European
Commission

JRC TECHNICAL REPORTS

Preparatory study for solar photovoltaic modules, inverters and systems

(Draft) Task 3 Report: User Behaviour and System Aspects

Peeters, Karolien; Soares, Ana
Van Tichelen, Paul: VITO
Voroshazi, Eszter: IMEC
Dodd, Nicholas; Espinosa, Nieves;
Bennett, Michael: JRC

June 2018

Joint
Research
Centre

Contact information
Nicholas Dodd and Nieves Espinosa
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-b5-photovoltaics@ec.europa.eu
Tel.: +34 954 488 728/476

JRC Science Hub
https://ec.europa.eu/jrc

How to cite this report: Dodd, N and Espinosa, N, *Preparatory study for solar photovoltaic modules, inverters and systems – Task 1 product scope*, European Commission, Joint Research Centre, 2018

Contents

Tables

Figures

3. Task 3: User Behaviour and System Aspects

This report forms the third task in Preparatory Study for the product group 'solar modules, inverters and systems'. The aim of this task is to:

- analyse users, procurers and installers behaviour and practices;
- identify recent changes and trends;
- understand to what extent they are captured by the existing regulations and standards for the product group or service analysed;
- provide inputs and assumptions for the assessment in later tasks of the environmental impact and cost of the product and how the standard measurement conditions may vary.

User requirements can be influenced by product design and product information. Relevant user-parameters are an important input for the assessment of the environmental impact of a product during its use and end-of-life phase, in particular if they are different from the standard measurement conditions as described in existing test standards for the product (see Task 1).

In line with previous Tasks, the provisional scope of this analysis of user practices and related system aspects will comprise grid connected systems of the following type:

- residential (up to $10\ kWp$);
- commercial (private/public $\leq 1\ MWp$);
- ground mounted/utility scale ($> 1\ MWp$).

With respect to the previous objectives some factors to consider are the relationship between capital cost, the solar resource and performance.

The analysis, carried out at a first stage through literature research and a later stage through direct contact with stakeholders, aims to identify any distinct variation in user requirements linked to the type of installation or end-user and any related variation from the measurement conditions specified in standards.

3.0 Photovoltaic users, procurers and their requirements

Users of photovoltaic systems can be anyone that uses electricity from the grid because those systems generate electricity which becomes a commodity that can be bought, sold and/or traded. Electricity is from the end user perspective never the final application but only a means to activate energy services which are needed, for example to provide hot sanitary water (HSW). For the end users there are also several alternatives to generate electricity[1] or even to supply the end application (see 3.1.8). As a consequence many photovoltaic system 'users' can be identified.

Over the last decades photovoltaic systems gained an increased share in renewable energy generation (see Task 2). Compared to other renewable energy sources, photovoltaic systems are attractive because they do not generate nuisance under operation, e.g. such as potential risks for shading and noise nuisance with wind turbines (Abbasi, Monazzam, Akbarzadeh, Zakerian, & Ebrahimi, 2015). With regard to investment cost they are becoming increasingly price competitive[1] (Carlsson et al., 2014) and also their operational cost is very low (see Task 2). A major potential short-coming of photovoltaic systems and their user expectations is its weather dependency, meaning that the produced electricity do not necessarily match the demand. This is because some users may place an importance on self-sufficiency, which is a theme that will be discussed in more detail in section 3.2.3.

Photovoltaic systems are also attractive to many users because they can be easily installed either in small or large systems on various locations. Figure 1 shows for example a large utility scale plant with ground mounted systems. An important benefit of this larger type of system is the easier grid integration in the medium voltage distribution

---

[1] https://setis.ec.europa.eu/system/files/ETRI_2014.pdf

grid and reduced losses, see 3.2.2 and 3.4.1.5. In such an installation the modules are also more easily accessible for repair and maintenance.

Smaller installations can be installed closer to the end user and/or electricity user for example on a flat or gable roof (Figure 2 and Figure 3). A flat roof allows more freedom to select the slope and azimuth, which can be beneficial to optimise the yield. Module repair can be relatively more expensive for roof mounted systems because of the need to access many small installations. This can result in a need for higher module quality and life time requirements.

Also building integrated photovoltaics (BIPV) can introduce aesthetic requirements (e.g. full black) which are less important for large ground mounted systems. The inverter is usually installed on a location where it is easily accessible for indoor maintenance and repair, for example in the attic (Figure 4). The life time requirements for inverters attached on roofs may therefore be less demanding compared to modules on ground mounted sites, where the inverter may be more exposed to ambient conditions.

The subsequent section will explain who are the typical stakeholders directly involved in PV systems and what are their typical requirements.

Figure 1. Large utility scale plant (3077 kWp) with ground mounted PV systems on 8 acres in Lommel (BE) (source: IZEN)

Figure 2. Medium sized PV system (386 kWp) installed on a flat roof.

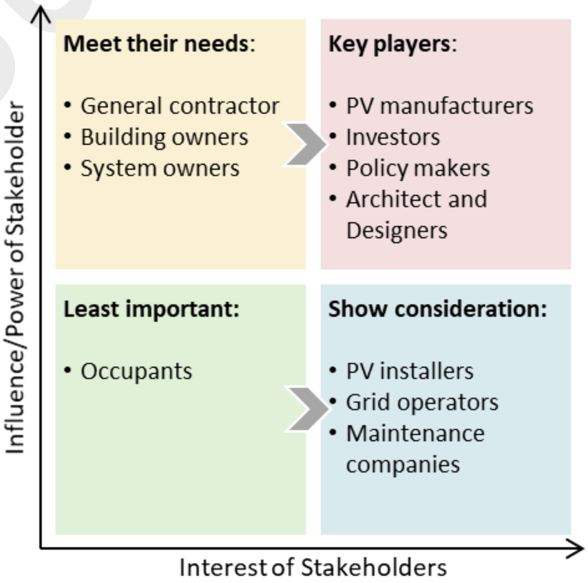
Figure 3. Small sized PV system (1,75 kWp) installed on an gable roof.

Figure 4. Small wall mounted photovoltaic inverter (1,75 kWp) indoor on an attic.

3.0.1 Overview of stakeholders involved in PV system use

There are several stakeholders involved in the PV market although their nomenclature is not uniform among the different literature. It is however possible to identify typical primary stakeholders such as end-users, system owners, the distribution utility, wholesale generators, the regulator, the transmission company. PV component manufacturers, investors, architect and designers and building owner (if other than the end-user or system owner) can be identified as secondary stakeholders (R2M, Onyx Solar, Flisom, BEAR-iD, & Acciona, 2016).

Figure 5. Classification of different stakeholders (power vs. interest) – adapted from (R2M et al., 2016)



The widespread deployment of distributed PV has distinct effects on the primary stakeholders since their interest and power of influence is different. Figure 5 relates the interests and power of influence for some of the previously mentioned stakeholders. Stakeholders relevance, challenges and benefits from PV deployment are summarized in Table 1.

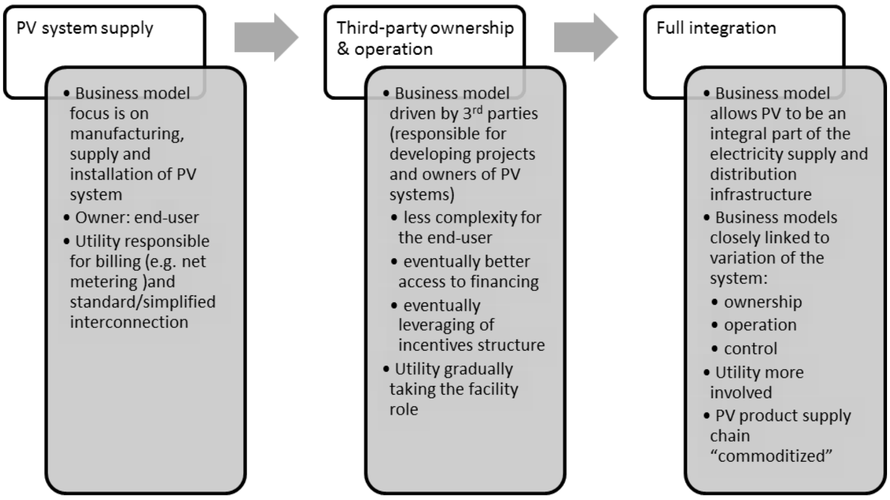
Table 1. Stakeholders' relevance, challenges and benefits from PV deployment

Stakeholder	**Relevance**	**Challenges & Benefits**
Prosumer - system owner	Usually also the owner of the PV system (system owner) and building.	Need to invest in PV systems. Cost-effective alternative to the grid.
Building owner (if other than the end-user)	Key stakeholder to be convinced to invest in PV technologies or to rent available roof for PV installation.	Needs to be aware of the advantages of PV deployment and receive an adequate payment/incentive.
Distribution utility	High penetration of the PV market influences the revenue associated with traditional tariff structures.	Need to ensure safety, operational integrity and reliability of the distribution grid. PV deployment can open the market to new products and services to be sold to customers.
Wholesale generator	High penetration of the PV market would compete in the wholesale market with other generating assets.	Need to be competitive. In a market environment competition is *per se* a benefit.
Regulator & Policymakers	Responsible for standards, rules, legislation. Policy enablers.	Need to create incentives and schemes balancing the needs of distinct sector and lobbies. Can positively impact on renewable energy penetration, among other aspects.
Transmission Company	Responsible for transmission.	High penetration of PV can impact on the demand for transmission services.
ESCOs	Responsible for designing and implementing projects.	Evolving legislation can be seen as a challenge. Return on investment.
PV manufacturers	Main investors on production and possible R&D of BIPV technology.	Need to meet any existent legislation + design and building specifications (mainly for BIPV). Revenues.
Investors	Financing the several stakeholders.	Evolving legislation can be seen as a challenge. Return on investment.
Architects and designers	Responsible for defining design features and specifications. Important role, especially in the case of BIPV.	Required knowledge on the optimal design. The fact that standard products are often the most cost effective can be seen as a challenge depending on the timescale and also on the type of PV systems (BAPV or BIPV). Building green can bring revenues and more clients.

The PV industry has been slowly moving away from business models in which the end-user financed, owned and managed the installation of the PV systems towards models in which these types of systems are attractive to a broader market.

According to (Frantzis, Graham, Katofsky, & Sawyer, 2008), and although this publication is not recent, the expected evolution of business model was considered to be one which would allow a greater integration of the PV systems into the grid and would accommodate a more proactive role from the utility (Figure 6). This is still true in the present context and part of this has already been introduced to the market as will be explained later (see section 3.0.2). The utility involvement is motivated mainly by concerns for grid infrastructure, safety and possible revenue loss.

Figure 6. Expected evolution of PV business models - adapted from (Frantzis, Graham, Katofsky, & Sawyer, 2008)



Typical current PV ownership application models are presented in Table 2. Herein prosumers are PV system owners who are simultaneously energy consumers and producers. PV systems for producers only can be either self-owned or have third-party ownership. In Table 2 new *versus* existing (retrofit) buildings are discriminated according to the Energy Performance of Buildings Directive (EPBD) which strives towards Nearly Zero Energy Buildings for new constructions as of 31 December 2020 and as explained in section 3.1.8 BIPV/BAPV can be an option for this. Moreover on new buildings there can also be some synergy with other construction works and therefore cost benefits.

Table 2. Current PV ownership application models (source: own estimate)

	Application				
Ownership	**BIPV/BAPV Residential buildings**		**BIPV/BAPV Non-residential buildings**		**Ground mounted systems**
	New building	Building retrofit	New building	Building retrofit	
Prosumers	●●●	●●	●●●	●●	○
Energy producers only *Self-owned*	●●	●	●●	●	●●●
Energy producers only *Third party*	●	○	●●	●	●●

●●●: well established and promoted by the Energy Performance of Buildings Directive (EPBD)

●●: well established

●: emerging

○: minimal activity

An example of the value chain for residential end-users in a retrofitting case (existing building) is illustrated in Figure 7 while an overview of downstream sector (utility PV application) is illustrated in Figure 8.

Figure 7 shows the main stakeholders involved in retrofitting and some of the transactions and flows of value between them. The main stakeholders are the prosumer; the utility; the regulator; the financier (if needed); the aggregator (facultative) and the government. The upstream supply side is comprised of the operation, maintenance and monitoring providers (when hired), the PV system distributor and the installer. Most of these stakeholders are also present in the case of:

- end-user owned systems in new residential constructions (the key difference is the home builder),
- third-party owned in the case of commercial retrofitting (key difference is the third-party owner),
- third-party owned in the case of a grid sited project (key difference when compared to the previous type is the payment scheme which can rely on power purchasement agreements – PPAs).

Figure 7. Example of value network: residential end-user - retrofitting case - adapted from (Frantzis et al., 2008)

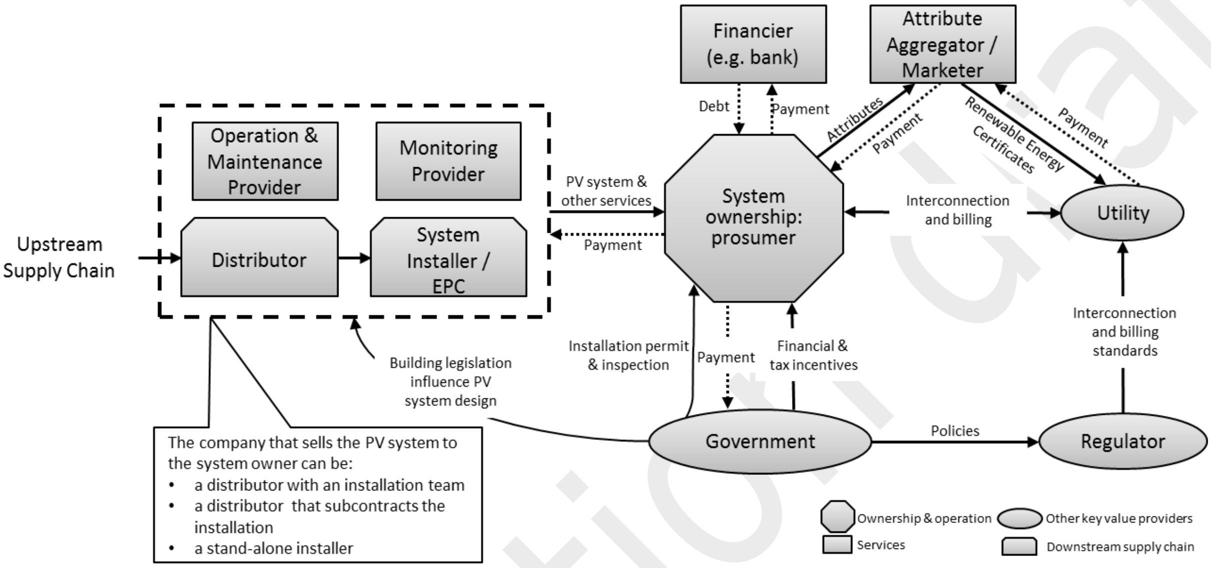
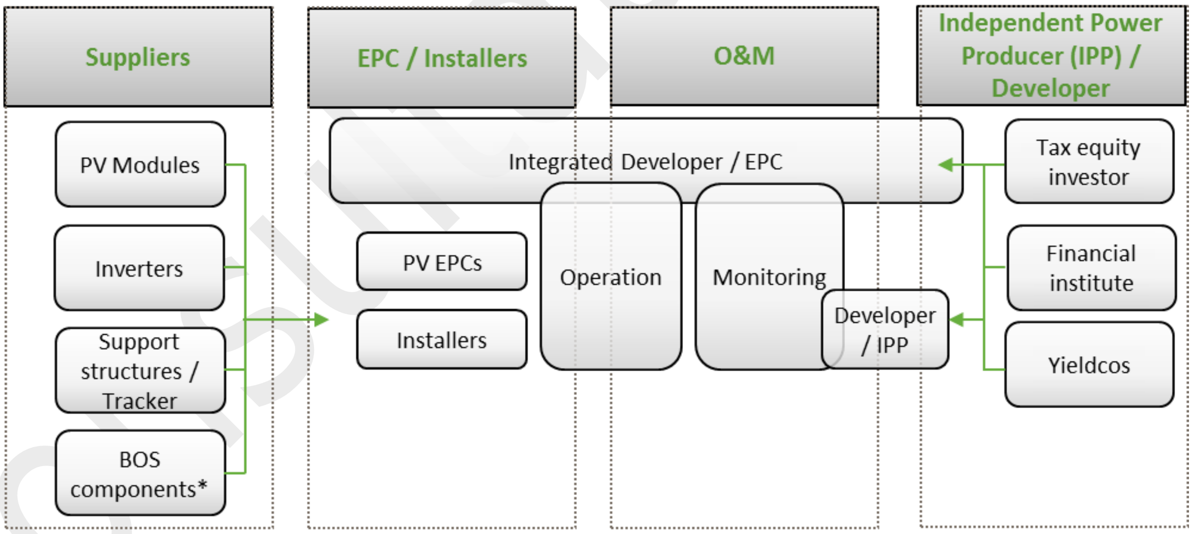


Figure 8. Overview of downstream sector (utility PV application) (IEA PVPS, 2017b)



* balance-of-system components (inverters, mounting structures, charge regulators, storage batteries, appliances, etc.).

3.0.2 Owners of PV systems

3.0.2.1 Ownership by energy producers only

In this section we discuss "Users of PV systems" or PV system owners who are only or exclusively energy producers, that is they do not consume the energy themselves. They will have a separate meter for measuring the production and this is probably the most common form of ownership today. They mostly rely on Feed-in Tariffs (FiT), Power Purchase Agreements (PPA) and/or Green Energy Certificates (GEC).

As was described in Task 1, FiTs are increasingly being awarded a result of a so-called "RES auction", which is a procurement auction, acting as a RES support allocation instrument, and in which power or energy are offered up for bidding (Mora et al., 2017). Bidders compete for delivering the volumes "on the basis of their required support level" usually in €/MWh. Those with the lowest required support level for the project generally win this type of auctions. They are then granted the right to construct the winning RES project and receive a support payment for a given period of time. This type of bidding process has been used in several countries in Europe, and due to the complexity of the bidding procedure and the pressure to drive down capital and operating costs it is generally used for the larger systems. Such Renewable energy auctions are based on competitive bidding processes, which aim to (Mora et al., 2017):

- identify the most adequate RES projects to be deployed within a certain time frame and geographical area;
- allocate appropriate support payments to the aforementioned projects.

3.0.2.2 Independent Power Producers

Independent Power Producers (IPPs) are entities, privately-held and thus not public utilities, which own facilities to generate electric power for sale to utilities and end-users. According to the definition are responsible for developing, building and operating power plants. They have, however, no affiliation to a transmission or distribution company (Global Capital Finance & Clean Energy Pipeline, 2014).

IPPs can also sell power to utilities under a long-term Power Purchase Agreements (PPA). Usually these agreements involve an entity (e.g. a single buyer or the distribution company) who buys the power generated by the IPP according to the terms specified in the contract. Whilst utilities may own transmission or distribution assets and sell electricity directly to retail or other small consumers, IPPs do not (Global Capital Finance & Clean Energy Pipeline, 2014).

For the IPPs there is a significant financing risk since projects under development have a higher risk profile than operating assets which turns into higher cost of capital. Also if revenues are lower than expected then cumulated debt service can be at risk (Global Capital Finance & Clean Energy Pipeline, 2014).

3.0.2.3 Third party ownership such as Energy Service Companies (ESCO)

An alternative ownership structure to IPPs is that the land or building on which the PV system is installed have different or mixed ownership.

In Belgium and Germany for example this arrangement is used for some public buildings in the form of an Energy Service contract[2,3]. It is an emerging area. The benefit is that the ESCO takes over all services and risks involved in installation and exploitation of PV systems but often also part of the complexity of tendering

An extra benefit of an ESCO is that they can deduct taxes and avoid that the client has to invest in upfront taxes in the PV system long before the benefit, see 3.4.1.1. In Belgium municipalities have to pay Value Added Taxes (VAT) on their expenses and therefore such a construction with an ESCO can avoid this upfront VAT investment cost.

Another option is to rent a PV installation for your building, e.g. which can be found in Germany[4]. It is a relatively new market segment the key difficulty being due to the shared ownership and contracts, for example in relation to equipment damage. For potential market and stock data please consult Task 2.

Third party ownership can complicate subsidy schemes(see 3.4.1.2) because these are often linked to ownership. Subsidy schemes providing revenue are a major driver for installing PV system (see 3.0.1) but vary across Europe and/or Regions (see Task 1).

Third party ownership is of relevance to public procurement because of the potential to reduce upfront capital costs, see 3.0.5.

---

[2] http://www.escolimburg2020.be/files/BROCHURES_2014/brochure_esco_EN_LR.pdf

[3] SAG Solar, Germany: http://www.sagsolar.com/en/solar-plant-lease

[4] https://www.dz-4.de/

3.0.2.4 *Ownership by prosumers*

In this section we discuss users of PV systems who simultaneously produce and consume energy behind the electricity meter. They are also referred to as ‘prosumers’. Prosumers can combine the benefits of energy producers as were discussed in the previous sections.

Examples of prosumers include:

- residential prosumers producing electricity at home mainly through the use of PV panels installed on the rooftop;
- citizen-led energy cooperatives;
- housing associations;
- commercial and industrial prosumers whose main business activity is not electricity production;
- public institutions.

Moreover, evolving electricity market legislation has introduced the concept of communities of prosumers – collective self-consumption. In this way each prosumer may have a different geographical location, but they may agree to share the self-produced electricity.

Defining what is a prosumer

According to the International Energy Agency (IEA) and cited by (GfK Belgium Consortium, 2017), prosumer installations below 10kW is defined as belonging to the residential sector. Typical residential PV systems do not exceed 20 kW and are usually roof mounted according to (IRENA, 2012). However, according to (GfK Belgium Consortium, 2017), this number is lower: “residential prosumer installations across Europe are generally lower than 10kW”.

The legal definition of residential prosumers is not clear or harmonised among different countries. According to (GfK Belgium Consortium, 2017), a regulatory definition of that term or a piece of legislation to specifically fully regulate this type of use is inexistent, at least concerning the countries analysed in that report. Also the definition of self-consumption or auto-consumption may differ and include different attributes. Some countries also refer to active consumers and self-producers[5]. In some countries, residential prosumers are defined according to the size or the capacity of the installation. However, in some countries the size or capacity is stated as being “small” without putting any numbers on it. The generation capacity used as a cap in prosumer-related national legislations, when clearly stated, is not the same in the different countries (GfK Belgium Consortium, 2017).

More recently there are also collective prosumers which perform collective self-consumption. In France for example in 2016 a law has been introduced to allow for this[6]. Article L 315-2 of the French energy code defines that self-consumption is collective when the electricity exchange is made between one or more electricity producers and one or more final consumers, linked together by a legal entity, and from which the injection and exit points are on the same low-voltage loop of the public distribution grid. The key benefit of such an approach is that it enables electricity users who have no suitable or a collective roof (e.g. apartment) to become photovoltaic prosumers.

Market testing of prosumer attitudes

In the context of the EU funded CLEAR project (Consumers Learn Engage Adopt Renewable Energy Technologies) a market enquiry was launched in Spain, Portugal, Italy and Belgium to identify *”the best approach to implement a group offer with regard to Renewable Energy Systems (RES)”* (Test-Achats/Test-Aankoop et al., 2015). The sample consisted of a target group mainly composed by intenders and thinkers and a basic level of adopters. 5012 respondents were gathered. According to the responses, the two aspects that a user most values concerning renewable energy solutions (RES) are how much money could be saved if they had a RES compared to their current energy source and total running costs. These two aspects are common in the four countries in which the survey was conducted.

---

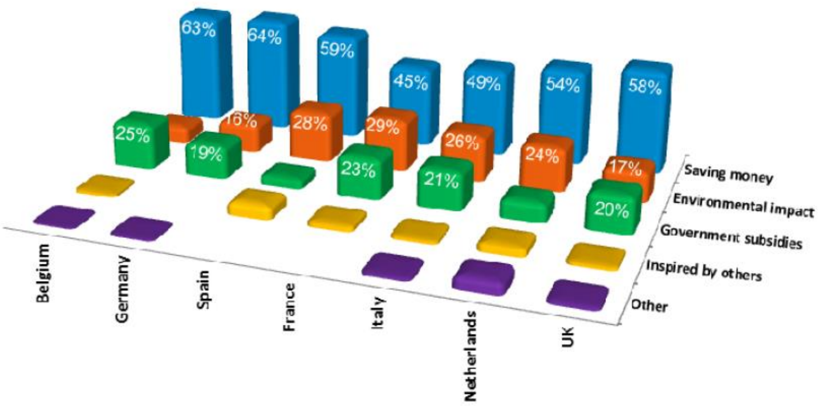
[5] A table summarizing that information can be found in (GfK Belgium Consortium, 2017): Table 1 - Definition of residential prosumers (page 37).

[6] http://www.pv-financing.eu/wp-content/uploads/2016/10/4.-Collective-self-consumption-in-France.pdf

For Spain, Italy and Portugal the least important information needs were information about performance warranties and the possibility to personalise the offer. For Belgium, the least important information was a tool to provide personalised solution and payment possibilities.

A major study on prosumers commissioned by DG Justice (GfK Belgium Consortium, 2017) has carried out a similar analysis and has included market enquiries in, amongst other Member States, Germany, France, the Netherlands and UK (Figure 9). This study also identified that the main driver that leads an end-user to invest in solar PV systems is saving money. Environmental impact and government subsidies play also an important role. The choice and purchase of PV systems from the end-users perspective would depend on price, aesthetics and payback time (GfK Belgium Consortium, 2017).

Figure 9. Main drivers for residential prosumers to invest in solar PV by country (GfK Belgium Consortium, 2017)



Concerning the product characteristics of PV solar panels, (GfK Belgium Consortium, 2017) conducted an experiment to identify which characteristics or combinations of characteristics are considered most important to the end-user when buying a PV system. Details of the experiment can be found in that report. The sample consisted of respondents owning a house with PV systems but interested in purchasing a PV system. Selected product features included:

- aesthetics,
- costs per solar panel,
- inverter type,
- installation,
- efficiency,
- lifetime, and
- maintenance costs

Other factors to be considered included the resale value of the houses after the PV system installation. The main conclusions from this part of the study are not yet available.

