The True Competitiveness of Solar PV

A European Case study

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European PV Technology and Innovation Platform Steering Committee
PV LCOE and Competitiveness Working Group

Final report 29.3.2017

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Disclaimer

"The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727272"

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1. INTRODUCTION

Photovoltaics (PV) is poised to become the cheapest form of electricity production in most European countries during the coming years. It has already reached a cost level that makes it competitive in several market segments in several European countries. The acceleration of module price decrease in the second half of 2016 has been considered in this report.

The cost of generating electricity from PV or "Levelised Cost of Electricity" (LCOE) has already reached parity with retail electricity prices in many European market segments, residential, commercial or industrial all over Europe. However, the notion of competitiveness for PV installations and especially the concept of "grid parity" is not always well defined.

In this report, the competitiveness of PV electricity in key European countries for PV prosumers has been studied. It assumes that PV competitiveness comes from a clear understanding of the self-consumption characteristics: a part of the PV electricity is locally consumed and reduces the electricity bill while the excess electricity is injected into the grid and receives a fair price. The ratio of self-consumption is at the core of the prosumers' competitiveness, with different values depending on the segment considered.
In addition, to approach an ideal and fair situation for all stakeholders, the retail electricity price includes only the variable components in the customer bill since the fixed monthly or annual fees cannot be saved by the prosumer. While such a tariff for grid costs will evolve in a near future, this report has considered the current situation, which will have to be scrutinised in the coming months and years. In that respect, self-consumed electricity is valued at the variable retail electricity price, whereas the surplus production will be valued at the wholesale electricity price or part of it.

As a conclusion, the "True grid parity" or the competitiveness for PV installations under a fair self-consumption framework has already been reached in many European countries such as Germany and Italy. To reach this conclusion, realistic parameters have been considered, such as realistic Weighted Average Costs of Capital (WACC) and self-consumption ratios. In moderate irradiation and low electricity price markets like Finland and Sweden, true grid parity in rooftop segments will be reached most probably within about 5 years without any subsidies.

The work for this report has been carried out under the framework of the European PV Technology and Innovation Platform (ETIP PV). The first version of this report has been published as a scientific paper during the 2016 EU PVSEC conference in Munich, Germany [1].

2. COMPETITIVENESS AND GRID PARITY, TWO SIDES OF THE SAME MEDAL

Photovoltaics (PV) has become one of the cheapest forms of electricity production during the past few years, in Europe and globally. With some tenders granted below 3 US dollar cents/kWh in 2016, PV is now in some regions the most competitive unsubsidised form of electricity. However, the cost of production for PV electricity doesn't guarantee that PV is truly competitive with other sources of electricity. This question has been debated for years and was analysed in various ways that we will review in this document. The final goal remains to show how competitive PV has become and how competitive it will be in the coming years in key countries in Europe.

What is grid parity?

"Grid parity (or socket parity) occurs when an alternative energy source can generate power at a levelised cost of electricity (LCOE) that is less than or equal to the price of purchasing power from the electricity grid".

Since solar PV can be installed on houses and buildings, this definition of the competitiveness of PV seems natural and logical. The price of PV electricity at which PV becomes cheaper than the price of electricity paid by consumers is then referred as "grid parity". Even though competitiveness implies to the state where it is possible to produce electricity with PV below the price of electricity that is consumed by electricity consumers, this is just a first step toward a true meaning of competitiveness.

The cost of PV generation has already reached this "grid parity" with retail electricity price in many markets and will continue to reach it in many others. However, the concept of grid parity is not always well defined, and moreover don't give a clear indication whether PV electricity can be considered as competitive.

With that aim, this report investigates what is the true competitiveness of PV regarding retail electricity prices. This report distinguishes itself from other reports in the same topic by several factors. First of all, the PV electricity value was calculated taking only direct self-consumption into account and no other support schemes or subsidies needed. By considering self-consumption, the report targets to analyse how the utilised ratio of self-consumption of PV production affects the true grid parity. The electricity surplus production, which is not self-consumed by the prosumer, is priced depending on the moment it is fed into the grid. This price is often the electricity wholesale price minus a small administrative fee. The value of PV electricity includes the value of the self-consumption electricity plus the value of the fed-in electricity to the grid.

Additionally, the competitiveness is defined by comparing the value of PV electricity with retail electricity price but only the variable part in the customer bill. The fixed annual or monthly power-related fees the customer has to pay cannot be saved by self-consumption, and therefore must be excluded from the comparison. The graph below illustrates the electricity bill saving by using a PV system for self-consumption in ideal case and the real case. It is clear that in reality, even when the electricity generated by PV can cover 50% of electricity demand, the percentage of saving in final electricity bill will be less than 50% due to some non-compensated grid/ power related fees.

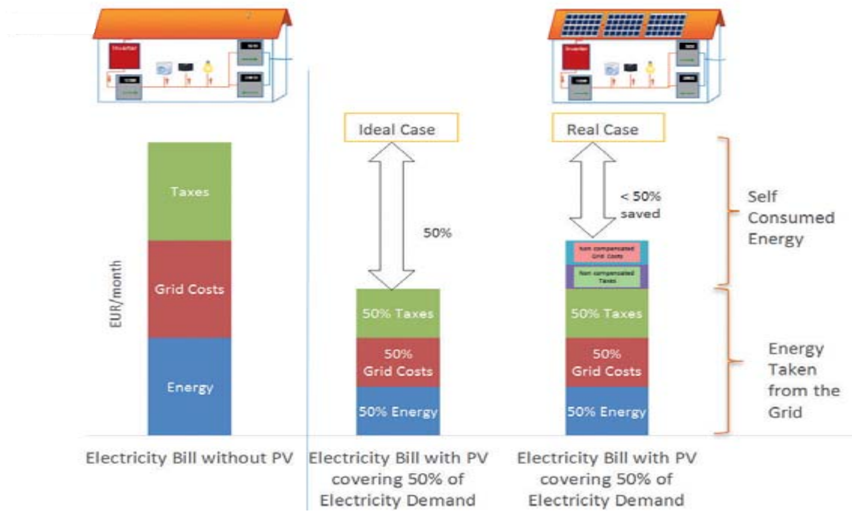

Figure 1. Electricity bill saving in ideal and realistic case – Source : Becquerel Institute

Across many primary PV markets in Europe, as shown in below graph, the percentage of saving on electricity bill can only be as high as 99%. In countries like Spain or Germany, the compensation ratio stays at a level relatively lower than market average.

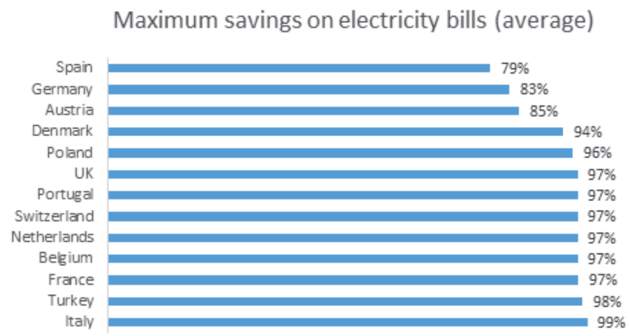

Figure 2. Maximum savings on electricity bills (average) – Source : Becquerel Institute

The outcome of the comparison between LCOE and the PV electricity value will determine the time when true grid parity happens across PV segmentations in main European countries.

3. METHODOLOGY

3. METHODOLOGY

3.1. Definition of competitiveness

The true competitiveness of PV has been assessed in this report by comparing the PV electricity value given the self-consumption ratios at different levels (from 25% up to 100%) with the PV LCOE calculated for every year until 2050 taking into account the fluctuation trends in all PV LCOE inputs.

If PV LCOE value in year t > the PV electricity value => PV is not competitive yet in year t
If PV LCOE value in year t ≤ the PV electricity value => PV is competitive already in year t

This report will consider the fluctuation in CAPEX, OPEX, WACC, and annual yield when identifying whether a PV market in a certain country is reaching grid parity or not.

3.2. Valuing PV electricity

The average PV electricity value in this report is defined as the sum of two components. The first component is electricity cost that prosumer saves by self-consuming electricity produced by its own PV system. This one is the result of multiplying self-consumption ratio with retail electricity price. The second component is the value of the surplus electricity fed into the grid.

The formula to calculate the average PV electricity value is presented as below in equation (1):

$$P_{ave}=SC*P_{retail}+(1-SC)*P_{feed\text{-}in} \quad (1)$$

where:

SC = ratio of self-consumption of the PV production
P_{retail} = variable retail electricity price
$P_{feed\text{-}in}$ = wholesale or other value of the electricity fed into the grid

P_{retail} excludes any fixed monthly or annual fees in the customer bill which cannot be saved by self-consumption. In the absence of electricity storage, self-consumption is the amount of PV generation which can directly be used by the consumer to reduce the electricity taken from the grid. That is, self-consumption is the part of PV production that is valued for the retail electricity price, whereas the rest has generally a much lower value.

3.3. Levelised Cost of Electricity (LCOE)

The LCOE here is defined as the average generation cost, i.e., including all the costs involved in supplying PV electricity at the point of connection to the grid. Possible grid integration cost is excluded here, but it can be argued whether it is fair to burden such cost solely on PV. After all, the old inflexible baseload generation technologies like coal and nuclear power do not have to pay grid integration cost either. On the other hand, this study does not take into account the various societal and environmental benefits of PV.

The PV LCOE here includes all the costs and profit margins of the whole value chain including manufacturing, installation, project development, operation and maintenance (O&M), inverter replacement, dismantling, etc. Residual value of the PV system after dismantling has not been considered since there is no agreed price for the second hand modules for the time being. But typically, the residual value of a dismantled PV system should be positive. PV LCOE also includes the cost of financing but excludes the profit margin of electricity sales and thus represents the generation cost, not the electricity sales price which can vary depending on the market situation.

The PV LCOE, expressed in €/kWh in real money, can be defined by equation (2):

$$LCOE = \frac{\left(CAPEX+\sum\left[\frac{OPEX(t)}{(1+WACC_{nom})^{t}}\right]\right)}{\sum\left[\frac{Yield(0)\,(1-Degr)^{t}}{(1+WACC_{real})^{t}}\right]} \quad (2)$$

where:

t is year number ranging from 1 to the economic lifetime of the system
CAPEX is total investment expenditure of the system, made at ***t*** = 0 in €/kWp
OPEX(t) is operation and maintenance expenditure in year ***t*** in €/kWp
Yield(0) is initial annual yield in year 0 in kWh/kWp without degradation
Degr is annual degradation of the nominal power of the system
$WACC_{nom}$ is nominal weighted average cost of capital per annum
$WACC_{real}$ is real weighted average cost of capital per annum

The relationship between $WACC_{nom}$ and $WACC_{real}$ is expressed with the formula below:

$$WACC_{real} = \left[\frac{(1+WACC_{nom})}{(1+Infl)}\right]-1 \quad (3)$$

where

Infl is the annual inflation rate

We will see in the next section the analysis of development trends regarding LCOE inputs to calculate the final LCOE for every year from 2016 to 2050.

4. PV LCOE CALCULATION PARAMETERS

4.1. Cost of capital and inflation (WACC)

The input data for the PV LCOE calculation follows the example of previous papers by the authors [1-3]. In those, it was concluded that apart from the location, the Weighted Average Cost of Capital (WACC) is the most crucial parameter affecting the PV LCOE. Since there is no fuel costs related to PV, the capital expenditure (CAPEX) has a relatively stronger influence than the operational expenditure (OPEX) on PV LCOE.

In this report, all results are given in real 2016 money. As we are using nominal WACC rates, inflation has to be taken into account in order to arrive at real values. For example, a 4% nominal WACC with 2% inflation rate corresponds to a 2% real WACC. Because the WACC rates are highly subjective and depend among other things on the country, market segment, investor type and risk appetite, we have included a set of 4 different WACC rates in our analysis.

For residential PV systems (5 kWp), 0%, 2%, 4% and 6% nominal WACC is used.

For commercial (50 kWp), industrial (1 MWp) and utility-scale (50 MWp) systems, 2%, 4%, 7% and 10% nominal WACC is used.

Inflation rate is set at 2% which is the historical average inflation of Euro area.

The WACC depends highly on local specifics, and especially the risk of the country and project.

4.2. Capital expenditure (CAPEX)

The capital investment of a PV system can be divided into two components: the PV modules and the Balance of System (BoS).

CAPEX = Modules+BoS (4)

CAPEX in this report is the all-inclusive turnkey PV system price that needs to be paid up front. It is assumed here that the CAPEX is paid in full during the year of installation of the system and the system starts producing electricity from the following year.

