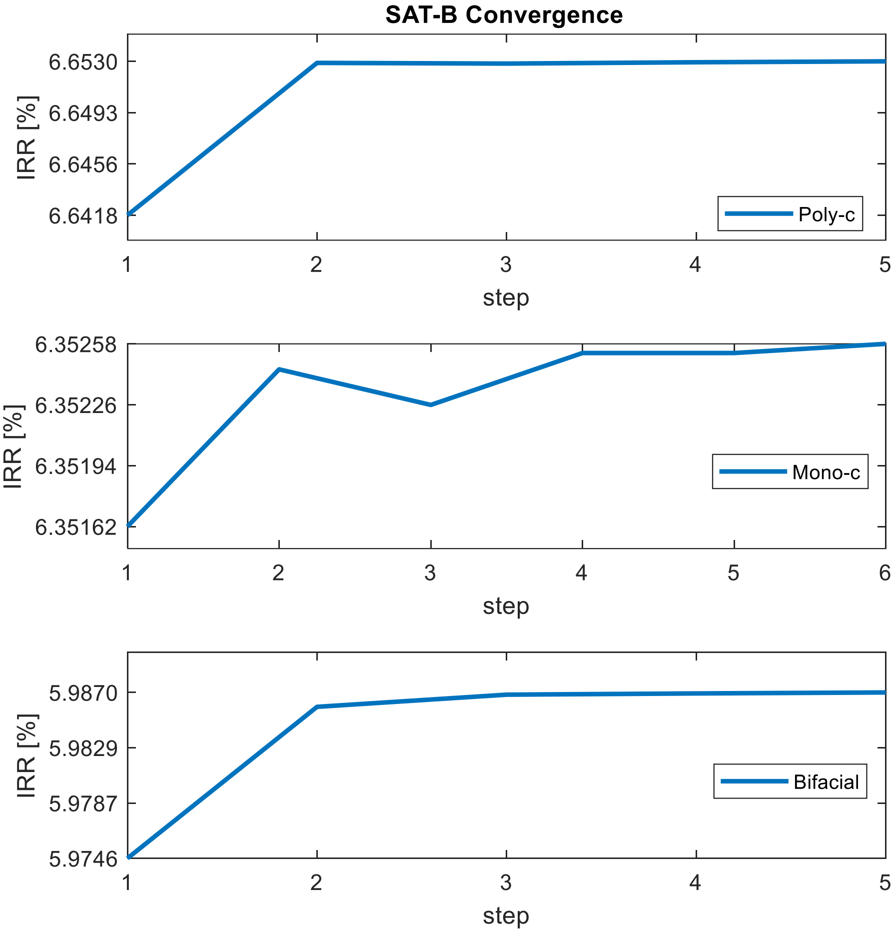

Figure 47 Convergence plot SAT-B

The central inverter has been tested in a similar way to the SAT-A system. As in the previous systems, the IRRs of the central inverter systems were lower with respect to the string inverter ones. The optimal design variables are listed in Table 23.

Table 23 SAT-B optimal values (Central inverter)

	Poly-c	Mono-c	Bi-facial
Power [kWp]	48950.4	51086.6	48877.1
DC/AC ratio	1.18	1.16	1.07
GCR	0.382	0.362	0.324
CF [%]	15.2%	15.3%	16.4%
Yield [kWh/kWp]	1331	1338	1437
PR [%]	79.5%	79.5%	84.7%

Post-tax IRR [%]	6.64%	6.33%	5.96%
LCOE [€/MWh]	49.05	49.94	51.04

The IRR at the tested points is show in Figure 48.

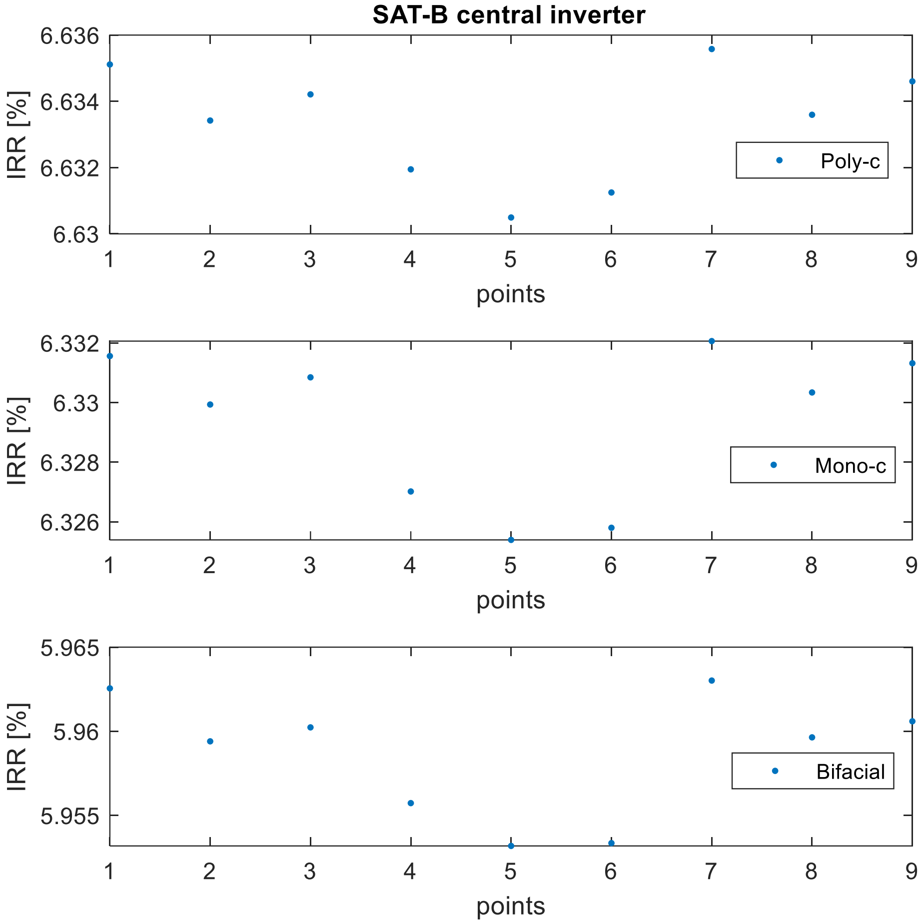

Figure 48 SAT-B - String inverter: IRR at tested points

4.3.4 Land acquisition

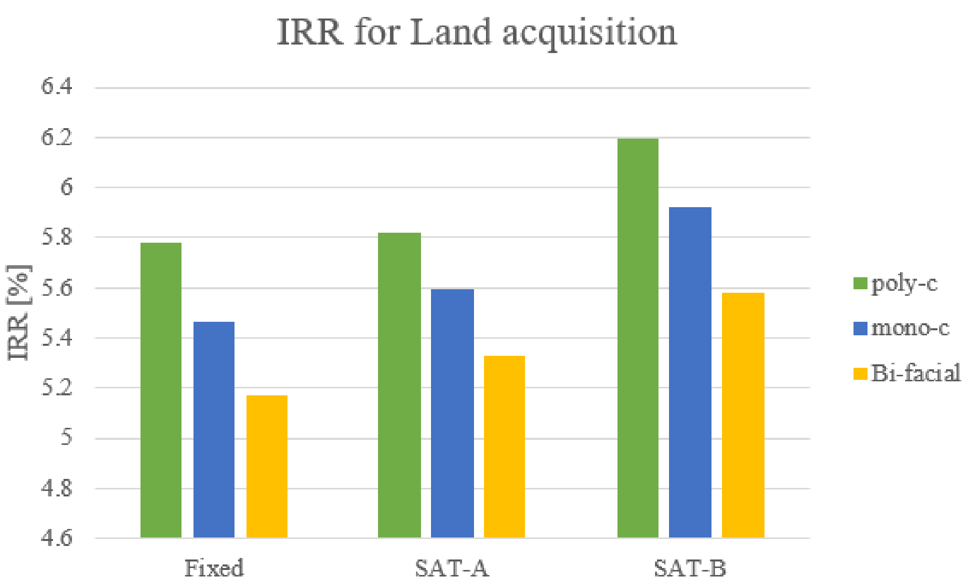

Figure 49 IRR String-inverter Land acquisition

As shown in Figure 49, Land acquisition has for all the optimal points of Table 18, Table 20 and Table 22 an IRR lower compared to the land rent case.

4.4 Results Comparison

The results of the optimisation process showed that in every system the string inverter had better results, in terms of IRR, with respect to the central inverter ones. The three system results have thus been compared in Figure 50. The system that had the highest IRR was, for all three the modules, the backtracking system. In case of polycrystalline and mono crystalline modules, the SAT-B system has Performances and spacing (GCR) which are in the middle between the fixed tilt design and the SAT-A. The combination allows a cost reduction for the OPEX compared to the SAT-A with a decrease in yield (which is proportional to the CF) which is compensated by the overall revenues increase. The bifacial module, on the other hand, reduces the cost compared to the SAT-A system, and increases the CF (yield). Indeed, when the modules are positioned off-axis, the rear face of the bifacial modules has a key role in the yield increase.