Defining self-consumption

An important practical parameter in seeking to define and meter self-consumption (SC) is the minimum time period to elapse between generation and consumption. This is typically 15 minutes, 30 minutes, 1 hour, over one day/night or per year depending on the billing scheme, which may differ per EU region or country[7]. The shorter time intervals are usually accounted for a system of net-billing i.e. electricity generated and consumed is metered separately and then reconciled on the bill. Aiming for self-consumption below a 15 minutes time period is

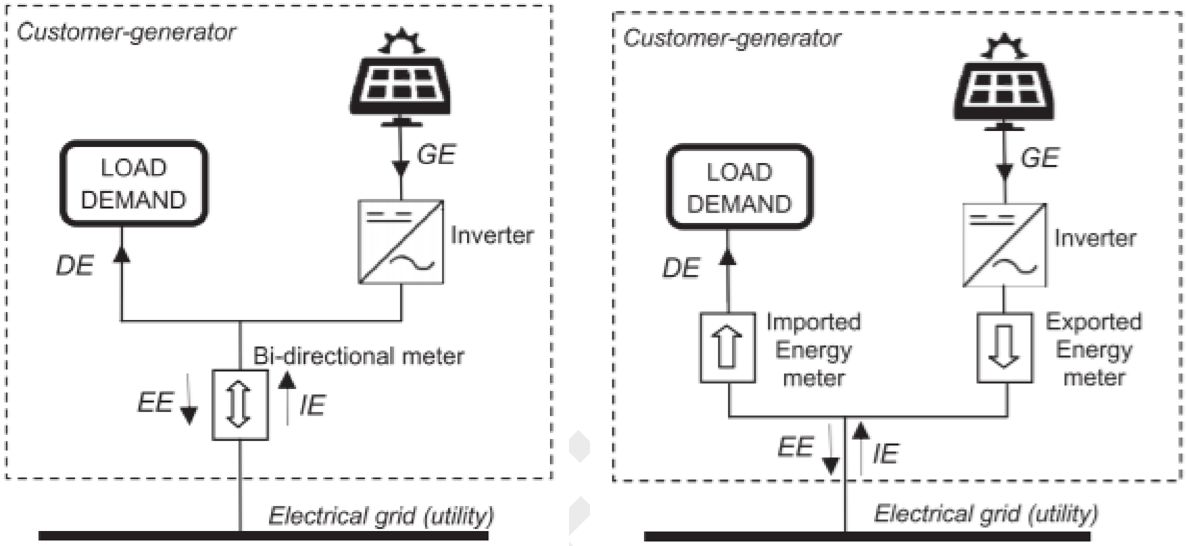
---

[7] 2014, European Commission: Cost-benefit analyses & state of play of smart metering deployment in the EU-27. Table 7 and 10 in: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014SC0189&from=EN

generally not considered useful because the peak loads of a group of domestic houses are easily averaged out. Amongst others, for this purpose the IEC or local grid code uses a diversity factor (e.g. IEC61439, NFC 14-100).

The longest time period used to define self-consumption is per year which is also commonly called 'net metering' (e.g. as used in Belgium, and the Netherlands). In this case the electricity grid acts as a free storage all year long and it can therefore act or compete to a certain extent with other technical solutions such a demand side management or batteries. Instead, it can be considered as being performed by a bidirectional running mechanical meter (running forward during times when net electricity consumption dominates, and backwards when net generation dominates). The main difference between net-metering and net-billing is illustrated in Figure 10.

Figure 10. Net-metering and net-billing schemes (Dufo-López & Bernal-Agustín, 2015)



The prosumer market can be influenced by local support policies, see 3.4.1.2, and retail electricity prices, see 3.4.1.3, which can differ strongly between member states and hence also the incentive to become a prosumer (see 3.4). More recently batteries are becoming more competitively priced and in some Member States receive investment subsidy. Battery storage systems can assist prosumers in increasing their self-consumption by storage as well as demand side management to control local loads, see 3.4.2.1.

According to (ACCIONA, NOBATEK, 2016), due to the progress towards grid parity and policies aiming to facilitate self-consumption, innovative business models have been slowly emerging (Table 3). Grid parity is achieved when the levelised cost of the PV electricity matches the net electricity price. When this parity exists, PV projects usually do not need financial support or incentives to be economically viable.

Table 3. Range of emerging business models from the prosumers' perspective - adapted from (ACCIONA, NOBATEK, 2016) and (GfK Belgium Consortium, 2017)

Production-based: FiT. **No self-consumption**	**Self-consumption + constraints**	**Self-consumption + FiT**	**Net-billing**	**Net-metering**	**Self-consumption + premium**
No right to self-consumption. Support mechanism such as FiT in place.	Grid-connection and self-consumption allowed with some fees or taxes. Usually no compensation for the excess	Self-consumption allowed. Prosumer can benefit both from bill reductions but also from support mechanisms,	Self-consumption without support mechanisms. Net-billing, considers both energy flows between the PV system and	Net-metering business model compensates the excess energy fed into the grid. The price is equal to the electricity retail price. Some	There might be an additional payment for on-site self-consumption, or a compensation for the excess exported electricity at a

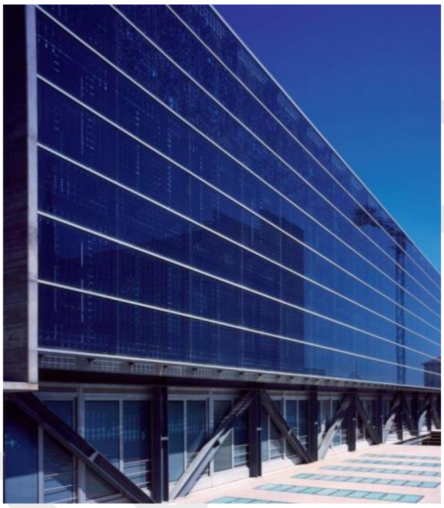
		electricity fed into the grid.	such as FiT. (e.g. Bulgaria)	the grid. Different prices for energy consumed from the grid and excess electricity injected into the grid may be used. time-scale: 15 min to 1h (e.g. Portugal)	taxes might usually charge for the grid availability and maintenance. time scale: over a long period (month/year) (e.g. Belgium)	higher price than retail electricity. (e.g. Czech Republic)
Right to self-consume	Not allowed	Yes	Yes	Yes	Yes	Yes
Revenues from self-consumed PV	-	Savings on the electricity bill	Savings on the electricity bill	Netting of production revenues and consumption costs	Savings on the electricity bill	Savings on the electricity bill
Additional revenues on self-consumed PV	-	No	No	No	No	Premium
Charges to finance transmission & distribution cost	-	Yes	No	No	No	No
Revenues from excess electricity	-	Zero	< retail price	<= retail price	= retail price	> retail price
Maximum timeframe for compensation	-	Real-time	Real-time	Long period	Long period	Real time

3.0.3 Different options for installing PV systems

Building attached (BAPV) photovoltaic systems refers to PV systems installed on an existing building (Figure 11) while Building integrated (BIPV) photovoltaic systems are integrated in the building envelope replacing typical building materials by PV ones (Figure 12). The Energy Performance of Buildings Directive (EPBD) is an important driver for BAPV and BIPV as it establishes targets for Nearly Zero Energy Buildings BIPV/BAPV can be an option to meet such targets, which vary between Member States. Moreover on new buildings there can also be some synergy with other construction works and therefore cost benefits.

Figure 11. BAPV at EnergyVille, Genk, Belgium (Yordanov et al., 2017)

Figure 12. BIPV – La Salle, Barcelona, Spain (Rasker, 2017)



Building integrated (BIPV) photovoltaic systems and the market for architectural BIPV in Europe have been growing in the last years according to (R2M et al., 2016) and (IEA PVPS, 2017b). The dominant PV technology in BIPV is crystalline silicon (c-Si) although a relatively high percentage of the product offerings uses thin film (TF) PV technology (Zanetti et al., 2017). Typical trends namely in The Netherlands include the use of prefab mounted BIPV in social housing renovation programs. In this context poorly insulated social housing get a new building skin using prefab constructed façade and roof elements. According to (Zanetti et al., 2017) coloured façades may also gain market share mainly due to their ability to reduce their visibility which contributes to a broader market acceptance of PV façades[8]. Solar glazing is another expectable trend although this technology is not new.

According to (IEA PVPS, 2017b), incentives for BIPV have been decreasing with the exception of a few countries such as France and Austria which still maintain support schemes to favour the development of BIPV. Higher FiT rates for BIPV systems are made available with the final aim of promoting structural integration of PV systems in the built environment (R2M et al., 2016).

3.0.4 Consumer requirements in the design stage of a PV installation

As documented before, by far the main driver for procuring a PV system is saving money (Figure 9). Therefore the most important consumer requirement is to calculate the annual Energy output from PV system (AC) (Eout). Based on the annual Energy output (Eout) forecast and the subsidy scheme, the return on investment or money saved can be calculated, see 3.4.1 or Task 2.

---

[8] Coloured PV façades have however the disadvantage of a "shading" over the PV cells which impacts negatively on the energy production (Zanetti et al., 2017).

This PV system energy output (Eout) is related to the Performance Ratio (PR), the reference yield (Yr) [hours/year] and the total PV array power rating in DC(P0) [kWp]. Therefore the following formula applies:

Eout [kWh/y] = PR x Yr[hours/y] x P0[kWp]

A more detailed insight on all factors that could affect the Performance Ratio (PR) and hence the annual Energy output (Eout) of a PV system is given in a later section 0 and a more complete overview of contributing derate factors[9] (IEC 61724-1) in Table 5. It should be clear from the later section 0, that not all parameters will contribute to the real measured AC output power under control of the installer and therefore there will always remain some margin of uncertainty left between what can be forecasted during the quoting and the real output. Therefore quality programs and procurement specifications also tend to focus on what can be controlled in standard conditions in the strict product scope, as explained in detail in section 3.1.3.

Potentially the most important part of the design process is therefore the energy yield forecast (Ey), which is discussed in detail in later section 0. A high-quality engineering project requires the selection of a reliable solar resource database, correct energy simulation, a good layout, and adequate electrical and mechanical dimensioning[10]. Depending on the size of the installation, type of mounting (roof-mounted or ground-mounted) and aim, several design aspects should be taken into consideration (see section 3.1.6).

A summary of the link between the performance parameters and energy yield calculations of a PV system is included in the subsequent section 3.1.6 and Table 11 while more technical details and reference data in its respective preceding sections (see 0).

Hereafter is a brief discussion per market of some typical consumer requirements during procurement. More background information and a detailed introduction for those who are not familiar with the topic can be consulted in dedicated literature (Luque & Hegedus, 2012).

3.0.4.1 PV design processes in the residential market

The previously described design process can look relative elaborate and expensive for small residential PV systems, however it can be automated and linked to predefined packages of module/inverter combinations. Therefore already today many large retailers start to offer PV systems to the residential market[11, 12, 13]. Mostly they carry out the design procedure for free during the quoting procedure, mainly related to the analysing the roof orientation and shading risk. These retailers can also differentiate in the amount of service that is included in the package deal, e.g. provide loans, insurance, extended warranty, maintenance, etc. Analysis of which roofs are suitable can also be automated by processing satellite/airplane images and laser range sensor data for a complete region[14]. Consumer expectations can also bring into the design process a range of other considerations such as aesthetics (e.g. the appearance of modules or the visual effect of a system on a roofline) as well as considerations of longer term aspects such as access to modules for cleaning and inverters for repair/replacement (Which? 2018).

From the user perspective various aspects may be of concern due to their influence on performance. The choice of the inverter is an important aspect. String inverters are usually cheaper but since they connect the panels in series, if one of the panels fails, it will impact in the whole system. Micro-inverters, usually more expensive, don't have this drawback and any problems will be potentially better identified through the power-monitoring system. The location of the inverter is another important aspect to take into account. Being placed near the panels minimises possible energy losses due to long cabling. The heat from solar irradiation however might have a negative impact on its performance. The colour of the panels, besides the aesthetic aspect, may or not influence their performance. Black panels without front surface busbars might, for example, see their efficiency decreased due to an associated temperature rise.

---

[9] Derate factors quantify individual sources of loss with respect to the nameplate's DC power rating (IEC 61724-1).

[10] http://www.etip-pv.eu/fileadmin/Documents/ETIP_PV_Publications_2017-2018/PV_Quality_report_ETIP_PV_SolarUnited_August_17.pdf

[11] http://ikea.solarcentury.com/

[12] https://www.vattenfall.de/de/sonnendach.htm

[13] https://www.engie-electrabel.be/nl/energie-besparen/zonnepanelen/opbrengst

[14] https://vito.be/en/media-events/press-releases/how-suitable-is-your-roof-for-the-installation-of-solar-panels-or-a-solar-boiler-see-for-yourself-on-the-solar-map

The choice between roof mounted or integrated, depends on the type of construction: for new constructions, BIPV is an option, but for old construction the only option left might be BAPV. In the case of retrofitting, it will be dependent on the depth of modifications: for example, replacement of roofs might allow the installation of BIPV. It is important to highlight that one advantage of BIPV is related to their positioning: they sit flush with the roof which leaves no room for birds to nest underneath. Birds nesting is a problem reported by several PV owners and thus the importance of making them aware of this possible situation ("Make the most of your solar panels - Which?," n.d.).

Additionally, and although PV panels might be self-cleaning through the rain when the roof has the right incline, some additional actions might be required if there are birds, trees or even a high amount of traffic in the area.

3.0.4.2 System and product tests made by selected consumer organisations

Hereafter is a brief selection of some other examples of different types of information and tests that *consumer organisations* carry out to support residential consumers in installing PV systems.

The Belgian consumer organisation 'Test-Achats' for example provides extensive support to their members for purchasing PV systems (Test-Achats/Test-Aankoop, 2015). They audit PV module manufacturers and check production samples on uniformity, compliance with the rated power, soldering errors with electroluminescence camera, visual errors in the back sheet laminates or frames and the quality system in place. They also offer group purchase promotions in which they audit the production accordingly. Moreover their requirements are:

- PV modules must comply with IEC 61215 (crystalline cells) or IEC 61646 (thin film cells) IEC 61730 (BAPV) with a third party certification (BELAC, TUV, ..), as detailed in Task 1.
- They refer to a reference contract proposed by the local authorities[15] for installers (Service Public Wallonie, 2015), see a later section in this task for more details.
- Minimum warranty in modules and inverter of 10 years.
- At least one of the installers must have followed the Rescert PV installer course[16].
- During installation the consumer organisation will perform regular audits.

The British consumer organisation Which?[17] provides similar information to its members based on module manufacturer audits and inspection combined with paid expert advice for selecting a PV systems. Another approach from the Spanish consumer organization OCU is to recommend a selection of tested PV systems or kits[18], which are preselected combinations of modules with inverters which are then given a scoring or rating based on their tested performance.

There are also international initiatives that developed collaboratively[19] PV system testing for their member consumer organizations. In principle what consumer organisations do is very close to what some retailers are doing [20], [21], the key difference is that they are also the contractor and single point of service. In many cases retailers and/or installers make proposals or quotes free of charge. Of course, test can also be done by third party accredited laboratories, as detailed in Task 1.

Of general interest are the technical terms of Walloon Reference contract for PV systems (Service Public Wallonie, 2015). It stipulates that the installer should estimate the AC output of the PV system (see 3.1.5.1) and compare it to the metered annual energy consumption of the client from the most recent year. This AC output is related to the Final Yield (Yf) which depends on the Performance Ratio (PR) and the Reference Yield (Yr) see 3.1.5.1 or standard IEC 61724-1.

---

[15] https://energie.wallonie.be/fr/installations-photovoltaiques-qualiwatt.html?IDC=8797

[16] https://www.rescert.be/fr/certificats-possibles

[17] https://www.which.co.uk/reviews/solar-panels/article/best-solar-panel-brands/solar-panel-brand-reviews

[18] https://www.ocu.org/vivienda-y-energia/gas-luz/test/comparar-kits-fotovoltaicos

[19] http://www.international-testing.org/

[20] https://www.ikea.com/gb/en/ikea/solar-panels/

[21] https://www.eon.de/de/pk/solar/aura/photovoltaikanlagen.html

The AC output must be projected for a life time of 25 years taking into account module degradation (see 3.1.4.5). It is also required to make a detailed listing of all object that could contribute to shading (see 3.1.5.2) and inform the client about potential consequences. The AC output must be compared to a system with optimum inclination angle (35°), south orientation (see 3.1.4) and without shading effects (see 3.1.5.2). This will make it more easy to compare tenders disregarding their often subjective estimate of the impact from shading.

3.0.5 Public procurement criteria and requirements for PV systems

3.0.5.1 General introduction to public procurement

During the procurement process a public authority will select a contractor for installing the PV system. The entity responsible for on-site system installation based on the intended design, equipment specifications is called herein the contractor. The Contractor can thus be seen as one of the entities with the greatest impact on the quality of the asset in terms of safety and actual system performance (Doyle et al., 2015).

The procurement process can vary according to the ownership. In the particular case of public authorities and green procurement, or Green Public Procurement, it means the process whereby public authorities seek to procure goods, services and works with *'a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured'*[22]. It is one of the objectives of this study to explore the potential for GPP criteria for PV modules, inverters and systems. Therefore this task will look for a set of representative examples according the different types[23] of criteria that are usually described or set so as to analyse how the priorities of public sector clients may influence technical requirements:

Selection Criteria (SC): Selection criteria refer to the tenderer, i.e., the company tendering for the contract, and not to the product being procured. It may relate to suitability and capability to pursue the professional activity, e.g. training. etc.

Technical Specifications (TS): Technical specifications constitute minimum compliance requirements that must be met by all tenders..

Award Criteria (AC): At the award stage, the contracting authority evaluates the quality of the tenders and awards points that will have a weighting together with to the price bid.

Contract Performance Clauses (CPC): Contract performance clauses are used to specify how a contract must be carried out. It may be linked to penalties or bonuses under the contract in order to ensure compliance.

The structure of the tender process is also linked to the preferred type of contractual arrangement, as illustrated by recent EU GPP criteria for Office Buildings (European Commission 2016). Figure 13 is taken from a guide developed for public authorities by the US Department of Energy and illustrates the different contracting routes that can be followed. Although the diagram is in a US context, the same broad options are available in a EU context.

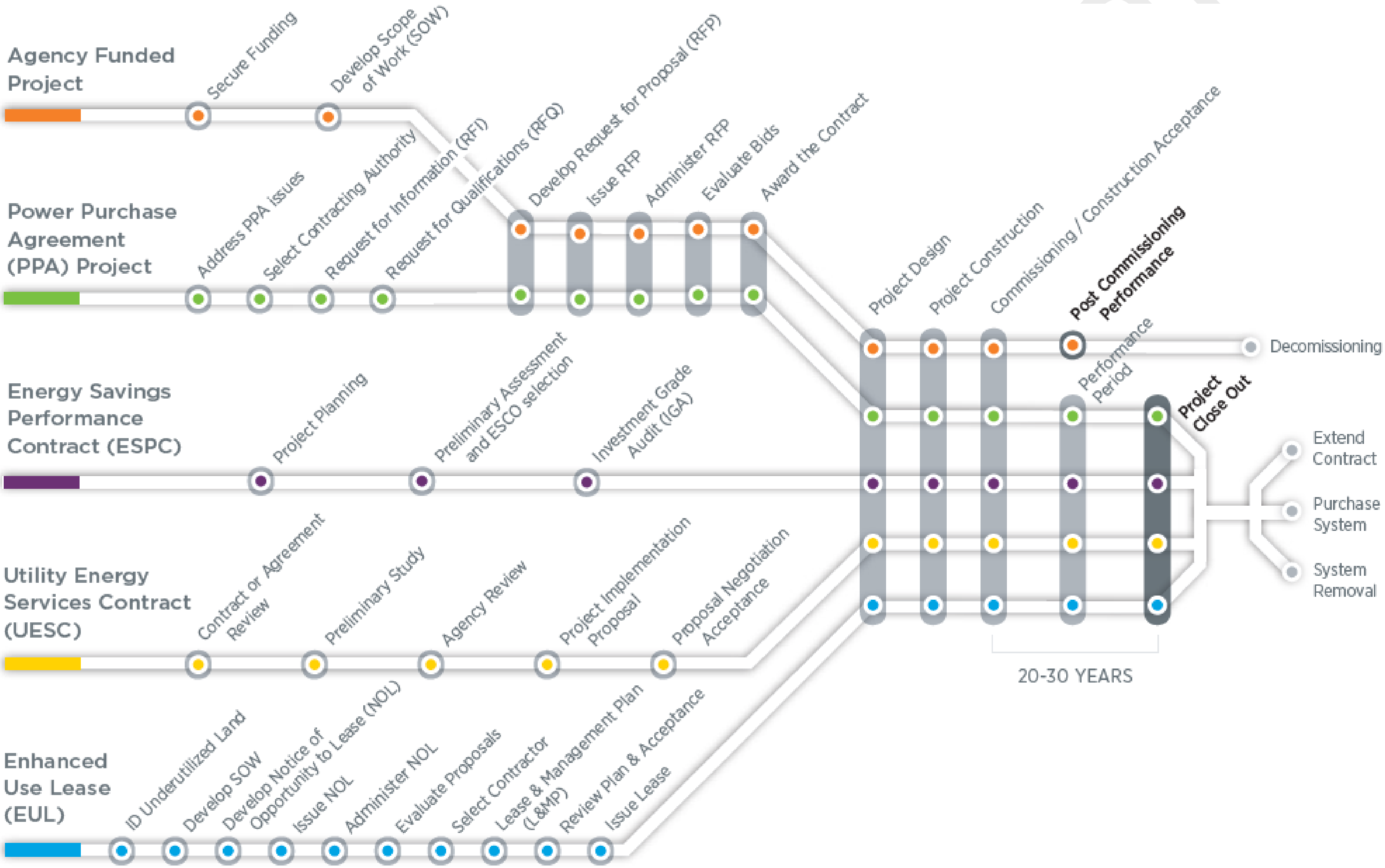
Careful consideration of the contracting route is important because it may have implications for the types of GPP criteria that can be used, and when they will be applied during the bidding and contract execution process.

---

[22] http://ec.europa.eu/environment/gpp/what_en.htm

[23] http://ec.europa.eu/environment/gpp/glossary_en.htm

Figure 13 Diagram illustrating different financing and contractual arrangements for public procurement (Source: US DoE, 2010)



3.0.5.2 Public procurement - some initial examples

The Office Journal of the EU's tenders database was consulted in order to review the types of criteria that are set when publishing calls for tender for PV systems. Relatively few European public tenders were found to be published[24], with 46 tender documents for a period from 7/2015 until 4/2018. The most active country was Poland followed by France, Germany, UK, Ireland, Italy and Switzerland. Note that public authorities can also procure green electricity but apparently do not often procure and/or own the PV systems used to generate this electricity themselves.

There was also one tender from the European Commission services, in Ispra (JRC) (2018/S 030-064302). Worth noting that in the technical specifications sometimes also monitoring is required, for example the tender from JRC 2018/S 030-064302 requires a monitoring system according to new standard IEC 61724-1: 2017 class B.

Examples of Award Criteria were based on the price per kWp but sometimes combined with extra points[25] for (Main-Kinzig(D)) the following were specified: a longer warranty on modules and inverter, installation time, reaction time in case of failure and how long spare parts are kept for repair of the inverter. Repair response times and installation time are sometimes specified only in the Contract Performance Clauses instead of the Award Criteria.

Another Tender (Monthey-Switzerland) combined the price (35%) with the forecasted AC output power (35%) combined with the judging on the technical quality of the proposal (10%), the project management (10%) and previous references (10%). Note that in these example elements such as project management and references that are usually Selection Criteria were taken into account in the Award Criteria.

Important in all tenders reviewed were the minimum quality requirements and/or the valuation of quality, which are related to performance as discussed in the subsequent section 0 but also trained staff (see 3.4.1.8.

Apart from directly procuring a PV installation there are also other procurement routes. A special form of public procurement is using an Energy Service Company (ESCO) with Third Party Ownership, which is discussed in the previous section 3.0.2.3 wherein also the example of the Flemish municipalities was given. This can be done by roof contracting to a Third party, for example in Germany the Berliner Energy Agentur[26] is doing this. In both the UK (Reading) and in Germany (Freiburg) renewable energy investment co-operatives have been established to finance systems that have been installed on a range of public and community buildings [27] [28].

As explained in section 3.0.2.3 an important benefit of third party energy service or ownership models is avoidance of Value Added Taxes (VAT) on the installed PV installation. In Belgium the Distribution Company offers ESCO services to the local municipalities for their buildings[29] meaning that they organise the tendering, servicing an financing. Finally, public authorities can simply also procure green electricity. A hybrid of this approach is being used in some cases due to the absence of FiTs Power Purchase Agreements (PPAs). For example in the case of Portsmouth City Council in the UK [30].

---

[24] OJEU Tenders Electronic Daily, http://ted.europa.eu/TED/

[25] http://www.versorgungsservice-main-kinzig.de/Ausschreibung-2018.2031.0.html

[26] Berlin Energy Agency, http://www.berliner-e-agentur.de/en/services/photovoltaic-contracting

[27] Reading Community Energy Society, readingenergy.coop

[28] see FESA www.fesa.de and Regiosonne www.regiosonne.solar-monitoring.de)

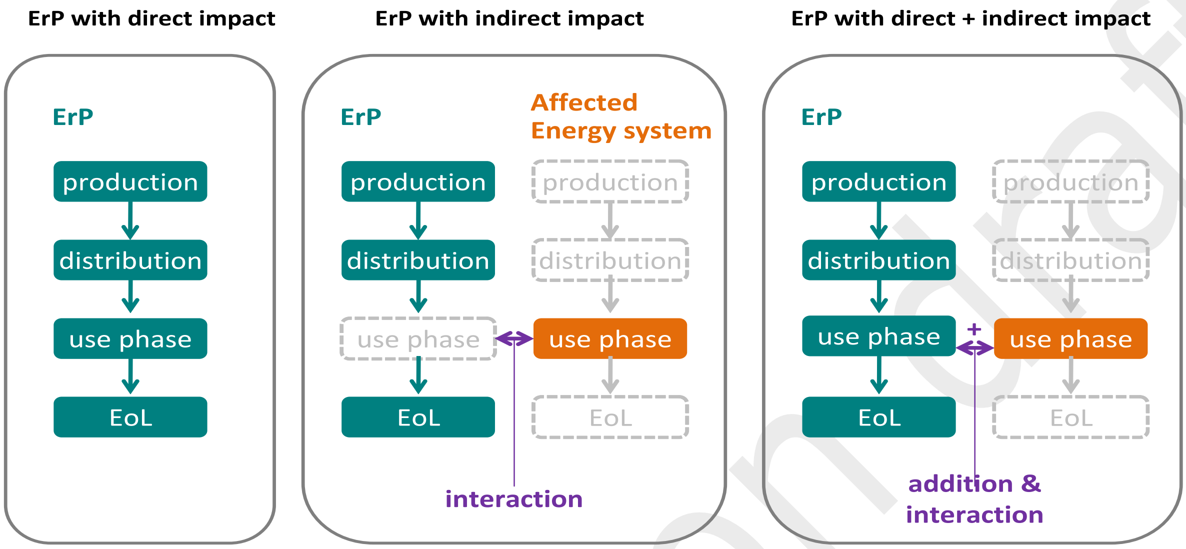
[29] http://www.eumayors.eu/about/covenant-community/signatories/key-actions.html?scity_id=5310

[30] Solar power portal, *Solar PPAs and the public sector*, 7th July 2016
https://www.solarpowerportal.co.uk/blogs/solar_ppas_and_the_public_sector_7834

3.1 Subtask 3.1: Systems aspects in the use phase of solar photovoltaics with direct impacts on the energy production

For the purpose of introducing the MEErP method [31] the concepts of: Energy related Products (ErP) with direct impact, ErP with indirect impact and ErP with direct + indirect impact, are illustrated in Figure 14.