PV module price

The PV module price is assumed to follow the "learning curve" which has been observed for many decades. Each time the global cumulatively produced volume of modules has doubled, the average price has been reduced by 20-25% [4-6]. During the last 8 years, the price has decreased significantly faster [7], due to a combination of accelerated economies of scale, massive industrialisation and most probably a change in the equipment cost due to newcomers from Asia. In order to cope with the market realities, this report assumes a realistic 25% learning rate.

4. PV LCOE CALCULATION PARAMETERS

To establish the future price for PV modules according to the learning curve, a projection for global cumulative installation volumes is needed. For 2015-20, the average compound annual growth rate (CAGR) for the base scenario is 15%, which is close to the recent estimate by PV Market Alliance [8]. From 2020 to 2030, 10% CAGR is assumed for the annual market size in the base case. After 2030, a CAGR of 2% is assumed which corresponds to about the average growth of global electricity consumption by IEA [9] in their 4DS scenario.

To have a sensitivity analysis, a slow and fast growth scenario are also considered. In the slow growth scenario, CAGR is 10% for 2015-20, 5% for 2020-30 and 2% for 2030-50. In the fast growth scenario, CAGR is 20% for 2015-20, 15% for 2020-30 and 2% for 2030-50. Annual market development for the three scenarios can be seen in Figure 3. For 2030-50, the annual market sizes include also the replacement market for PV systems installed in 2000-20, assuming an average 30 year lifetime.

Total installed cumulative PV capacity in the year 2050 would reach about 5, 9, and 16 TWp, for the slow, base and fast growth scenarios, respectively. Energy system analyses targeting very high shares of renewables as a result of the ongoing energy transition would lead to up to 30 TWp by the year 2050 [10]. This emphasizes the rather conservative applied assumptions in this report for the market growth and respective cost structures of PV in the decades to come. It can be noted that a comparison of this base scenario to the rather extreme slow (CAGR 5%) and high (CAGR 15%) growth scenarios from 2020 to 2030 would lead to a maximum difference of only about one doubling in the cumulative volume in 2030, meaning that the module price uncertainty from the volume is within +/-25%.

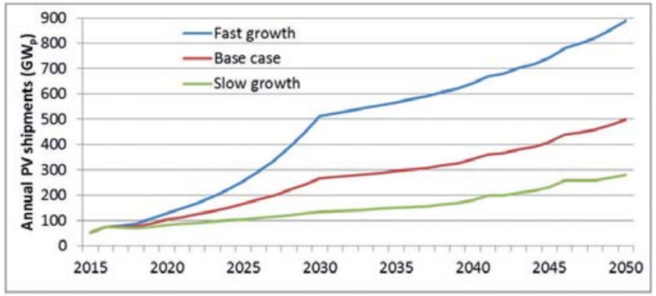

Figure 3: Annual global PV Market Development 2015 – 2050

The module price for the industrial (1 MWp) system is assumed to follow the average global module price according to the base learning curve. Module price for the residential (5 kWp) and commercial (50 kWp) systems is assumed to be 15% higher and for the utility-scale (50 MWp) system 15% lower than for the industrial (1 MWp) system.

Balance of System

The Balance of System (BoS) includes e.g. mounting structures, cabling, inverters, transformers and other electrical components, grid connection, infrastructure, installation work, planning, documentation and other work.

The price development of solar inverters is assumed to follow a 20% learning curve [11]. For the price development of other Balance of System (BoS) components, the methodology introduced by Fraunhofer ISE [5] is used. About half of the BoS cost components are proportional to the total area of the modules, and thus, inversely proportional to the module efficiency [3]. In addition, there is other cost reduction potential driven by, e.g., standardisation and modularisation, increase in DC voltage and more efficient installation processes.

The average module efficiency was about 16% in 2015 and the development is assumed to follow the average 0.4 percentage point annual increase of the past decade [12]. Fraunhofer ISE report [5] gave the 2015 average BoS price for a 1 MWp industrial system in Germany. It is true that the BoS price is currently not the same for all countries, due to local conditions related to e.g. grid connection, labour cost or higher profit margins. However, it is assumed that the prices will converge over time in Europe and therefore, only one price for each market segment is used here. A sensitivity analysis with a +/-20% CAPEX variation is presented in Section 7.

For the residential and commercial rooftop market segments, the BoS price is naturally higher. Based on the data gathered by German Solar Energy Association (BSW-Solar) [12,13] and PV module prices in Europe [14], it can be estimated that the BoS price for a commercial (50 kWp) rooftop system is about 50% and for a residential (5 kWp) system about 125% higher than for an industrial (1 MWp) system. For a utility-scale (50 MWp) system, the BoS price is estimated to be 15% less than for an industrial (1 MWp) system.

CAPEX forecast for 2015 - 2050

Below shows the CAPEX price development for the various market segments used in this study.

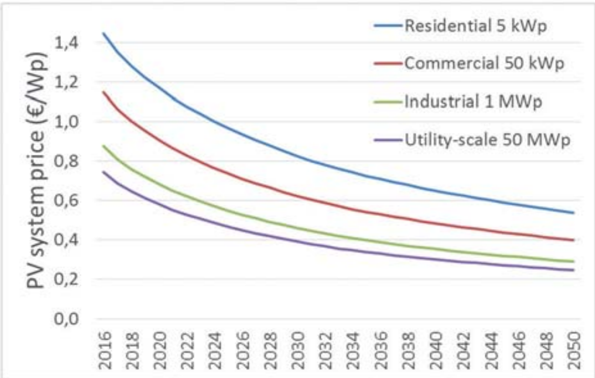

Figure 4: PV system CAPEX development 2016-2050 for different market segments. Prices are in real 2016 money and without VAT.

4.3. Operational expenditure (OPEX)

The operational expenditure (OPEX) of PV systems consists mainly of the operation and maintenance (O&M) cost because there is no fuel cost related to PV electricity generation. Historical OPEX data from different countries varies greatly and it is difficult to find a consensus opinion. In the past, many European countries had a very high feed-in tariff (FiT) which allowed high margins in both the system CAPEX and OPEX. Recently, the increased competition has clearly reduced the price of OPEX [15,16]. For example, in Germany the O&M price for large systems is already below 10 €/(kWp·year) [17]. Total OPEX price of 20 €/(kWp·year) is used here for 2015 for the three consumer market segments, the OPEX price for utility-scale (50 MWp) system is 25% less [3].

It is assumed that 50% of the OPEX is area-dependent, and thus reducing with the efficiency improvement of the modules. By 2050, this will lead to a 30% reduction of the OPEX. It is also assumed that standardisation, more efficient processes and competition will result in a further 30% reduction of the OPEX by 2050 compared with 2015. Inverter replacement cost is not included in the OPEX but incurs separately at the half-point of the lifetime of the system.

Fig. 5 shows the prediction for OPEX price from 2016 to 2050.

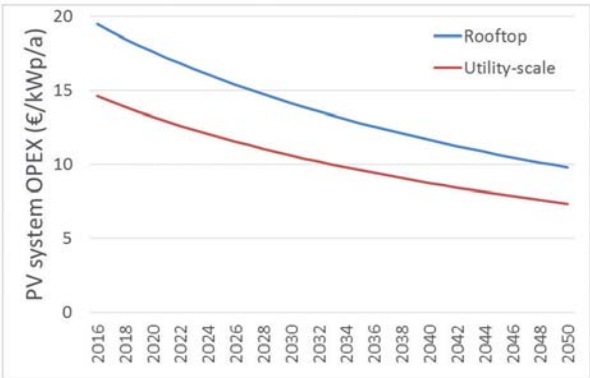

Figure 5. PV OPEX price development for 2016-50. Prices are in real 2016 money

4.4. Yield, degradation and system lifetime

The annual yield of a PV system depends on the local irradiation and performance ratio (PR). Ten European locations were selected for a detailed study: Helsinki, Stockholm, London, Berlin, Amsterdam, Brussels, Paris, Rome, Istanbul and Madrid, representing the most populous cities in each country.

The irradiation values are given according to Solargis database averages for 20 years [18]. The average Performance Ratio (PR) in 2015 was assumed to be 0.775 in the warmest countries (Spain, Turkey and Italy) and 0.8 in the other locations. The main reason for the difference is the negative temperature coefficient of the majority of PV modules, which means that the average operating efficiency of modules is lower in warmer climates.

The average PR of PV systems has been increasing over the years. A study by Fraunhofer ISE [19] showed that the median PR of the monitored German systems increased by more than 5 percentage points during the first decade of this century. This trend is expected to continue because of, e.g., more efficient inverters, less ohmic losses with higher voltage modules, better temperature coefficients and better low light response of the modules. It is assumed here that the PR of all systems will increase by 0.5 percentage points per year from 2015 to 2030 and then will remain the same from 2030 to 2050. The annual irradiation is assumed to be stable. Table I shows the annual yields for the chosen locations with GHI and irradiation for a surface tilted 30º towards South, which gives almost the maximum annual yield for all locations. The annual yields are calculated for the tilted surface with the given performance ratios.

Table I. Annual GHI, irradiation on surface tilted 30º to South, and yield for different locations in 2015 and 2030; source for irradiation data: Solargis, 2016

	Irradiation (kWh/(m2·a)		Yield (kWh/(kWp·a)	
	GHI	30°S	2015	2030
Stockholm	950	1160	930	1020
Helsinki	950	1160	930	1020
Amsterdam	1030	1200	960	1050
Paris	1130	1130	1050	1050
Brussels	1030	1200	960	1050
Istanbul	1500	1680	1300	1430
London	1000	1160	930	1020
Berlin	1030	1200	960	1050
Madrid	1710	2000	1550	1700
Rome	1580	1830	1420	1560

Note that there are several locations with similar yields, but the electricity price in these countries may be different, and therefore, the competitiveness of PV varies. The annual yields in Table I are initial values, i.e., without any degradation. The power guarantees (80% of nominal power after 25 years) of most PV module manufacturers would mean maximum average degradation of 0.9% per year. In reality, most systems in Europe degrade far less and, e.g., an average degradation of 0.2% per year has been reported for German rooftop systems [20]. A conservative value of 0.5% per year is used here for properly installed PV systems, based on the findings of IEA PVPS Task 13 recent report [21].

Clearly, system lifetime is related to the degradation of the system. A system lifetime of 30 years was recommended by IEA PVPS Task 12 for life cycle assessment studies [21] and reflects the quality of current PV systems, even though it is expected that the technical lifetime will increase in the future and give added financial, environmental and social benefits.

5. THE PV ELECTRICITY VALUE CALCULATION PARAMETERS

This section will provide the detailed explanation on PV electricity value. As mentioned in the beginning, the total PV electricity value bases on two parts: the value of the self-consumption electricity and the value of surplus or feed-in the grid electricity part.

5.1. Value of PV self-consumption for 10 European countries

PV LCOE is compared with the average value of generated PV electricity for the three market segments in ten countries. The self-consumed PV generation is valued for the variable retail electricity price the customer has to pay for each consumed kWh in the electricity bill.

Eurostat [22] gathers the electricity price data from all European countries and publishes the annual averages in several consumption bands. The consumption bands selected for the price comparison with different sizes of PV systems are listed in Table II.

Table II. PV system sizes and consumption bands where PV LCOE is compared with the average electricity value

PV segmentation	Size	Annual consumption
Residential	5 kWp	5- 15 MWh
Commercial	50 kWp	20- 500 MWh
Industrial	1MWp	2- 20 GWh

In the residential segment, annual 10 MWh consumption would give an average 1.1 kW power load in the house. Considering that many household activities do not happen during the midday hours when the PV generation is the highest, it is clear that significant surplus generation will accumulate. In this study, we will consider a range from 25% to 75% self-consumption for the residential PV systems. With proper sizing of the PV system, 50% self-consumption can often be reached, while higher self-consumption ratios may require shifting part of the consumption to the hours of PV generation, or storing the surplus electricity.

In the commercial segment, most of the consumption happens during daytime and the best PV generation hours. Annual 250 MWh consumption would give an average 29 kW load which is close to the maximum generation power of the PV system. It is likely that most of the PV generation can be self-consumed and even all at the higher end of the consumption band. A range from 50% to 100% self-consumption is considered here. Because of the higher return expectations in the commercial segment, it is not likely that PV systems with lower than 50% self-consumption will be installed.

In the industrial segment, 10 GWh annual consumption would give an average 1.1 MW power load. This means that e.g. in the case of continuous manufacturing industry, all PV generation could be self-consumed in practice. However, at the lower end of the consumption band, some surplus generation will accumulate. We consider 50% to 100% self-consumption also in the industrial segment.

Eurostat divides the retail electricity price into three different components: energy, grid cost, and taxes and other fees. In most cases, the energy price and taxes are almost entirely variable, i.e., the price is charged

per kWh. However, this is not the case with the grid cost. There is often a fixed annual, monthly or daily fee and also a per kW charge which depends on the maximum power or current that can be withdrawn from the grid. These fixed and power charges the customer cannot avoid with own PV generation, they have to be paid anyway. Therefore, the fixed charges have to be deducted from the grid cost component when comparing the retail electricity prices with PV LCOE. In some cases, it might be possible to shave off peak loads with PV or electricity storage, and thus reduce the power charge, but that is not considered here.