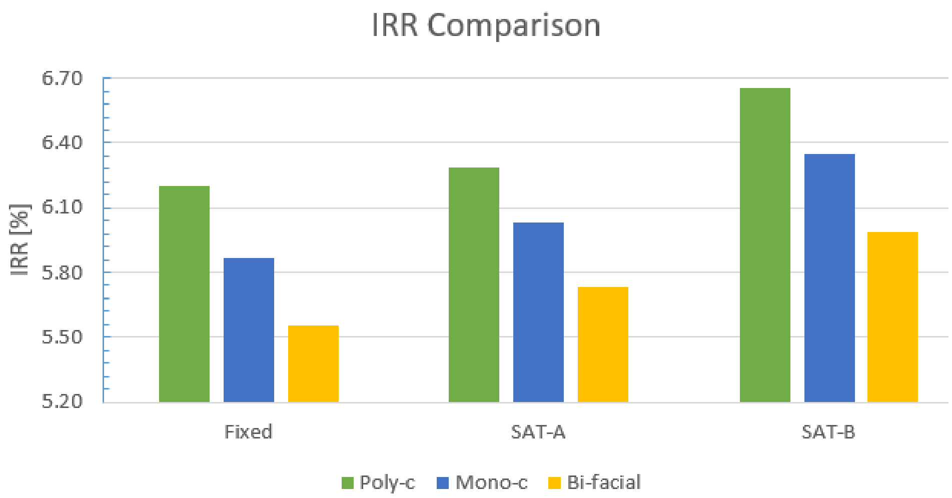

Figure 50 Comparison IRR (Central inverter)

The LCOE has an opposite trend compared to the IRR: the system with the highest IRR has the lowest LCOE. The different LCOE are shown in Figure 51. The SAT-B polycrystalline system shows a LCOE of 48.9 €/MWh. The IRENA report showed an LCOE of 68 USD/MWh (around 56 €/MWh with a change of 1 € = 1.2 $) for Sicily [4]. The difference could be related to the different cost assumed and to the Equity cost used for the WACC calculation.

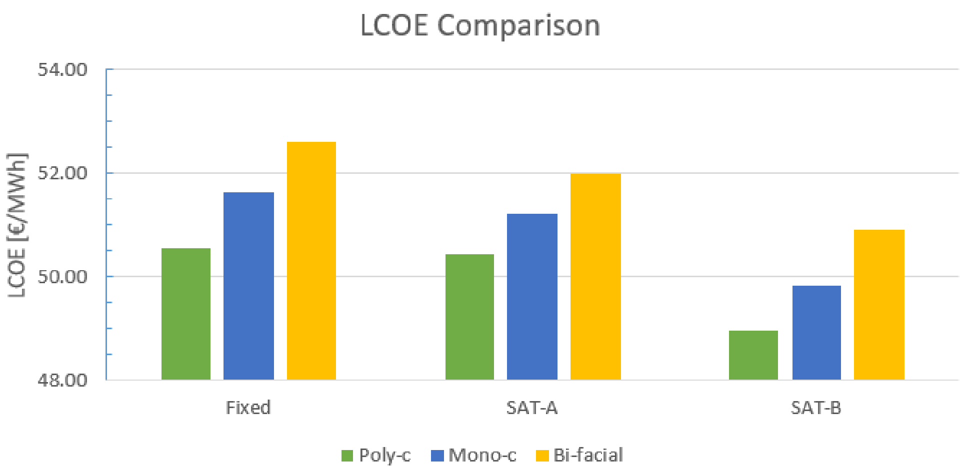

Figure 51 LCOE Comparison with land rent and central inverter

As briefly explained before, the capacity factor is higher in the SAT-A for the polycrystalline and monocrystalline module, while it is higher in the SAT-B for the bifacial module due to the back-face energy production. A PV system has a capacity factor that strongly depends on the location and the system. The tracking systems have higher capacity factors because they can increase the production with the improved orientation. SAT-A and SAT-B have, indeed, higher capacity factor compared to the fixed mounting system. The bifacial modules have even higher capacity factors thanks to the energy produced from the back of the module. The values in the three cases are shown in Figure 52.

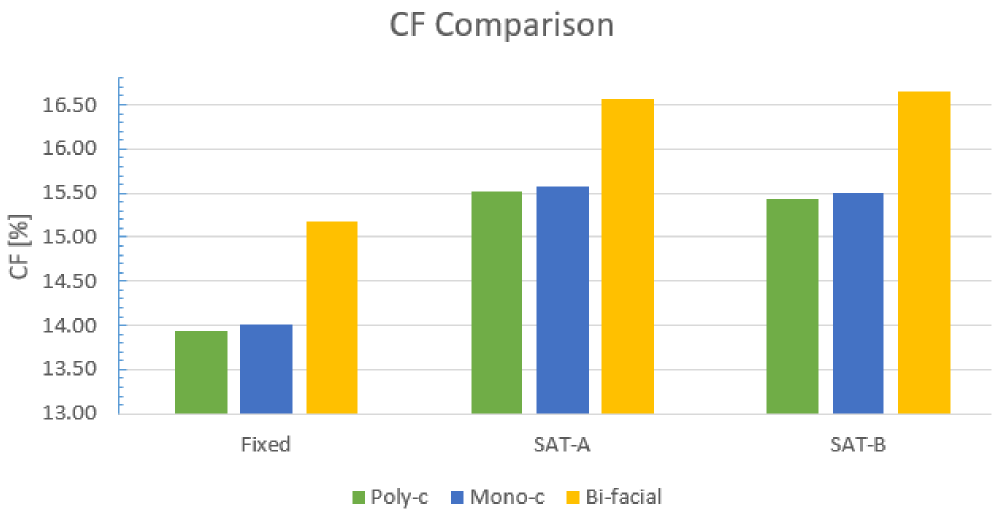

Figure 52 CF comparison

The PR is around 80-81 % for polycrystalline and monocrystalline modules in case of fixed and SAT-B systems. The bifacial modules have higher performances in all the configurations thanks to the energy produced from the rear face. The SAT-A system has a performance ratio which is lower compared to the other systems. The reason is that the formula of the PR has at the denominator the POA Irradiation. The POA Irradiation is maximized for a SAT-A system because the modules are spaced enough to reduce shading and the tracking mechanism tries to always minimize the incidence angle. However, such increase in the POA Irradiation is not compensated by an increase in production. The performance ratios are plotted in Figure 53.

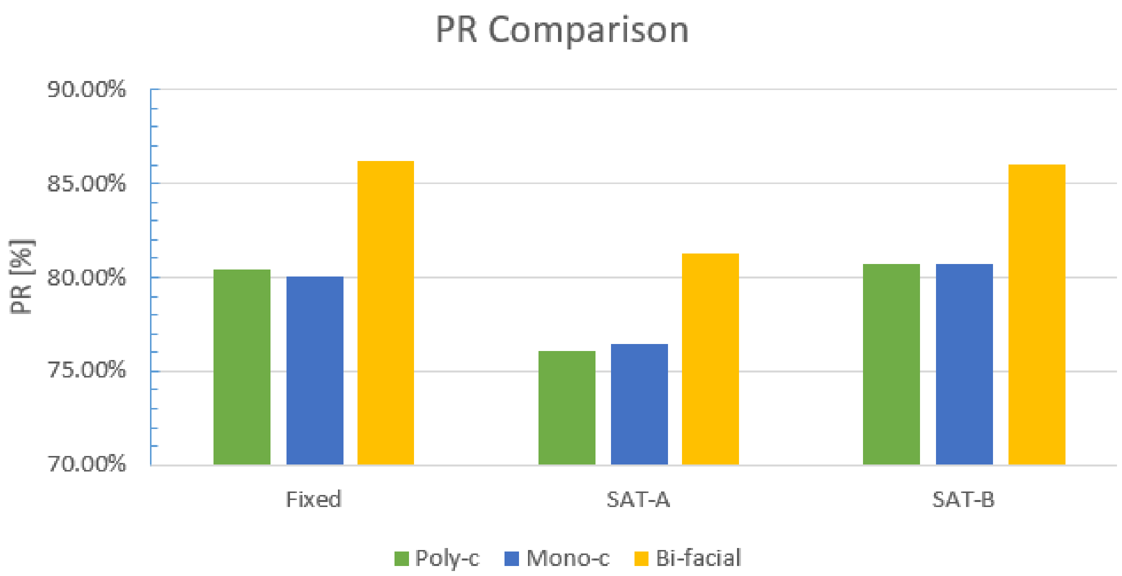

Figure 53 PR comparison

From a technoeconomic point of view, the SAT-B system yielded the best results. The system CAPEX depends on the module chosen: for poly-c, mono-c and bifacial modules it is, respectively, 676.0 €/kW, 709.8 €/kW and 809.7 €/kW with installed capacities of 48950 kW, 51087 kW and 48877 kW. The breakdown is shown in Figure 54. (see *Annex 2* for specific cost).