Figure 14. Ill (Source: MEErP, 2011)



The MEERP guidance (2011) refers to **direct impacts** as those related to energy consumption in the use phase. Given that solar PV is an energy generating product it might be needed to consider direct impacts in negative terms i.e. those parameters that may constrain or reduce the amount of electricity generated during the use phase, or which may be considered as direct losses from a system during the use phase. Direct impact for PV systems herein means any impact that is directly related to the PV system itself and it can therefore be interpreted as relating to the system design and specification decisions which can have a direct impact on the performance of a module, inverter or system. Consequently this are mainly those aspects taken into account in the **Performance Ratio (PR)** of the PV system and **the in plane irradiation(Hi)**.

In the case of **indirect impacts** the MEErP guidance refers to these as being related to an 'affected energy system'. Solar photovoltaic electricity generation will therefore displace or **substitute centralised non-renewable electricity generation**, thereby indirectly reducing environmental impacts. **Other** indirect impacts are also possible. For example, local on-site production will also indirectly **reduce transmission and distribution losses**. It also has to be taken into account that not all indirect impacts have a positive indirect benefit for example **matching the local load profile**. More details on these indirect impacts and the modelling thereof will be discussed in a subsequent section 0.

A summary overview of direct and indirect impacts related to the use phase is in Table 4, see section 3.1.2 and later for more detailed technical definitions.

The analysis is based on different scoping levels in the subsequent section; starting with a strict product scope, and then extending this perspective to an extended product approach, thereafter proceeding to a technical system approach and finally discussing lifts from a functional system approach.

Table 4. Direct and indirect impacts

Direct impacts	**Indirect impacts**
related to energy production in the use phase	**related to an affected energy system**

---

[31] http://www.meerp.eu/

– Performance Ratio(PR), which is is the quotient of the system's final yield Yf to its reference yield Yr, and indicates the overall effect of losses – Derate Factors (DRx) to decompose Performance Ratio (IEC 61724-1:2017): $DR_{capture}$ for capture losses DR_{BOS} for BOS losses – In plane irradiation(Hi) [kWh/m^2] over the specified time period ..	– Environmental impacts due to substitution of non-renewable electricity with photovoltaic energy – Transmissions and distribution losses associated with the grid – Increased need for demand side management – Increased need for grid storage – Increased use of storage and therefore losses – Ancillary grid support, e.g. congestion management. – Substitute hot water production with fossil fuel in a building. – Provide renewable energy for local consumption (HVAC, home appliances, etc., ..)

3.1.1 Scoping levels with their system boundaries and functional unit

According to the MEErP method there are typically four different scoping levels:

- **Strict product approach**: In the strict product approach, the system boundary just contains the PV installation with its components. The operating conditions are nominal as defined in traditional standards.
- **Extended product approach**: In the extended product approach, the influence of real-life deviations from the testing standard will be discussed.
- **Technical system approach**: When viewed from the technical system perspective, the PV system is embedded in the surrounding building system or site.
- **Functional approach**: In the functional system approach, only the basic function of a photovoltaic, i.e. producing renewable energy, is maintained, yet other ways to satisfy this basic function are reviewed, as well. For example wind turbines can be installed at grid scale for RES or a solar collector for DHW at building level.

The **users or procurers will consider PV system design and specification first before they decide later on the product requirements,** which is more or less the reverse order of these sections.

The following boundaries can be defined (see also Task 1):

The **module 'product' boundary** includes all integrated components up to the DC terminals. For the module, the functional unit (see Task 1) is defined as a 1 kWh of DC power output from a reference system under fixed climatic conditions for 1 year and assuming a service life of 25 years.

The **inverter 'product' boundary** includes all integrated components between the DC supply to the inverter and up to the AC terminals. For the inverter, the proposed functional unit is defined as a 1 kWh of AC power output from a reference system (excluding the efficiency of the inverter) under fixed climatic conditions for 1 year and assuming a service life of 10 years.

The **'PV system'** encompasses all components required to deliver the functional unit. An extension of the boundaries of the system used to supply AC electricity should be done if storage options, like for example batteries, are included.. If a transformer is required, for example on larger utility scale installations, it is proposed that it is excluded from the boundary, but in the case that it is may require allocation if only part of its capacity is used. For the PV system, the proposed functional unit(see Task 1) is defined as a 1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to IEC 61853 part 4) and assuming a service life of 25 years.

The **'higher level' system** mainly refers to the electricity grid, but possibly also domestic hot water systems (in the case of PV powering a heat pump and thermal storage tank) and the petrol/diesel fuel supply chain (in the case of PV supplying an electric car battery).

3.1.2 The Performance Ratio(PR) of a PV system and the Derate factors(DR_k) for the scoping levels and product boundaries

The standard IEC 61724-1:2017 defines **the Performance Ratio (PR)** as the quotient of the system's final yield Yf [hours/period] to its reference yield Yr [hours/period] and indicates the overall effect of losses on the system output due to both array temperature and system component inefficiencies or failures, including balance of system components.

According to informative Annex C of IEC 61724-1:2017 the performance ratio can be defined as a series of multiplicative factors contributing to the performance ratio (PR) whereby DRk are individual deratings corresponding to different loss mechanisms.

In general, elements which reduce/determine performance losses in PV systems are:

- Effective solar irradiation available, therein taking into account:
  - diffuse radiation
  - direct sunlight
  - orientation, this especially relevant for BIPV but also others
  - shading, this especially relevant for BIPV but also others
- Ambient temperature
- Inverter Clipping which is efficiency derating when the expected output of the inverter is higher than the manufacturer-specified maximum
- Power Factor Correction, If the maximum inverter capacity is larger than the vector sum of the reactive power and real power produced by the inverter then a similar situation to that of inverter clipping can occur and losses in the inverter can increase due to this function.
- Excessive Soiling
- String/Module faults
- Degradation
- Mismatch between the string voltage and the input voltage range of the inverter
- Mismatch between the maximum power of the modules and the inverter

Taking into account the MEErP approach with its scoping levels and product boundaries (see 3.1.1) for the purpose of this study derate factors are defined in Table 5. The proposed **derate factors** in Table 5 are defined and **explained in more detail in subsequent sections**. This Table 4 has been elaborated based on IEC 61724-1:2017 terminology with the references to other standards included herein, and is considered to provide a good fit with the decomposition requested by the MEErP. Despite this we are aware that in literature non standardised terminology and ad hoc approaches are often used for decomposing the Performance Ratio depending on the data available and the purpose of the analysis. This may complicate the data collection for this study (see 3.1.6.)

Table 5. Overview of Derate factors for a PV system and relation to the scoping levels and product boundaries wherein STC means Standard Test Conditions.

Derate Factor(DF) **Performance Ratio = $DR_{capture}$ x DR_{BOS}**	**PV system**		**Extended Product (non STC)**		**Strict product (STC)**	
	overall	**detailed**	**overall**	**detailed**	**overall**	**detailed**
array capture losses derating	$DR_{capture}$	-	-	-	-	-
shading losses	-	$DR_{shading}$	-	-	-	-
snow cover losses	-	DR_{snow}	-	-	-	-
soiling losses	-	SL	-	-	-	-
DC array cable losses	-	DRarraywr	-	-	-	-
array mismatch losses	-	DR_{MISM}	-	-	-	-
optical reflection losses	-	DRrefl	-	-	-	-
other module level capture losses	-	$DR_{cap-mod}$	$DR_{cap-mod}$	-	-	-
module thermal capture loss	-	-	-	DR_{therm}	-	-
module degradation capture loss	-	-	-	DR_{degrad}	-	-
optical reflection losses	-	-	-	DRrefl	-	-
spectral effects	-	-	-	DRspect	-	-
module derating at STC	-	-	-	-	1	-
Balance of system (BOS) efficiency	DR_{BOS}	-	-	-	-	-
AC wiring losses	-	DRacwire	-	-	-	-
AC transformer losses (if available)	-	DRtrafo	-	-	-	-
losses due to network availability (curtailment)	-	DRcurt	-	-	-	-
losses due to inverter failures (drop out)	-	DRinv-fail	-	-	-	-
inverter losses (= DR_{inv-ns} x η_{inv})	-	DRinv	-	-	-	-
derating non standard inverter total	-	-	DRinv-ns	-	-	-
derating non standard inverter loading	-	-	-	$DR_{inv-load}$	-	-
derating non standard MPPT transients	-	-	-	$DR_{inv-MPPT}$	-	-
total inverter efficiency standard conditions	-	-	η_{t-inv}	-	η_{t-inv}	-
static inverter converter efficiency	-	-	-	-	-	ηconv
MPPT inverter efficiency	-	-	-	-	-	η_{MPPT}

Standard Test Conditions (STC): irradiation: 1000 W/m^2, temperature: 25°C, air mass: 1,5

Non-Standard Test Conditions (Non-STC)

3.1.3 The strict product approach

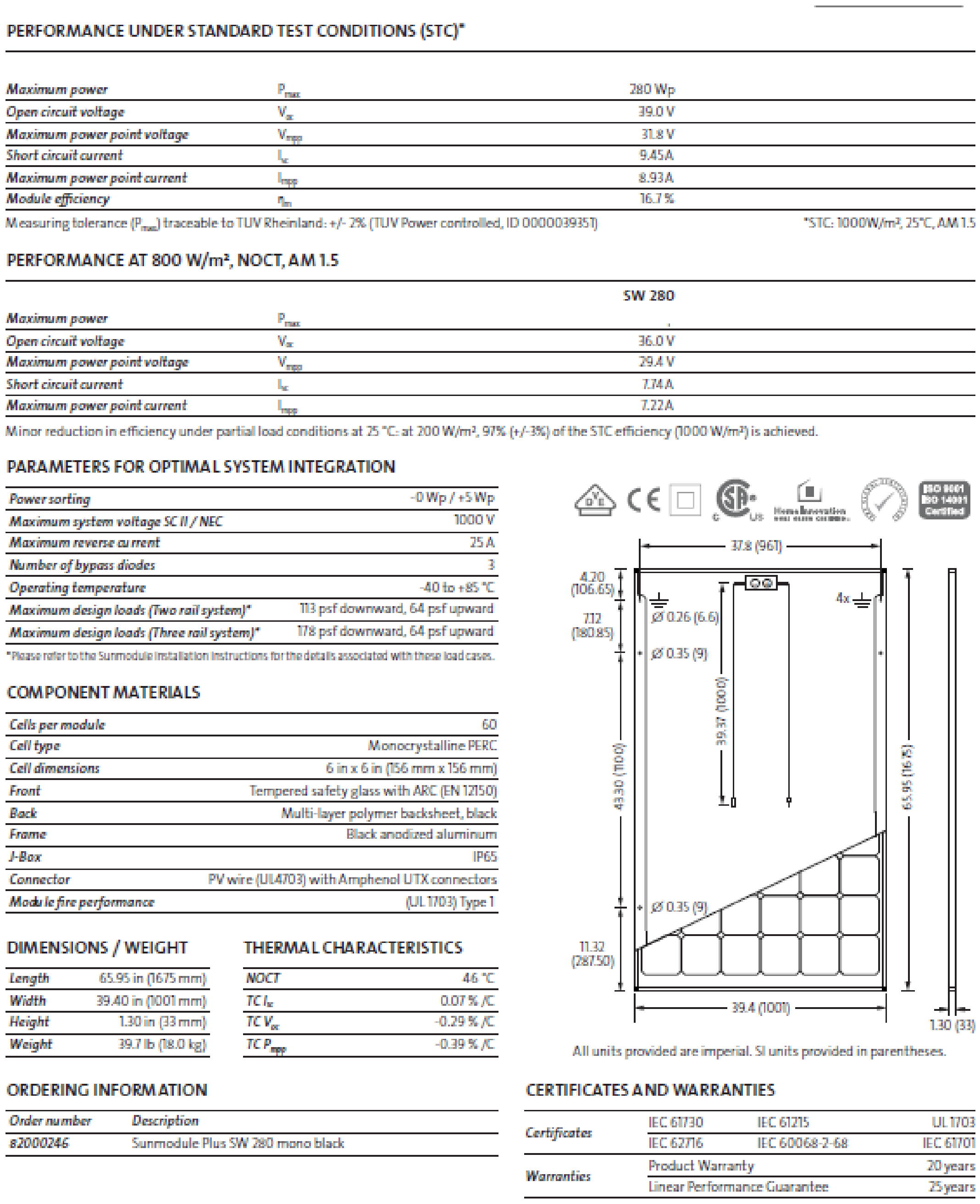
3.1.3.1 Standard Test Conditions for PV modules and main rating parameters

Standard Test Conditions (STC) refers to reference values of in-plane irradiance (1000 W/m^2), PV cell junction temperature (25 °C), and the reference spectral irradiance (AM1.5) defined in IEC 61853-1.

In line with this STC the main module product performance parameter is the '**Maximum Power at STC' P_0 [kWp]** (see Task 1). It is the input parameter For estimating the annual yield(Yf) of a PV system. Typical PV module performance data is in Figure 15.

When the total area of the PV installation matters, the efficiency of converting solar radiation into electricity or **'Module Efficiency' n_A[%]** is an important secondary parameter. A typical commercial PV module today has an efficiency of 18 %, which means that a module of 1.60 m^2 will have a maximum power at STC of 290 Watt. In utility scale 72-cell modules are becoming standard with 2 m^2 surface and over 300-350 Wp STC power. Acceptable deviation range (0%-5%) from the nameplate rating is also stated in the datasheet. Further electrical properties measured at STC: maximum power point voltage and current, open-circuit voltage and short-circuit current as well as maximum operating voltage are also specified in a module datasheet.

Figure 15. Typical PV module data sheet



PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

Maximum power	P_{max}	280 Wp
Open circuit voltage	V_{oc}	39.0 V
Maximum power point voltage	V_{mpp}	31.8 V
Short circuit current	I_{sc}	9.45 A
Maximum power point current	I_{mpp}	8.93 A
Module efficiency	η_m	16.7 %

Measuring tolerance (P_{max}) traceable to TUV Rheinland: +/- 2% (TUV Power controlled, ID 0000039351)

*STC: 1000W/m², 25°C, AM 1.5

PERFORMANCE AT 800 W/m², NOCT, AM 1.5

		SW 280
Maximum power	P_{max}	
Open circuit voltage	V_{oc}	36.0 V
Maximum power point voltage	V_{mpp}	29.4 V
Short circuit current	I_{sc}	7.74 A
Maximum power point current	I_{mpp}	7.22 A

Minor reduction in efficiency under partial load conditions at 25 °C: at 200 W/m², 97% (+/-3%) of the STC efficiency (1000 W/m²) is achieved.

PARAMETERS FOR OPTIMAL SYSTEM INTEGRATION

Power sorting	-0 Wp / +5 Wp
Maximum system voltage SC II / NEC	1000 V
Maximum reverse current	25 A
Number of bypass diodes	3
Operating temperature	-40 to +85 °C
*Maximum design loads (Two rail system)**	113 psf downward, 64 psf upward
*Maximum design loads (Three rail system)**	178 psf downward, 64 psf upward

*Please refer to the Sunmodule Installation Instructions for the details associated with these load cases.

COMPONENT MATERIALS

Cells per module	60
Cell type	Monocrystalline PERC
Cell dimensions	6 in x 6 in (156 mm x 156 mm)
Front	Tempered safety glass with ARC (EN 12150)
Back	Multi-layer polymer backsheet, black
Frame	Black anodized aluminum
J-Box	IP65
Connector	PV wire (UL4703) with Amphenol UTX connectors
Module fire performance	(UL 1703) Type 1

DIMENSIONS / WEIGHT

Length	65.95 in (1675 mm)
Width	39.40 in (1001 mm)
Height	1.30 in (33 mm)
Weight	39.7 lb (18.0 kg)

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.07 % /C
TC V_{oc}	-0.29 % /C
TC P_{mpp}	-0.39 % /C

All units provided are imperial. SI units provided in parentheses.

ORDERING INFORMATION

Order number	*Description*
82000246	Sunmodule Plus SW 280 mono black

CERTIFICATES AND WARRANTIES

Certificates	IEC 61730	IEC 61215	UL 1703
	IEC 62716	IEC 60068-2-68	IEC 61701
Warranties	Product Warranty		20 years
	Linear Performance Guarantee		25 years

3.1.3.2 Standard Test Conditions for Inverters and key performance parameters

The inverter efficiency or so-called Euro-efficiency for standard load profiles is defined in the standard EN 50530 (year to define, under review[32]) and EN 50524 for data sheet and name plate for photo-voltaic inverters, see Task 1.

The **Overall efficiency (n_t)** is ratio of the AC energy output to the theoretically available energy in the Maximum Power Point (MPP) within a defined measuring period.

The **conversion efficiency (n_{CONV})** is ratio of the AC energy output to the DC energy input within a defined measuring period. The conversion efficiency depends on the load profile of the inverter and for this purpose

---

[32] https://www.researchgate.net/publication/228652218_prEN_50530-the_new_European_standard_for_performance_characterisation_of_PV_inverters

standard load profiles are defined, it is a static efficiency not taking into account load variations die to changing weather conditions.

The **MPPT efficiency (n_{MPPT})** is the ratio of the energy drawn by the device under test within a defined measuring period T_M to the energy provided theoretically by the PV simulator in the **(**MPP**)**. A photovoltaic system is only rarely operated under constant ambient conditions, because the sun's radiation values are subject to changes related to the weather and the time of day. Since the solar inverter is responsible for managing the output of the entire PV system, it must react dynamically to these changes. The standard EN 50530 defines standard transient load profiles for inverters.

Typical inverter efficiencies[33] are 96% conversion efficiency and 99,9 % MPPT efficiency. More details on inverter efficiency will be discussed in Task 4.

3.1.4 Extended product scope

This complements the previous strict product approach.

3.1.4.1 Impact of real life weather conditions on the final system yield(Yf)

Components and systems respond to climatic variations, i.e. where in the EU a system is located. This means that the same PV module and inverter will have a different performance based on the intensity of solar radiation, ambient temperature and wind speed and other weather factors. These environmental factors are inherently varying which in turn leads to changes in the PV system performance. For precise performance assessment of PV systems this requires the use of recorded weather data over entire year to capture the hourly, daily, and seasonal variations. The time interval of the data used will influence the accuracy of design simulation of a PV system performance.

The **final system yield (Yf)** (IEC 61724-1:2017) [hours/period] is defined as is the net energy output of the entire PV system (AC) per rated kW (DC) of installed PV array. This yield forecast is necessary for an owner to estimate his annual revenue, for example based on a subsidy scheme with feed-in-tariffs (FiT) (see 3.4.1.2).

The final system yield is dependant (IEC 61724-1:2017) on the performance ratio (PR), which is subject of other sections, but also on **the reference yield (Yr**) [hours/period].

The following formulas apply:

$Y_f = PR \times Y_r$

Yr = Hi/Gi,ref

Wherein,

Yf = system yield which is the energy output divided by the array power rating.

Yr = reference yield which are the equivalent hours of solar radiation at Gi,ref

Hi = in plane irradiation [kWh/m²] over specified time period or Plane-of-array (POA)

Gi,ref = in plane reference irradiance which is 1 kW/m² due to STC definition

PR = Performance ratio (pollution, degradation, thermal loss,..)

In order to estimate the reference yield this various calculation tools are available, e.g. the European Solar Atlas provided by JRC[34] (Figure 16).

PV syst[35] is the most widely used PV system design tool by project developers for commercial and utility scale projects. This tool is the most trusted by investors and insurance companies for historic reasons. This commercial software allows for the calculation of more complex systems that include for example geographic location,

---

[33] For example: https://www.fronius.com/en/photovoltaics/products/all-products/inverters/fronius-galvo/fronius-galvo-3-1-1

[34] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

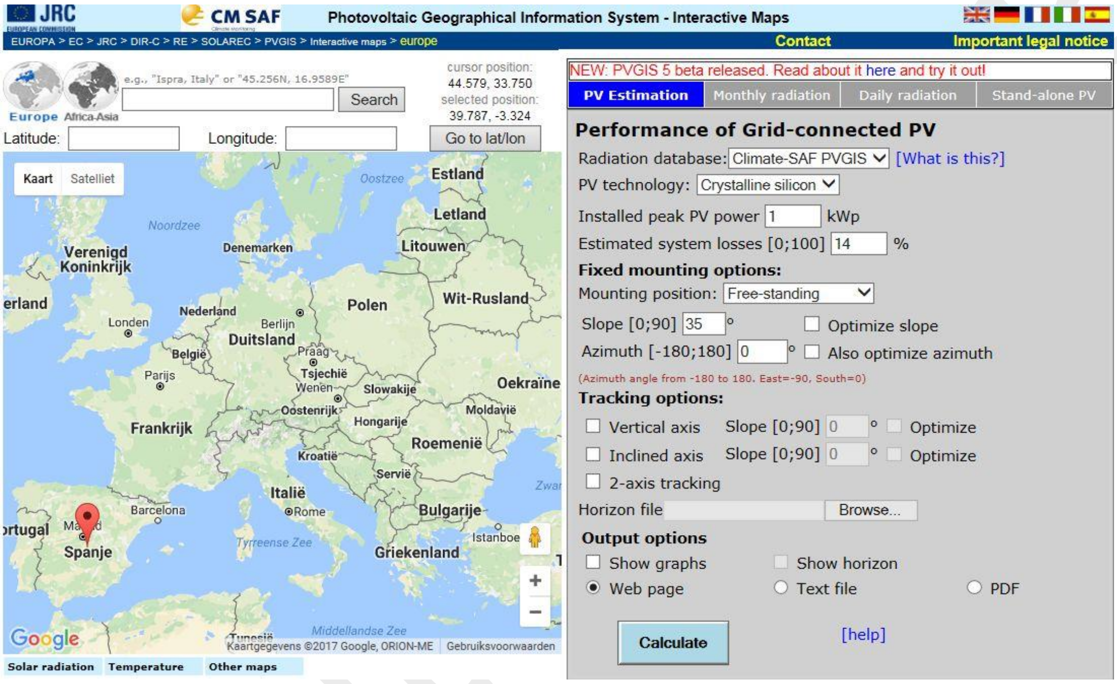
[35] http://www.pvsyst.com/en/

orientation, shading, module efficiency, module technology, inverter efficiency, etc. Weather data with hourly resolution are used in this simulation tool.

Fine-grain temporal simulation (hourly and shorter time series without averaging) of the PV system performance improves its precision. Relative errors up to 5% in precision are found for annual energy yield simulation between using either hourly or averaged weather input (Thomas Huld, Gottschalg, Beyer, & Topič, 2010). This is particularly important for PV system design integrated with batteries or connected to a congested electrical grid.

One should equally consider that significant uncertainty in the PV power generation arises from the difference between irradiation databases. Use of long-term dataset and/or combination of values from different databases are recommended[36]. To further improve the precision of solar irradiance measurements relevant tools and methods are have been developed by the Performance Plus project[37].

Figure 16. Tool for PV yield estimation (source: PV GIS Tool JRC)



cursor position: 44.579, 33.750
selected position: 39.787, -3.324

NEW: PVGIS 5 beta released. Read about it here and try it out!

Performance of Grid-connected PV

Radiation database: Climate-SAF PVGIS [What is this?]
PV technology: Crystalline silicon
Installed peak PV power 1 kWp
Estimated system losses [0;100] 14 %

Fixed mounting options:
Mounting position: Free-standing
Slope [0;90] 35 ° ☐ Optimize slope
Azimuth [-180;180] 0 ° ☐ Also optimize azimuth
(Azimuth angle from -180 to 180. East=-90, South=0)

Tracking options:
☐ Vertical axis Slope [0;90] 0 ° ☐ Optimize
☐ Inclined axis Slope [0;90] 0 ° ☐ Optimize
☐ 2-axis tracking
Horizon file

Output options
☐ Show graphs ☐ Show horizon
● Web page ○ Text file ○ PDF

The reference Yield (Yr) depends on the location's climate mostly due to variation in solar irradiance, duration of days and temperature. To enable systematic comparison between studies for different PV application based on simplified version of the Koppen-Grieger climatic zones (Figure 17) the current draft IEC61385-4 lists 6 reference international climates covering different irradiance, temperature and humidity conditions. These climate zones are the following:

- Humid tropical,
- Subtropical arid,
- Subtropical costal,
- Temperate coastal,
- High altitude,
- Temperate continental.

---

[36] Solar Bankability project: Technical risks in PV projects

[37] FP7 PErformancePlus project final report: https://cordis.europa.eu/docs/results/308/308991/final1-308991_perfplus_finalreport_20151219_f.pdf

By way of comparison, and considering mostly the irradiance, the PVsites project which focussed on BAPV and BIPV module design and assessment in Europe has narrowed this selection to 4 climates: Southern, Western, East and North Europe as shown in Figure 18.