Unfortunately, Eurostat does not give separately the variable and fixed costs in the annual statistics. There was a recent study ordered by the European Commission [23], which has tables on the fixed and variable share of the distribution tariff in various countries. However, it does not cover all the focus countries of this study and the consumption bands selected do not match the ones used here. As a result, a survey of the distribution tariffs of the biggest grid companies was made for each focus country and the results are used here. With this method of collecting data, the report encountered several problems. To be specific, in some markets there are big differences between the responses of companies leading to difficulty in establishing an average at the country level. Another problem is that the tariff structure varies with different maximum power consumption, fuse size or even by contract. In this study, 10 kW maximum power consumption was used for the residential, 100 kW for the commercial and 2 MW for the industrial segment.

It must be noted that the threshold of market segments varies by country or sometimes by region or even by customer. Therefore, it is not always obvious which consumption band and which distribution tariff should be used. For that reason, the average share of the fixed component in the grid cost, given by Table III, must be taken only as an indicative.

Country	Fixed share
Sweden	60%
Finland	30%
The Netherlands	10% / 100% (residential)
France	35%
Belgium	30%
Turkey	0%
UK	10%
Germany	10%
Spain	60%
Italy	40%

Table III. The share of fixed and power-related components in the grid cost in each country

It is also clear that the balance between variable and fixed or power-related grid costs is changing because of the increasing amount of grid-connected distributed renewable power systems which reduce the revenue for the distribution companies. There is a trend to increase the fixed or power-related component, even towards 100% of the grid cost. How far this can go is still an open question, as the consequence to energy efficiency measures should be carefully considered.

It is interesting to note that the share of fixed grid cost in residential segment is already 100% in the Netherlands, whereas it is very small in the commercial and industrial segments. Apart from the Netherlands, the same average share is used for all segments in each country, although differences do exist as explained. The effect of a different fixed share can be addressed in the sensitivity analysis.

Fig. 6 shows the average residential variable electricity retail price in each country. Note that the estimated fixed component according to Table III has been deducted from the grid cost, as is the VAT on the fixed cost from the taxes and fees. It is interesting to see that grid cost is, apart from Belgium, relatively small, typically 20% or less of the total variable retail price. This means that even though the fixed share might increase in the future, it does not significantly reduce the competitiveness of PV since the PV LCOE is continuing to decrease.

In Italy, there still exists a progressive tariff, which means that the more electricity you consume, more you pay. However, this is going to change in 2018, which will reduce the competitiveness of small PV systems with low electricity consumption. Another notable observation is that the variable retail price in Germany is more than double of that in Sweden and Finland. This has a profound effect on the PV competitiveness since the level of annual yield is quite similar in these countries.

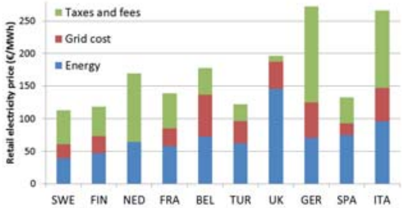

Figure 6. Average residential variable retail electricity price in Europe 2015 (source: Eurostat). Fixed/power-related component has been deducted from the grid cost and taxes. Self-consumption tax of 44.5 €/MWh has been deducted from the energy price in Spain

Fig. 7 shows the average commercial variable electricity retail price in each country. Notable exceptions are the self-consumption taxes in Spain and Italy which have been deducted from the Eurostat energy price. Moreover, 40% of the EEG charge has been deducted from the German taxes and fees column.

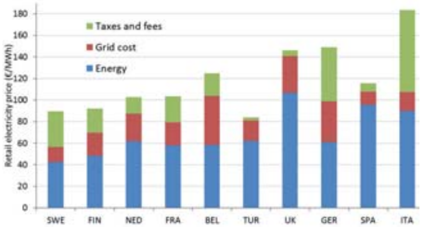

Figure 7. Average commercial variable retail electricity price in Europe 2014 (source: Eurostat). Fixed/power-related component has been deducted from the grid cost. Self-consumption tax in Spain (22 €/MWh) and Italy (5%) has been deducted from the energy price. 40% of the EEG charge in Germany has been deducted from the taxes and fees.

Fig. 8 shows the average industrial variable electricity retail price in each country. The same exceptions apply as in the commercial segment.

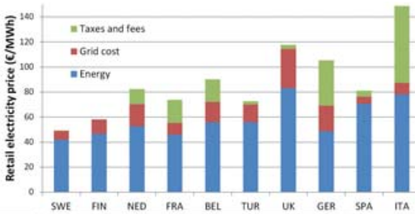

Figure 8. Average industrial variable retail electricity price in Europe 2014 (source: Eurostat). Fixed/power-related component has been deducted from the grid cost. Self-consumption tax in Spain (13 €/MWh) and Italy (5%) has been deducted from the energy price. 40% of the EEG charge in Germany has been deducted from the taxes and fees.

5. THE PV ELECTRICITY VALUE CALCULATION PARAMETERS

5.2. Value of surplus electricity

The value of surplus PV generation which cannot be self-consumed immediately depends on many things. In many countries, there still exist feed-in tariffs, or similar schemes as green certificates, which usually guarantee a relatively good remuneration for the surplus PV generation. However, the feed-in tariff era is coming to an end as PV generation is already competitive in many markets and subsidies are not needed anymore. Moreover, the European Union has issued directives pushing to replace progressively feed-in tariffs by market-based instruments, at least for the larger systems. For this reason, feed-in tariffs are not taken into account here. There are also other forms of incentives, such as net metering and billing, which essentially mean a feed-in tariff at the retail electricity price, investment grants, income tax deductions or green electricity certificates. Since these incentives can also be regarded as temporary solutions, they are neither included in this analysis.

In general, the surplus PV generation should be sold in the wholesale market where the value of electricity changes over time. The most common market place is the electricity day-ahead and intraday market where the price changes hourly or even with shorter time period like every 15 minutes in Germany. Since most electricity consumers are not market players themselves, they usually have to pay a small administrative fee to a market player which can be the electricity retail company or an aggregator for selling the electricity to the market. There are sometimes also grid fees related to the fed-in electricity. For example, in Finland the distribution companies can charge a fee up to 0.7 €/MWh from customers with systems below 1 MW. On the other hand, there is a grid benefit payment in Sweden where the customer receives about 5 €/MWh for the electricity fed in to the grid.

In this analysis, the fed-in surplus PV generation is valued at the annual average spot market price minus a 10% administrative fee. The average spot market electricity prices in 2016 are presented in Fig. 9. In recent years, these prices have been going down and are already at a level which will not alone encourage investments to hardly any new generation capacity. It is possible that the prices continue to fall, especially during daytime when a lot of surplus PV generation is available. However, the average volume-weighted price that PV generation gets is still above the annual average prices in most markets. It can also be questioned, what would be the fair remuneration for PV if its obvious societal and environmental benefits were also taken into account. For example, Sinha et al. [24] concluded that the cost of non-use of renewable electricity, mainly solar PV, would be in the range of 49-390 €/MWh, comprising grid stabilising, financial fuel hedging, value of avoided capacity etc.

There is currently one notable exception regarding the value of the surplus PV generation. In Spain, grid feed-in is not remunerated at all for smaller than 100 kWp systems. In this analysis, it means that the value of surplus PV generation for residential and commercial market segments in Spain is zero. In the industrial segment, the 6% electricity tax has to be deducted from the wholesale market price in Spain.

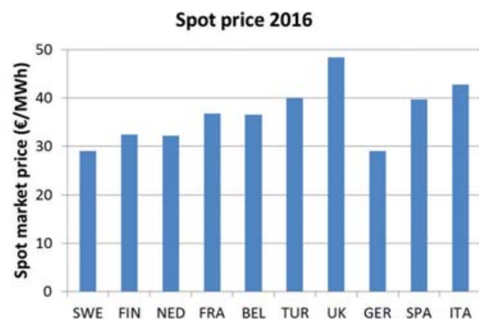

Figure 9. Average spot market electricity price in 2016 in ten European countries

5.3. Other EU countries

It was not possible to cover all EU countries in detail in this report. However, the rest of the countries are all close to some of the ten focus countries regarding the retail electricity price and annual yield, as can be seen from Fig. 10. Eurostat 2015 variable residential retail electricity prices are shown for all countries. Swiss price is calculated as an average of the company-specific data by Eidgenössische Elektrizitätskommission ElCom. For the ten focus countries, the fixed share of grid cost is excluded according to Table IV. For other countries, this fixed share is assumed to be 30%.

Countries with high irradiation and relatively high retail electricity price like Portugal, Greece, Cyprus and Malta are similar to Spain, which means that the true grid parity has been reached in all market segments and with every nominal WACC rate. Countries like Croatia, Slovenia and Romania have good irradiation but relatively low electricity price and they resemble Turkey. Denmark and Ireland are like the UK, they have moderate irradiation but high electricity price. Estonia and Lithuania are similar to Finland and Sweden with moderate irradiation and low electricity price. Norway has the lowest retail electricity price in Europe and with moderate irradiation, it is the furthest from PV competitiveness in Europe.

In the next sections, detailed results are shown for the ten focus countries in Figures 11-30. The results for the other countries are shown in summary Tables IV-VI. For the other than focus countries, the value of surplus PV electricity has been assumed as 30 €/MWh, according to the EEX European Electricity Index (ELIX) in 2016 [25].

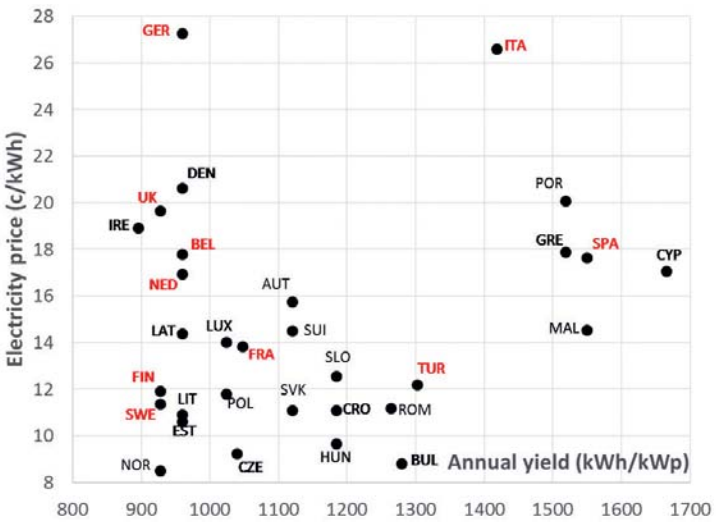

Figure 10. Summary of the residential variable retail electricity prices versus annual yields of EU countries + Turkey, Norway and Switzerland

6. PV COMPETITIVENESS RESULTS

6.1. Residential 5 kWp PV system

Fig. 11 shows the PV competiveness for a 5 kWp residential system in Sweden. PV LCOE with 0% nominal WACC (red column) was about 77 €/MWh in 2016. Average value of PV electricity Pave with 50% self-consumption (black solid line) is about 72 €/MWh in real 2016 money, which means that true grid parity in this case was not yet reached in 2016. However, with 75% self-consumption (black dashed line), Pave is about 93 €/MWh, which means that true grid parity was reached already in 2016 with 0% nominal WACC. With 2% nominal WACC (green column added), true grid parity with 75% self-consumption is reached this year (2017) when PV LCOE falls below 90 €/MWh. With 4% nominal WACC (brown column added) this would happen in 2021 and with 6% (yellow column added) in 2026. With 25% self-consumption (black dotted line), Pave is about 50 €/MWh which means that true grid parity is not reached before 2025 even with 0% WACC. This shows that with low spot market prices and in the absence of feed-in tariffs, proper sizing of the PV system is imperative in order not to generate too much surplus.

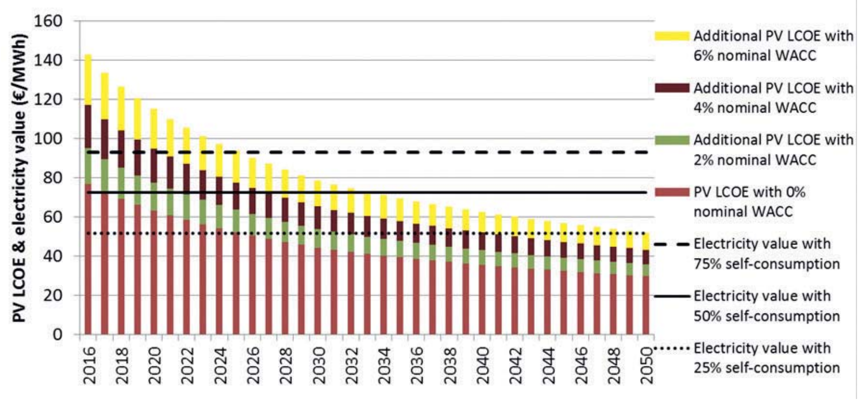

Figure 11. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Stockholm, Sweden. Prices are in 2016 real money.