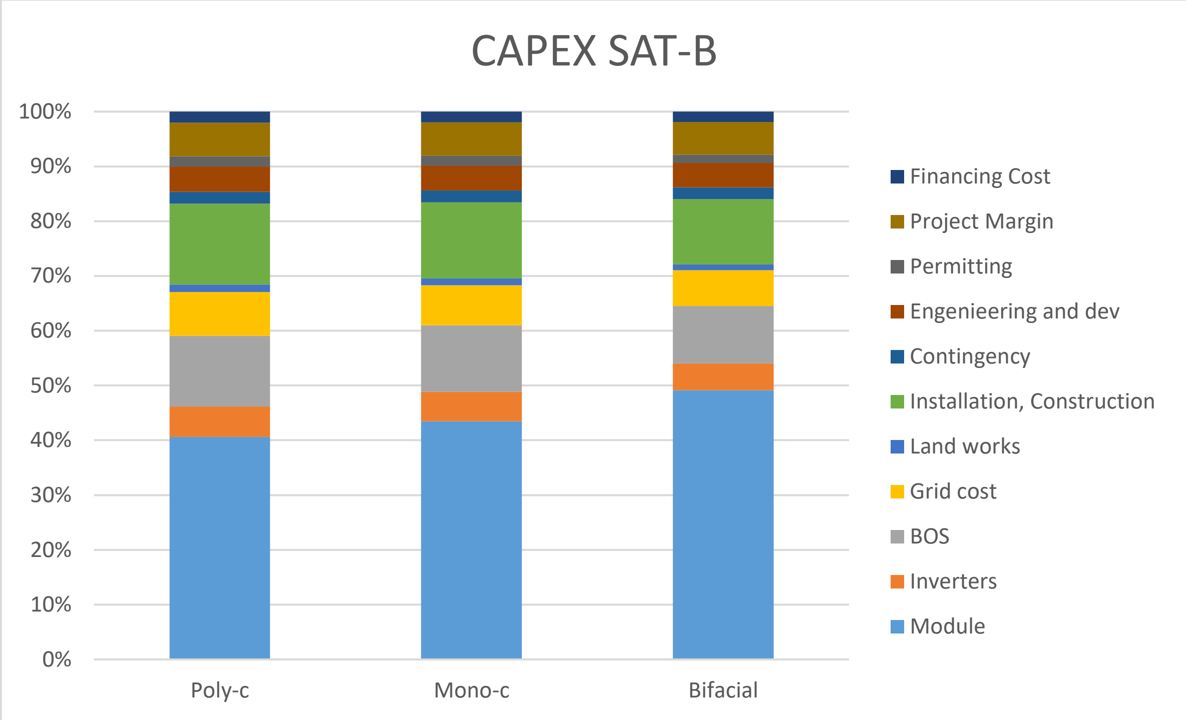

Figure 54 CAPEX breakdown SAT-B (Land rent and string inverter)

The difference in system CAPEX is dependent upon the module cost. The bifacial modules account for 49 % of the total CAPEX of the bifacial system.

In conclusion, the comparison has shown that the SAT-B system had the best IRRs for all three type of modules. The polycrystalline modules had the highest value of 6.65 %, followed by the monocrystalline modules with 6.35 % and lastly, the bifacial ones with a value of 5.99 %. The advantage of the backtracking system in optimising land consumption and energy production has resulted in the higher IRR values. Moreover, the lower cost of polycrystalline modules resulted in an overall CAPEX reduction that led to an improved IRR. The SAT-B system has been chosen for the Cashflow analysis and the Sensitivity analysis.

CASH FLOW

The cashflow diagram, in Figure 55, has been drawn for the SAT-B system with polycrystalline modules.

As previously said, the debt amount has been divided equally during the construction years and the taxation has been considered. The debt term starts from when the PV plant is constructed because there is a stream of revenues to repay the lender. The increase in the equity cashflow (yellow bars) from the 13th is linked to the end of the PPA contract (term assumed of 10 years), which allows all the energy to be sold to the electricity market, which has a higher energy price. The taxation, it being proportional to revenues, shows a step at the 13th year. Moreover, the end of the amortisation shield after 25 years reflects in a descending step between year 27th and year 28th with a correspondent increase of the taxation.

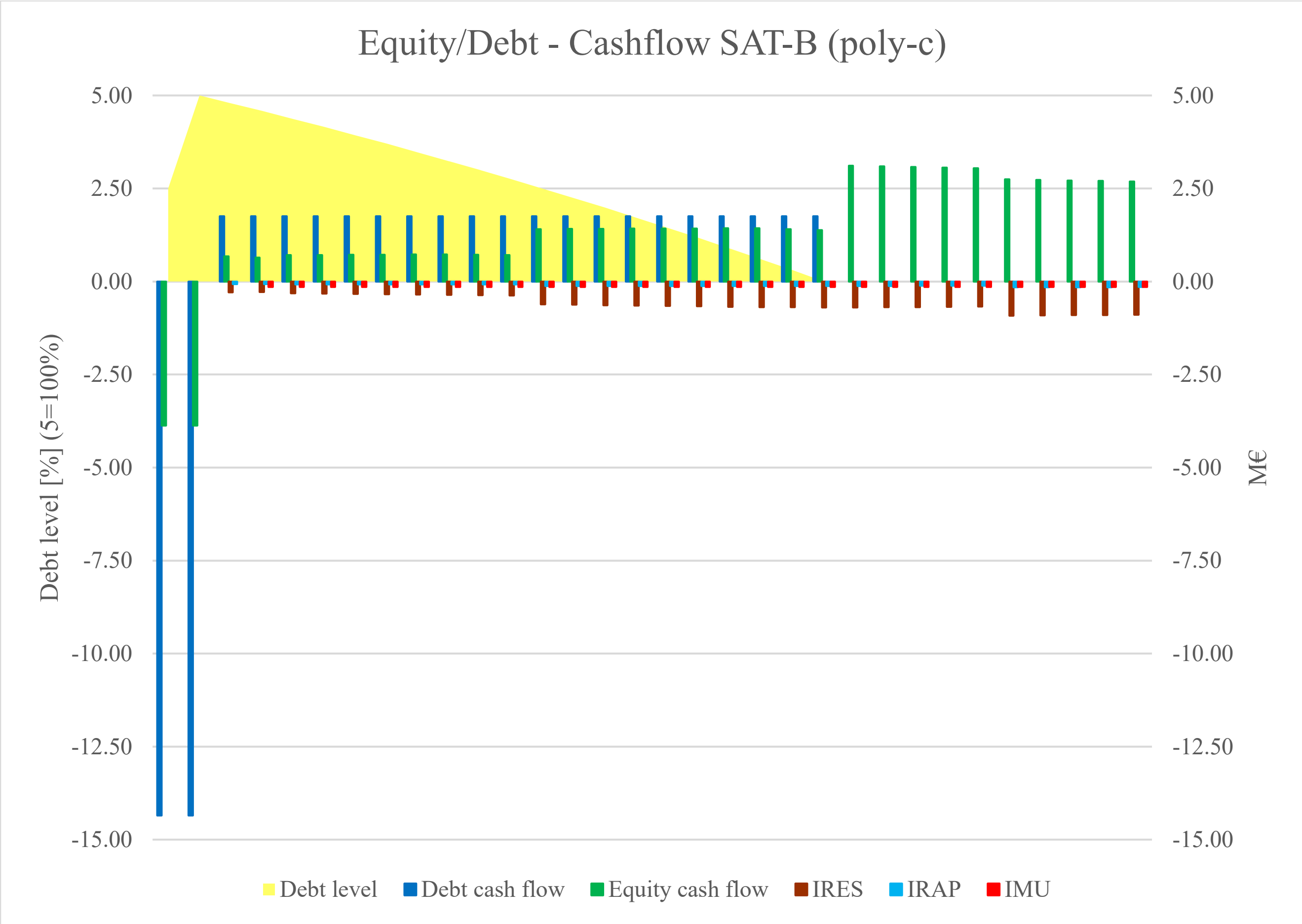

Figure 55 Equity/Debt - Cashflow SAT-B poly-c (debt level values have been multiplied by 5)

The two steps can be better visualized in the next figure, Figure 56. The figure represents the project cashflow, and it represents the 30 years of lifetime. The 3 steps: firstly, at 10 years the PPA ends and the revenues increase due to the higher energy price, secondly, at 20 years the debt is repaid, and the debt service goes to 0, and lastly, at 25 years the tax shield of the amortisation ends, resulting in an increment of the tax amount to pay. One important feature is that the project cashflow is always above the debt service graph, which means that the revenues are sufficient to payback the bank/lender and the equity investors. The difference between the two curves is the equity cashflow of Figure 55.