Figure 17. Koppen-Grieger climatic zones

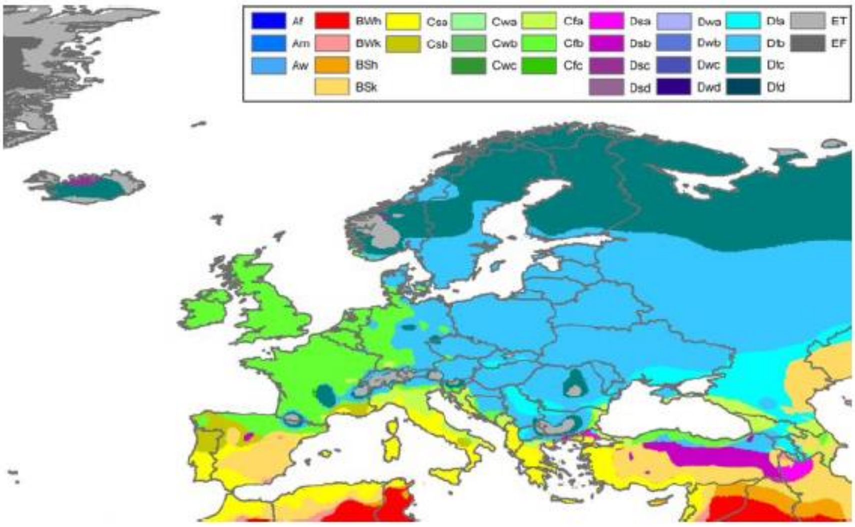
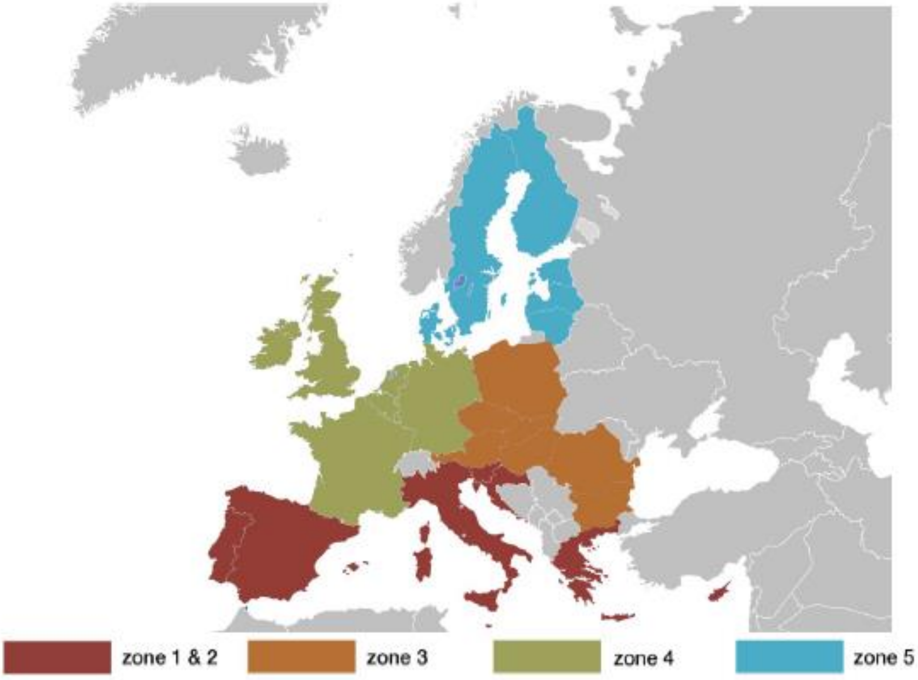


Figure 18. Climate zones defined by PVsites project



For Ecodesign and Energy Labelling Regulations for air conditioners and solar heaters the temperature was the most critical factor. The EU regulation 812/2013 defines 3 climate zones for labelling solar heaters which are average climate conditions, colder climate conditions and warmer climate conditions. An overview and corresponding categories between the different climates is listed in the table below.

For accurate energy yield assessment it is important to consider both irradiance (and relevant soiling, snow cover) and temperature hence it is proposed to consider a four climate zone. For each climate zone a specific location has been suggested based on the availability of high-quality weather and module power measurement data for detailed assessment. The typical irradiation values for these locations are indicated in Table 6.

Table 6. Overlay of climate zones and corresponding location options

IEC61385 (latitude)	PVSites	EU Regulation 812/2013	Location options
Subtropical arid (33°N33’)	Southern Europe	Warm	Madrid, Rome, Athens
Temperate Coastal (56°N)	Western Europe	Average	Dijon, Paris
Temperate Continental (57°N)	Eastern Europe	Average	Berlin, Budapest
Temperate Continental (34°N)	Northern Europe	Cold	Helsinki, Stockholm

3.1.4.2 Module capture losses due to temperature impact (parameter: DRtherm)

Potentially one of the greatest impacts on real module performance comes from technology specific temperature effects in comparison to Standard Test Conditions (STC) when temperature is 25°C. In the case of crystalline silicon cells the module performance decreases as the temperature increases. The module power decreases by approx. 0.5%/°C. This technology specific parameter is listed on the module datasheet and further comparison between simple and more advanced crystalline silicon cells and other thin-film PV technologies is also possible using the planning software, e.g. the PVGIS tool from JRC[34]. It is important to note that temperature coefficient of certain thin-film PV technologies are positive, i.e. meaning that their performance improves at higher temperature.

The average operating temperature of a PV system is 45-50°C in residential roof or ground mounted PV panel. The temperature increase compared to ambient temperature arises due to radiative heating for the sun and the environment, ambient temperature, heat generation within the PV module linked to resistive losses to name a few elements. The temperature of the PV module can be mostly lowered through natural and forced convection, e.g. wind. Therefore installation conditions play a critical role in determining the front and back ventilation of the PV modules. In certain cases where ventilation of the PV panel is limited for example in BIPV installation the module temperature can raise up to 70-80°C.

Table 7. Capture losses due to temperature impact and low irradiance (source: PVGIS tool[34])

	Berlin (D)		Dijon	Rome
	optimum	BIPV	optimum	optimum
Slope angle [°]:	33	45	35	35
Azimuth angle [°]:	0	-45	-7	-8
Temperature and low irradiance [%]:	-5	-8	-8	-11,3
DRtherm	0,95	0,92	0,92	0,89

3.1.4.3 Module capture losses due to spectral differences (DRspect)

Spectral variations refer to difference in the bandgap and absorption coefficient of the photo-active material used in the PV module. In single-junction crystalline silicon cell based modules the variation linked to spectral variations is minimal and largely averages out between the different seasons on yearly basis. This effect can become more important in various thin film PV (TFPV) technologies and tandems. Consumers may also choose to purchase higher performance heterojunction cell-based modules which incorporate more complex combined crystalline and thin film structures. For a set of reference applications data is included in Table 8.

Table 8. Capture losses due to spectral effects (source: PVGIS tool34)

	Berlin (D)		Dijon(F)	Rome(IT)
	optimum	BIPV	optimum	optimum
Slope angle [°]:	33	45	35	35
Azimuth angle [°]:	0	-45	-7	-8
Spectral effects [%]:	1,5	1,5	1,5	1
DRspect	1,015	1,015	1,015	1,010

3.1.4.4 Module capture losses due to reflection and angle of incidence (parameter: DRrefl)

The reflection losses in PV modules is linked to reflection from the glass surface as optical constants of all other materials is well optimized. This reflection loss can amount to 4% in case the glass has no surface treatment However, the use of anti-reflective coating to eliminate these losses is rapidly becoming industry standard[38]. Reflection losses can have significant seasonal variation, also depending on orientation and location. Certain effects average out over the year and studies estimate that losses amount to approx. 1%[39]. For a set of reference applications data is included in Table 9.

Table 9. Capture losses due to reflections (source: PVGIS tool34)

	Berlin (D)		Dijon(F)	Rome(IT)
	optimum	BIPV	optimum	optimum
Slope angle [°]:	33	45	35	35
Azimuth angle [°]:	0	-45	-7	-8
Angle of incidence [%]:	-3	-2,9	-3	-2,6
DRrefl	0,970	0,971	0,970	0,974

3.1.4.5 The impact from module degradation over life time (parameter: DRdegrad)

Typically crystalline silicon modules will degrade in performance at up to 1.0% per year which in turn influences the module life time which is further discussed in a later section 3.3.1. This is a technical issue that will be even further elaborated into more detail in Task 4.

All market players requires as minimum a certification of the PV module by an independent organisation based on IEC 61215 standard. Further application and installation condition demands complementary certification of the PV module following these standards: IEC 62804, Complementary testing for PID resistance, IEC 62716: Ammonium and IEC 61701 salt mist corrosion tests (depending on location, installation) and later with the new standards in preparation (see reports prepared by JRC).

Furthermore industrial players often require extended testing compared to conditions listed in the IEC 61215 and demand an extensive factory inspection.

3.1.4.6 The impact from inverters in non-standard conditions (parameter: DRinv-ns)

The energy efficiency of an inverter (%) can be measured according to standard EN 50530. This information is included in the datasheet of manufacturers or sourced from a well-documented online database[40], for example Figure 19. As can be seen from the example in the data sheet in Figure 19.

---

[38] ITRPV Edition 2017

[39] D. L King et al., IEEE PVSEC 2002

[40] http://www.photon.info/photon_site_db_wechselrichter_en.photon

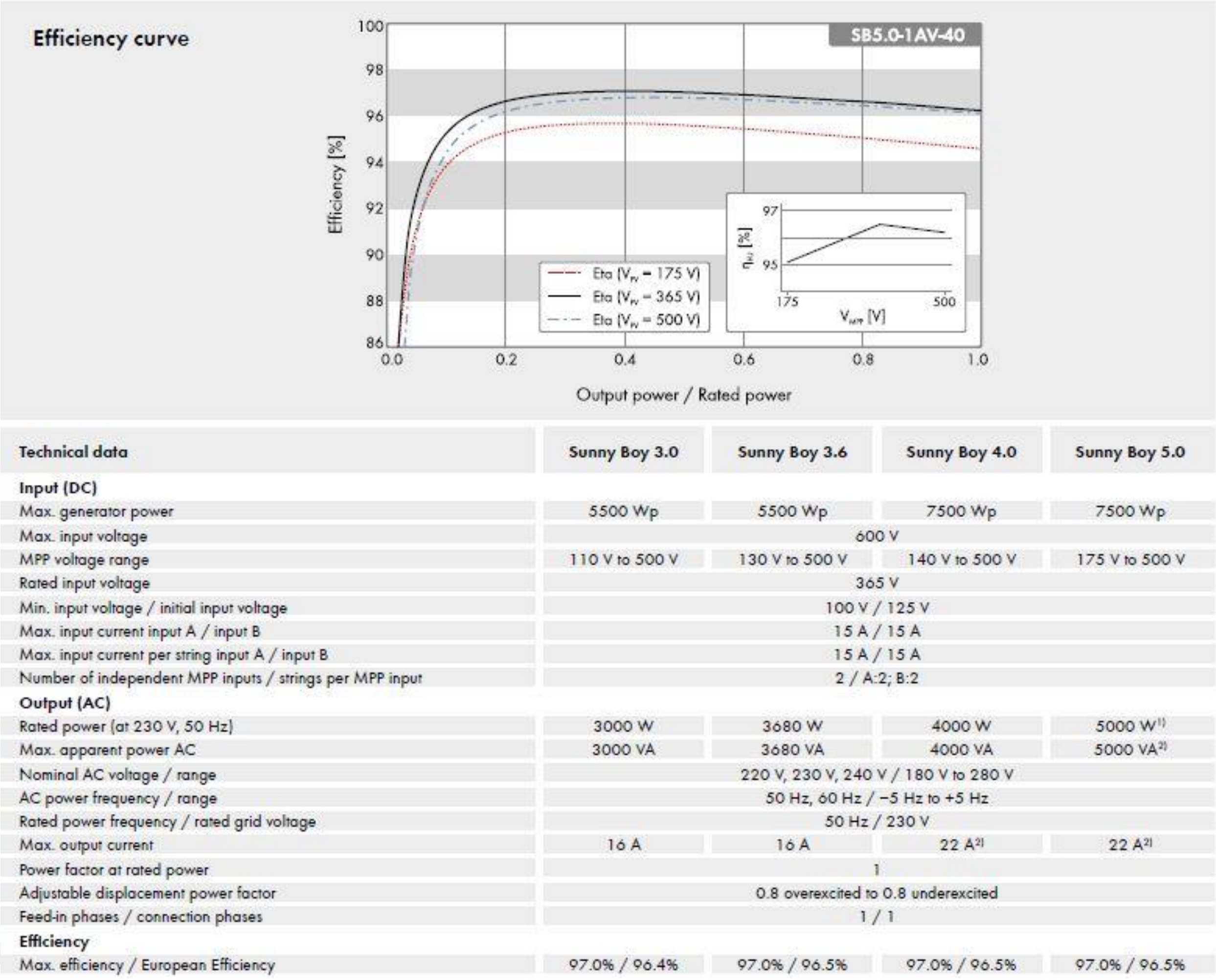
The European Efficiency (EN 50530) and the maximum Efficiency can deviate from the real life efficiency because:

- The real string voltage might be different depending on the selected type and amount of PV modules compared to those used in the standard;
- Real weather conditions and production profile;
- The standard does also not cover all new inverter topologies in detail, in particular inverters that incorporate charge controllers for battery storage (see next paragraph).

In principle an inverter converts DC (direct current) from PV modules into AC grid power, see Task 1. Because batteries are also working on DC, an opportunity exists to integrate the storage battery with the inverter and avoid conversion losses, see 3.4.2.1. Several manufacturers such as SMA already start to bring these inverters with combined battery storage on the market. In this case it will impact and complicate the definition and calculation of the inverter efficiency, and development of metrics and standards is ongoing[41] (see also Task 1).

Moreover it is also possible to integrate BAPV with storage and loads on a DC building network. Recent research found that relative to a conventional AC system, a DC network improves energy efficiency by approximately 2% without storage and 4% with storage for a simulated single family low energy home with heat pump located in central Europe[42]. The technology behind this will be further explained in Task 4.

Figure 19. Typical inverter data sheet



Technical data	Sunny Boy 3.0	Sunny Boy 3.6	Sunny Boy 4.0	Sunny Boy 5.0
Input (DC)				
Max. generator power	5500 Wp	5500 Wp	7500 Wp	7500 Wp
Max. input voltage	600 V			
MPP voltage range	110 V to 500 V	130 V to 500 V	140 V to 500 V	175 V to 500 V
Rated input voltage	365 V			
Min. input voltage / initial input voltage	100 V / 125 V			
Max. input current input A / input B	15 A / 15 A			
Max. input current per string input A / input B	15 A / 15 A			
Number of independent MPP inputs / strings per MPP input	2 / A:2; B:2			
Output (AC)				
Rated power (at 230 V, 50 Hz)	3000 W	3680 W	4000 W	5000 W[1)]
Max. apparent power AC	3000 VA	3680 VA	4000 VA	5000 VA[2)]
Nominal AC voltage / range	220 V, 230 V, 240 V / 180 V to 280 V			
AC power frequency / range	50 Hz, 60 Hz / −5 Hz to +5 Hz			
Rated power frequency / rated grid voltage	50 Hz / 230 V			
Max. output current	16 A	16 A	22 A[2)]	22 A[2)]
Power factor at rated power	1			
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited			
Feed-in phases / connection phases	1 / 1			
Efficiency				
Max. efficiency / European Efficiency	97.0% / 96.4%	97.0% / 96.5%	97.0% / 96.5%	97.0% / 96.5%

---

[41] http://www.bves.de/wp-content/uploads/2017/04/Effizienzleitfaden_V1.0.4_April2017.pdf

[42] https://infoscience.epfl.ch/record/213389/files/7_HOFER.pdf

3.1.5 Technical system approach

This complements the previous extended product approach at system level.

3.1.5.1 Annual AC output energy of the PV system

The **final annual AC output energy(Eout)** is simply related to the final system yield (Yf) and the rated array power rating (Po) with the following formula:

Eout = Yf x Po

For the final system yield (Yf) definition see section 3.1.4.1.

3.1.5.2 The impact from shading (parameter: DRshading)

PV system shading in the different categories can arise liked to inter-array or nearby objects (trees and buildings). Shading is particularly critically important in residential PV and BIPV application. Although the effect of shading can be simulated, its impact on the PV system is more complex to estimate as it depends on the plant configuration, and the use of Module level Power Electronics such as bypass diodes, DC optimisers and micro-inverters must be considered. This factor is described by DRshading. More details on these technologies will be discussed in Task 4 on technology.

To decrease the impact from shading, bypass diodes are standardly implemented in all PV modules. Furthermore DC power optimisers added between each module and the inverter are becoming common in residential PV installation. They will be discussed in Task 4 on technology. This is particularly the case for residential PV installation BIPV systems.

3.1.5.3 The impact from snow cover (parameter: DRsnow)

Snow coverage is considered as a specific case of soiling, naturally linked to the local climate. Models for its assessment given weather conditions are proposed as well as yield loss analysis studies. In general snow coverage leads to <1% annual energy yield loss[43].

3.1.5.4 The impact from soiling and regular cleaning (parameter: SL)

PV module soiling is caused by pollution, bird droppings, the accumulation of various forms of dust and local growth of moss. Soiling effects largely vary according to local rain fall and pollution. In temperate climate regions with regular rainfall losses 0-5% are estimated while in arid climate this can increase up to 25%[44]. This impact is related to maintenance that is also discussed in section 3.1.7. Especially larger PV systems do regular cleaning services and these are requested by owners and investors in order to maximise yield. For larger buildings this can be combined with the cleaning cycles for windows. In the residential market some installers now offer aftercare services that include periodic cleaning. Some companies in the market are specialised in cleaning[45]. Cleaning is usually done with distilled or demineralized water without using detergents because they could harm the anti-reflective coating. Demineralized water can be for example obtained with mobile reverse osmosis water purification system.

3.1.5.5 Impact of other PV system losses in cables and transformers behind the meter (parameters: DRacwire and DRtrafo)

When the system is connected to the low voltage distribution grid, transformer and AC cable losses are indirect losses which are discussed in section 3.2.2. Large installations (≥ 250 kVA) can be directly integrated into the Medium Voltage (MV) distribution or transmission grid. In these large installation it is possible that those transformer losses are taken into account in the energy bill of the PV system owner when the meter is located at

---

[43] R. W. Andrews et al., http://digitalcommons.mtu.edu/materials_fp

[44] Solar Bankability Project: Technical Risks in PV projects

[45] http://www.solarclean.be/en/references/

the medium voltage and grid side of the transformer. In large installations with their own step up transformer it is possible to disconnect the transformer after curfew to eliminate no-load losses.

Transformer losses are regulated by Commission Regulation 548/2014 on Commission Regulation 548/2014 “On Ecodesign Requirements For Small, Medium And Large Power Transformers” and did set maximum loss requirements on transformers since July 2015 (Tier 1). For example in Tier 1 a 400 kVA transformer can have maximum 430 W no-load losses and 4600 Watt load losses, hence they are low (<1%). Total transformer losses (Ptot) are a combination of load and no-load losses (Tichelen et al., 2011).

3.1.5.6 Impact from system unavailability due to grid curtailment and other system failures (DRcurt)

These derate factors are related to the down time of the installation. They are related to the impact from catastrophic module and inverter failures are discussed in sections 3.3.1.2 and 3.3.1.4. It can also be result from grid curtailment due to for example grid congestion and over voltages, which is discussed in section 3.4.1.5.

3.1.6 Summary of typical performance ratios for a set of European reference installations and impact from design, monitoring and maintenance

The role of the system designer and the general concept was already discussed in the previous section 3.0.4. Some examples of design aspect to be considered are presented in Table 10. All mentioned design tasks should aim to maximize the overall Performance Ratio (PR) within the local boundary conditions, i.e., in other terms carefully minimising the impact of each Derate factors (DFx) listed below and the reference yield (Yf). Table 11 contains an overview of the impact of PV plant layout, connection to the grid as well as factors linked to design monitoring and maintenance on the various factors that were described in detail in previous sections.

Table 10. Some of the design aspects to be considered – based on (Doyle et al., 2015) and updated

General Site	**Roof** (if roof-mounted)	**Structure**	**Electric**	**New equipment location**
Building footprint	Dimensions	Wind speed or snow load	Service type and size, main service panel, and breaker size	Inverter
Distance to property lines	Required minimum roof dimensions	Design roof snow load	Service panel make and model	Conduit run
Age of roof covering (if roof-mounted)	Type of roof covering	Rafter or truss spacing	Availability of breaker spaces	PV modules
Age of home (if roof-mounted)	Underlayment type and lap dimensions	Framing lumber dimensions	Meter location relative to the building	Service disconnect
Easements, restrictions, open permits	Roof condition	Rafter or truss spacing		
	Existence of obstruction locations	Max. rafter span or longest truss top chord panel length between struts		Monitoring equipment
	Safety & liability considerations	Lumber species and grade		
		Sheathing thickness and type		

Table 12 will contain typical performance parameters. These data will be elaborated in a further review after deciding on the typical reference locations.

Table 11. Summary of impact from design, monitoring, maintenance on the PV system performances (source: own estimate)

Derate Factor(DF) **Performance Ratio = $DR_{capture}$ x DR_{BOS}**	**impact from design /specification**	**impact from maintenance**	**impact from monitoring**
array capture losses derating	x (specify monitoring)		xxx
shading losses	xxx	x	xxx
snow cover losses			xx
soiling losses		xxx	xx
DC array cable losses	xxx		
array mismatch losses	xx	xx	xx
optical reflection losses			
other module level capture losses	x (module selection)		xxx
module thermal capture loss			
module degradation capture loss			
optical reflection losses			
spectral effects			
module derating at STC			
Balance of system (BOS) efficiency			
AC wiring losses	xx		
AC transformer losses (if available)			
losses due to network availability (curtailment)			xxx
losses due to inverter failures (drop out)			xxx
inverter losses (= DR_{inv-ns} x η_{inv})			x
derating non standard inverter total	xx (match string voltage/inverter)		
derating non standard inverter loading	x		
derating non standard MPPT transients	x		
total inverter efficiency standard conditions			
static inverter converter efficiency	xxx		
'Module Efficiency' ηA[%]	x (fit with available area)		
Annual Reference Yield Yr[KWh/KWp]	xxx		xxx

Table 12. Typical PV system performance parameters (TBD to be defined)

Derate Factor(DF) **Performance Ratio = $DR_{capture}$ x DR_{BOS}**	**PV system**		**Extended Product (non STC)**		**Strict product (STC)**		**typical value (range)**		
	overall	**detailed**	**overall**	**detailed**	**overall**	**detailed**	**residential**	**commercial**	**utility scale**
array capture losses derating	$DR_{capture}$	-	-	-	-	-	0,75	0,8	0,8
shading losses	-	$DR_{shading}$	-	-	-	-	TBD	TBD	TBD
snow cover losses	-	DR_{snow}	-	-	-	-	TBD	TBD	TBD
soiling losses	-	SL	-	-	-	-	TBD	TBD	TBD
DC array cable losses	-	DRarraywr	-	-	-	-	TBD	TBD	TBD
array mismatch losses	-	DR_{MISM}	-	-	-	-	TBD	TBD	TBD
optical reflection losses	-	DRrefl	-	-	-	-	TBD	TBD	TBD
other module level capture losses	-	$DR_{cap-mod}$	$DR_{cap-mod}$	-	-	-	TBD	TBD	TBD
module thermal capture loss	-	-	-	DR_{therm}	-	-	TBD	TBD	TBD
module degradation capture loss	-	-	-	DR_{degrad}	-	-	TBD	TBD	TBD
optical reflection losses	-	-	-	DRrefl	-	-	TBD	TBD	TBD
spectral effects	-	-	-	DRspect	-	-	TBD	TBD	TBD
module derating at STC	-	-	-	-	1	-	TBD	TBD	TBD
Balance of system (BOS) efficiency	DR_{BOS}	-	-	-	-	-	TBD	TBD	TBD
AC wiring losses	-	DRacwire	-	-	-	-	TBD	TBD	TBD
AC transformer losses (if available)	-	DRtrafo	-	-	-	-	TBD	TBD	TBD
losses due to network availability (curtailment)	-	DRcurt	-	-	-	-	TBD	TBD	TBD
losses due to inverter failures (drop out)	-	DRinv-fail	-	-	-	-	TBD	TBD	TBD
inverter losses (= DR_{inv-ns} x η_{inv})	-	DRinv	-	-	-	-	TBD	TBD	TBD
derating non standard inverter total	-	-	DRinv-ns	-	-	-	TBD	TBD	TBD
derating non standard inverter loading	-	-	-	$DR_{inv-load}$	-	-	TBD	TBD	TBD
derating non standard MPPT transients	-	-	-	$DR_{inv-MPPT}$	-	-	TBD	TBD	TBD
total inverter efficiency standard conditions	-	-	η_{t-inv}	-	η_{t-inv}	-	TBD	TBD	TBD
static inverter converter efficiency	-	-	-	-	-	ηconv	TBD	TBD	TBD
'Module Efficiency' ηA[%]							20%	18%	16%
Annual Reference Yield Yr[KWh/KWp]							site dependent		

3.1.7 Operation, monitoring and maintenance practices

The key to the successful operation of a PV plant is the monitoring system. Without accurate monitoring with suitable time resolution that enables downloading any available parameters from any collection of plant elements across any time span, there is little possibility for optimizing operational activities. With a quality monitoring system, it is possible to optimize maintenance tasks such as e.g. module washing frequency and ascertain if string fuses have blown before and detect any other need for intervention. Preventative maintenance activities should thus take place in order to assure the good performance of the system (IEA PVPS, 2017a).

The following references have been identified as detailing good practices for installing monitoring to support maintenance and repair:

- IEC 61724 – Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis
- Operation and Maintenance guidelines from Solar Power Europe (2017): http://www.solarpowereurope.org/reports/o-m-best-practices-guidelines/
- Best Practices in Photovoltaic System Operation and Maintenance 2nd Edition, from NREL (2016)
- Analytical Monitoring of Grid-Connected Photovoltaic Systems: Good Practices for Monitoring and Performance Analysis from IEA PVPS (2014)
- There are internet forums on data logging of PV for small and residential users, e.g.: https://www.photovoltaikforum.com/datenlogger-f5/ or https://www.zonstraal.be/forum/
- There are also tools for data analytics based on artificial intelligence and machine learning which can be used to verify the performance behavior of PV plants and at a later stage improve and automate the optimization of performance (http://www.3e.eu/data-services/pv-health-scan/ and http://www.3e.eu/pv-performance-verification-meets-big-data/). The use of this type of tools may detect early faults and performance degradation give actionable recommendations on the root causes.

The standard IEC 61724-1:2017 defines three classes (A, B, C) of monitoring systems. The practical implementation of monitoring and maintenance depends on the size of the installation. Especially the cost for a local weather station for solar irradiation and wind can be expensive, as well as the cabling for monitoring individual cell temperatures. A power meter hence it is mainly a data logger that needs to be added[46], when a digital meter is present from the utility it can often be used. Measurements per module exists and technology will be further discussed in Task 1. Detailed monitoring can reveal the origin of a low performance ratio (see 0).

In its most simple and low cost form, people can compare their annual yield as calculated free online with PVGIS[47,48] in kWh/kWp and compare it with their annual metered data. To correct for annual weather variation data from the nearby weather station can be consulted[49] or compared to similar installations in the neighbourhood[50]. This remains however inaccurate and does not reveal much details about the causes for underperforming, e.g. soiling, degradation, defected module in a string, shading, .. Therefore several commercial companies offer O&M services, each with their own technology, some of them do not require a local weather station and use advanced weather modelling tools. Professional operation and maintenance (O&M) of a PV system lowers the levelized cost of electricity and results in a better return on investment. These benefits have been recognised by most players in the value chain as listed above.

Both preventive and corrective maintenance are generally considered as part of contracts for larger PV systems. For preventive maintenance detailed visual and physical inspections (e.g. aerial IR imaging, on-site characterization for selected modules) are required and checklists are proposed in the guidelines for the various installation types.