Figures 12-20 show the PV competiveness for a 5 kWp residential system in Helsinki, Amsterdam, Paris, Brussels, Istanbul, London, Berlin, Madrid and Rome, respectively. It is not a surprise that a country like Italy with good irradiation and high retail prices is already in true grid parity with all realistic interest rates and self-consumption rates. Germany is also in true grid parity apart from the 25% self-consumption rate with higher interest rates. The same applies to the UK which has a lower electricity retail price but higher spot market price than Germany.

Turkey has excellent solar resource but the retail electricity price is very low, which means that true grid parity with low self-consumption and high interest rates is a few years away. In Spain, a relatively high self-consumption rate is needed because of the zero compensation for the surplus electricity. Belgium and the Netherlands have relatively high retail prices but moderate irradiation. France has slightly lower retail price but higher irradiation. Finland is similar to Sweden apart from the higher share of variable grid cost in the electricity bill.

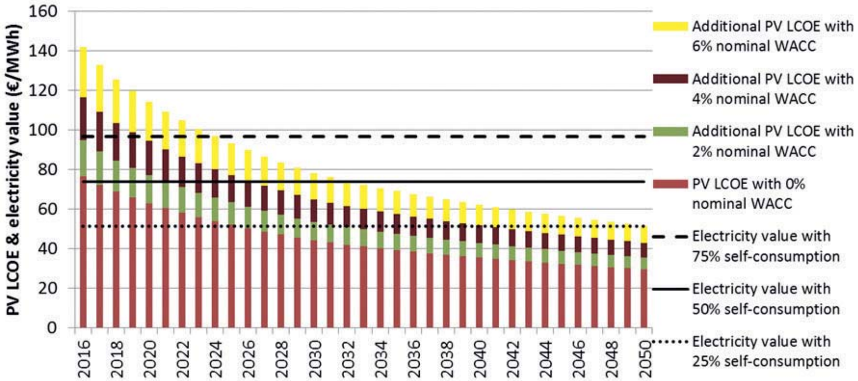

Figure 12. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Helsinki, Finland. Prices are in 2016 real money.

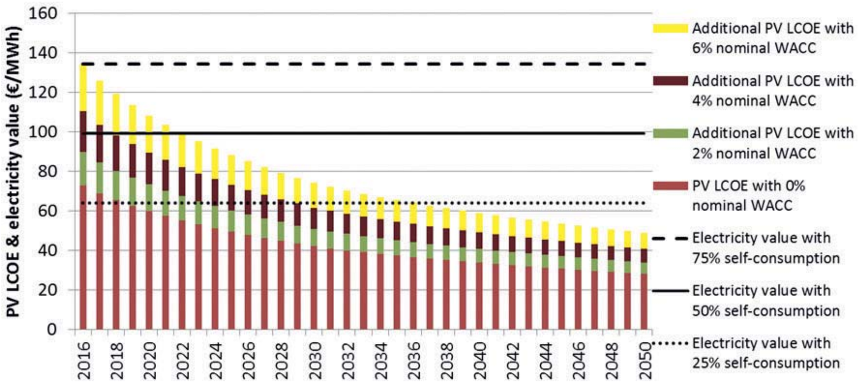

Figure 13. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Amsterdam, Netherlands. Prices are in 2016 real money.

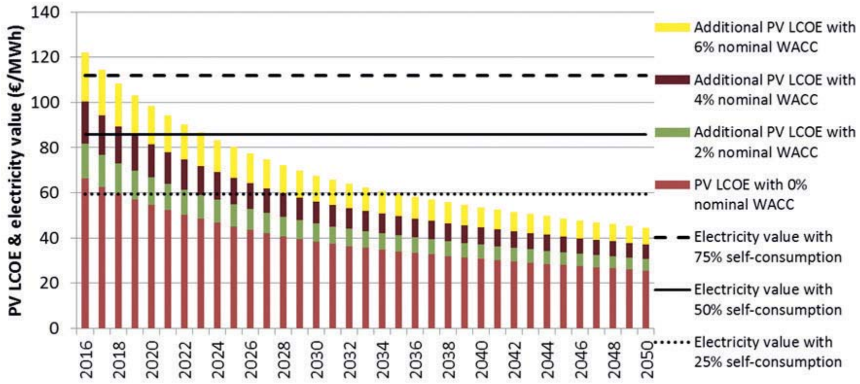

Figure 14. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Paris, France. Prices are in 2016 real money.

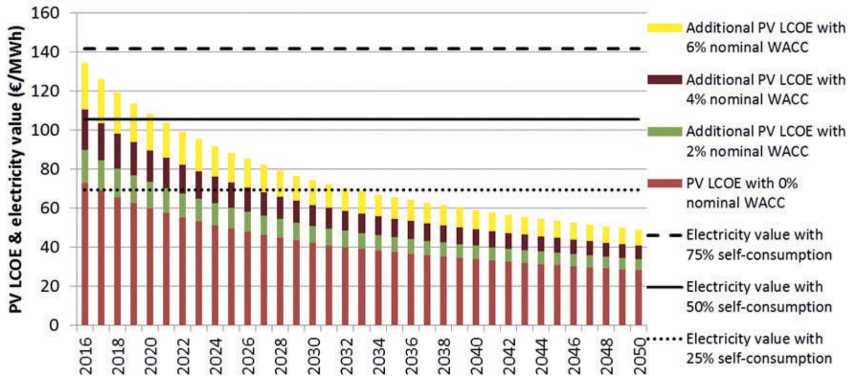

Figure 15. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Brussels, Belgium. Prices are in 2016 real money.

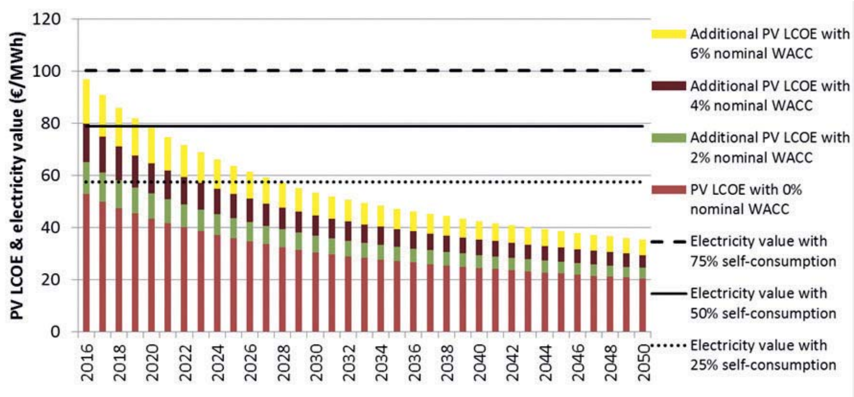

Figure 16. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Istanbul, Turkey. Prices are in 2016 real money.

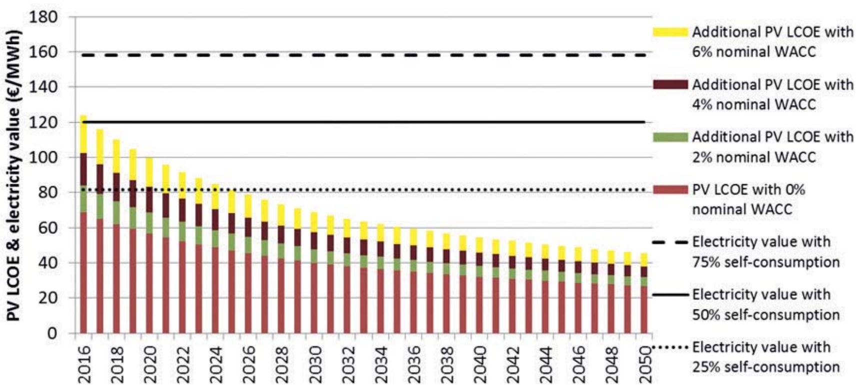

Figure 17. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in London, UK. Prices are in 2016 real money.

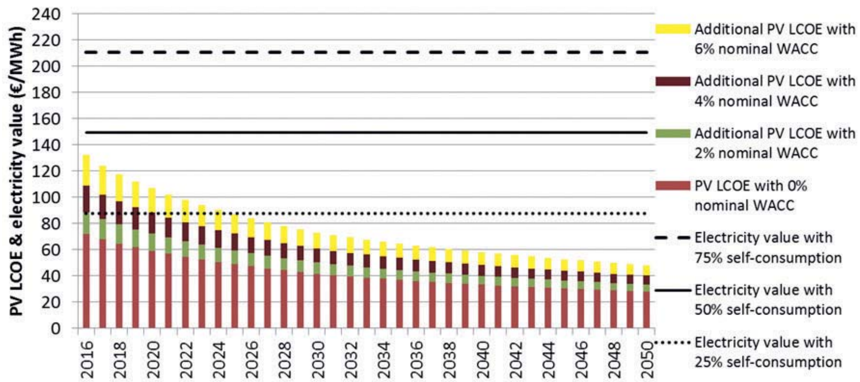

Figure 18. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Berlin, Germany. Prices are in 2016 real money.

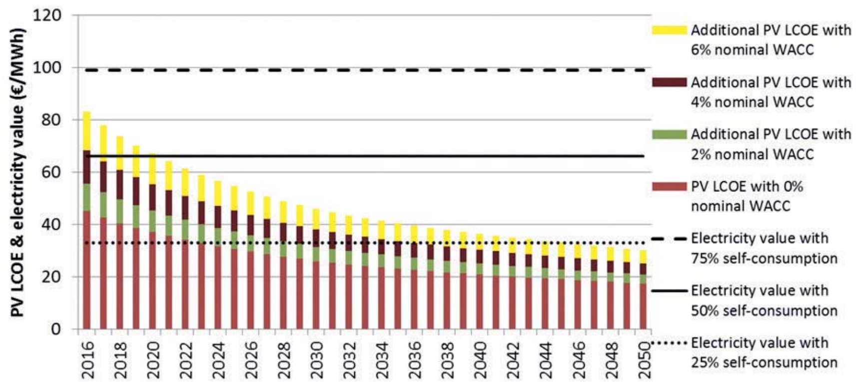

Figure 19. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Madrid, Spain. Prices are in 2016 real money.

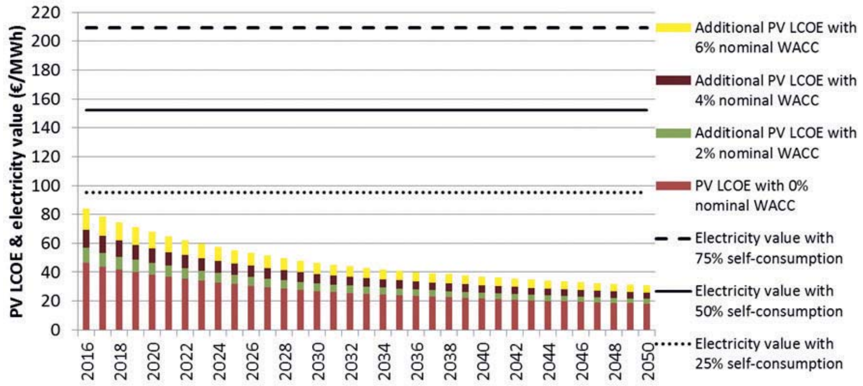

Figure 20. Comparison of PV LCOE with average residential PV electricity value for a 5 kWp rooftop PV system in Rome, Italy. Prices are in 2016 real money.

Table IV summarises the years when true grid parity is reached in the residential segment with 50% self-consumption in European countries. With 2% nominal WACC, all ten focus countries except for Sweden and Finland are already in true grid parity. With 4% nominal WACC, the same is true within two years. With 6% nominal WACC, only Italy, Germany and the UK are in true grid parity by this year (2017).

From the other European countries, Greece, Cyprus, Malta and Portugal are in true residential grid parity with all realistic nominal WACC rates, this is also true for Denmark in a couple of years. The Czech Republic, Estonia and Lithuania will reach true grid parity with 0% nominal WACC this (2017) or next year, but for Norway it will take another 6 years. The rest of the countries either are already in true grid parity with 2% nominal WACC or will reach that within 3 years.