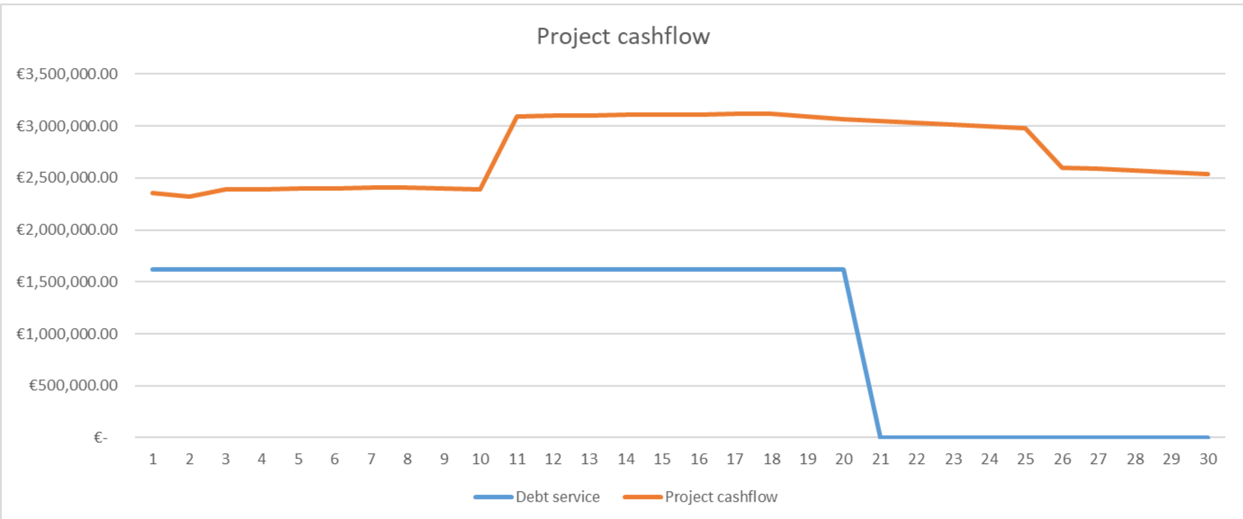

Figure 56 SAT-B Poly-c project cashflow

4.5 Sensitivity Analysis

The IRR and the LCOE of the different system have been calculated with some assumptions on the CAPEX, the OPEX, the wholesale market price, the PPA price and the productivity of the system. The IRR changes if any of the previous listed variables change because it is dependent on both revenues and expenditures. The LCOE instead depends on the expenditures and the energy production. A variation has been assumed for all the parameters in a range between ± 30% and resulting effect on the LCOE and IRR variation has been evaluated. For the OPEX variation, only the O&M cost and the land lease cost have been varied: the insurance depends upon the CAPEX and it changes already when the CAPEX changes. The LCOE sensitivity is shown in Figure 57, Figure 58 and Figure 59, while Figure 60, Figure 61 and Figure 62 show the IRR sensitivity.

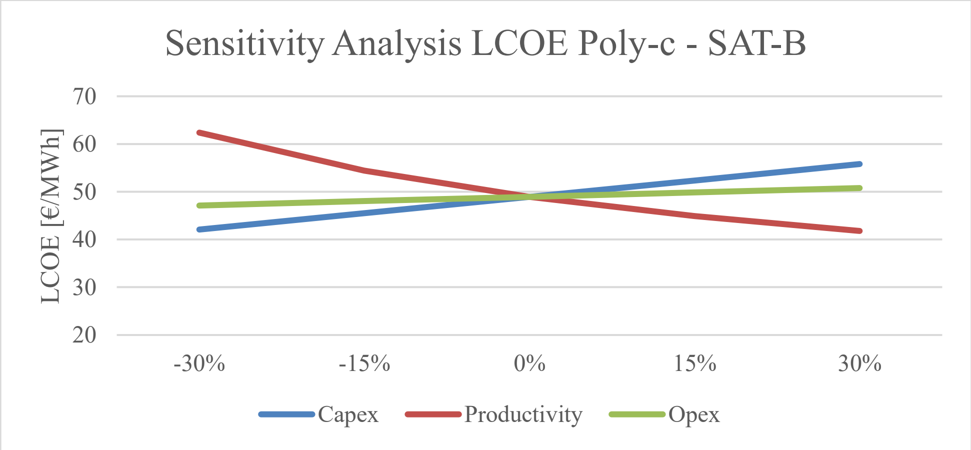

Figure 57 Sensitivity Analysis LCOE - SAT-B - poly-c

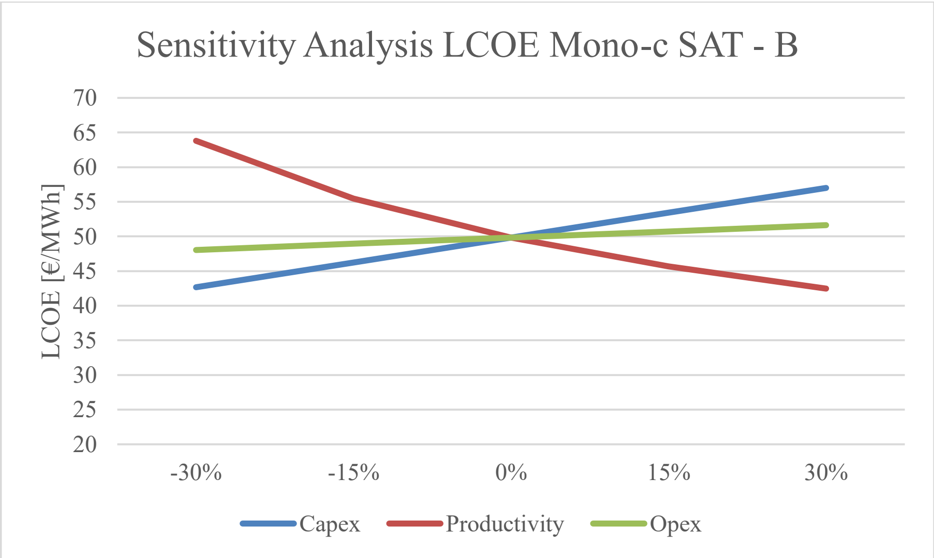

Figure 58 Sensitivity Analysis LCOE - SAT-B - mono-c

The LCOE has a similar variation in all three cases, at decreasing values of productivity the drop in LCOE is higher compared to an increase of the same variable of the same amount. A reverse behaviour occurs for the CAPEX: an increase in CAPEX has a higher effect on the LCOE. The bifacial module should have a CAPEX 10 % lower to have an LCOE lower than the polycrystalline modules. This would translate in a 20 % reduction in the module cost (from 0.33 €/Wp to 0.27 €/Wp) because the bifacial module account for around 49 % of the total CAPEX (Figure 54).

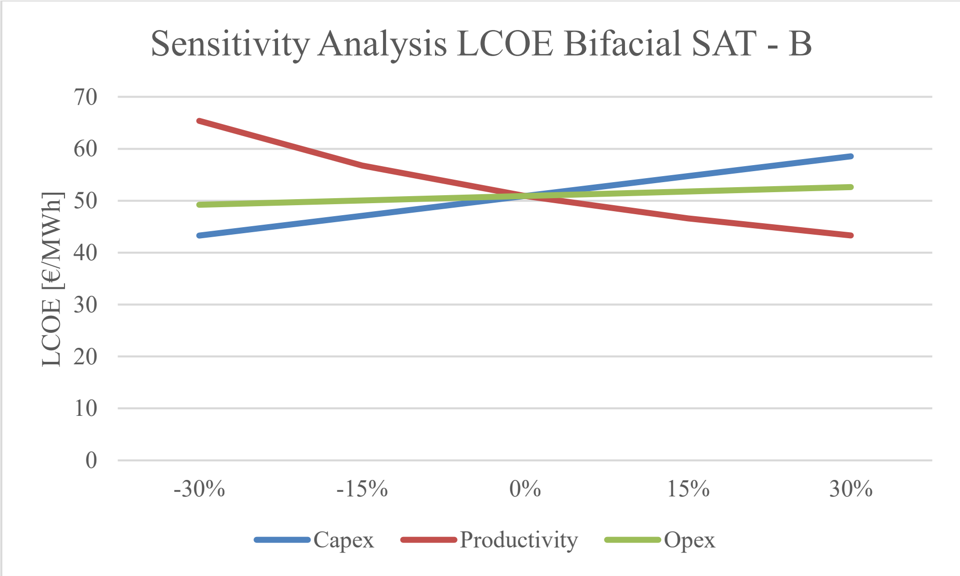

Figure 59 Sensitivity Analysis LCOE - SAT-B bi-facial

For the IRR, for all three modules the trends are similar: the productivity, the CAPEX and the market electricity price have a stronger impact on the IRR. The sensitivity to these parameter changes if the variation is positive or negative.