---

[46] https://www.photovoltaikforum.com/datenlogger-f5/

[47] http://re.jrc.ec.europa.eu/pvgis/

[48] PVGIS allows the user to do a geographical assessment of solar resource and performance of photovoltaic technology. It has been developed at the European Commission Joint Research Centre, at the JRC site in Ispra, Italy.

[49] For example https://www.dwd.de/DE/Home/home_node.html

[50] https://pvoutput.org/l

Maintenance services can also include cleaning, vegetation cutting and eventually snow/sand removal. To minimize downtime of the PV system critical spare part stock is also listed as indispensable. Part of the maintenance contract is the data recording and monitoring which enables remote supervision of the energy flow and early detection of any sub-optimal performance. Similarly to maintenance detailed guidelines on the data collection, key performance indicators to extract are also available.

Guidelines also cover personnel and their training as adequate training is indispensable for safe and responsible for work. Furthermore the rapid evolution in the field and variety of the products ask continuous formation of the technical teams on the field.

Projects developers and investors usually look for certification and quality insurance at all steps of a PV project. This also includes the qualification of the technical personnel during installation and maintenance. Following the EU Directive (2009/28/EC) Member States (MS) are encouraged to develop a mutual acknowledged certification scheme. Across Europe the availability of certification schemes for PV installers has rapidly increased however it varies greatly between countries[51]. PVTRIN and other European projects aimed to harmonise these systems but they remain fragmented[52] (PVTRIN, 2013).Its Europe wide acceptance has not followed until now. Equivalent certification scheme has been developed in the US with the NABCEP Solar PV Installation Professional Certification[53].

Table 13 gives an overview of some operation and maintenance services already available in the market and which are intended to keep the performance of the PV system as high as possible through its lifetime.

---

[51] Belgium: https://rescert.be/fr/lists; France: https://www.qualit-enr.org/annuaire;

[52] PVTRin project final report, 2013 https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/final_report_pvtrin_en.pdf

[53] http://www.nabcep.org/

Table 13. Example of some O&M services already available in the market (Solarsense 2018)

	Operation & Maintenance services	
	Commercial	**Domestic**
System Health Check	— Visual check of all rails and mountings — Visual check of module condition — Full string test — Visual & physical check of all module connectors — Interrogation of inverter display error codes and logs — Full inverter diagnostic testing and checking of monitoring connectivity — Visual check of all system AC & DC electrics — Inverter & fan dust and clean — Irradiance test and other tests using Seaward diagnostic technology — Full report of system condition & operation provided to system owner	— Visual check and test of key connections, switches and electrical components; — Visual check of panels, mountings and other hardware components; — Inverter diagnostics; — Irradiance & DC circuit test; — Clean inverter and fan; — AC electrical safety certificate compliant with BS7671 (for thermal systems) — Report and recommendations
Solar Panel Cleaning*	— Use of specialist equipment and *super-clean water* to clean the panels (with low water usage) — Extremely pure water produced on-site by mobile 3 stage filtration, reverse osmosis and de-ionisation equipment to ensure near zero deposits — Specialist brushes clean and rinse panels thoroughly without damaging delicate mysophobic coatings — Water-fed pole system offer up till a certain lateral reach — Visual check of array condition	
System Upgrades		— Battery Storage technology — Air Source Heat Pumps — Immersion Controllers (to convert the excess electricity produced by the PV system into piping hot water)

* The majority of solar panels have a mysophobic coating (i.e., self-cleaning surface) to resist dirt and contaminants. Further anti-soiling coating are in development by most major glass/coating suppliers. Nevertheless in periods of low rainfall or in locations near busy roads or with a high number of birds, proximity to trees, farms, etc, panels may accumulate deposits which may impact on the performance of the system.

3.1.8 Functional approach

This complements the previous technical system approach.

3.1.8.1 Design trade-offs for achieving Nearly Zero Energy Buildings(NZEB) with BIPV

The Energy Performance of Buildings Directive (EPBD) (see Task 1) requires all new buildings to be Nearly Zero Energy Buildings as of 31 December 2020.

The EPBD's article 2 defines ‘nearly zero-energy building’ as a building that has a very high energy performance, as determined in accordance with Annex I of the Directive.

For buildings there exist a choice of different technologies that can be used to deliver either:

- a specific level of reduction in primary energy use and CO_2 emissions, or
- to supply a specific proportion of a buildings energy from renewables.

It says also that the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. Therefore photovoltaics can be in important design option to achieve NZEB (Adhikari, Aste, Pero, & Manfren, 2012; Attia, 2018; D’Agostino & Parker, 2018; Salom et al., 2013). However one should be aware that this is not the only option to achieve NZEB[54]. For example passive heating/cooling design options for windows and shading can be compared with increasing photovoltaics. Another important comparison that can be made is between installing a solar collector for Domestic Hot Water (DHW) versus photovoltaics with a heat pump. The design of such buildings is outside the scope of this study. Building energy calculation tools today already include photovoltaic solar forecasting tools[55] making it easy for the architect to compare design those options.

---

[54] https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_executive_summary.pdf

[55] http://passivehouse.com/04_phpp/04_phpp.htm
https://www.cadvilla.com/de/index.php
https://sustainabilityworkshop.autodesk.com/buildings/pv-panel-factors-revit

3.2 Subtask 3.2 – The indirect impacts from solar photovoltaics

General objective of subtask 3.2:

This task complements the previous task 3.1 as both direct and indirect impacts must be addressed within the Preparatory Study according to the MEErP methodology. It is therefore important to read the introduction in section 0 as it illustrates the difference between direct and indirect impacts as defined in the MEErP[56] methodology as well providing clear examples. Please see Table 4 for an overview of the aspects addressed under direct and indirect impacts.

3.2.1 The substitution effect of non-renewable energy or primary energy from fossil fuel on the grid

This study follows the Methodology for the Ecodesign of Energy-related Products (MEErP[56]) for which a spreadsheet tool for Life Cycle Analysis (LCA) is made available. The discussion hereafter is on how to model the positive impact from PV systems herein.

PV modules or systems are in a strict sense not energy using products because they produce instead of using electricity. Therefore the suggested approach in later tasks is to consider the positive impact from the produced electricity due to the substitution effect of average electricity. The MEErP tool has modelled the average impact from EU electricity, hence it can be simply adapted for this in Task 5.

Important metrics here are the:

- Primary Energy Factor: for a given energy carrier, non-renewable and renewable primary energy divided by delivered energy, where the primary energy is that required to supply one unit of delivered energy, taking account of the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building in which the delivered energy will be used.
- Global Warming Potential[57] (GWP): term used to describe the relative potency, molecule for molecule, of a greenhouse gas, taking account of how long it remains active in the atmosphere.

For modelling purposes, the MEErP tool uses the default Primary Energy Factor for electricity:

- “Primary Energy” as defined in the EED (2012/27/EU) means gross inland consumption, excluding non-energy uses.

In practice the concept of Primary Energy means that the energy utilised in generating electricity is used, i.e., 2.5 Mtoe Primary Energy including generation for every 1 Mtoe of final electricity used.

For 2014 the average GWP of electricity was 276 gCO2eq/kWh[58] while for PV this is obviously lower[59], e.g. about 40 gCO2eq/kWh only (2020 forecast).

As a conclusion, such a substituted average grid energy approach is proposed in order to model all positive impacts from photovoltaics in Task 5.

---

[56] http://ec.europa.eu/growth/industry/sustainability/ecodesign_nl

[57] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Global-warming_potential_(GWP)

[58] https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment

[59] https://setis.ec.europa.eu/system/files/ETRI_2014.pdf

3.2.2 Indirect impact on distribution and transmission grid losses

Grid losses can increase or decrease when the load profile does not match with the production, this is often the case as explained in more detail in section 3.2.3.

The average losses in transmission networks (TNs) in EU(2015) vary between 1%-2.6% while for distribution networks (DNs) between 2.3%-13.4%[60], This variation has mainly to do with the historical development and current state of the grids in each country with regard to age, design, etc. Therefore in general, distribution networks present the highest losses and therefore can be further considered for this study. This European study (2016) also identified that the starting conditions of grids (e.g. voltage level; number of transformers) and potentials for energy efficiency improvement vary widely in the EU. A list of factors that have a key impact on the level of losses in the system were identified, including: loading (including peak demand), number of energized transformers, lengths of the feeders, presence of distributed energy resources.

A more detailed example is given in

Figure 20. Percentage of losses in transmission and distribution networks in selected EU countries (source: Tractebel (2016))

Country	Average % of losses in TNs	Average % of losses in DNs
France	2.3%	5.0%
Austria	1.5%	4.5%
Czech Republic	1.5%	7%
Slovakia	1%	8.3%
Romania	2.6%	13.5%

Figure 21 comparing Germany, France and the UK. Herein on should be aware that transformers have load and no-load losses and can therefore be optimized to match the loading profile (Tichelen et al., 2011)[61]. Power cables are easier from an energy saving point of view because the larger their cross section the lower the losses (Tichelen, Ectors, Stevens, Chung, & Peeters, 2015)[62].

Figure 20. Percentage of losses in transmission and distribution networks in selected EU countries (source: Tractebel (2016)[63])

Country	Average % of losses in TNs	Average % of losses in DNs
France	2.3%	5.0%
Austria	1.5%	4.5%
Czech Republic	1.5%	7%
Slovakia	1%	8.3%
Romania	2.6%	13.5%

---

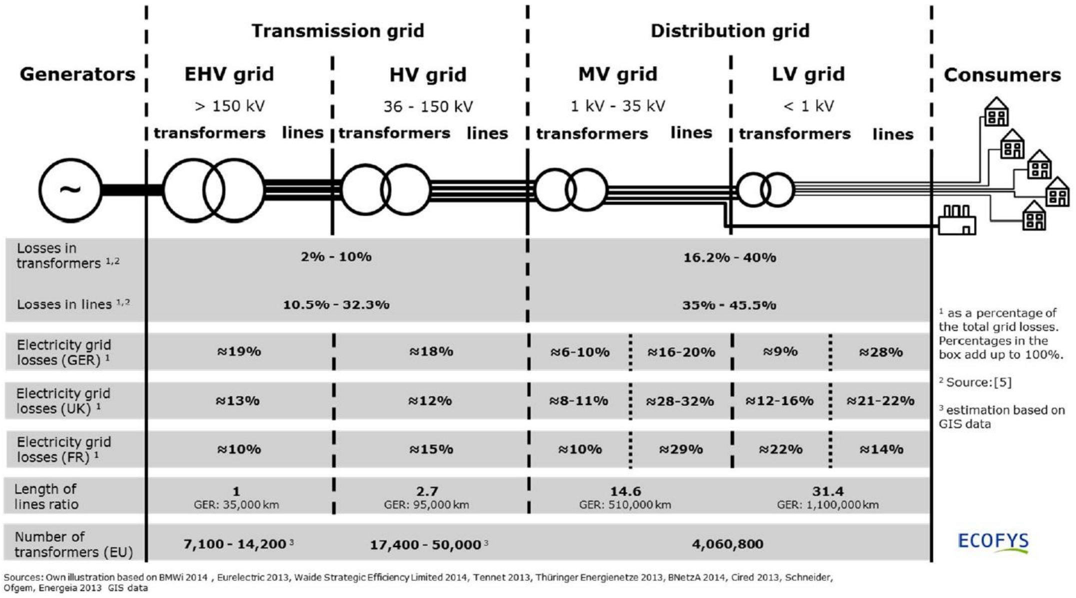
[60] https://ec.europa.eu/energy/sites/ener/files/documents/GRIDEE_4NT_364174_000_01_TOTALDOC%20-%2018-1-2016.pdf

[61] https://transformers.vito.be/

[62] erp4cables.net/

[63] https://ec.europa.eu/energy/sites/ener/files/documents/GRIDEE_4NT_364174_000_01_TOTALDOC%20-%2018-1-2016.pdf

Figure 21. Mapping of losses based on voltage level and components for different EU countries (source: Tractebel (2016[64]))



	EHV grid	HV grid	MV grid transformers	MV grid lines	LV grid transformers	LV grid lines
Losses in transformers [1,2]	2% - 10%		16.2% - 40%			
Losses in lines [1,2]	10.5% - 32.3%		35% - 45.5%			
Electricity grid losses (GER) [1]	≈19%	≈18%	≈6-10%	≈16-20%	≈9%	≈28%
Electricity grid losses (UK) [1]	≈13%	≈12%	≈8-11%	≈28-32%	≈12-16%	≈21-22%
Electricity grid losses (FR) [1]	≈10%	≈15%	≈10%	≈29%	≈22%	≈14%
Length of lines ratio	1 GER: 35,000 km	2.7 GER: 95,000 km	14.6 GER: 510,000 km		31.4 GER: 1,100,000 km	
Number of transformers (EU)	7,100 - 14,200[3]	17,400 - 50,000[3]	4,060,800			

[1] as a percentage of the total grid losses. Percentages in the box add up to 100%.

[2] Source:[5]

[3] estimation based on GIS data

Sources: Own illustration based on BMWi 2014 , Eurelectric 2013, Waide Strategic Efficiency Limited 2014, Tennet 2013, Thüringer Energienetze 2013, BNetzA 2014, Cired 2013, Schneider, Ofgem, Energeia 2013 GIS data

The FP7 Parity project studied in more detail the impact from photovoltaics and demand response (DR) on distribution grid losses, see Figure 22. It also shows that Demand Response (DR) can evidently further reduce distribution grid losses (<0,2%). As explained later on in section 3.4.1.4 demand response can also be a good value proposition. Other Ecodesign studies already focus on implementing demand response functionalities for smart appliances (Lot 33[65]). The EC is also investigating the development of a new Smart Readiness Indicator (SRI)[66] within the context of the ongoing review of EPBD [67]. This indicator will amongst others also cover Demand Response at building level, which is useful for buildings that use electricity for heating/cooling for example with a heat pump. This shows that for low PV penetration (<10%) there is a decrease in grid losses because energy can be consumed locally and less distribution is needed. For higher penetration rates the losses rise again and for large penetration rates losses increase due to unbalance with local consumption resulting in a reverse power flow. This study did not calculate the impact from local storage (see 3.4.2.1), which could have a similar impact compared to Demand Response or in combination with Demand Response. This study did not yet consider new opportunities for inverters to provide grid ancillary services to grid operators, e.g. inject reactive power to avoid congestion, which are discussed in later section 3.4.2.3 and it's technology in Task 4.

---

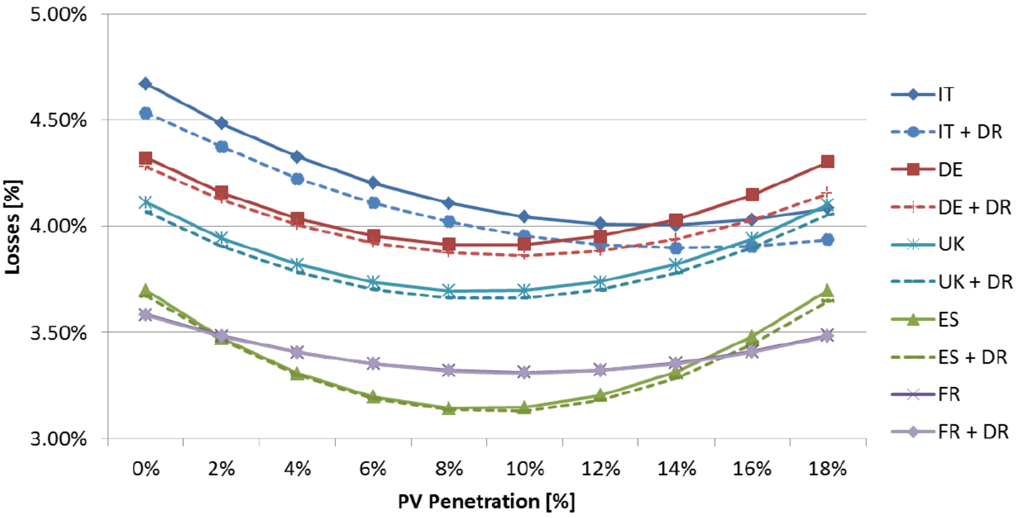
[64] https://ec.europa.eu/energy/sites/ener/files/documents/GRIDEE_4NT_364174_000_01_TOTALDOC%20-%2018-1-2016.pdf

[65] http://www.eco-smartappliances.eu/Pages/welcome.aspx

[66] https://smartreadinessindicator.eu/

[67] http://www.europarl.europa.eu/legislative-train/theme-resilient-energy-union-with-a-climate-change-policy/file-energy-performance-of-buildings-directive-review

Figure 22. Impact of increased PV penetration and combination with Demand Response (DR) on distribution network losses in Germany, Spain, France, Italy and the UK (source: PV Parity project [68]).



High penetration rates in terms of annual energy generation do also not match with the average load factor of distribution transformers. In the Lot 9 Eco-design study on transformers[69] the base case transformer had an average load factor of 15 %(α) only with a load form factor(Kf) of 1,07. Installing significantly more in the low voltage grid could result in grid congestion, see section 3.4.1.5.

Conclusion:

The large difference between losses in the Transmission Network (TN) or grid and Distribution Network (DN) indicates that for high PV penetration rates it is practically a better option to install grid scale PV compared to residential PV in order to keep grid losses low and/or to avoid congestion.

It is suggested to use as base case no impact on grid losses in later tasks but +/- 2 % can be used in a sensitivity analysis in Task 7. When comparing the benefits of local consumption it is suggested to use the average grid loss of 9 %, see Figure 22.

Demand response for local consumptions is evidently the most efficient solution and can reduce grid losses and provide also a good value proposition[65,66].

It can be concluded that grid losses, see **Error! Reference source not found.**, are reported much lower as torage losses reported[70] for pumped-hydro[71] or batteries today (typically 80 %). Hence it will be difficult for new emerging local battery storage solutions (see 3.4.2.1) to compete on energy efficiency grounds with using the distribution and transmission grid to average out local generation and production, see also subsequent sections 3.2.3.

3.2.3 Self-sufficiency and self-consumption by prosumers

As explained section 3.0.2.4, prosumers are a new category of PV system owners. They will be motivated to increase their self-consumption due to the deployment of PV systems and consequent energy generation. As a rule of thumb for planning cost-effective self-consumption systems, the system yield should be adjusted to about the

---

[68] https://helapco.gr/pdf/PV_PARITY_D44_Grid_integration_cost_of_PV_-_Final_300913.pdf

[69] https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/distribution-power-transformers/final-report-feb2011.pdf

[70] https://setis.ec.europa.eu/system/files/ETRI_2014.pdf

[71] [71] It cannot be neglected the fact that pumped hydro storage can be expensive to install and use, depending on government imposed tariffs.

level of annual electricity consumption[72]. The opportunities and barriers for this are explained into more detail in sections 3.4.2.1 but they are linked to demand response as explained in lot 33 on smart appliances[73] but also to new PV systems that are coming on the market that include:

- monitoring (4-noks, 2018) and/or
- some type of optimization (Huawei, 2018; Panasonic, 2018) and/or
- battery storage (see Task 2).

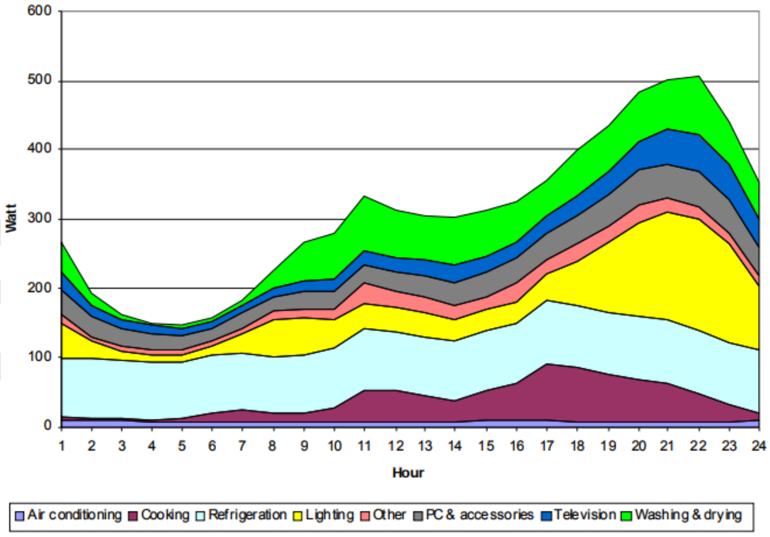
Technology options will be discussed in Task 4 but the section hereafter looks at the typical load profiles and PV generation profiles to quantify typical self-consumption.

Prosumers were introduced in section 3.0.2.4 as well as the issue on defining the minimum time period for metering which will be supposed hereafter 15 minutes. Energy generated from local PV is dependent on the location, orientation efficiency of the panel and several other parameters already mentioned. The usage of the energy locally produced could be important to take advantages from the deployment of PV systems.

In the **residential** sector there is typically a mismatch between generation and consumption. An average disaggregated residential power profile is represented in Figure 23. Three illustrative examples of this mismatch in the residential sector are displayed in Figure 24 and Figure 25. Figure 24 presents the estimated annual distribution of demand and PV generation for a residential building in Ireland and two specific examples for winter and summer daily distribution of PV generation and demand. It is important to highlight that this specific example in Ireland might exclude the use of air conditioning systems and thus strongly differ from the typical summer distribution of demand in southern countries. Figure 25 presents as an illustrative example real data from the REnnovates project ("REnnovates," n.d.), in another geographical location, for a whole week in 4 distinct periods of the year.

From this it can be concluded that the degree of self-sufficiency or autarky for residential users is not large without additional measures. Hence this creates opportunities for increased self-sufficiency that are discussed in section 3.4.2.1.

Figure 23. Typical average residential electricity profile disaggregated by end-usage ("REMODECE," 2008)

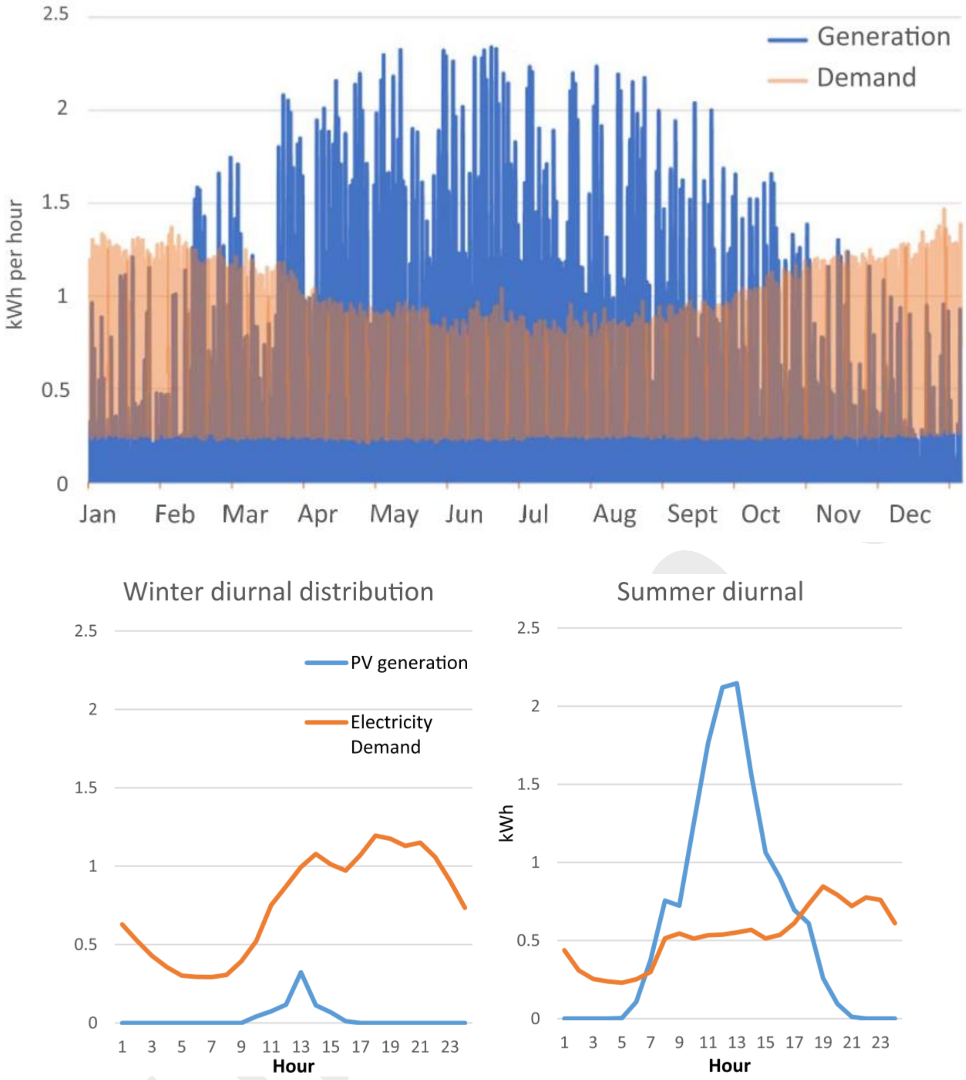


---

[72] Typically the rate of self-sufficiency in simple PV systems does not go above 30-40%.