6. PV COMPETITIVENESS RESULTS

Table IV. Summary of when true grid parity is reached in the residential segment with 50% self-consumption with 4 different nominal WACCs. Parity = true grid parity has been reached by 2016

Location	Nominal WACC			
	0%	2%	4%	6%
Stockholm	2018	2022	2027	2034
Helsinki	2017	2022	2027	2033
Amsterdam	Parity	Parity	2018	2023
Paris	Parity	Parity	2019	2024
Brussels	Parity	Parity	2017	2021
Istanbul	Parity	Parity	2017	2020
London	Parity	Parity	Parity	2017
Berlin	Parity	Parity	Parity	Parity
Madrid	Parity	Parity	2017	2021
Rome	Parity	Parity	Parity	Parity
Sofia	Parity	2019	2023	2028
Prague	2018	2023	2028	2035
Copenhagen	Parity	Parity	Parity	2019
Tallinn	2018	2022	2027	2034
Dublin	Parity	Parity	2018	2022
Athens	Parity	Parity	Parity	Parity
Zagreb	Parity	2017	2022	2027
Nicosia	Parity	Parity	Parity	Parity
Riga	Parity	2017	2021	2026
Vilnius	2017	2022	2027	2033
Luxembourg	Parity	Parity	2020	2024
Budapest	Parity	2020	2025	2030
Valletta	Parity	Parity	Parity	Parity
Wien	Parity	Parity	2017	2020
Warsaw	Parity	2019	2024	2029
Lisbon	Parity	Parity	Parity	Parity
Bucharest	Parity	Parity	2019	2024
Ljubljana	Parity	Parity	2019	2024
Bratislava	Parity	2018	2022	2027
Oslo	2023	2028	2036	2045
Zurich	Parity	Parity	Parity	2020

It is likely that these results are rather conservative because the wholesale electricity prices and energy component in the retail price is quite low at the moment. We have assumed that they stay at the current real level. Moreover, the self-consumption rates are bound to get higher with the increase of battery systems. This issue will be discussed in Section 8.

6.2. Commercial 50 kWp PV system

Fig. 21 shows the comparison of PV LCOE with the average commercial PV electricity value in Sweden. A self-consumption range from 50% to 100% is shown since the electricity use in commercial buildings concentrates more on daytime compared with residential buildings. On the other hand, higher interest rates are used since companies usually expect faster returns than households.

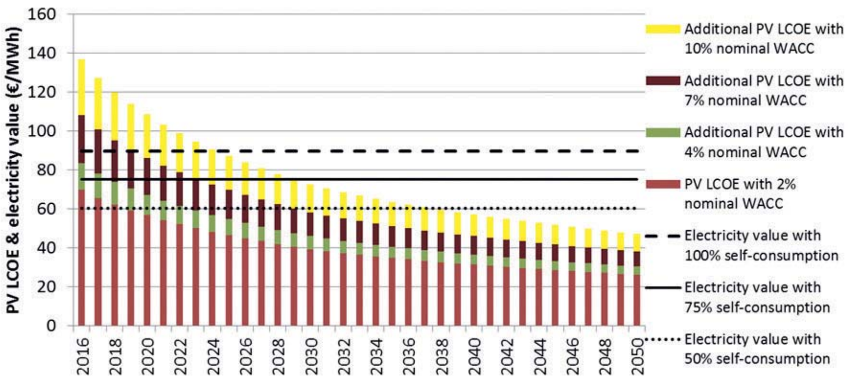

Figure 21. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Stockholm, Sweden. Prices are in 2016 real money

As can be seen, true grid parity with 75% self-consumption and 2% nominal WACC has already been reached in 2016. With 4% nominal WACC, it is reached in next year (2018). With 100% self-consumption, true grid parity already exists with lower than 4% WACC, and with 7% nominal WACC it is reached in two years, and with 10% nominal WACC in 7 years. It must be emphasised that 10% nominal WACC is very high. For example, with 70/30 debt to equity ratio and 4% interest on debt, 10% nominal WACC would mean 24% return on equity.

Figures 22-30 show the comparison of PV LCOE with the average commercial PV electricity value in Finland, Netherlands, France, Belgium, Turkey, the UK, Germany, Spain and Italy, respectively. The results with 75% self-consumption in commercial segment are quite similar to the ones with 50% self-consumption in residential segment. Probably the biggest difference is in Spain where PV in commercial segment is more competitive than the residential one. This is because the average electricity price that the consumer can save with own PV generation is relatively higher because of the lower self-consumption tax. For this reason, true grid parity has been reached with all interest rates in Italy and Spain, while this will be true in Germany and the UK next year. For the other focus countries, true grid parity has been reached with 4% nominal WACC, except for Sweden and Finland, where it will be reached next year (2018).

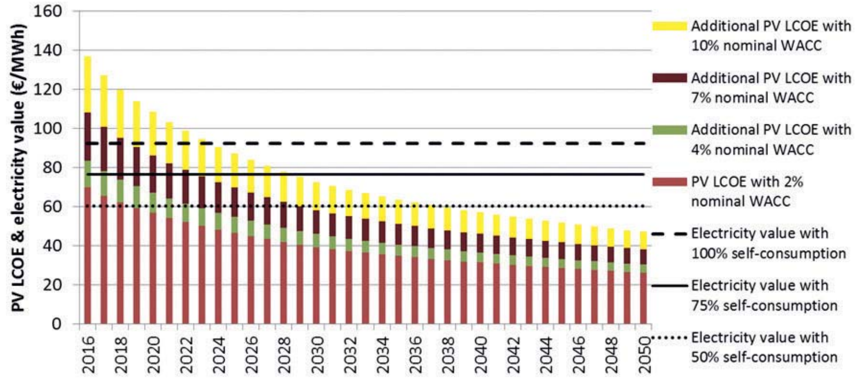

Figure 22. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Helsinki, Finland. Prices are in 2016 real money.

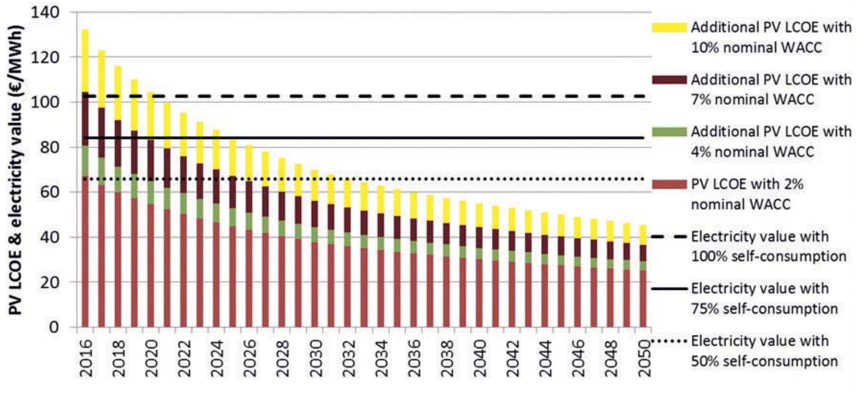

Figure 23. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Amsterdam, the Netherlands. Prices are in 2016 real money.

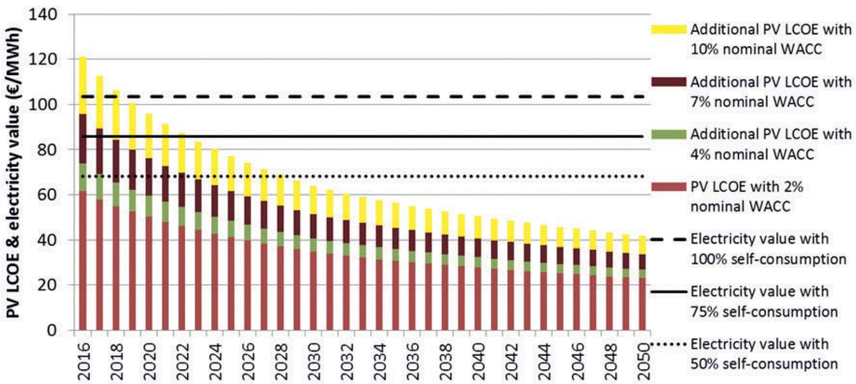

Figure 24. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Paris, France. Prices are in 2016 real money.

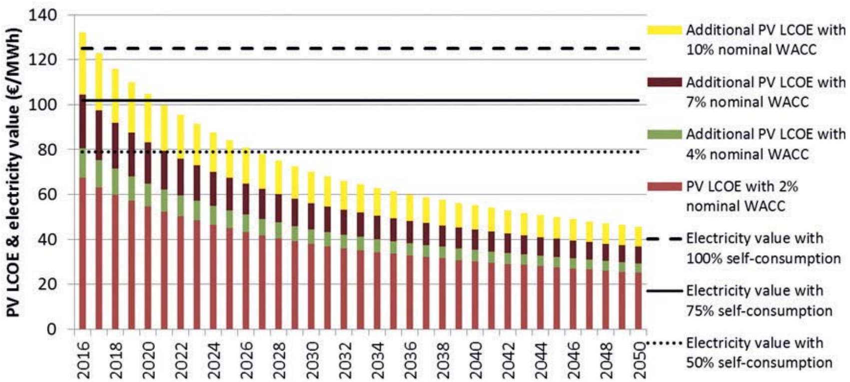

Figure 25. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Brussels, Belgium. Prices are in 2016 real money.

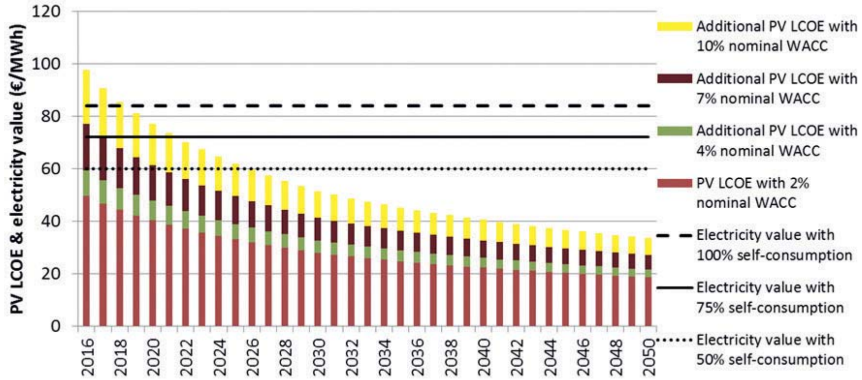

Figure 26. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Istanbul, Turkey. Prices are in 2016 real money.

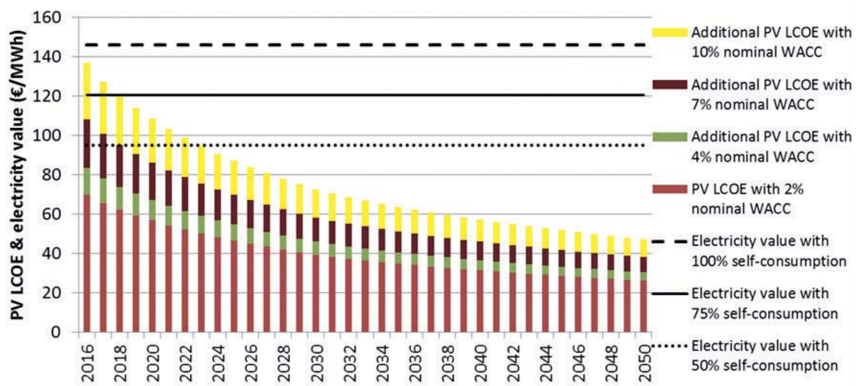

Figure 27. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in London, UK. Prices are in 2016 real money.

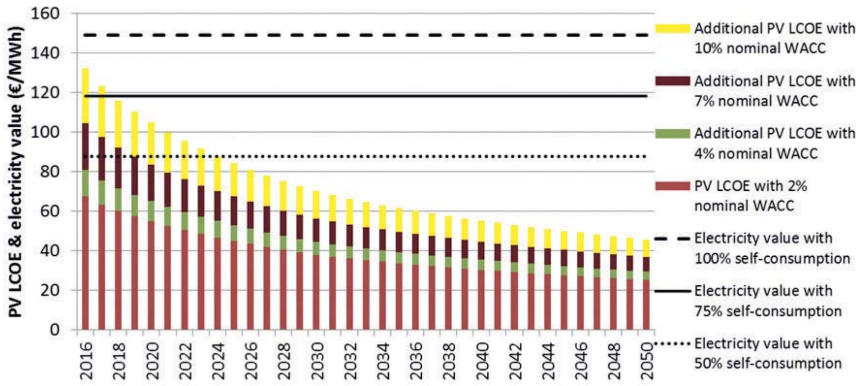

Figure 28. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Berlin, Germany. Prices are in 2016 real money.