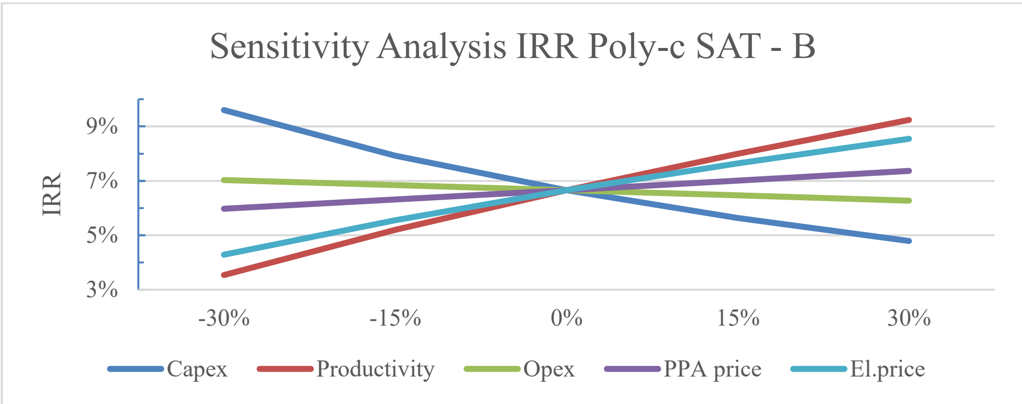

Figure 60 Sensitivity Analysis IRR - SAT-B - poly-c

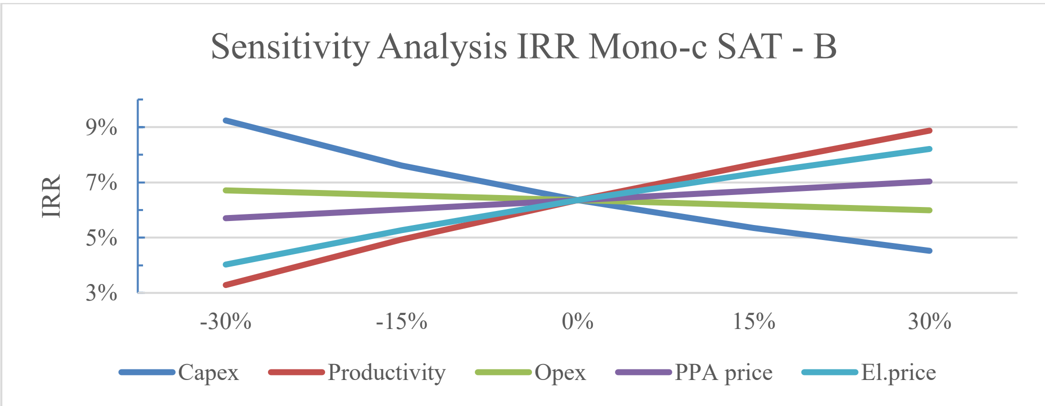

Figure 61 Sensitivity Analysis IRR - SAT-B - mono-c

In all the three cases, in case of negative variation (reduction of production, revenues or increase of capex), the productivity has the strongest impact followed by the electricity price and the CAPEX. In case of a positive variation, the productivity has a stronger impact on the IRR compared to the CAPEX in a 15% variation. Between 15% and 30% variation, the CAPEX has a stronger impact.

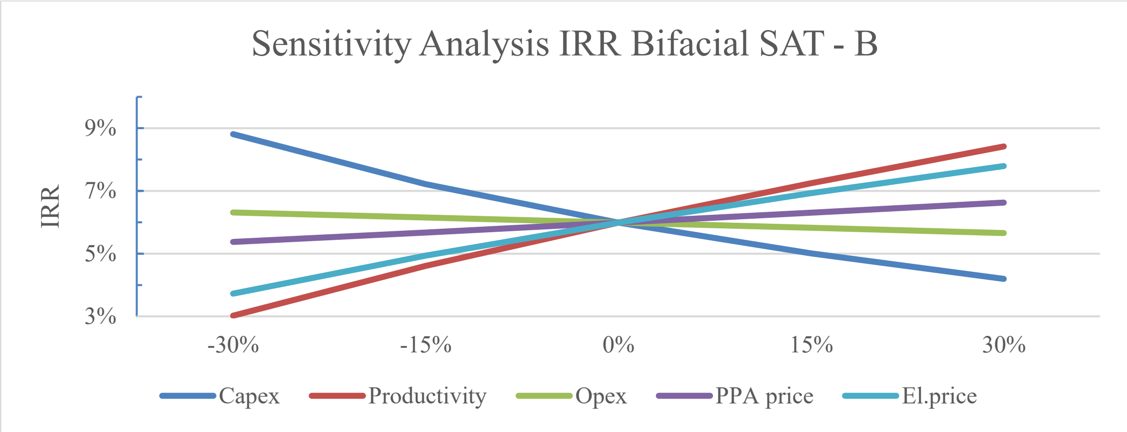

Figure 62 Sensitivity Analysis IRR - SAT-B - Bifacial

For the bifacial backtracking system, the CAPEX cost should decrease of around 10 % (IRR around 6.8%), thus also in this case the modules' cost should reduce 20 %. The bifacial modules are still relatively new on the market. Nevertheless, the PV market trends show a strong potential of cost reduction. In addition, the price of PV modules depends on the EPC contractor chosen: an EPC contractor acquiring large volumes of modules for several projects could receive a discount.

5 CONCLUSIONS

Finally, the thesis conclusions have been derived and are presented in this chapter. Moreover, ideas for future works are given.

This study focused on the utility scale photovoltaic energy market in Italy. Utility scale photovoltaic energy in Italy has reached the stage of grid parity, becoming competitive with fossil fuels without the need of government subsidies.

The first part of the study was aimed at giving the reader a general background on PV technology and PV system deployment in the world and Europe. The PV market is in an ongoing evolution with the final aim of further reducing the cost of the already existent technology, but also to introduce new module technologies with higher efficiencies.

In the second part the Italian market has been analysed to give an overview of the current photovoltaic energy scenario, and to understand what the future development of the photovoltaic energy in the country will be. The Italian PNIEC/INECP defined two important milestones in the renewable energy sector for 2025 and 2030. The final aim is to increase the photovoltaic installed power at more than 50 GW by 2030. The government has also recognized the criticalities in the current permitting process which is long. Indeed, the "Decreto Semplificazioni" released in 2020 is aimed at reducing the time for the permitting process. Another threat that was identified in the renewable energy development consisted of the grid connection capacity. No data is available on the connection capacity at the different points of the grid and investors can be discouraged by the lack of information. Moreover, the land procurement is also another bottleneck given the numerous constraints and different limitations among regions and municipalities.

The feasibility study has shown how the available instruments of the regions can be used to identify suitable areas for the PV installations. In the case study, it was assumed the availability of capacity in the identified ESS, which could not always be the case. The comparison of the three different types of systems has shown the strong advantage of the backtracking system (SAT-B) which achieves a good trade-off between land occupation and yield. Therefore, it could be an extremely optimal solution in countries like Italy where it can be hard to procure a suitable land area. Moreover, the feasibility study has shown that for this site in the north of Italy, the Bi-facial modules are not competitive with the less expensive technologies (poly-c and mono-c). However, the expected cost reduction in the future years or large-volume purchase discounts could change this result.

In conclusion, the Italian PV market is in current evolution, the expected arrival of the PPA will probably boost utility-scale projects. On the other hand, several difficulties arise on the procurement of the land, the grid connection and the long permitting process which could demotivate investment or lead to delays. Nevertheless, the government long-term targets do not pose any political threat to the renewables' deployment.

The financial model used for the analysis accounted also for the tax calculation. Future works would be to refine the economic assumptions such as debt term and debt share. The CAPEX of the system could be refined, and the cost assumption could be verified also contacting EPC contractors to obtain prices effectively used for the components.

Nevertheless, some assumptions could be furtherly refined: the analysis assumed a fixed yearly price for the energy, but PV production happens only during daytime. Therefore, it would be better to consider in the next step of the development a more detailed power price curve (accounting for the hourly variations) and the hourly PV production. In addition, the long-term electricity price forecast of the TSO could deviate from the real price trends.

On the technical design, once the site is identified the design should be detailed. The azimuth could be optimized as well considering both the power curve variation and the PV production curve. It could also be interesting to test the integration of a storage system to assess the possible benefits deriving from grid services (frequency regulation, etc…) and from the power price curve (market price could be higher in the evening).

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APPENDICES

Additional information is provided in the appendix.