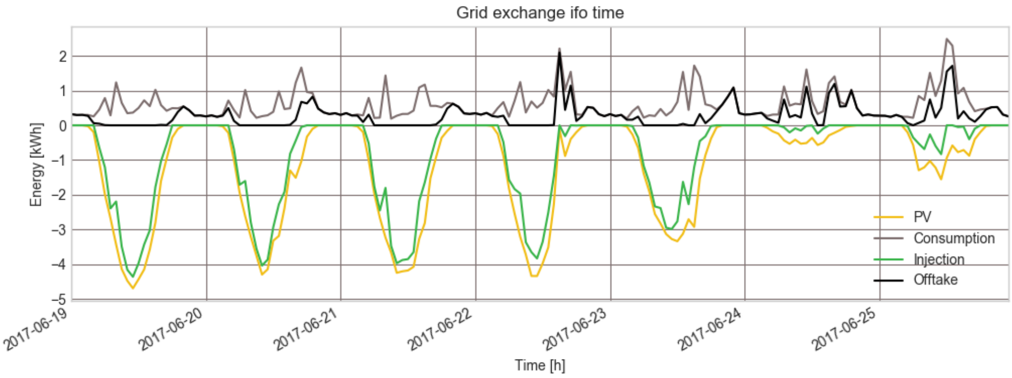
[73] http://www.eco-smartappliances.eu/Pages/welcome.aspx

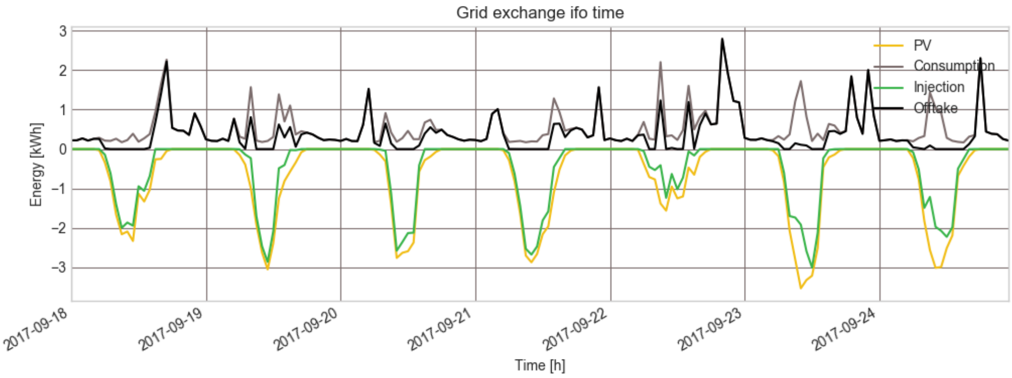
Figure 24. Annual distribution of demand and PV generation in Ireland and two examples for winter and summer daily distribution of PV generation and demand.(La Monaca & Ryan, 2017)

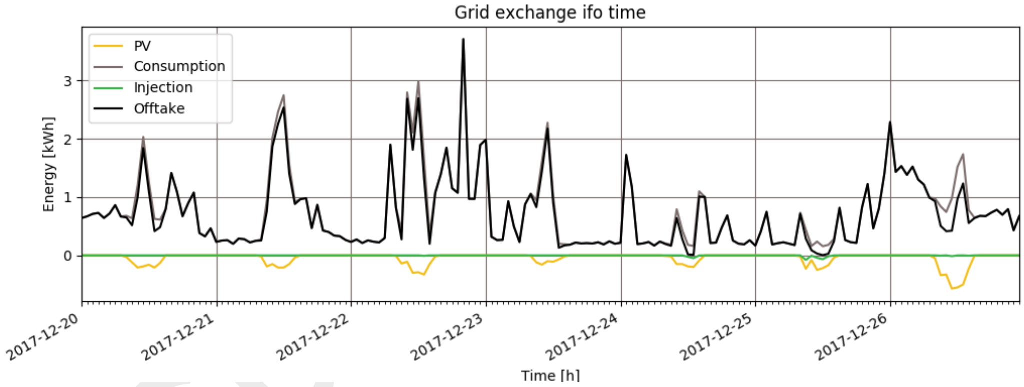


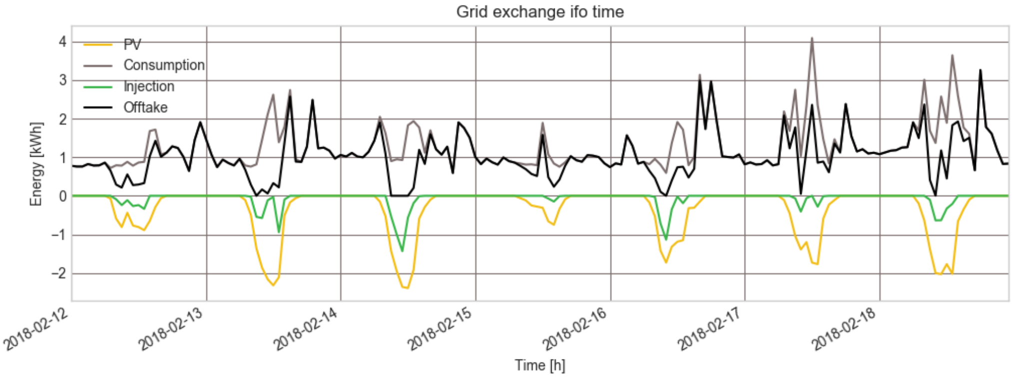
NOTE: According to (La Monaca & Ryan, 2017) "Ireland has a relatively low solar resource and only a negligible amount of residential PV currently exists".

Figure 25. Illustrative example with real data from one house in The Netherlands in 4 distinct periods of the year-PV generation (total local energy generation), consumption (total energy consumption), injection in the grid (total energy injection in the grid) and offtake (total energy consumption which was not covered by local PV energy generation)





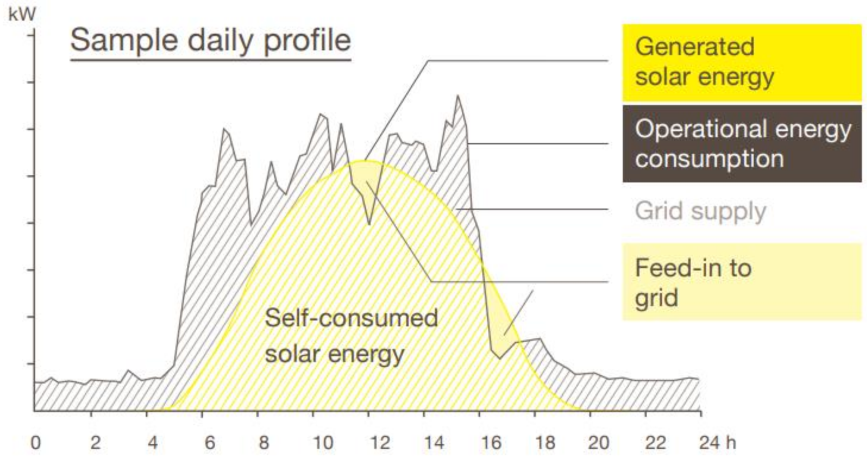




On a cloudy day quarterly solar production can become irregular while over a larger region this will be averaged out due to clouds movements (Luthander, Lingfors, Munkhammar, & Widén, 2015). Averaging out cloud effects requires a larger spatial distribution of the PV generation but this is solved by the electrical grid and its load aggregation. An alternative solution is using a battery as discussed in section 3.4.2.1.

Concerning **commercial** prosumers, such as department stores and office buildings, often a better match between the energy consumption profile and onsite renewable generation may be possible. An illustrative example, for a sunny day with a high amount of energy locally generated and assuming clear sky conditions, can be seen in Figure 26.

Figure 26. Illustrative example of the matching between consumption and solar generation (Kraftwerk, 2013)



Conclusion:

Self-sufficiency for residential consumers is not large without employing additional measures that will be discussed in 3.4.2.1. However, the electricity grid can act as storage up to a certain degree of PV penetration, since electrical grids are efficient, and therefore the impact on grid losses is also moderate (see 3.2.2). Previous section 3.2.2 also showed that a small degree of PV penetration will reduce losses when it matches local loads reducing therefore loading on the distribution grid.

3.3 Subtask 3.3 –End-of-Life behaviour

General objective of subtask 3.3:

Identification of actual user requirements (average across the EU) regarding end-of-life aspects. This includes:

- Product use & stock life (i.e., time between purchase and disposal)
- Present fractions to recycling, re-use and disposal;
- Present fraction of second-hand use and refurbishment.
- Repair & maintenance practice (frequency, spare parts, trip km, other impacts)
- Collection rate (by fraction, consumer perspective)
- Second-hand use, fraction of total and second hand life
- Available good practice in product use.

In this subtask the focus has been placed on user choices and system/component specification data that can have an impact on forecasting future waste volumes in later Tasks 5-7. However due to the long life time of PV modules (>20 years) and inverters, reliable and representative data for this tasks is not yet available. The little evidence found today on user choices might be therefore be anecdotal and not yet representative for 2030 and beyond.

3.3.1 Lifetime of the PV system

Scope: The generation of waste or collection rate is inherently influenced by the time after which the product is replaced with a new one. Product lifetime will therefore have an important impact on Life Cycle Analysis (LCA) of photovoltaics because it will influence the negative impact from production and waste against the benefits of producing electricity. Therefore the subsequent sections will describe suitable input data, and these will be further processed in Task 5 on LCA. However when looking at the life time of a PV system there are several potential definitions serving various purposes which are briefly discussed hereafter.

In this section mechanisms leading to power losses additional to the derate factors defined in Section 3.1 are listed. Mechanisms are considered which lead to decreases or complete loss of the PV module and system performance that cannot be recovered upon cleaning and requires repair or replacement.

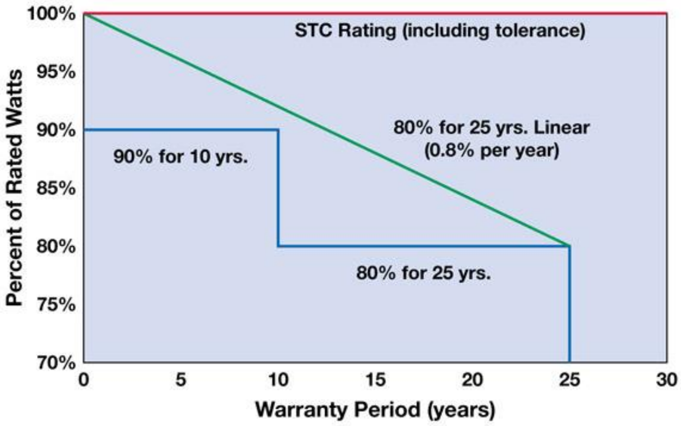
The technical aspects related to module life time will be discussed into more detail in section 4, herafter the focus is on the user and waste generation. Products can also have a second life, which is discussed in 3.3.1.8.

3.3.1.1 Definition of the name plate life time relative to degradation rates for modules

PV module lifetime is defined as 80% of the initial nameplate rating (M. Köntges et al., 2014; Meydbray & Dross, 2017). This means that an annual degradation rate of 0.8%-1% enables a PV module to deliver the expected power for 20-25 years. Thus, similar length warranties are issued by PV module manufacturers. For novel generation of PV modules, especially with strengthened packaging even lower degradation rates are expected and hence also extended operational lifetime up to 30 years.

In today's PV module warranty either step-wise degradation or linear performance loss is assumed within the 20-25 years operational lifetime. For the purposes of this study the warranty duration is considered to reflect the economic lifetime. The PV system in reality can however maintain more than 80% of its initial lifetime beyond 20-25 years. According to (Meisel et al., 2016), (recent) modules showing 0.5-0.6% annual degradation rate on the field, combined results of accelerated degradation studies and considering good operations and maintenance practices suggests that the PV system lifetime can be extended up to 35 years

Figure 27. Example of PV Module Warranty



*Blue line is worst case for a stepped power warranty

Annual PV module degradation rate is theoretically defined as the performance loss (maximum power measured at STC upon define years of operations of the PV module versus the maximum power measured at STC upon fabrication) averaged over the name plate lifetime of the PV module. It is expressed in relative power loss % over one calendar year in this study. Degradation rate refers to gradual power loss of the PV module and system over time. This metric is mostly extracted from outdoor measurement of the PV module and corrected for temperature, irradiation, and other variations. The degradation rate of PV module varies from year-to-year influenced by both weather and technology. Moreover adapted statistical approaches can influence the values and their uncertainty[74].

It is important to distinguish between degradation rate and failure rate. This later metric refers to complete loss of PV module or system performance, or its necessarily shut down due to safety reasons. It is expressed in relative % of failed PV module over a given sample population.

3.3.1.2 Definition of life expectancy in function of catastrophic failure rate for modules

In the context of waste generation or Life Cycle Analysis the 'life expectancy' is a more relevant definition of life time (Fthenakis et al., 2011) and it is not de facto equivalent to degradation. In principle the life time for a PV systems will mostly depend upon technical life time of a system, meaning that the PV system is assumed to operate until it fails or dismantled due to underperformance. A catastrophic failure means hereafter that the module stops functioning and/or cannot be installed or operated safely. This event often occurs suddenly and leads to entire loss of the power production capabilities. Hence it is considered as end of the expected lifetime. A purely cosmetic issue which does not harm the module power and its safety is not considered.

3.3.1.3 Degradation and catastrophic failure rate under operation

Flawed and poor quality modules in general fail rapidly upon installation and their replacement fall within the manufacturer's warranty. This still implies loss in energy production of the PV plant, and often requires early replacement of the panel, hence generates waste. German statistics from a German distributor based on 2 million modules over 2006-2010 indicate that 2% of the PV modules will not meet predicted performance upon ~10-12 years of operations. Major causes of the failure are linked to J-box and cabling, glass breakage and cell and interconnection damage[75].

Overview of the degradation rates for different PV module technologies and at various climates have been summarized from more than 40 studies by(Jordan, Silverman, Wohlgemuth, Kurtz, & VanSant, 2017). The median annual degradation rate of - 0.5-0.6 %/year or average of -0.7%/year for c-Si PV modules is calculated from long-

---

[74] (Phinikarides 2014) Alexander Phinikarides et all, RenewableandSustainableEnergyReviews40(2014)143–152, Review of photovoltaic degradation rate methodologies

[75] http://www.iea-pvps.org/fileadmin/dam/intranet/ExCo/IEA-PVPS_T13-01_2014_Review_of_Failures_of_Photovoltaic_Modules_Final.pdf

term fielded samples. This value has been extracted from over 10.000 data points of PV system which has been investigated for different durations, different x-si technology generation, climates. In this study the most common degradation modes for PV modules are hot spot, IC discoloration, glass breakage and encapsulant discoloration[76].

For thin-film technologies a more dispersed and smaller dataset is obtained spreading from

0.2 to 4.2%/year, although the average is typically around 1.5%/year according to (Meisel et al., 2016).

Figure 28. Degradation rate for x-Si Pv module depending on climate[77]

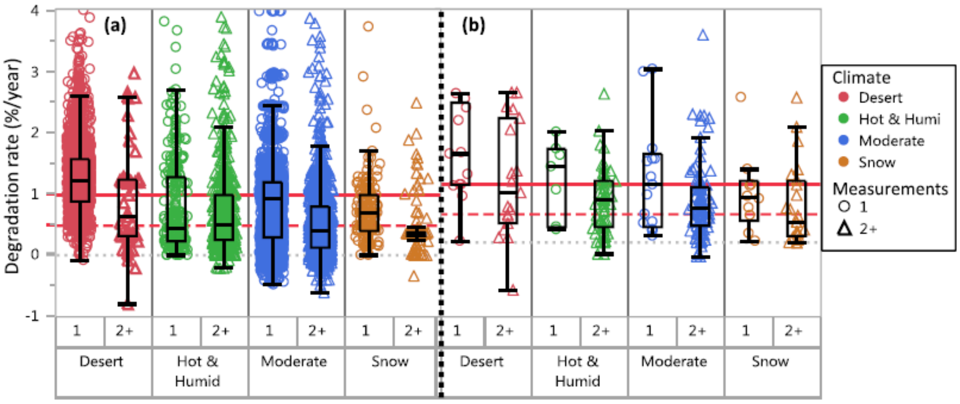


Table 14. Key parameters of silicon-based single-crystalline and CdTe photovoltaic cells and modules and values used in the three scenarios BAU (Business as Usual), REAL (realistic improvement) and OPT (optimistic improvement) (source: IEA PVPVS Task 13 report on 'LCA of future photovoltaics electricity production (Stolz & Frischknecht, 2017)')

Parameter	Single-Si				CdTe			
	TODAY	BAU	REAL	OPT	TODAY	BAU	REAL	OPT
Cell efficiency	16.5 %	25.0 %	27.0 %	29.0 %	15.6 %	22.8 %	24.4 %	26.0 %
Derate cell to module efficiency	8.5 %	8.5 %	6.8 %	5.0 %	13.9 %	10.0 %	7.5 %	5.0 %
Module efficiency	15.1 %	22.9 %	25.2 %	27.6 %	13.4 %	20.5 %	22.6 %	24.7 %
Wafer thickness / layer thickness	190 µm	150 µm	120 µm	100 µm	4.0 µm	2.0 µm	1.0 µm	0.1 µm
Electricity demand in CdTe laminate manufacture	-	-	-	-	100 %	86 %	81 %	74 %
Kerf loss	190 µm	150 µm	120 µm	100 µm	-	-	-	-
Silver per cell	9.6 g/m^2	9.6 g/m^2	5.0 g/m^2	2.0 g/m^2	-	-	-	-
Fluidized-bed reactor (FBR) Share of Poly Si Production	0 %	20 %	40 %	100 %		-	-	
Glass thickness	4.0 mm	4.0 mm	3.0 mm	2.0 mm	3.5 mm	3.5 mm	3.0 mm	2.0 mm
Operational lifetime	30 years	30 years	35 years	40 years	30 years	30 years	35 years	40 years

3.3.1.4 *PV module degradation and catastrophic failure during shipment and installation*

The EU funded project PV bankability ranked the major degradation and catastrophic failures based on their cost considering reduced/loss of power generation, repair etc. They have noted the most important elements both in

---

[76] Jordan et al. Progress in Photovoltaics 2017

[77] Jordan et al. Prog. Photovolt: Res. Appl, 2016

utility and residential PV installation are incorrect installation and broken modules (Moser et al., 2016). During transportation, solar modules can undergo mechanical stress that can lead to cracks that affect both their short and long term performance. During transport, PV modules packed on pallet experience shock and vibrations which induced and/or accelerates the propagation of cracks. These defects are invisible to the eye, and trigger power loss on the longer term and are hence often unnoticed during installation. Previous study cites up to 5% damage linked to transport and installation (M. Köntges et al., 2014).

The IEC 62759-1:2015 standard, conceived to assess the transportation risks of module package units, suggests shake and vibration tests. Several studies provide guidelines to minimize the risk of transportation damage(Marc Köntges et al., 2016).

Next to packaging, and transport conditions, installers' knowledge is critical for the correct handling of the PV handles and safe and technically correct installation.

3.3.1.5 Inverter catastrophic failure rate and average technical life time

Inverters have shorter life times (5-20 years) and are comparable to other electronic products. The very limited number of independent reviews of inverter failure rates suggest 1%-15% yearly failure rate[78]. These are related to their electronic component reliability, mainly: DC bus capacitors; IGBT power module solder joint life time, main DC contactor (if any), cooling fans (if any), etc. In this context Design for Serviceability (DFS) to reduce "Mean Time To Repair" are important parameters, together with the projected inverter life time. Recycling of inverters is similar to other electronic converters and also has to follow the WEEE Directive.

With these varying reports we assume in this study average 10 years of inverter technical lifetime, and in best up to 20 years of technical lifetime.

Next to failures considering replacement, one needs to consider downtime of the inverter linked to failure which should be serviced. This can be linked to both the software and/or hardware failure. Reports cite an average of 20 days/year downtime for string inverters and 3 days/year for central inverters. This difference simply arises from the service contract mostly purchased for the latter type (Golnas, 2013; Kröger-Vodde, Armbruster, Hadek, Heydenreich, & Kiefer, 2010).

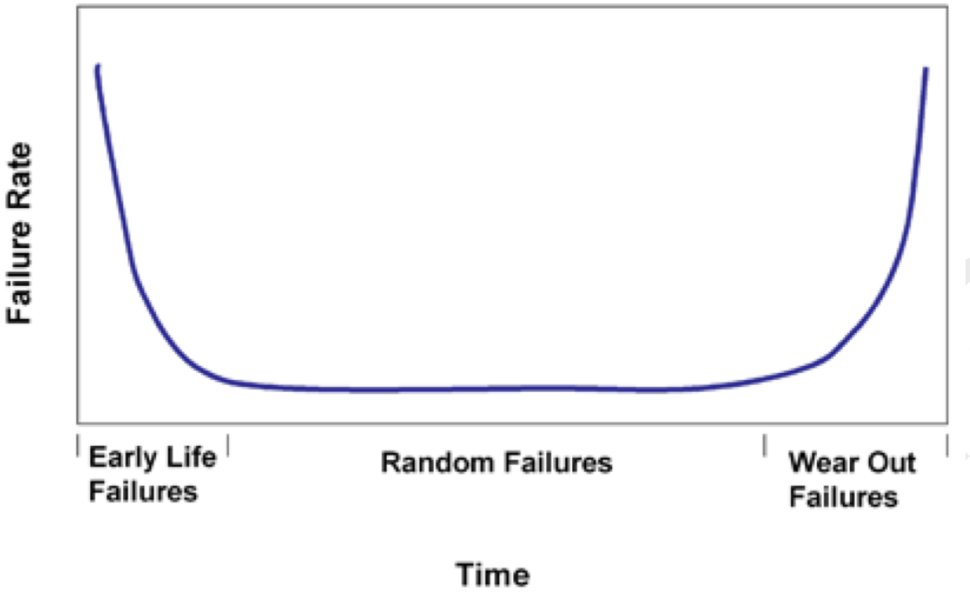
Most common failures of inverter on the field go beyond an "*unknown error message*", to include the failure of the fan and other damage linked to overheating.

According to an IEA Task 13 report on financing PV (IEA PVPS, 2017a) (p. 52), the life of an inverter is considered to be between 10-15 years. The technical lifetime of the PV system in general and the inverter in particular, follows a so-called "bathtub" failure profile shown in Figure 29.

---

[78] Laukamp et al., 2002

Figure 29. Bathtub curve showing probability of failures over the technical lifetime (TL-tech) of a product or project (IEA PVPS, 2017a)



A warranty of two years covers the early life failure of a system when the failure probability is still high. These defects are most linked to production defects. . It is obvious that the risk of failure in the flat line area of random failures is the lowest nevertheless several inverter manufacturers offer extended warranty services.

3.3.1.6 Consumer average required life time and relation with maintenance costs

A recent enquiry was launched recently by (GfK Belgium Consortium, 2017) to identify which characteristics or combinations of characteristics are most important to the end-user when buying a PV system (as mentioned in section 3.0.2.4). Based on the answers it may be possible to identify the average required life time from end-users' perspective. The relation between lifetime and maintenance costs are also a combined characteristic analyzed in (GfK Belgium Consortium, 2017).

3.3.1.7 Additional system components failure

In the PV system the clamps, railing, cabling, and increasingly trackers should be considered. Their failure can lead to loss or significant reduction of the power generation. Among them trackers are one of the most critical to consider for the operational lifetime. Trackers are used to orient the PV panels towards the sun to reduce the angle of incidence using single or dual axis motorized system. Although still employed in ~10% of the current utility scale projects it is expected that up to 40-50% of newly installed system will integrate them[79]. This technology is currently nearly never deployed in commercial and residential application both for technical, safety and economical reasons.

Critical elements that can influence the reliability of trackers are the number and type of motors, power supply system and mechanical design considering snow and wind load. Last but not least, this part of the system also requires regular preventive maintenance.

.

3.3.1.8 Repair, refurbishment and second hand use of PV systems

When considering life time it is also important to look at the potential for repair and refurbishment, possibly also leading to a second hand use – a second service life. Upon maturity of the PV industry in the last 5 years in some

---

[79] ITRPV, 2017 edition

EU Member States with a large PV deployment several companies are now offering 2nd hand PV modules. Notably pvXchange[80], SecondSol, Solar-Pur offer mostly for business to business PV module, component exchange platform. Both platform operators can provide quality control, repair and installation services.

In parallel several companies are specialized in repair, re-powering of PV modules. The following type of damage can be repaired:

- faulty bypass diodes and connectors,
- punctured backsheets,
- damaged frames.

The 'healing' of PV modules affected by Potential Induced Degradation (PID) is equally proposed by companies. Faulty connector sockets have been cited as one of the most common failure on the German market. For this later problem on-site repaid method have been developed to avoid de-installation, transport, re-installation cost and time. Failures that cannot be repaired are linked to damaged cell connection, delamination of the encapsulant and glass breakage to cite the most common ones. Most repair companies provide a 2 year warranty on their repair work[81].

Beyond repair, replacement of the damaged PV modules, adjusting the PV system design and eventually re-cabling of the PV string is necessary for optimal performance. In case of removal/replacement of a PV module a lower performing PV module can limit the performance of all other panels connected on the same string. Therefore, adapted system layout is equally important for overall system repair.

In general inverter repair on the field is less common, mostly faulty inverters are replaced. In order to maintain the (expensive) inverter warranty only the inverter providers or a company commissioned by them is allowed to intervene for repair. Second hand inverter similar to PV modules are little or not at all covered by warranties[82].Summary on life time of PV modules and inverters

Previous sections defined the following life times:

- ‘Operational life time for stock modelling’ relative to replacement rate, see Task 2.
- ‘Name plate life time’ for modules, relative to degradation.
- Catastrophic failure rate of life time of modules and inverter.
- Ecological ‘life expectancy’ can be defined for Life Cycle Analysis (Fthenakis et al., 2011)
- the average required life time from the users and the minimum warranty expected life time.

In this context it is important to be aware that life time is the reciprocal value of replacement rate, for example a life time of 50 years is equivalent to a replacement rate. Replacement rate is a metric often used in stock modelling, see Task 2.

Note that apart from these technical life times related to waste also a ‘financial life time’ can be defined, for example for the calculating of the levelized cost of Electricity (LCOE) for PV systems, see section 3.4.1.1 (T Huld et al., 2014).

A summary overview of data is given in Table 15.