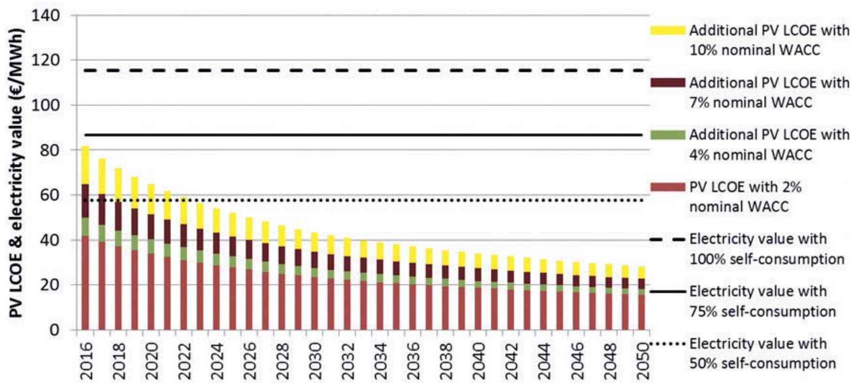

Figure 29. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Madrid, Spain. Prices are in 2016 real money.

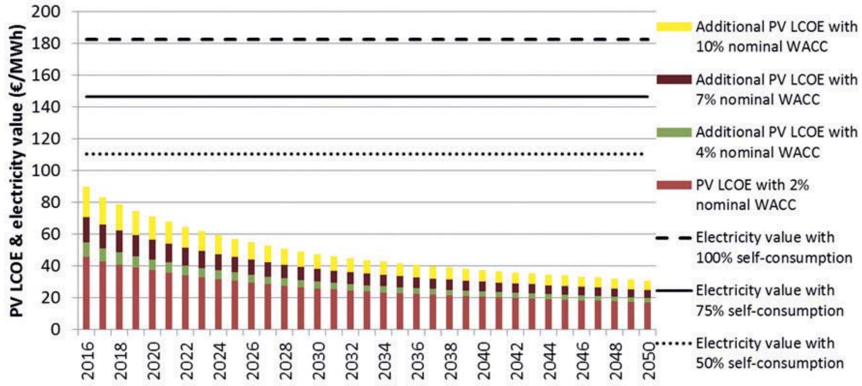

Figure 30. Comparison of PV LCOE with average commercial PV electricity value for a 50 kWp rooftop PV system in Rome, Italy. Prices are in 2016 real money.

Table V summarises the years when true grid parity is reached in the commercial segment with 75% self-consumption. Of the focus countries, Italy and Spain are in true grid parity with all nominal WACC rates, and Germany and the UK will be next year. Turkey and Belgium will reach true grid parity with 7% nominal WACC this year, France will reach it next year and Netherlands in three years. Finland and Sweden will reach true grid parity with 4% nominal WACC next year (2018).

Of the other European countries, Greece, Cyprus, Malta and Portugal are in true grid parity with all nominal WACC rates. Most of the other countries are already or will reach true grid parity with 7% nominal WACC within two years. Only Norway has not yet reached true grid parity even with 2% nominal WACC.

Table V. Summary of when true grid parity is reached in the commercial segment with 75% self-consumption with 4 different nominal WACCs. Parity = true grid parity has been reached by 2016

Location	Nominal WACC			
	2%	4%	7%	10%
Stockholm	Parity	2018	2024	2030
Helsinki	Parity	2018	2023	2029
Amsterdam	Parity	Parity	2020	2025
Paris	Parity	Parity	2018	2023
Brussels	Parity	Parity	2017	2021
Istanbul	Parity	Parity	2017	2022
London	Parity	Parity	Parity	2018
Berlin	Parity	Parity	Parity	2018
Madrid	Parity	Parity	Parity	Parity
Rome	Parity	Parity	Parity	Parity
Sofia	Parity	Parity	2017	2022
Prague	Parity	Parity	2019	2023
Copenhagen	Parity	2017	2022	2028
Tallinn	Parity	2018	2024	2029
Dublin	Parity	Parity	Parity	2020
Athens	Parity	Parity	Parity	Parity
Zagreb	Parity	Parity	2018	2022
Nicosia	Parity	Parity	Parity	Parity
Riga	Parity	Parity	2018	2023
Vilnius	Parity	Parity	2019	2024
Luxembourg	Parity	Parity	2019	2024
Budapest	Parity	Parity	2018	2023
Valletta	Parity	Parity	Parity	Parity
Wien	Parity	Parity	Parity	2020
Warsaw	Parity	Parity	2020	2025
Lisbon	Parity	Parity	Parity	Parity
Bucharest	Parity	Parity	2018	2023
Ljubljana	Parity	Parity	2018	2022
Bratislava	Parity	Parity	Parity	2019
Oslo	2019	2022	2029	2037
Zurich	Parity	Parity	Parity	2017

6.3. Industrial 1 MWp system

Competitiveness in the industrial segment with 100% self-consumption is very similar to the one in the commercial segment with 75% self-consumption. In manufacturing industries, 100% self-consumption is rather easy to achieve with a proper sizing of the PV system relative to the electricity consumption. On the other hand, self-consumption rate is not as important in industrial as in the other segments because the retail electricity price is closer to the spot market price. Figures 31-40 shows the comparison of PV LCOE with the average industrial PV electricity value in Sweden, Finland, Netherlands, France, Belgium, Turkey, the UK, Germany, Spain and Italy, respectively.

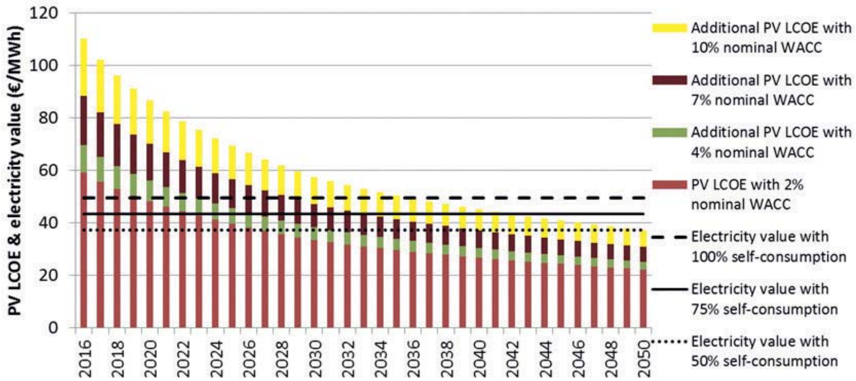

Figure 31. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Stockholm, Sweden. Prices are in 2015 real money.

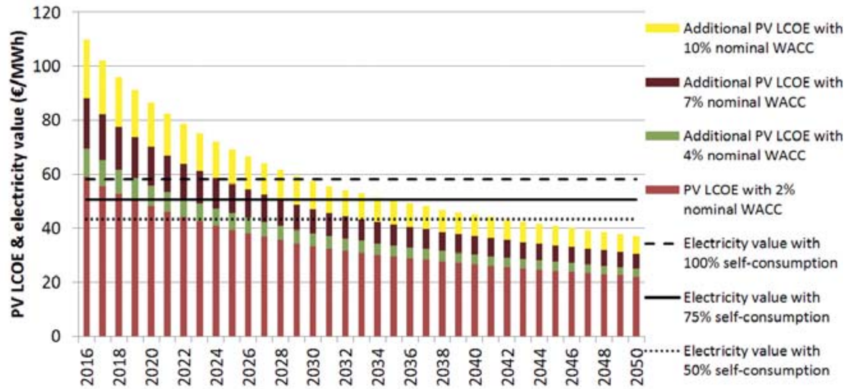

Figure 32. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Helsinki, Finland. Prices are in 2016 real money.

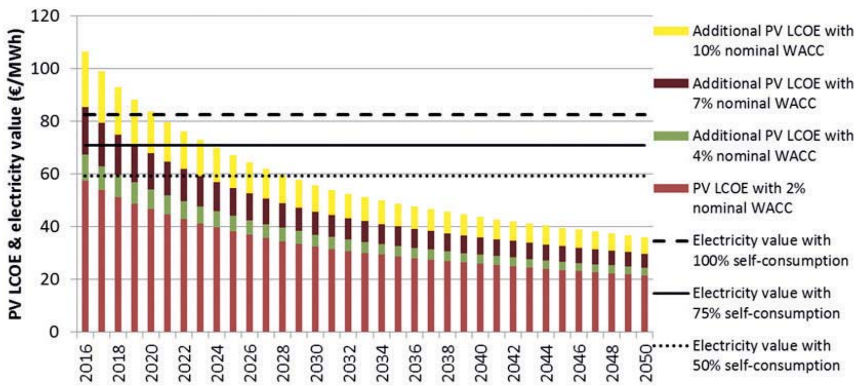

Figure 33. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Amsterdam, the Netherlands. Prices are in 2016 real money.

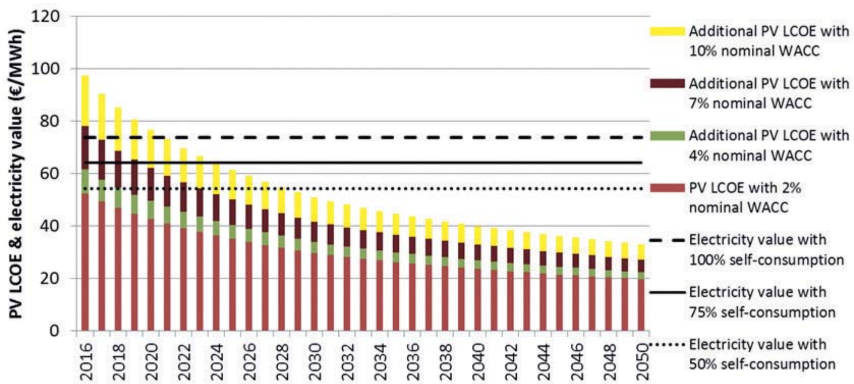

Figure 34. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Paris, France. Prices are in 2016 real money.

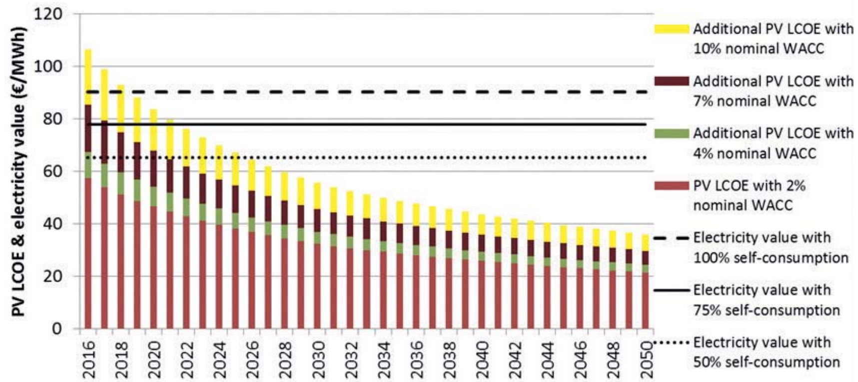

Figure 35. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Brussels, Belgium. Prices are in 2016 real money.

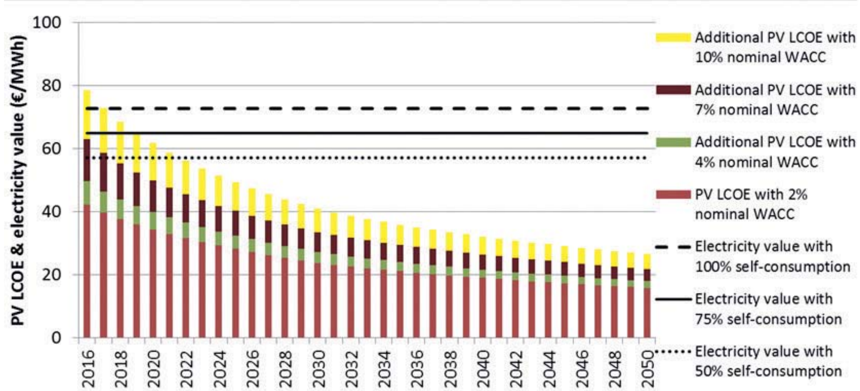

Figure 36. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Istanbul, Turkey. Prices are in 2016 real money.

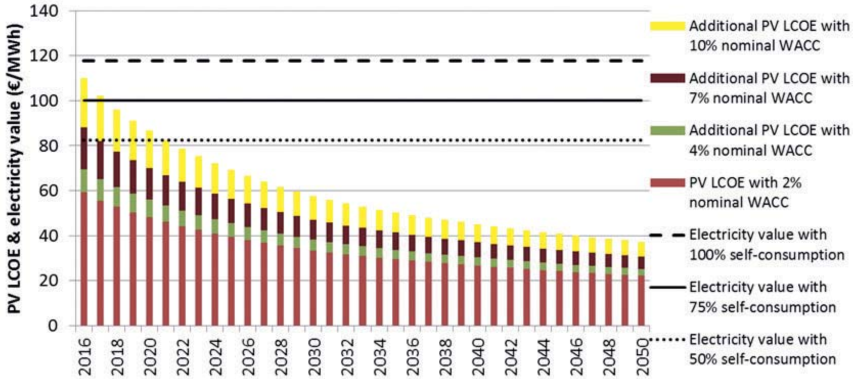

Figure 37. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in London, UK. Prices are in 2016 real money.