ANNEX 1

The TSO average costs are listed in the following table

category	Type	Price [k€/km]
OHL	380 kV DT	760
	380 kV ST	500
	220 kV DT	450
	220 kV ST	350
	120-150 kV DT	410
	120-150 kV ST	270
Cable	380 kV - 1200 MVA	3,250
	220 kV 550 MVA	2,850
	220 kV - Cu- 400MVA	2,050
	220 kV - Al - 400 MVA	1,950
	120-150 kV Cu 250 MVA	1,800
	120-150 kV AL 250 MVA	1600

Stations	Type	Cost [k€]
Station - AIS	Smist 380 kV ds	3,200
	Stallo 380 kV ds - AIS nrm	980
	Stallo 380 kV ds - AIS rid	468
	Smist 380 kV ss	1891
	Stallo 380 kV ss - AIS nrm	958
	Stallo 380 kV ss - AIS rid	446
	Smist 220 kV ds	2550

	Stallo 220 kV ds - AIS nrm	650
	Stallo 220 kV ds - AIS rid	336
	Smist 220 kV ss	1736
	Stallo 220 kV ss - AIS nrm	637
	Stallo 220 kV ss - AIS rid	323
	Smist 132 - 150 kV ds	2350
	Stallo 132 - 150 kV ds - AIS nrm	450
	Stallo 132 - 150 kV ds - AIS rid	236
	Smist 132 - 150 kV ss	1780
	Stallo 132 - 150 kV ss - AIS nrm	439
	Stallo 132 - 150 kV ss - AIS rid	225
Station - GIS	Smist 380 kV ds -GIS	4850
	Stallo 380 kV ds - GIS nrm	2,250
	Stallo 380 kV ds - GIS rid	1093
	Smist 220 kV ds GIS	3450
	Stallo 220 kV ds - GIS nrm	1300
	Stallo 220 kV ds - GIS rid	681
	Smist 132 - 150 kV ds GIS	3280
	Stallo 132 - 150 kV ds - GIS nrm	950
	Stallo 132 - 150 kV ds - GIS rid	507

Financial model CAPEX calculation tab and cost references

CAPEX Calculation example (SAT-B Bifacial with string inverter)					
Subsystem	Unitary Cost			Total Cost	
	Name	Value	Units	Value	Units
PV components	Module	330.00	€/kWp	16129443	€
	Inverters	35.00	€/kW_AC	1624000	€
	Structure	100.00	€/kWp	4887710	€
	BOS	70.00	€/kWp	3421397	€
	MV/LV ESS	40.00	€/kVA_AC	1856000	€
Subtotal PV system		571.20	€/kWp	27918550	€
Grid cost	MV Line	100454.82	€/km	381728.3159	€
	MV/HV ESS	1630000.00	€	1630000.00	€
	HV line	364038.05	€/km	72807.61	€
	Connection TSO	67977.62	€	67977.62	€
Grid cost subtot		44.04	€/kWp	2152513.549	€
Land	Land Acquisition	3.50	€/m2	2450000	€
	Land works	0.50	€/m2	350000	€
Land cost subtot		57.29	€/kWp	2800000	€
Installation, Construction		80.00	€/kWp	3910168	€
Contingency		2.00	%	750637.3785	€
Direct cost		767.88	€/kWp	37531868.93	€
Engenieering and dev		4.00	%	1563827.872	€
EPC cost		799.88	€/kWp	39095696.8	€
Permitting	STMG request	2500	€	2500	€
	STMD elaboration	12850.00	€	12850	€
	AU &other	10	€/kWp	488771	€

Permitting subtot		10.31	€/kWp	504121.00	€
Project Margin		5.00	%	2084200.937	€
Cost BF		852.8333051	€/kWp	41684018.74	€
Financing Cost		2.00	%	677788.92	€
Total Capex		866.7005133	€/kWp	42361807.66	€

Inverter	Central	0.025	€/WAC
	String	0.035	€/WAC
Module	Bi-facial	0.33	€/W
	poly-c	0.22	€/W
	mono-c	0.25	€/W
Structure	Tracking	0.10	€/W
	Fixed	0.08	€/W
BOS Components	Tracking	0.07	€/W
	Fixed	0.07	€/W
MV/HV ESS	32 MVA	1,530,000.00	€/n
	50 MVA	1,630,000.00	€/n
	80 MVA	1,730,000.00	€/n
	126 MVA	2,450,000.00	€/n
Trafo LV/MV		40.00	€/kVA_AC
MVLine	10 MVA	40,000.00	€/km
HV Line	250 MVA	1,000,000.00	€/km
Land preparation		0.50	€/m2

Modules and Inverter Datasheets

TALESUN

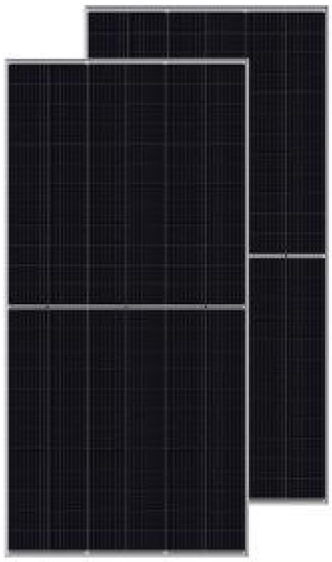
BISTAR

TP6F72M
TP6F72M(H)

144 half-cell

395 - 415W

9BB half-cut mono perc



KEY FEATURES

9BB half-cut cell technology
New circuit design, lower internal current, lower Rs loss

Significantly lower the risk of hot spot
Special circuit design with much lower hot spot temperature

Lower LCOE
2% more power generation, lower LCOE

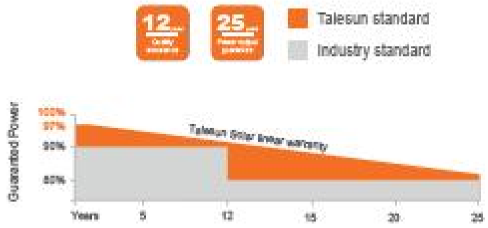
Excellent Anti-PID performance
2 times of industry standard Anti-PID test by TUV SUD

IP68 junction box
High waterproof level

SYSTEM & PRODUCT CERTIFICATES

- IEC 61215 / IEC 61730 / UL 1703
- ISO 9001: 2015 Quality Management System
- ISO 14001: 2015 Environment Management System
- ISO 45001: 2018 Occupational Health and Safety Management Systems

PERFORMANCE WARRANTY



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TALESUN

ELECTRICAL PARAMETERS

Performance at STC (Power Tolerance 0 ~ +3%)

Maximum Power (Pmax/W)	395	400	405	410	415
Operating Voltage (Vmpp/V)	40.3	40.5	40.7	40.9	41.1
Operating Current (Impp/A)	9.81	9.89	9.96	10.04	10.11
Open-Circuit Voltage (Voc/V)	48.9	49.1	49.3	49.5	49.8
Short-Circuit Current (Isc/A)	10.35	10.43	10.50	10.58	10.66
Module Efficiency ηm(%)	19.6	19.9	20.1	20.4	20.6

Performance at NMOT

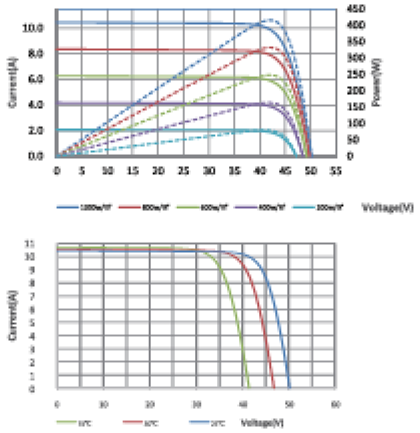
Maximum Power (Pmax/W)	294.6	298.5	302.1	305.9	309.5
Operating Voltage (Vmpp/V)	37.5	37.7	37.9	38.0	38.3
Operating Current (Impp/A)	7.85	7.93	7.98	8.04	8.09
Open-Circuit Voltage (Voc/V)	45.5	45.7	45.9	46.1	46.4
Short-Circuit Current (Isc/A)	8.35	8.42	8.48	8.54	8.60

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5 NMOT: Irradiance at 800W/m², Ambient Temperatue 20°C, Air Mass AM1.5, Wind Speed 1m/s

MECHANICAL SPECIFICATION

Cell Type	Mono-Crystalline Silion (9Busbar)
Cell Dimensions	158.75*158.75mm (6inches)
Cell Arrangement	144 (6*24)
Weight	22.5kg (49.6lbs)
Module Dimensions	2008*1002*35mm (79.06*39.45*1.38inches)
Cable Length (Portrait)	(+)300mm (11.81inches) / (-)300mm (11.81inches)
Cable Length (Landscape)	(+)1200mm (47.24inches) / (-)1200mm (47.24inches)
Cable Cross Section Size	4mm² (0.006inches²)
Front Glass	3.2mm High Transmission, Tempered Glass
No. of Bypass Diodes	3/6
Packing Configuration(1)	31pcs/carton, 682pcs/40hq
Packing Configuration(2)	31+4pcs/carton, 726pcs/40hq
Frame	Anodized Aluminium Alloy
Junction Box	IP68

I-V CURVE



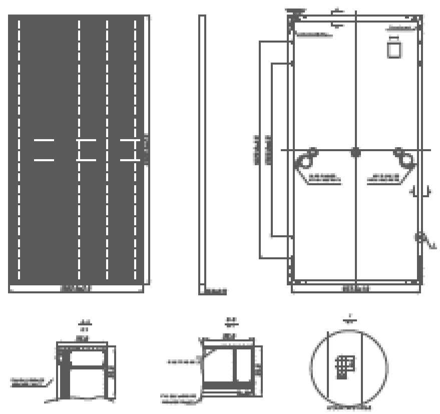
OPERATING CONDITIONS

Maximun System Voltage	1000V/1500V/DC(IEC)
Operating Temperature	-40°C ~ +85°C
Maximun Series Fuse	20A
Static Loading	5400pa
Conductivity at Ground	≤0.1Ω
Safety Class	II
Resistance	≥100MΩ
Connector	MC4 Compatible

TEMPERATURE COEFFICIENT

Temperature Coefficient Pmax	-0.36%/°C
Temperature Coefficient Voc	-0.26%/°C
Temperature Coefficient Isc	+0.043%/°C
NMOT	43±2°C

TECHNICAL DRAWINGS



The specification and key features described in this datasheet may deviate slightly and are not guaranteed. Due to ongoing innovation, R&D enhancement, Suzhou Talesun Solar Technologies Co., Ltd. reserves the right to make any adjustment to the information described herein at any time without notice. Please always obtain the most recent version of the datasheet which shall be duly incorporated into the binding contract made by the parties governing all transactions related to the purchase and sale of the products described herein.