---

[80] From eBay to pvBay – getting used to used PV, PV magazine, 2016 https://www.pv-magazine.com/magazine-archive/from-ebay-to-pvbay-getting-used-to-used-pv_100024935/

[81] Repairing solar modules: sometimes easier than buying new ones, PV Europe, 2017 http://www.pveurope.eu/News/Solar-Generator/Repairing-solar-modules-sometimes-easier-than-buying-new-ones

[82] Solar advice: Exchange or repair the inverters?, PV Magazine, 2018
http://www.pveurope.eu/News/Planning-Operation/Solar-advice-Exchange-or-repair-the-inverters

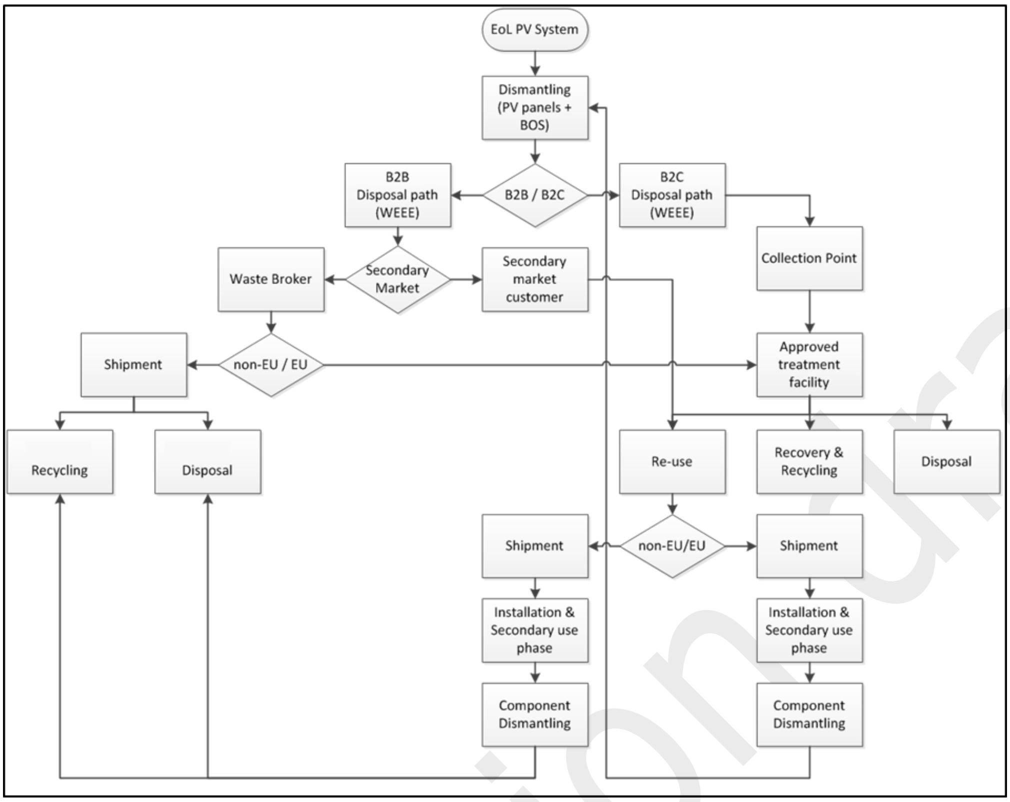
Table 15. Types of life time for different components and corresponding values (NA means Not Applicable)

	PV system	Modules	Inverter	Task/source
	Typ. (y)	Typ. (y)	Typ. (y)	
'Operational life time for stock modelling'	NA	TBD	TBD	Task 2
Name plate life time for modules	NA	20	NA	Data sheets/ IEC61215
LCA Life expectancy	NA	30	Small(<15kVA): 10 Large: 30 +10%parts/10y	IEA PVPS Task 12 (Fthenakis et al., 2011)
Warranty	NA	≥10?	≥5?	Market data
Average required life time BIPV With central inverter	NA	≥10?	≥10?	Own estimate/stakeholder feedback
Average required life time BIPV With module level inverter	NA	≥20?	≥10?	Own estimate/stakeholder feedback
Average required life time BAPV With central inverter	NA	≥40?	≥40?	Own estimate/stakeholder feedback
Average required life time BAPV With module level inverter	≥40?	NA	≥NA	Own estimate/stakeholder feedback
Average required life time for ground mount systems	≥10?	≥10?	≥10?	Own estimate/stakeholder feedback
Technical life time (task 4)	>20 y	>20 y	5-10	Task 4

3.3.2 Recycling and disposal practices and the collection rate

The dismantling of photovoltaic systems and modules typically follow the logic of a business-to-business (B2B) waste management scenario. It can also be assumed that private household photovoltaic systems will eventually end up in a B2B context as the dismantling is mostly done by a trained professional. The decision tree depicted the different options for dismantled PV systems which will be investigated further.

Figure 30: Decision tree for the end-of-life management of a PV system installed in the European Union[83]



Due to the long life time end-of-life of PV modules (>20 years) and inverters, recycling is mainly an aspect for the future. It might be incorrect to extrapolate the current recycling data because it is today a minor issue and work for setting up recycling is in progress as explained before. Waste projections will be needed, for example see Figure 31.

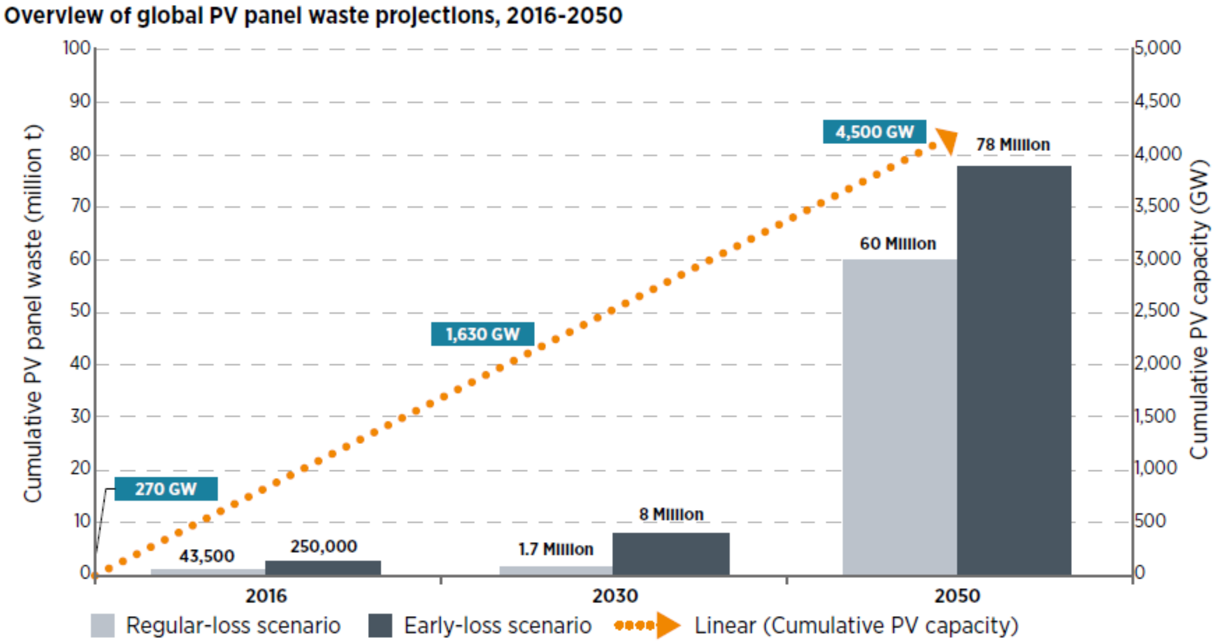
Data for Europe that is provided for each Member State in the new WEEE calculator tool has been brought together through the ProSUM project (Huisman et al., 2017). This project resulted in the online Urban Mine Platform (www.urbanmineplatform.eu). The platform has been consulted to get an overview of the waste projections for EU. Estimates are only available till 2020. 5000 tonnes of solar cell (Si-based) will become available in 2020 (see Figure 32). This source reports a waste release of 2500 tonnes solar Si cells in 2016 in the EU. This number is much lower than the global PV panel waste projection for 2016 (43 500 tonnes – see Figure 31). It will be further investigated in the project if the PV waste in the EU will follow a similar trend as the global waste projections from IRENA (2016) (Weckend, Wade, & Heath, 2016).

Hence for recycling rates potentially assumptions will need to be made based on similar products and data available from recycling technology.

---

[83] Wade, Sinha, Drozdiak, & Brutsch, 2017

Figure 31. PV panel waste projections (Weckend et al., 2016)



In the framework of WEEE, EU countries are setting up PV module recycling schemes such as PV CYCLE[84]. It is also reported that PV Si-modules can be recycled up to 96 %[85], meaning that not only glass and aluminum is recycled but also silicon. Important parameters are module lifetime, both from an economic and technical perspective. Also the market leader in thin film CdTe cells (First Solar), which contains hazardous Cd, have for many years operated a closed loop collection and recycling scheme.

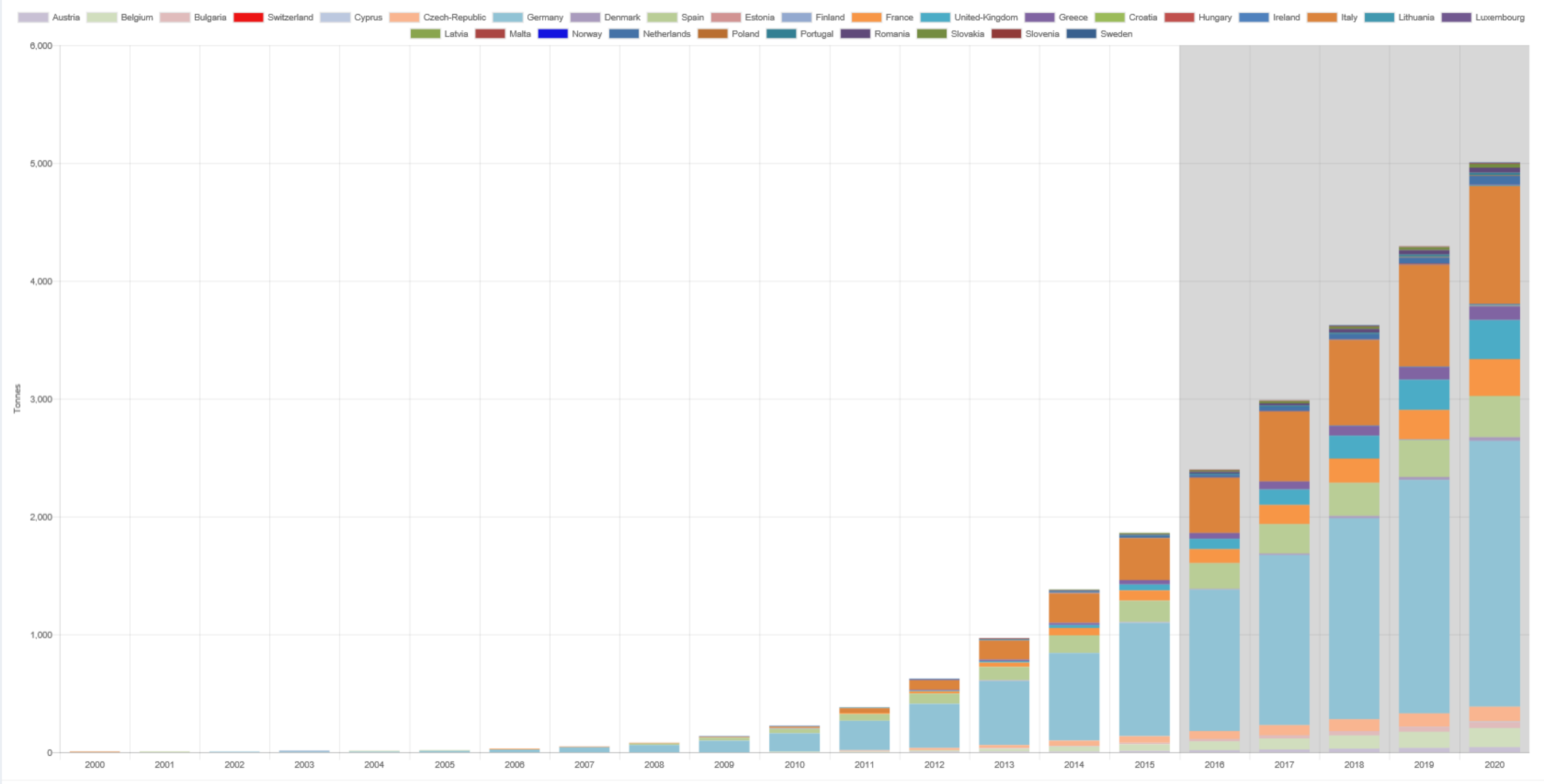
The IEA recently released a new report on recycling trends (Komoto & Lee, 2018) and research to prepare for the future is ongoing.

---

[84] http://www.pvcycle.org/

[85] http://www.pvcycle.be/press/breakthrough-in-pv-module-recycling-3/

Figure 32:.Solar cell (Si based) waste generated per EU country in tonnes (Huisman et al., 2017)[86]



---

[86] http://www.urbanmineplatform.eu/composition/eee/components

3.4 Subtask 3.4 – Local infrastructure (barriers and opportunities)

General objective of subtask 3.4:

This section includes an assessment of the following aspects:

- Energy: reliability, availability and nature
- Installers, e.g. availability, level of know-how/ training
- Physical environment, e.g. possibilities for product sharing

3.4.1 Barriers

3.4.1.1 High upfront-cost for PV systems, access to and the cost of capital

The main barrier is often the high upfront cost relative to the long term revenue combined with the cost for capital to invest in a PV project. It can also explain why investors sometimes prefer low price low life time products over high price high quality products or ultimately they do not want to invest in PV but prefer more rewarding other options. The consequence of this might be that for ground mounted systems, in which components can be easily replaced, the quality matters less than the price per KWh in comparison to roof mounted systems due to their more expensive repair and/or dismantling costs. It can also explain why residential PV are sometimes more popular compared to grid scale.

It is important to understand the common practice for investors to calculate the Levelized Cost of Energy (LCOE) for PV systems[87]. The "Levelized Cost of Energy" (LCOE) which is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel and cost of capital. The cost of capital takes also interest and inflation into account (see Task 2), the same approach as Life Cycle Cost calculations will be done in Task 5 according to the MEErP.

Inflation and interest rates change frequently over time and depend on the Central European Bank policy that is regularly reviewed[88]. Looking, for example, to the prevailing market conditions in 2016 inflation in the Eurozone was 1,1 %[89] and the MFI (Monetary Financial Institutions) interest rates on new euro-denominated loans to the euro area for non-financial corporations for loans of longer than ten years with an initial rate fixation was 1,84 %[90]. These are usually risk free loan conditions. Utilities and industry however might take into account their own risk premium and use their Weighted Average Cost of Capital (WACC) as a discount rate. The rationale is that companies raise money from a number of sources (debts, stocks, etc.) each with their own expectation on return. The more complex the company's capital structure, the more laborious it is to calculate the WACC.

The European Commission has recently developed a better regulation toolbox[91], of which Chapter 8 tool #58 discusses discount rate assumptions. The recommended social discount rate herein is 4%. This 4% rate is intended to be applied in real terms and is therefore applied to costs and benefits expressed in constant prices. It can, however, be adjusted for inflation such that if one were dealing with nominal prices, and inflation were to be, say, 3% per annum then a 7% nominal social discount rate would be used.

The JRC LCOE PV map study[87] was based on a 5% cost of capital, which is somewhat above what a private investor could currently expect from an investment of comparable duration in government bonds. The results for a reference residential system are illustrated in Figure 33 and as can be seen the major cost herein is capital. Figure 33 also shows that residential users sometimes have to invest in VAT at the time of purchase long before seeing the return. This Figure 33 shows the relative importance of capital cost and therefore also access to low interest

---

[87] https://setis.ec.europa.eu/related-jrc-activities/jrc-setis-reports/cost-maps-unsubsidised-photovoltaic-electricity

[88] https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html

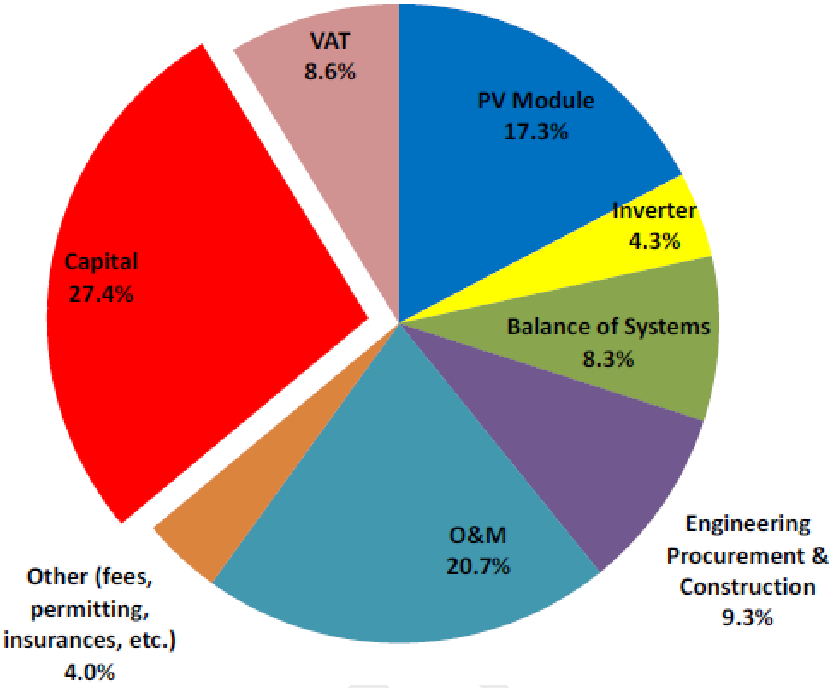
[89] http://ec.europa.eu/eurostat/statistics-explained/index.php/Inflation_in_the_euro_area

[90] https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/bank_interest_rates/mfi_interest_rates/html/index.en.html

[91] http://ec.europa.eu/smart-regulation/guidelines/docs/br_toolbox_en.pdf

loans, several banks already offer low interest loans for VV systems[92, 93]. Also some countries therefore reduces the VAT for small residential photovoltaic installations to compensate this VAT capital investment barrier[94].

Figure 33. LCOE cost breakdown for a residential system costing 1 400 EUR/kWp +20%. VAT, 2% operation, maintenance and repair (O&M) cost, an annual generation of 1 000 kWh/kWp/y, financial lifetime of 20 years and 5% discount rate (T Huld et al., 2014)



3.4.1.2 Uncertainties in support policies

According to (IEA PVPS, 2017b), PV development has been powered by the deployment of support policies, aiming at reducing the gap between PV's cost of electricity and the price of conventional electricity sources over the last ten years. This report says that about only 1% of the world PV market was driven by pure self-consumption or the sole competitiveness of PV installations in 2016. It also means 99% of the global PV market depends either on support schemes or adequate regulatory frameworks. Given the long life time for PV systems a stable and long term support policy framework must be available to convince investors.

Most support schemes rely on FiTs, an overview of support schemes is in Figure 34. Net-metering allows consumers who generate their own electricity to use that electricity anytime, the balance is made per year or the meter turns back. Therefore net-metering is a kind of indirect support scheme because the grid costs and taxes should not be paid on all transported and sold or purchased energy (see Figure 37). Other support schemes rely often on Power Purchase Agreements (PPA) which are much combined with competitive auctions.

In many countries the debate on the financing of support schemes is ongoing creating uncertainty for investors.

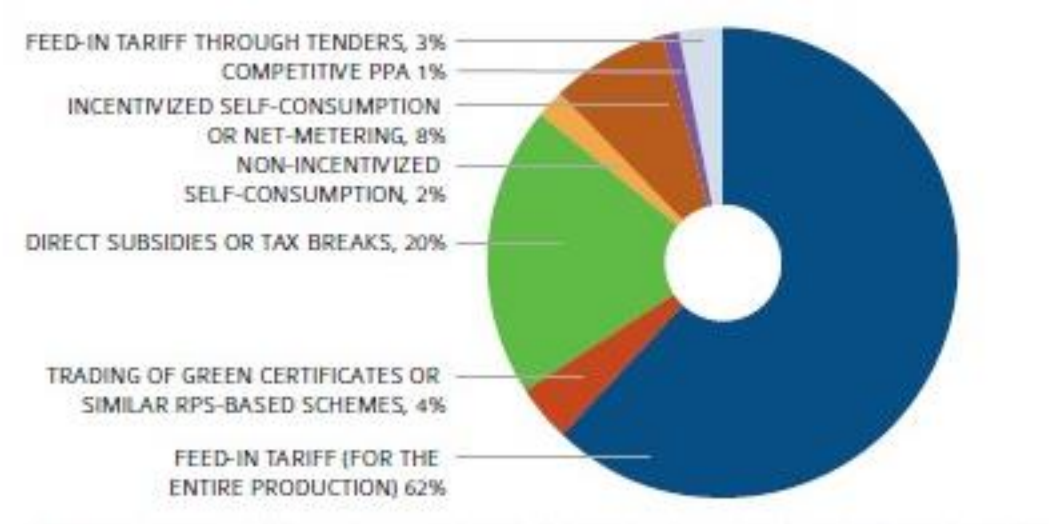
---

[92] https://www.finanzierung-photovoltaik.info/solarkredit.html#dkb

[93] https://www.vlaanderen.be/nl/bouwen-wonen-en-energie/lenen/energielening

[94] http://www.photovoltaique.info/Fiscalite#TauxdeTVA

Figure 34. Historical market incentives and enablers for PV (IEA PVPS, 2017b)



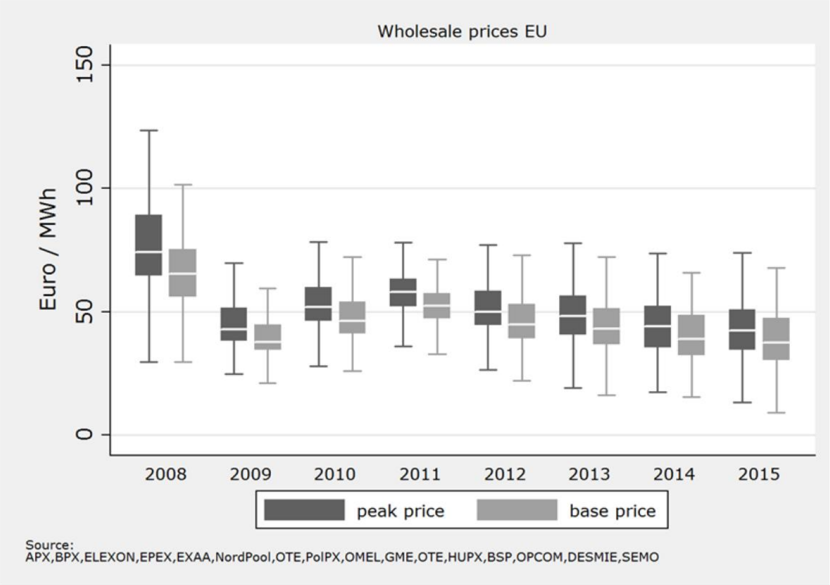
3.4.1.3 Uncertainties in future energy prices

Apart from the support scheme (see 3.4.1.2) part of the return on investment will come from the value of the solar produced electricity per KWh. *For details on electricity market prices, the* market trends and the typical cost of PV systems please *consult Task 2* on photovoltaic system markets. The purpose of the section hereafter is not to analyse the electricity market into the details but only to illustrate the prospects and uncertainties that potential PV system owners will face.

When looking to the market value of electricity it is important to discriminate the wholesale market price from the retail price, for more details see Task 2. For PV system owners the wholesale market price is representative for the electricity sold to the grid and the retail price for self-consumed electricity.

The wholesale electricity market prices vary around 0,04 euro/kWh (Figure 35), it has so little value that projects are uneconomic and did not produce a return on investment (p.10, (Dunlop & Roesch, 2016)).

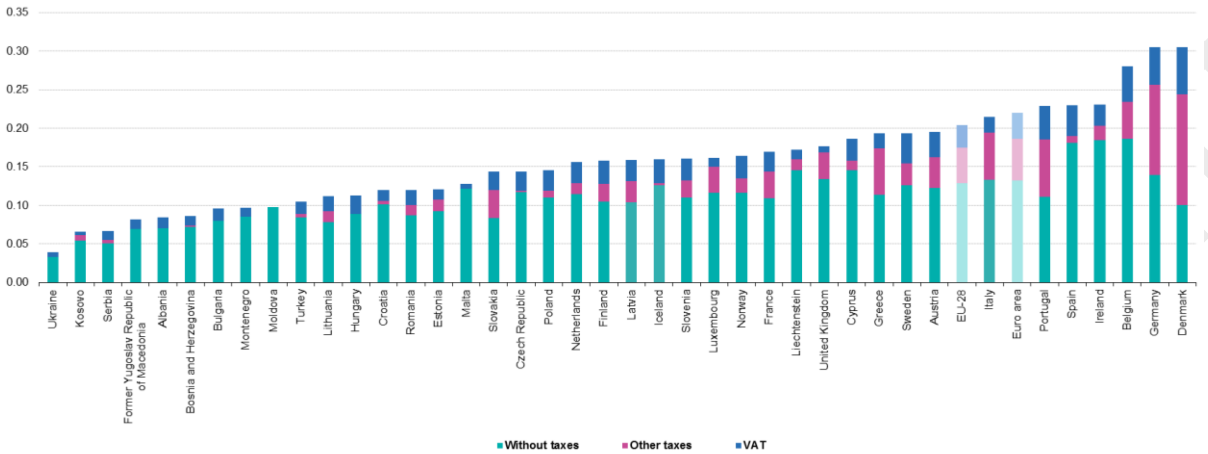
Figure 35. Annual wholesale electricity prices in the EU between 2008 and 2015 of EU Member States (Ecofys, 2016)



Source:
APX,BPX,ELEXON,EPEX,EXAA,NordPool,OTE,PolPX,OMEL,GME,OTE,HUPX,BSP,OPCOM,DESMIE,SEMO

Nevertheless, retail prices can be significantly much higher compared to wholesale market price which is illustrated in Figure 36 and therefore they can provide an important driver for investing in PV systems and in particular for self-consumption, for details consult Task 2 or Eurostat[95]. As illustrated in Figure 37 electricity prices can be very different per Member State and/or Region and consequently the driver to procure a PV system for self-sufficiency. Paradoxically enough these country differences are partially due to 'other taxes' which are often related to green levies to subsidize PV systems.

Figure 36. Electricity prices for household consumers, first half 2017 (EUR per kWh) (source/ Eurostat)



*This designation is without prejudice to positions on status, and is in line with UNSCR 1244 and the ICJ Opinion on the Kosovo Declaration of Independence.

Source: Eurostat (online data code: nrg_pc_204)

Future projections on electricity price are given in 'EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050' elaborated by the European Commission, which are summarized in Figure 37. In order to understand the uncertainty it is worth considering the future projections on electricity price The most commonly accepted source for this is the 'EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050' elaborated by the European Commission, see Figure 37. These complex electricity cost scenarios assume a continued uptake of renewables. Over time, the structure of costs slightly changes; capital intensive investments of RES such as photovoltaics and increasing grid costs bring a decrease of the share of variable cost components and a corresponding increase in the capital cost components.

The expected increase in grid costs are related to smart grids[96] and in particular the transition towards distributed RES, as discussed in subsequent section 3.4.1.5. More specifically, capital costs and fixed costs increase significantly. Higher shares of RES in power generation with similar fuel prices imply a reduction of the fuel cost component. Smaller components of the cost increase are national taxes and ETS allowance expenditures. In addition, there are the arithmetic effects of successful energy efficiency policies, which through curtailing electricity demand reduce the denominator for sharing out the electricity costs while the numerator is less affected due to the high share of fixed costs in electricity generation and supply.