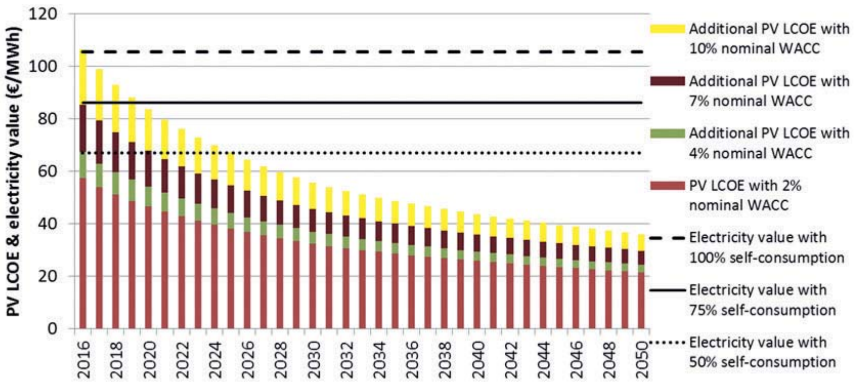

Figure 38. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Berlin, Germany. Prices are in 2016 real money.

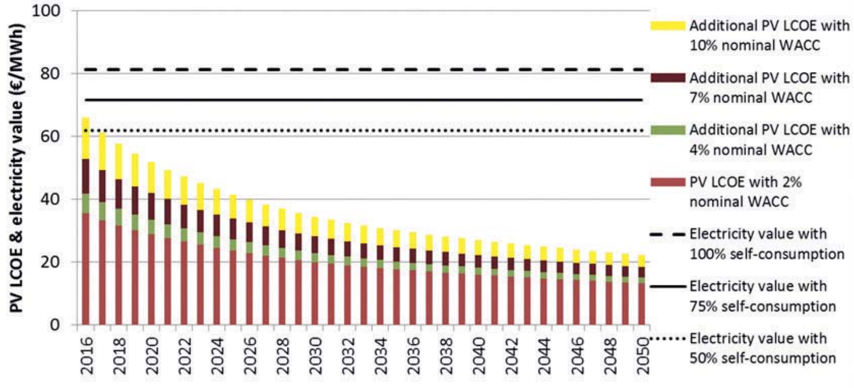

Figure 39. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Madrid, Spain. Prices are in 2016 real money.

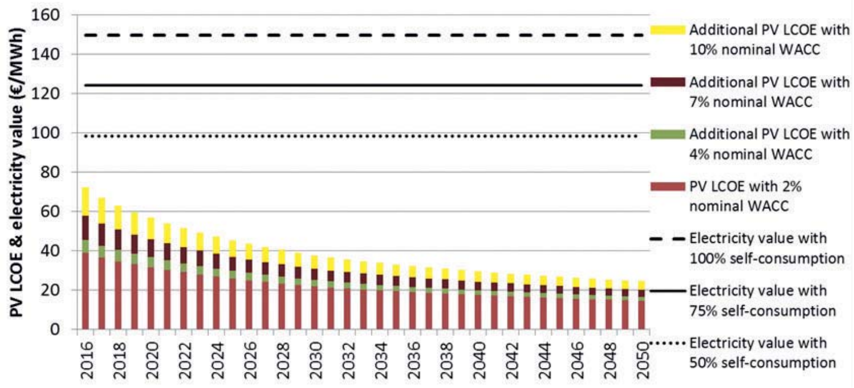

Figure 40. Comparison of PV LCOE with average industrial PV electricity value for a 1 MWp PV system in Rome, Italy. Prices are in 2016 real money.

Table VI summarises the years when true grid parity is reached in the industrial segment with 100% self-consumption in European countries. Apart from Sweden and Finland, all focus countries achieve true grid parity slightly earlier than the commercial segment with 75% self-consumption. Italy, Spain, the UK and Germany are all in true grid parity by this year (2017) with all interest rates. The same applies to Greece, Cyprus, Malta, Portugal, Switzerland, Ireland, Lithuania, Hungary, Austria and Slovakia. With 2% nominal

WACC, even Norway and Finland are in true grid parity this year, but Sweden is not because they have the lowest industrial retail electricity price in Europe according to Eurostat. It must be noted that this study applies mainly to the small industries, heavy industries usually get their electricity very close to the wholesale price which is lower than the retail price.

Table VI. Summary of when true grid parity is reached in the industrial segment with 100% self-consumption with 4 different nominal WACCs. Parity = true grid parity has been reached by 2016

Location	Nominal WACC			
	2%	4%	7%	10%
Stockholm	2020	2023	2029	2036
Helsinki	2017	2020	2025	2030
Amsterdam	Parity	Parity	2017	2021
Paris	Parity	Parity	2017	2021
Brussels	Parity	Parity	Parity	2019
Istanbul	Parity	Parity	Parity	2018
London	Parity	Parity	Parity	Parity
Berlin	Parity	Parity	Parity	2017
Madrid	Parity	Parity	Parity	Parity
Rome	Parity	Parity	Parity	Parity
Sofia	Parity	Parity	Parity	2020
Prague	Parity	Parity	2019	2024
Copenhagen	Parity	Parity	Parity	2019
Tallinn	Parity	Parity	2018	2023
Dublin	Parity	Parity	Parity	2017
Athens	Parity	Parity	Parity	Parity
Zagreb	Parity	Parity	Parity	2020
Nicosia	Parity	Parity	Parity	Parity
Riga	Parity	Parity	Parity	2018
Vilnius	Parity	Parity	Parity	2017
Luxembourg	Parity	Parity	2021	2025
Budapest	Parity	Parity	Parity	2017
Valletta	Parity	Parity	Parity	Parity
Wien	Parity	Parity	Parity	2017
Warsaw	Parity	Parity	2021	2025
Lisbon	Parity	Parity	Parity	Parity
Bucharest	Parity	Parity	2017	2020
Ljubljana	Parity	Parity	Parity	2020
Bratislava	Parity	Parity	Parity	2017
Oslo	Parity	2019	2024	2029
Zurich	Parity	Parity	Parity	Parity

6.4. Utility-scale 50 MWp system

Although the focus of this report has been in comparing PV LCOE with retail electricity prices, it is interesting to see what is the competitiveness of PV against wholesale electricity. Spot market electricity prices have been very low in recent years and have not enabled investments to any market-based power generation. It can be questioned whether the current market design, based on marginal cost of power generation, is relevant any more since most of the new generation capacity is wind and solar which have zero marginal cost. Nevertheless, we have compared utility-scale PV LCOE with current wholesale market prices in ten European countries.

To make a detailed analysis, hourly prices could be used to determine the real value of PV generation. In most cases, consumption and spot market prices are still highest in the hours when PV electricity is generated. This means that the value of PV electricity is higher than the average spot market price. However, year 2016 average spot market prices are used as the base case in this analysis. To take into account annual variations, a price level of +/-25% of average price is also shown. Utility-scale 50 MWp PV LCOE is calculated with a 15% lower module and BoS price and with a 25% lower OPEX price compared with the industrial 1 MWp. It must be emphasised, that the utility-scale CAPEX price used here for Europe is still considerably higher than what is possible with current module market prices [26] and BoS prices in countries like India [27].

As an example of utility-scale PV competitiveness, a comparison with wholesale electricity is shown in Figures 41-43 for Finland, the UK and Italy, respectively. As can be seen, competitiveness is not yet reached with current (2016) wholesale prices in Finland. However, PV would be competitive in Finland already next year with 2% nominal WACC if wholesale price were to increase to 40 €/MWh. In the UK, PV is competitive with current wholesale price with 4% nominal WACC next year (2018). Were the wholesale price to increase to £50/MWh (about 60 €/MWh), PV in the UK would be competitive even with 7% nominal WACC next year. In Italy, PV is competitive with current wholesale electricity price with 7% nominal WACC this year and with 10% nominal WACC within four years. Were the wholesale price in Italy at the 2015 level, competitiveness with 10% nominal WACC would be reached already this year.

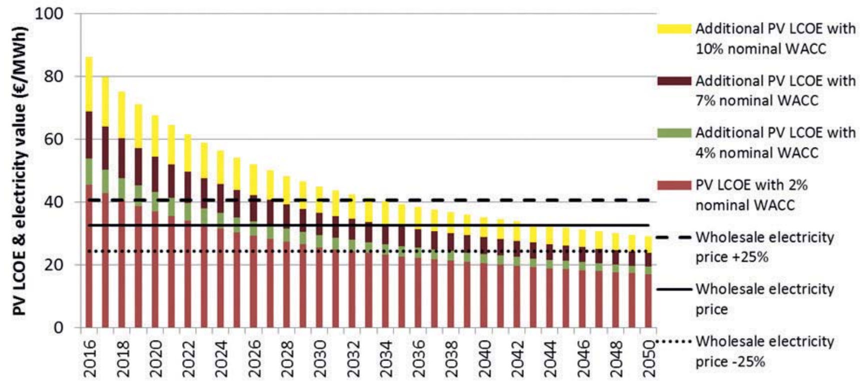

Figure 41. Comparison of PV LCOE with wholesale electricity price for a 50 MWp utility-scale PV system in Helsinki, Finland. Prices are in 2016 real money.

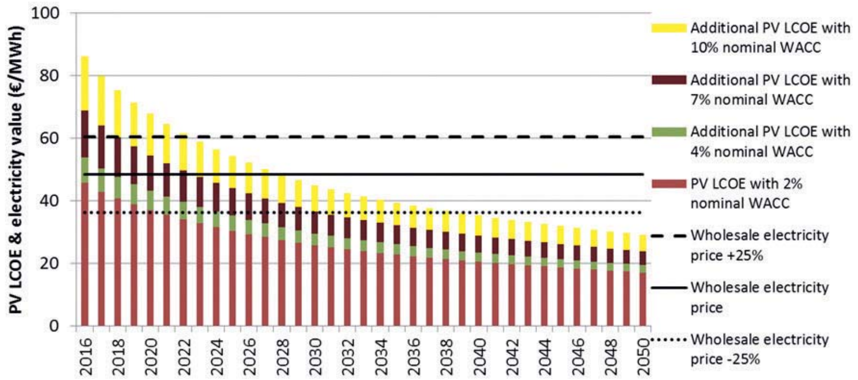

Figure 42. Comparison of PV LCOE with wholesale electricity price for a 50 MWp utility-scale PV system in London, UK. Prices are in 2016 real money.

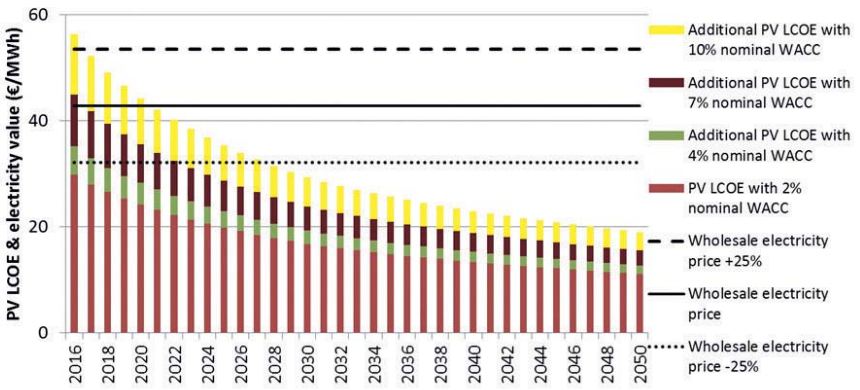

Figure 43. Comparison of PV LCOE with wholesale electricity price for a 50 MWp utility-scale PV system in Rome, Italy. Prices are in 2016 real money.

Table VII summarises the years when utility-scale PV is competitive with wholesale electricity price in ten European countries. With 4% nominal WACC, competitiveness has already been reached in Italy, Spain and Turkey. UK will follow next year (2018) because of its relatively high spot market price. Sweden, Finland, Netherlands and Germany have quite similar annual irradiation as the UK but they have currently extremely low spot market prices and will probably have to wait for PV competitiveness for almost a decade, whereas France and Belgium should reach competitiveness with current spot market electricity prices with 2% nominal WACC within a few years.

Table VII. Summary of when competitiveness with wholesale electricity price is reached for utility-scale PV with 4 different nominal WACCs. Parity = true grid parity has been reached by 2016.