TALESUN

Figure 63 Talesun TP6F72M-405 [89]

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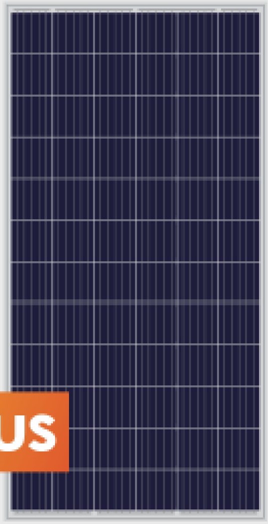
YOUR BEST PV SUPPLIER

Alibaba TOP 1 Suppliers
Trade Assurance Supplier



plus

what we offer
YOUR BEST PV SUPPLIER

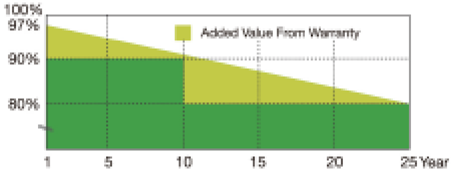
BSM355P-72/5BB
Polycrystalline 72 cells 335w-355w

1 Reliable Quality

- Positive power tolerance: 0~+5W
- 100% EL double-inspection ensures modules are defects free
- Modules binned by current to improve system performance
- Potential Induced Degradation (PID) Resistant

2 Superior Warranty

- 10-year product warranty
- 25-year linear power output warranty



3 Key features

- Polycrystalline modules designed for commercial and solar farm grid-tied applications
- High power output and highest conversion efficiency
- Anti-reflective and anti-soiling surface reduces power loss from dirt and dust
- Outstanding performance in low-light irradiance environments
- Excellent mechanical load resistance: Certified to withstand high wind loads (2400Pa) and snow loads (5400Pa)
- High salt and ammonia resistance certified by TÜV SUD

+86-158-5821-3997
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www.bluesunpv.com

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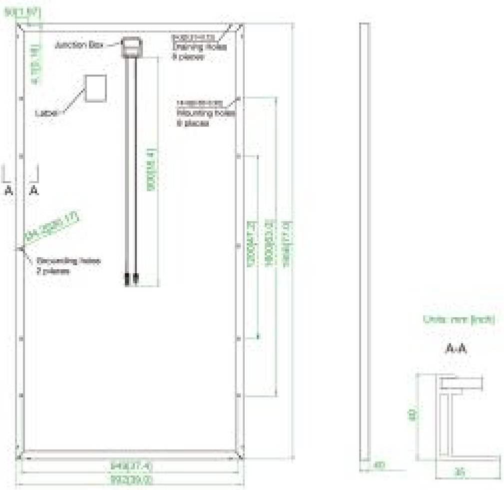
Mechanical Parameters

Cell (mm)	Poly 156x156
Weight (kg)	21 (approx)
Glass Thickness	4 / 3.2mm
Dimensions (L×W×H) (mm)	1956×992×35/40
Cable Cross Section Size (mm^2)	4
No. of Cells and Connections	72 (6x12)
Junction Box	IP67, 3 diodes
Connector	MC4 Compatible
Packaging Configuration	26 Per Pallet

Working Conditions

Maximum System Voltage	DC 1000V/1500V (IEC)
Operating Temperature	-40℃~+85℃
Maximum Series Fuse	20A
Maximum Static Load, Front (e.g., snow and wind) Maximum Static Load, Back (e.g., wind)	5400Pa (112 lb/ft^2) 2400Pa (50 lb/ft^2)
NOCT	45±2℃
Application Class	Class A

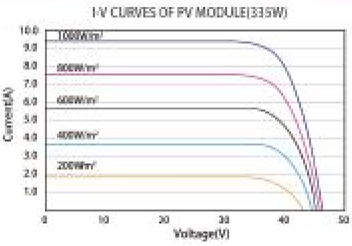
Engineering Drawings



Electrical Parameters

Module	BSM335P-72	BSM340P-72	BSM345P-72	BSM350P-72	BSM355P-72
Peak Power Watts-P_{MAX} (Wp)*	335	340	345	350	355
Power Output Tolerance-P_{MAX} (W)	0 ~ +5				
Maximum Power Voltage-V_{MPP} (V)	37.9	38.2	38.4	38.5	38.7
Maximum Power Current-I_{MPP} (A)	8.84	8.90	9.00	9.09	9.17
Open Circuit Voltage-V_{OC} (V)	46.3	46.5	46.7	46.9	47.0
Short Circuit Current-I_{SC} (A)	9.36	9.45	9.50	9.60	9.69
Module Efficiency η_m (%)	17.3	17.5	17.8	18.0	18.3
Temperature Coefficient of Isc (αIsc)	+0.058%/℃				
Temperature Coefficient of Voc (βVoc)	-0.330%/℃				
Temperature Coefficient of Pmax (γPmp)	-0.410%/℃				
STC	Irradiance 1000W/m^2, Cell Temperature 25℃, Air Mass 1.5				

I-V Curve



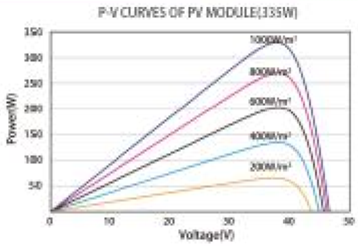
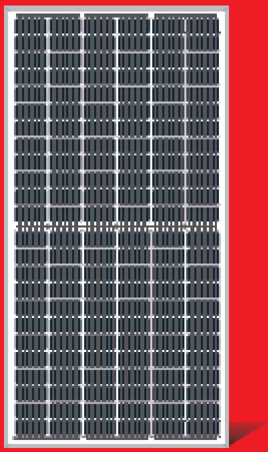


Figure 64 BlueSun BSM355p-72 [90]

LR4-72HBD
425~455M

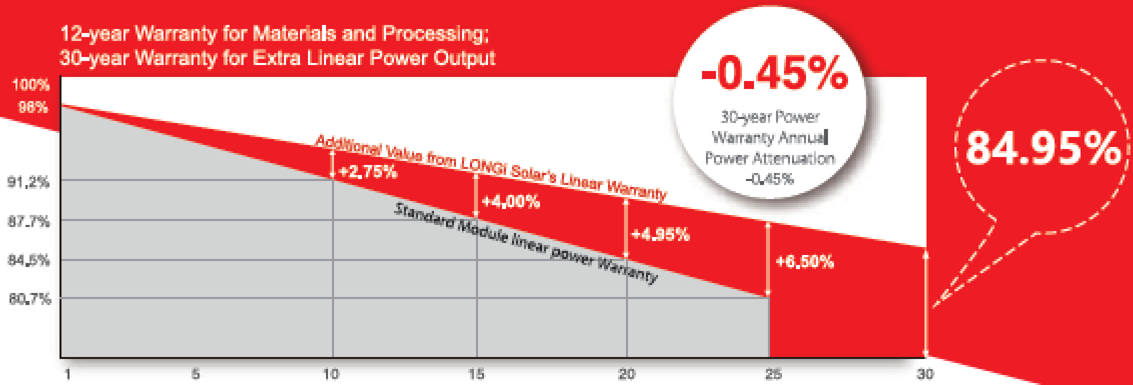
Hi-MO 4
NEW

High Efficiency
Low LID Bifacial PERC with
Half-cut Technology



*Both 6BB & 9BB are available

12-year Warranty for Materials and Processing;
30-year Warranty for Extra Linear Power Output



Complete System and Product Certifications

IEC 61215, IEC 61730, UL 61730

ISO 9001:2008: ISO Quality Management System

ISO 14001: 2004: ISO Environment Management System

TS62941: Guideline for module design qualification and type approval

OHSAS 18001: 2007 Occupational Health and Safety

* Specifications subject to technical changes and tests. LONGi Solar reserves the right of interpretation.