Location	Nominal WACC			
	2%	4%	7%	10%
Stockholm	2027	2031	2040	2051
Helsinki	2024	2028	2035	2044
Amsterdam	2023	2027	2034	2043
Paris	2018	2021	2027	2033
Brussels	2020	2024	2030	2037
Istanbul	Parity	Parity	2020	2025
London	Parity	2018	2023	2028
Berlin	2026	2030	2039	2049
Madrid	Parity	Parity	2018	2022
Rome	Parity	Parity	2017	2021

7. SENSITIVITY ANALYSIS

In order to get an understanding of the various parameters affecting the PV competitiveness, a thorough sensitivity analysis was made. As a base case, a residential 5 kWp system in Finland with 50% self-consumption, 2% nominal WACC, 32 €/MWh spot market electricity price, 2015 average variable retail electricity price, 930 kWh/kWp annual yield, 80% performance ratio, 1.8 €/Wp (including 24% VAT) CAPEX and 20 €/(kWp·a) OPEX in 2016, 30% fixed share of the grid cost, 30 years system lifetime, 0.5% annual degradation and 25% learning rate for modules was used. Fig. 44 shows the sensitivity on the various parameters compared with the base case as a difference in years when true grid parity is reached.

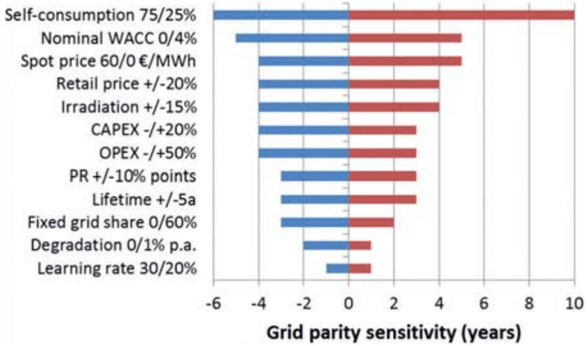

Figure 44. Sensitivity of true grid parity year on various input parameters for a residential 5 kWp system in Finland with 50% self-consumption, 2% nominal WACC, 32 €/MWh spot market electricity price, 2015 average variable retail electricity price, 930 kWh/kWp annual yield, 80% performance ratio, 1.8 €/Wp (including 24% VAT) CAPEX and 20 €/(kWp·a) OPEX in 2016, 30% fixed share of the grid cost, 30 years system lifetime, 0.5% annual degradation and 25% learning rate for module, 20% learning rate for inverter.

As is evident from Figs. 11-20, the level of self-consumption plays a major role in the PV competitiveness. The difference between 75% and 25% self-consumption ratio compared with 50% is from -6 to +10 years. This is because the value of self-consumed PV generation, i.e. the retail electricity price, is currently much higher than the value of surplus generation, which is often the spot market price. This means that in the absence of lucrative feed-in tariffs, it does not pay off anymore to generate much surplus by oversizing the PV system in relation to the electricity consumption.

The second most important parameter is the cost of capital or WACC. A difference of -/+2% in nominal WACC means -/+5 years in the true grid parity year. The value of surplus generation is also very important as it can range from zero to about 50 €/MWh in the ten focus countries in this study. Retail electricity price is as significant and it does not vary only by country but has a wide range between different companies within one country. In this study, it was assumed that the retail electricity price will stay at its current real value over time. But even assuming a 2% real annual increase, equalling 4% nominal annual increase, would mean about 10% real increase over 5 years, which would bring true grid parity only 2 years earlier.

A more profound change can be foreseen in the structure of the distribution grid tariff which in many countries has shifted emphasis from variable or per kWh price to the fixed or power-related fee during the recent years. However, as this sensitivity analysis shows, the effect of increasing the fixed share of the grid component does not have a major impact on the PV competitiveness, as the grid component is relatively small compared with the energy or taxes and fees component, typically 20% or less of the total retail electricity price. It is likely that more significant threats to PV competitiveness are the various legal, tax and regulatory changes which happen at alarming frequency in some countries and make it very difficult to create a confident environment for the PV investors.

Yield or irradiation and performance ratio obviously have some effect on PV competitiveness, as many European countries cover a geographically diverse area. And even at the same location, there might be different PV systems having varying yields because of different orientation, inclination or shadowing from the nearby buildings or trees. However, the effect of yield is not as significant as self-consumption or interest rate. The same can be said about CAPEX or OPEX which also have significant variation both between countries and installations in the same area. This is a very important conclusion, as it means that PV competitiveness does not solely rely on continuing decrease of investment cost and more efficient system operation. It can also be noted that increasing the learning rate of PV modules from 25% to 30% would only influence true grid parity by 1 year. PV system lifetime has some effect with low interest rates. Other parameters like PV module degradation have only a minor effect on PV competitiveness.

For comparison, Fig. 45 shows the sensitivity in the commercial segment in Finland with 7% nominal WACC and 75% self-consumption ratio. The main difference to the residential segment is that the self-consumption ratio is not as significant because the average retail electricity price in the commercial segment is closer to the wholesale price. On the other hand, the effect of interest rate is relatively greater since the WACC rates are higher. Wholesale electricity value has smaller effect since the amount of feed-in is lower. PV system lifetime is also less significant because of the higher WACC rates.

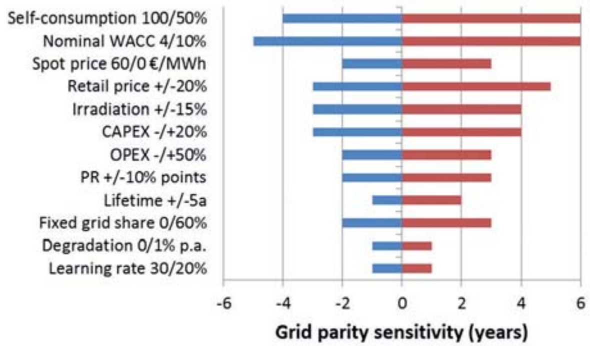

Figure 45. Sensitivity of true grid parity year on various input parameters for a commercial 50 kWp system in Finland with 75% self-consumption, 7% nominal WACC, 32 €/MWh spot market electricity price, 2014 average variable retail electricity price, 930 kWh/kWp annual yield, 80% performance ratio, 1.15 €/Wp CAPEX and 20 €/(kWp·a) OPEX in 2016, 30% fixed share of the grid cost, 30 years system lifetime, 0.5% annual degradation and 25% learning rate for module, 20% learning rate for inverter.

It is obvious that the various subsidy mechanisms still have a role to play in the countries and market segments where true grid parity has not yet been reached. For example, in Sweden subsidised PV competitiveness already exists with low interest rates because of tax deductions, investment grants, and green electricity certificates in the residential and commercial segments. In Finland, household income tax deduction is not quite enough for the residential segment to make a big difference, but a typical 25% investment grant in the commercial segment makes PV already viable with a 4% nominal WACC.

8. DISCUSSION

The analysis in this report clearly indicated that for the financial attractiveness of PV prosumer systems, the PV self-consumption is the key parameter to be increased. This is expected to be easier for commercial and industrial PV systems, since a good match of the load profile to the generation and the ratio of total generation on available roofs to the total demand can be better achieved. However, for residential PV prosumers, the mismatch of PV generation and the load profile is rather inconvenient, since social activities are often at other places during daytime, and for the times of high electricity demand in the buildings, which is typically in the evening hours, the PV generation is typically low or zero.

Batteries are an excellent component to overcome the mismatch of generation and demand for residential PV prosumers. Batteries start to become financially attractive in cases when the difference of the variable electricity price to the wholesale price is the same or larger than the cost of storing a respective kWh in a battery system. For example, in Germany this leads to the following requirement: variable electricity price is about 270 €/MWh and wholesale price about 30 €/MWh which equals a value for a stored MWh of 240 €. Assuming for the battery a technical lifetime of 15 years, full charge and discharge availability, nominal WACC of 2% and annual OPEX of 2% of CAPEX, roundtrip efficiency of 90% and 200 full charging and discharging cycles a year, leads to a breakeven CAPEX for the battery of about 500 €/kWh of storage capacity.

The battery systems in the German market currently cost about 1350 €/kWh per usable storage capacity on average, with a range from about 750 €/kWh up to 2500 €/kWh including all the leading battery system providers in Germany [28]. There are about 10 different offers from 4 different companies, including the top 3 battery system suppliers, for less than 1000 €/kWh available in the market. The cost of battery systems currently declines by about 18% p.a. [29], which will lead to an accelerated market growth in coming years, and a breakeven price within 3 years for the aforementioned 3 suppliers. Battery system prices are expected to decline substantially in the years to come, since the learning rate of batteries is about 15-20% [30], which is comparable to PV modules. The least cost market prices for comparable automotive Li-ion batteries are 145 USD/kWh for delivery in the years 2016 to 2018 [31]. The PV self-consumption can be increased for a country such as Germany up to 70% for economic system designs with a most cost-efficient PV system size of 0.8 kWp and usable battery capacity of 1.1 kWh per MWh of annual electricity consumption [32].

Additionally, having some hundred litres of water as a storage reservoir available for the heating system optimises the utilisation of PV electricity and maximises the self-consumption. In most European countries a heating system is required from autumn to spring. In particular in the autumn and in the spring months the solar PV system can provide the major part of the energy for heat pumps, which can be used in a most efficient way. However, in the winter time the PV system can only contribute partly to the heat demand. Depending on the location, the energy efficiency of the building and the type and size of the building, a family may need about 2500-5000 kWh of electricity for operating the heat pump. The direct hot water demand can be covered from spring to autumn almost fully with PV electricity.

Electric vehicles are a further option to increase the self-consumption. Assuming a specific energy demand of 20 kWh/100 km and a usage of 10000 km per year is equivalent to a further self-consumption potential of up to 2000 kWh per year. At least a part of it may be realised, however this is strongly dependent whether the electric vehicle is grid-connected to the residential PV system during daytime.

In a nut shell, when net metering or net billing schemes are not present, batteries become increasingly attractive to increase the self-consumption for residential PV prosumers to values of 70% depending on the PV system size, the electricity demand and the load profile. Electric heat pumps and electric vehicles can further improve the self-consumption and may become increasingly attractive for PV prosumers in the years to come. This is also a further example how the formerly separated energy sectors power, heat and mobility converge towards electricity in the future. A detailed analysis would require an hourly calculation to match best the PV generation with the respective load profiles, the flexibility options and storage capacities.

However, it needs to be highlighted that zero impact areas, and in particular the roofs should be fully covered by PV to enable a maximum PV generation, which will be finally needed in all European countries. PV self-consumption as only income option for the PV system operator is not appropriate enough to ensure the maximum PV electricity generation. From a societal perspective it is not efficient not to use the whole available zero impact rooftop area for PV generation. Therefore, further policy tools will be needed to guarantee a maximum PV generation with the aim of reaching COP21 targets for a net zero CO_2 emission society by the mid-21st century and yet still create an attractive business case for investors.

9. CONCLUSIONS

This report has assessed whether PV systems in key European markets could have reached or could reach in the coming years a reasonable level of competitiveness. This has been assessed for PV prosumers, under current self-consumption regulations, with existing and forecasted PV system prices, and under the constraining tax policies existing for prosumers in several European countries.

The report separates itself from others in the same topic in several perspectives. Firstly, by considering only the variable part in electricity bills, it is able to assess the true competitiveness feature of the addressed PV market. Moreover, the report focus is not only to identify the true competitiveness but to examine the relation between true competitiveness and self-consumption ratio. Depending on the level of self-consumption utilised, the grid parity can be achieved sooner or later.

Additionally, regarding the evolution of PV market in the next 35 years, three scenarios were used, based on the “Global PV Market Development 2016 – 2020” report of PV Market Alliance which is a consortium of regional solar PV experts across five continents and believed to be the most comprehensive and reliable market analyst. The forecast of LCOE input parameters was made taken into account the effects of the well-known learning curve in PV industry.

The conclusion is rather simple: if PV systems could be financed with a cost of money corresponding to the low level of risk associated with PV systems, they would be competitive already now in most European countries and for most market segments. A higher cost of capital would delay the moment where PV could reach competitiveness under the current conditions, especially in the Nordic countries. With reasonable cost of capital, self-consumption schemes without incentives and market-based remunerations for excess PV electricity injected into the grid, PV will be competitive in almost all cases within the coming five years. It is interesting to note, that PV also starts to be competitive with the current low wholesale electricity prices in South European countries.

Current PV system prices in Europe already allow a good level of competitiveness for PV installations in most segments. Further cost decline of battery storage and integration of PV systems with electric heat pumps and electric vehicles will make residential PV self-consumption increasingly attractive in more and more countries in Europe.

10. ACKNOWLEDGEMENTS

The work for this report has been carried out under the framework of the EU PV Technology and Innovation Platform (ETIP PV). The authors would like to thank ETIP PV Steering Committee and Expert Pool Members for their valuable contributions and comments during the work. The OPEX data provided by Bloomberg New Energy Finance and solar irradiation data obtained from Solargis database is also gratefully acknowledged.

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