Front side performance equivalent to conventional low LID mono PERC:
- High module conversion efficiency (up to 20.9%)
- Better energy yield with excellent low irradiance performance and temperature coefficient
- First year power degradation <2%

Bifacial technology enables additional energy harvesting from rear side (up to 25%)

Glass/glass lamination ensures 30 year product lifetime, with annual power degradation < 0.45%, 1500V compatible to reduce BOS cost

Solid PID resistance ensured by solar cell process optimization and careful module BOM selection

Reduced resistive loss with lower operating current

Higher energy yield with lower operating temperature

Reduced hot spot risk with optimized electrical design and lower operating current

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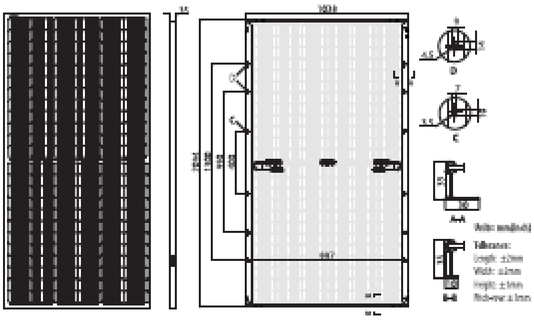
20200401V11

LR4-72HBD **425~455M**

Design (mm)



Mechanical Parameters

Cell Orientation: 144 (6×24)
Junction Box: IP68, three diodes
Output Cable: 4mm², 300mm in length, length can be customized
Glass: Dual glass 2.0mm coated tempered glass
Frame: Anodized aluminum alloy frame
Weight: 27.5kg
Dimension: 2094×1038×35mm
Packaging: 30pcs per pallet 150pcs per 20'GP 660pcs per 40'HC

Operating Parameters

Operational Temperature: -40℃ ~ +85℃
Power Output Tolerance: 0 ~ +5 W
Voc and Isc Tolerance: ±3%
Maximum System Voltage: DC1500V (IEC/UL)
Maximum Series Fuse Rating: 25A
Nominal Operating Cell Temperature: 45±2℃
Safety Class: Class Ⅱ
Fire Rating: UL type 3
Bifaciality: Glazing 70±5%

Electrical Characteristics

Test uncertainty for Pmax: ±3%

Model Number	LR4-72HBD-425M		LR4-72HBD-430M		LR4-72HBD-435M		LR4-72HBD-440M		LR4-72HBD-445M		LR4-72HBD-450M		LR4-72HBD-455M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	425	317.4	430	321.1	435	324.9	440	328.6	445	332.3	450	336.1	455	339.8
Open Circuit Voltage (Voc/V)	48.7	45.6	48.9	45.8	49.1	45.9	49.2	46.0	49.4	46.2	49.6	46.4	49.8	46.6
Short Circuit Current (Isc/A)	11.22	9.06	11.30	9.13	11.36	9.18	11.45	9.25	11.52	9.30	11.58	9.36	11.65	9.41
Voltage at Maximum Power (Vmp/V)	40.4	37.7	40.6	37.9	40.8	38.0	41.0	38.2	41.2	38.4	41.4	38.6	41.6	38.8
Current at Maximum Power (Imp/A)	10.52	8.42	10.60	8.49	10.66	8.54	10.73	8.60	10.80	8.65	10.87	8.70	10.93	8.76
Module Efficiency(%)	19.6		19.8		20.0		20.2		20.5		20.7		20.9	

STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25℃, Spectra at AM1.5

NOCT (Nominal Operating Cell Temperature): Irradiance 800W/m², Ambient Temperature 20℃, Spectra at AM1.5, Wind at 1m/S

Electrical characteristics with different rear side power gain (reference to 445W front)

Pmax /W	Voc/V	Isc /A	Vmp/V	Imp /A	Pmax gain
467	49.4	12.09	41.2	11.34	5%
490	49.4	12.67	41.2	11.88	10%
512	49.5	13.24	41.3	12.42	15%
534	49.5	13.82	41.3	12.96	20%
556	49.5	14.40	41.3	13.50	25%

Temperature Ratings (STC)

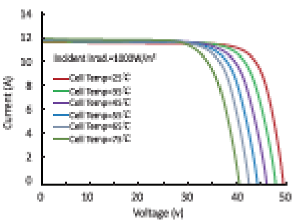
Temperature Coefficient of Isc	+0.050%/℃
Temperature Coefficient of Voc	-0.284%/℃
Temperature Coefficient of Pmax	-0.350%/℃

Mechanical Loading

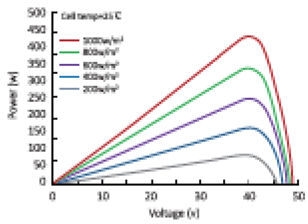
Front Side Maximum Static Loading	5400Pa
Rear Side Maximum Static Loading	2400Pa
Hailstone Test	25mm Hailstone at the speed of 23m/s

I-V Curve

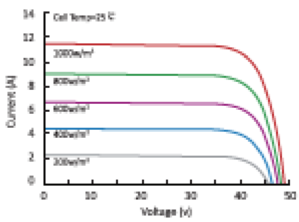
Current-Voltage Curve (LR4-72HBD-440M)



Power-Voltage Curve (LR4-72HBD-440M)



Current-Voltage Curve (LR4-72HBD-440M)



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Note: Due to continuous technical innovation, R&D and improvement, technical data above mentioned may be of modification accordingly. LONGi have the sole right to make such modification at anytime without further notice; Demanding party shall request for the latest datasheet for such as contract need, and make it a consisting and binding part of lawful documentation duly signed by both parties.

20200401V11

Figure 65 Bifacial module Longi Solar [91]

Smart String Inverter

SUN2000-100KTL-USH0

Smart

- 12 strings intelligent monitoring and fast trouble-shooting
- Power Line Communication (PLC) supported
- Smart I-V Curve Diagnosis supported

Efficient

- Max. efficiency 99.0%
- CEC. efficiency 98.5%
- 6 MPPT per unit, effectively reducing string mismatch

Safe

- DC AFCI compliant to UL 1699B Type I
- Residual Current Monitoring Unit (RCMU) integrated inside
- Fuse free design

Reliable

- Natural cooling technology
- Protection degree of Type 4X
- Type II surge arresters for both DC and AC

Always Available for Highest Yields

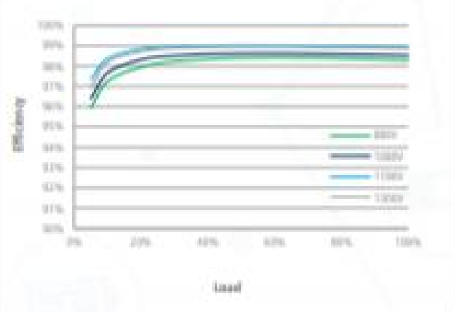
solar.huawei.com/na

Smart String Inverter (SUN2000-100KTL-USH0)

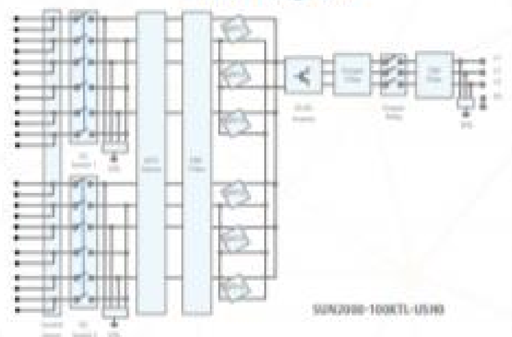
HUAWEI

Technical Specifications	SUN2000-100KTL-USH0
	Efficiency
Max. Efficiency	99.0%
CEC Efficiency	98.5%
	Input
Max. Input Voltage	1,500 V
Max. Current per MPPT	22 A
Max. Short Circuit Current per MPPT	40 A
Start Voltage	650 V
MPPT Operating Voltage Range	600 V – 1,500 V
Full Power MPPT Voltage Range	880 V – 1,300 V
Number of Inputs	12
Number of MPP Trackers	6
	Output
AC Active Power	100,000 W
Max. AC Apparent Power	100,000 VA @40°C, 90,000 VA @50°C
Max. AC Active Power (cosφ=1)	100,000 W
Rated Output Voltage	800 V, 3W + PE
Rated AC Grid Frequency	60 Hz
Rated Output Current	72.9 A
Max. Output Current	72.9 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	< 3%
	Protection
DC Arc Fault Circuit Interrupter	Yes, compliant to UL 1699B Type I
Input-side Disconnection Device	Yes
Anti-islanding Protection	Yes
DC Reverse-polarity Protection	Yes
AC Overcurrent Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
Residual Current Monitoring Unit	Yes
	Communication
Display	LED Indicators, Bluetooth + APP
USB	Yes
RS485	Yes
Power Line Communication (PLC)	Yes
	General
Dimensions (W x H x D)	1,075 x 605 x 310 mm (42.3 x 23.8 x 12.2 inch)
Weight (with mounting plate)	77 kg (169.8 lb.)
Operating Temperature Range	-25°C – 60°C (-13°F – 140°F)
Cooling Method	Natural Convection
Relative Humidity	0 – 100%
DC Connector	Staubli MC4
AC Connector	Waterproof Cable Connector + Terminal Clamps
Protection Degree	Type 4X
Topology	Transformerless
	Standard Compliance (more available upon request)
Certificate	UL 1741, UL 1699B, UL 62109-1, CSA C22.2 #107.1-16, FCC Part 15
Grid Code	IEEE 1547, IEEE 1547a

Efficiency Curve



Circuit Diagram



Always Available for Highest Yields

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Figure 66 Datasheet String Inverter [92]