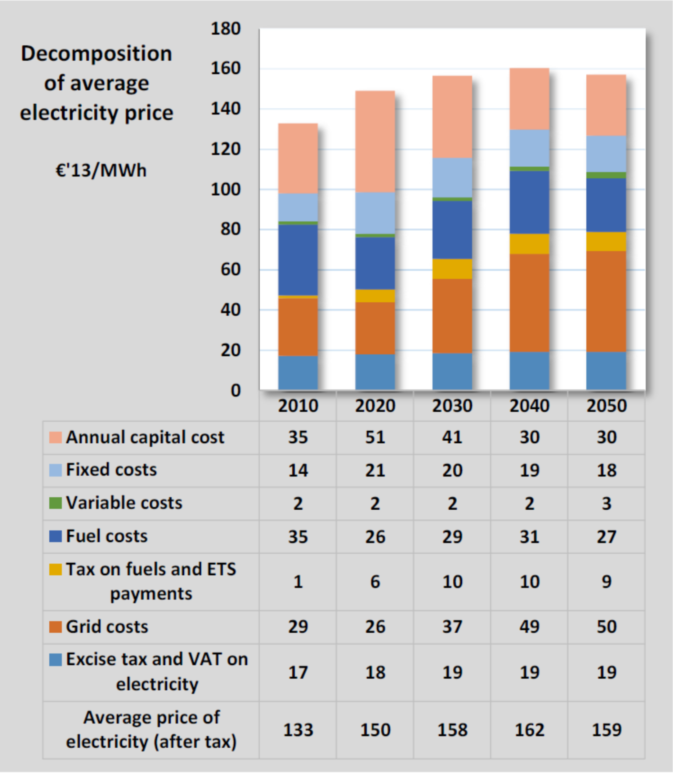
As a consequence another barrier to investing in solar is simply the fact that electricity sold on the wholesale market has so little value that projects are uneconomic and do not produce a return on investment (p.10, (Dunlop & Roesch, 2016)).

---

[95] http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

[96] https://ec.europa.eu/energy/en/topics/markets-and-consumers/smart-grids-and-meters

Figure 37. Components of average retail electricity price in EU (€ per MWh) historical and forecast values (source:EC (2016[97]))



	2010	2020	2030	2040	2050
■ Annual capital cost	35	51	41	30	30
■ Fixed costs	14	21	20	19	18
■ Variable costs	2	2	2	2	3
■ Fuel costs	35	26	29	31	27
■ Tax on fuels and ETS payments	1	6	10	10	9
■ Grid costs	29	26	37	49	50
■ Excise tax and VAT on electricity	17	18	19	19	19
Average price of electricity (after tax)	133	150	158	162	159

3.4.1.4 *Uncertainties in forecasting the operational revenue*

Forecasting the operational revenue of a photovoltaic system over its long life time (>20 years) might be the most important one given the interest of potential owners (see 3.0.1). In principle this is related to forecasting the yield of a PV system discussed in section 0.

3.4.1.5 *Potential technical barriers related to grid integration*

The European Technology paper issued a white paper on this topic[98]. In a nutshell the main potential limitations for the distribution grid are related to:

- Grid congestion and therefore overvoltage issues
- Harmonics and malfunctioning of inverters
- Reverse power flows and transformer overloading

High shares of PV might in future also create system wide issues, related to the energy balance and ancillary services, that are the responsibility of the transmission system operators[99].

Most of these technical barriers on grid integration are directly related to the requirements of the grid code, for example most European countries follow the German requirements VDE VDE-AR N 4105 on 'Power generation systems connected to the low-voltage distribution network' with the 'Technical minimum requirements for the

---

[97] https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

[98] http://www.etip-pv.eu/fileadmin/Documents/FactSheets/English2015/EU_PVTP-Grid_Integration_white_paper_low.pdf

[99] https://www.entsoe.eu/about-entso-e/market/balancing-and-ancillary-services-markets/Pages/default.aspx

connection to and parallel operation with low-voltage distribution networks'[100]. Note that before 2016 the electrical grid codes was not harmonized and that this European harmonization is only recently initiated by the Commission Regulation (EU) 2016/631 that establishes a European network code on requirements for grid connection of generators. For a more detailed list on product requirements, European Regulations and Standards please see task 1.

Note that the white paper[101] also put forward mitigation techniques and therefore this barrier is also an opportunity for future PV grid inverters, see 3.4.2.3.

3.4.1.6 Market access and metering schemes for small producers

The way countries deal with the monitoring of energy locally generated from PV panels is not the same. For example, while in Belgium the most common situation in the residential sector is net metering (energy meter running backwards) and the residential prosumer receiving at the end of the billing period a corrected bill which includes the net excess generation, in other countries such as Germany there are two separate energy meters, being the second meter used for measuring the power generated by the PV panels and injected in the grid. In this case, the local utility provider pays the prosumer for the energy injected on the grid based on a price previously agreed. It may happen that the price for injecting energy on the grid was extremely subsidized and therefore very high.

3.4.1.7 Ownership of the roof and/or façade for BIPV/BAP, type of roof and building permits

The concept of prosumers and BIPV/BAPV is explained in section 3.0.2.4. There are also potential prosumers that do not own the roof or have only co-ownership which therefore forms an important barrier for investment. The related section 3.0.2.4 on prosumers also gives examples of new business models and legislation to overcome this barrier.

Not all roofs are suitable to install PV panels taking into account the wind resistance and roof loading[102]. Especially flat roofs are often unable to withstand the additional wind load created by the PV panels and their counterweight or fixation. For flat roofs the fixation of the support structure must also be done carefully in order to avoid water leakage. Therefore from a constructional point of view attic roofs are in general more suitable compared to flat roofs.

3.4.1.8 Lack of knowledge or skilled subcontractors

The deployment, repair and maintenance of PV systems requires highly-qualified technicians (Tsoutsos et al., 2013) which should demonstrate some form of certification attesting their qualification.

In this context, certification schemes can be used. However, across Europe these schemes may vary or might even be inexistent in some countries, even though training for PV installers exists might exist (PVTRIN, 2013). Still, different eligibility requirements and qualifications may exist for the training courses. To avoid these situations and assure uniformity among the different Member States, the EU Directive (2009/28/EC) sought to lay down uniform requirements for accreditation and mutual recognition.

A training and certification scheme, for technicians responsible for installation and maintenance of small PV systems, compliant with 2009/28/EC RES Directive (Article 14, Annex IV) was proposed in (PVTRIN, 2013).This training scheme was initially implemented in Greece, Bulgaria, Croatia, Cyprus, Romania and Cyprus. It involved key stakeholder groups to transfer the market's experience and needs and surveys were conducted in order to identify important aspects, namely "*to record the attitudes, perceptions and considerations of the PV industry/market actors regarding the training, certification and skills of PV installers and to record their opinion for the market growth, the adequacy of the existing workforce and the quality of current installations*". In one of those surveys installers skills

---

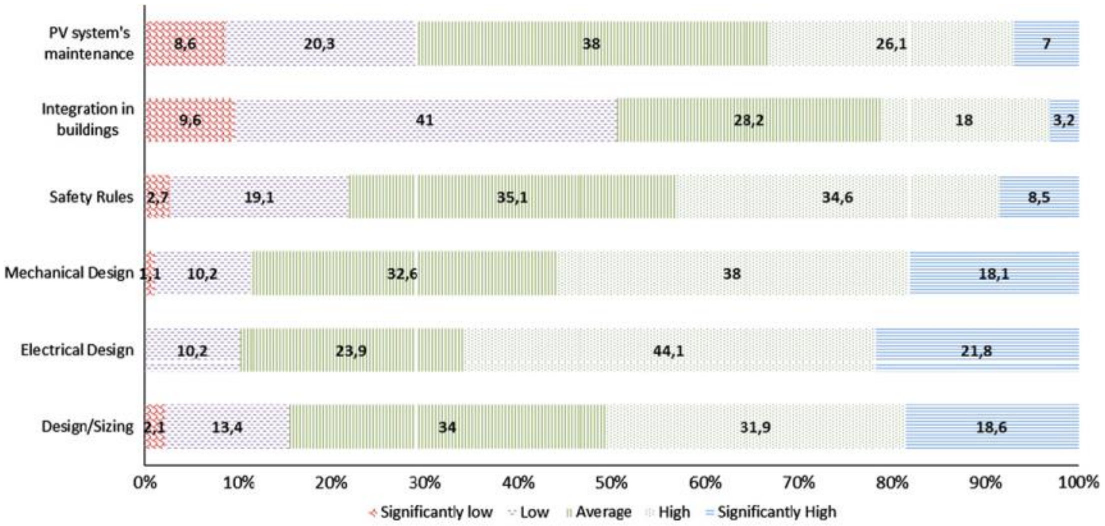
[100] https://www.entsoe.eu/Documents/al/Germany/170623%20E-VDE-AR-N%204105%20zur%20Konsultation.pdf

[101] 98

[102] http://iawe.org/Proceedings/8APCWE/Daisuke%20Somekawa.pdf

were evaluated and *safety rules, integration in buildings and proper maintenance* were rated as inadequate raising important concerns (Figure 38).

Figure 38. Rating of installers' skills according to the PVTRIN survey responders (Tsoutsos et al., 2013)



According to (PVTRIN, 2013), installers following this training and certification scheme receive:

- "Appropriate, acknowledged training courses;
- Practical training materials and tools (handbooks, checklists and tips, e-learning platform;
- practical guides, lists of useful resources);
- Advancement and continuous updating of their knowledge and technical skills;
- Employability; recognition and professional competitive advantage due to their certification;
- according acknowledged quality standards;
- Mobility; the certification provides the "passport" to the EU job market".

This type of scheme certification will thus contribute to increase the knowledge and skills of installers and subcotractors.

It is worth noting that recently the IEA PVPS has also issued a guideline to introduce quality Renewable Energy Technician training (IEA-PVPS, 2017).

3.4.2 Opportunities

3.4.2.1 Opportunities for batteries and demand response management to increase self-consumption

As it was mentioned in section 3.2.3, and mainly in the residential sector, there is a mismatch between PV production and the typical demand which opens up the way to energy storage. Also, as discussed in the previous section 3.4.1.5 high penetration rates in low voltage distribution grids can result in grid congestion or overvoltage.

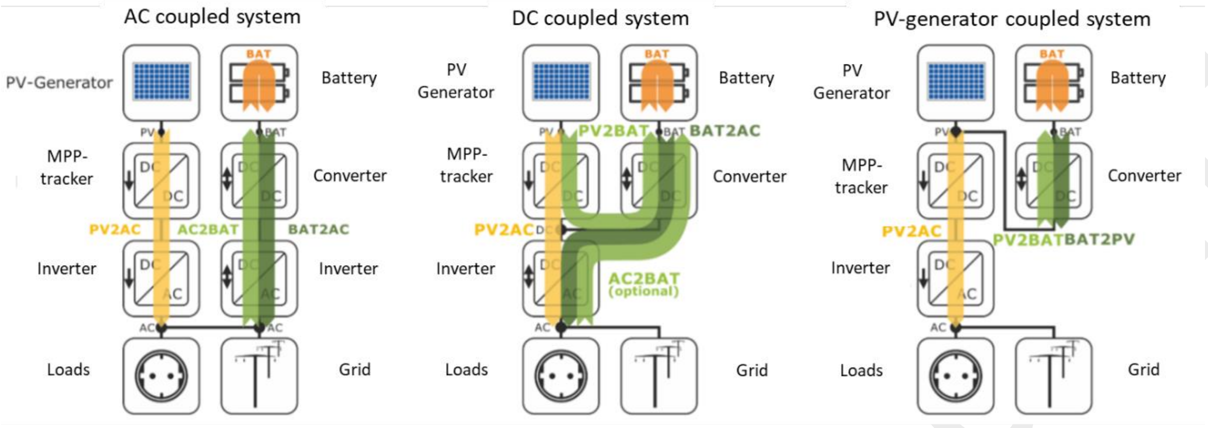
Next to the existing solutions this can create opportunities for batteries and Demand Response Management (DRM). As far as it is relevant and within the scope of this study the technology can be discussed in Task 4. From a technical perspective various solutions exist depending on if and how the battery is integrated with the inverter, three possible topologies exist (BVES & BSW Solar, 2017):

- AC coupled battery systems, i.e. an AC integrated battery/PV system.
- Batteries directly coupled to the PV modules, i.e. PV modules integrated with batteries.

- Batteries coupled to the internal DC bus of the inverter after the MPPT DC/DC converter, i.e. PV inverter with DC bus integrated battery.

The last system with batteries coupled to the internal DC bus of the inverter offers efficiency gains, see Figure 39.

Figure 39. Illustrative example of PV systems with batteries (BVES & BSW Solar, 2017)



An alternative future solution might be Demand Response Management (DRM) in to support the Smart Grid[103,104] which provides electrical load flexibility to cope with fluctuations in renewable energy supply. For appliances or plug loads, including domestic how water storage tanks, heat pumps and EV charging another Ecodesign preparatory study is already ongoing[105]. Hence these issues can be left outside the scope of this study.

Concerning batteries, the principal is to use batteries to store the excess of local PV production and use that energy at a later time of the day when there is demand and no local energy is being generated (Labastida, 2017). Nevertheless, residential batteries have not completely reached economic profitability in most of the current grid-connected situations (Pena-Bello, Burer, Patel, & Parra, 2017) which is a major disadvantage concerning the use of that option to maximize self-consumption from PV. Indeed, as illustrated in section 3.2.3 that in the European climate it is not evident to cover the local load due to high variations in load profile in combination production variations due to clouds and seasonal differences.

Still in this storage need context, E.ON recently began offering a new product which allows solar power producers to “*store an unlimited amount of the energy they produce on a virtual electricity account and then draw on it anytime they like*” [106].At the initial phase this product, called SOlarCloud, will be firstly introduced on the German market.

---

[103] https://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartGrids/Pages/default.aspx

[104] http://smartgridstandardsmap.com/

[105] http://www.eco-smartappliances.eu/Pages/welcome.aspx

[106] https://www.eon.com/en/about-us/media/press-release/2017/eon-announces-a-new-initiative-in-digital-energy-products.html ; https://www.eon.com/en/about-us/media/press-release/2018/eon-brings-innovation-to-the-energy-market-storing-solar-power-without-batteries.html

3.4.2.2 Upward trend in retail electricity prices and self-sufficiency

Section 3.4.1.3 explained the impact from of electricity prices on users, the expected upward trend of retail prices in some countries for some type of consumers will also create an investment opportunity in PV systems in particular to cover self-consumption.

3.4.2.3 Opportunities for inverters to provide grid ancillary services

Many of the barriers mentioned in section 3.4.1.5 on grid integration can be solved with control functions implemented in PV inverters. Task 4 will give more technical information. The European Technology & Innovation Platform PV issued a white paper on this topic[107].

---

[107] http://www.etip-pv.eu/fileadmin/Documents/FactSheets/English2015/EU_PVTP-Grid_Integration_white_paper_low.pdf

3.5 Summary findings and conclusions

In this section the initial findings and conclusions that can be drawn from the Task 3 analysis of user behaviour and system aspects are presented. Alongside these findings, key points for discussion with stakeholders, together with requests for information and case studies, are also presented so that they can be addressed during the first stakeholder meeting and associated written consultation period.

3.5.1 Photovoltaic users, procurers and their requirements

3.5.1.1 The stakeholders involved in PV system ownership and use

A range of potential stakeholders are involved in PV system use whose influence over the decisions and processes involved in installation is an important first factor to consider. The interaction between the system owner or end-user, the designer or installer and other 'primary' stakeholders, such as the electricity distribution utility, is particularly important because of financial or regulatory requirements.

In order to understand the motivation and requirements of owners or end-users the possible ownership structures for a PV systems have been reviewed, together with the possible contractual routes used for the design, financing and installation. Based on a combination of the analysis made in Task 2 and in this Task 3, four broad types of ownership have been identified:

- Ownership by energy producers only: This type of ownership is increasingly becoming limited to larger systems that are able to win bidding processes for electricity price subsidies in each Member State. Self-consumption is forfeited for the security and revenue from an electricity price support contract..
- Independent power producers (IPP): These are entities without affiliation to a transmission, distribution or generation utility and who are responsible for developing, building and operating solar PV plants. An IPP may also serve as an investment vehicle.
- Third party ownership by Energy Service Companies (ESCo): A version of an IPP in which the land or building on which the solar PV system is installed may be owned by another party, with whom a lease or access rights are negotiated.
- Ownership by 'prosumers': Users that are both producers and consumers of electricity, usually at the same location or potentially as part of a community of collective self-consumers with systems installed at different locations on the same portion of the public distribution network.

The dual role of system owners as both producers and consumers of electricity is becoming increasingly important because of a reduction in subsidies. These so-called prosumers tend to be owners of smaller scale systems, typically less than 10-20 kW or in accordance with Member State electricity market legislation, whereas the first three types of ownership tend to encompass a range of public and private 'commercial' scale systems of >10 kW up to MW size.

A range of other public and private stakeholders are involved in, and may influence PV system design, installation and use. The influence and power of these stakeholders over the decisions and processes can play an important role. They will primarily include,

- Central and regional government: Although their role is diminishing, government subsidies are still an important support mechanism for system owners and users, both at the point of making an investment and during a systems service life.

- Municipalities: Building permitting requirements will increasingly require Nearly Zero Energy performance, which in turn increase the focus on BAPV and BIPV as a solution.

- Banks and investors: Project finance or equity investment will come with associated due diligence requirements that may encompass system and component-level certification and quality assurance.
- Electricity distribution utilities: The local utility will impose financial and regulatory requirements on the system owner or end-user and their design and installation contractors.

Each of these stakeholders will impose specific technical requirements in order to receive finance, subsidies, permits and grid connections.

3.5.1.2 Consumer requirements for PV systems

The findings from a major consumer market testing exercise carried out for the CLEAR project in 2014 and from a more recent study for DG Justice in 2017, they both emphasise the importance to domestic consumers of financial savings relative to their current electricity source. Other factors to take into consideration include the capital and running costs, the payback time and the aesthetics upon installation on their property. The potential to reduce their environmental impact also registered as an important, but secondary, driver.

The priority placed by consumers on the savings potential means that an important factor at the design stage for a PV installation is the estimation of a systems annual AC energy yield. Making this estimation entails as a minimum an understanding of a system's Performance Ratio, as defined in IEC 61724-1, and the annual solar irradiation for the location.

The design of PV systems for the residential PV market is generally carried out using automated simulation tools and pre-defined packages of modules and inverters. This forms part of the quotation process for installers and retailers. Consumer expectations can also bring into the design process other considerations such as aesthetics (e.g. the appearance of modules or the visual effect on a roofline) or longer term maintenance such as access for cleaning and repair/replacement.

Consumer organisations across the EU provide advice on the installation of PV systems, as well the purchase of modules and inverters. Some of this advice is backed up by their own in-house performance testing and auditing of products according to varying and sometimes non-standard methods and metrics. Their priorities and focus e.g. the Belgian *Test Achats* and UK *Which?* audit PV manufacturers factory quality procedures and checks production samples. In contrast, the Spanish *OCU* field tests PV module and inverter kits which are then rated based on their performance in comparison to manufacturers claims.

3.5.1.3 Public procurement criteria and requirements for PV systems

Public authorities across the EU are increasingly looking at the potential to install solar PV systems on a range of buildings and sites. Calls for tender for installations may include four main types of criteria:

- Selection Criteria (SC): These criteria refer to the suitability and capability of the tenderer.
- Technical Specifications (TS): These criteria constitute minimum compliance requirements that must be met by all tenderers..
- Award Criteria (AC): At the award stage, the contracting authority evaluates the quality of the tenders and awards points that will have a weighting together with the price bid.
- Contract Performance Clauses (CPC): These clauses are used to specify how a contract must be executed and they may be linked to penalties or bonuses in order to ensure compliance.

Initial evidence from a search of tenders published in *OJEU* suggest that some public authorities are awarding points or establishing performance clauses on the basis of AC output power, warranty length, failure response services and the availability of spare parts. Monitoring of performance upon grid connection had also been specified.

The tender process itself and the potential to set criteria will be influenced by the type of contractual arrangement. Examples include:

- The purchase of PV equipment that is then installed by their own direct works company,
- The contracting of a designer, installer or turnkey contractor for PV systems, or
- To confer access rights to roofs or sites to an energy services company or renewable energy investment funds, who will then finance and install the PV systems.

There is some evidence that the third party financing PV installations on the basis of Power Purchase Agreements (PPAs) is emerging as another type of contractual arrangement. This option is being used where subsidies are no longer readily available.

Photovoltaic users, procurers and their requirements

Stakeholder consultation points

3.1 Of the consumer motivations and requirements identified which do you consider the most important to take into account in our PV system and component modelling?
3.2 Of the performance aspects addressed by EU consumer organisation which do you consider the most important to take into account in our PV system and component modelling?
3.3 Are you aware of any studies or information sources on the types of PV contracting used by public authorities?
3.4 In the case that you have participated in a call for tenders for a public authority relative to solar photovoltaics, what were the technical criteria?

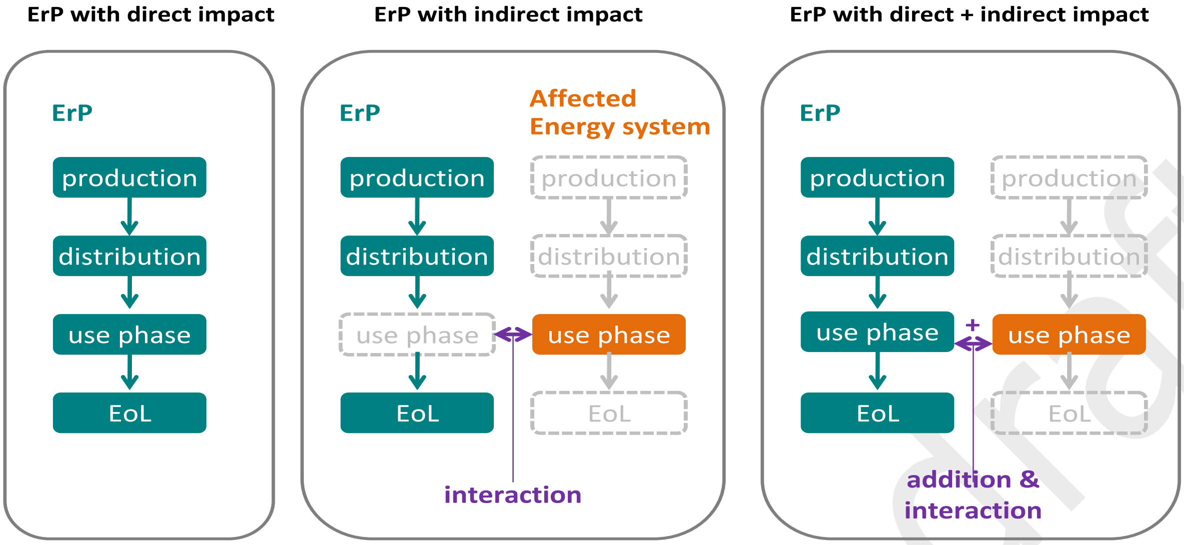
Requests for information and case studies

- Further examples of consumer organisations that carry out testing and audits of PV systems and components
- Further examples of public authority calls for tender and the associated technical specifications for solar PV installations are requested.
- Further examples of the inclusion of Green Public Procurement criteria in calls for tender for solar PV installations are requested.

3.5.2 System aspects in the use phase of solar photovoltaics

The Preparatory study follows the MEErP method, which establishes the concepts of analysing the direct and indirect impacts of an Energy related Product (ErP) on associated energy systems. Direct impacts are defined as those related to energy consumption in the use phase and indirect impacts as being related to an ‘affected energy system’ (see Figure 40). Both of these impacts require interpretation in order to apply them to solar photovoltaic systems and components, because the MEErP method was not developed with energy generating products in mind.

Figure 40. Illustration of possible system boundaries for direct and indirect impacts (Source: MEErP, 2011)



3.5.2.1 Direct impacts on energy production

Given that solar PV is an energy generating product it is proposed to consider direct impacts in negative terms i.e. those parameters that may constrain or reduce the amount of electricity generated during the use phase, or which may be considered as direct losses from a system during the use phase. In this way a relation can be made to system design and specification decisions which can have a direct impact on the performance of a module, inverter or system.

The following direct impacts have therefore been identified and proposed as being taken into account in the modelling of base cases and scenarios in subsequent tasks:

- Performance Ratio (PR), which is the quotient of the system's final yield Yf to its reference yield Yr, and indicates the overall effect of losses
- Derate Factors (DRx) to disaggregate the Performance Ratio:
  - DRcapture for capture losses
  - DR_{BOS} for Balance of System losses
- In plane irradiation(Hi) [kWh/m^2] over the specified time period

For the purposes of this study the reference standard for the Performance Ratio is proposed as IEC 61724-1:2017. A detailed proposal of the Derate factors to be taken into consideration in the modelling of a PV system during the use phase has been made in table 5 on page 24.

In line with the MEErP method four different approaches to the definition and modelling have been interpreted and applied to a PV system as the 'product' have been considered:

- Strict product approach
- Extended product approach
- Technical system approach
- Functional approach

The findings from an initial scoping of these four approaches are briefly summarised in Table 16. This scoping is supported by a review of current system design, yield estimation, operation, monitoring and maintenance practices in the market. Assumptions derived from these real-life practices, which may be requested and/or required by consumers and system owners in different market segments, will play an important role in the later modelling under Tasks 5 and 6. The functional approach to the choice of building technical systems is considered to fall outside the scope of this study.

Table 16. Scoping of the system boundary and approach to direct impact modelling

MEErP approach	**Description of the approach**	**Technical implications**
Strict product approach	In the strict product approach, the system boundary only contains the PV installation with its components. The operating conditions are nominal as defined in traditional standards.	• Modelling of a PV systems performance shall be carried out under Standard Test Conditions (STC) as defined in IEC 61853-1 • Standardised methods of estimating a PV modules efficiency and yield under STC, as well as the conversion and MPPT efficiency of the selected inverter according to a standard load profile, shall be used.
Extended product approach	In the extended product approach, the influence of real-life deviations from the testing standard are introduced, such as the use of local weather data for a chosen location.	• Weather data that is representative for the location of the PV system shall be used to estimate the final system yield in comparison to a reference yield. • A reference source of solar radiation data, as well as ambient temperature and wind speed data for the location is required. This shall have an hourly time interval, and represent a Typical Meteorological Year (TMY) based on a 20-30 year time series. • For the purposes of modelling base cases 3-4 representative EU locations and climatic conditions shall be selected. • The use of representative climate data will enable more accurate modelling of module capture losses due to the temperature, spectral mismatch, reflection and degradation – each of which has a derate factor.
Technical system approach	When viewed from the technical system perspective, the PV system is embedded in the surrounding building system or site, and therefore there is scope for interactions between the supply and demand for electricity.	• Factors related to the urban siting of the PV system and its integration into the built environment shall be described. • These factors include shading, soiling from various sources, and losses from low voltage cabling within metered premises. • Grid related curtailment and system failures will inform assumptions about potential downtime. System failures could include catastrophic module or inverter failures, necessitating a probabilistic assessment of reliability about failure rates. • A knowledge of operational, monitoring and maintenance practices shall be used to make assumptions about how derate factors may be managed, e.g. maintenance to clean module soiling, fault identification to prioritise repairs or replacements.
Functional approach	In the functional system approach, only the basic functions of a photovoltaic system, i.e. producing renewable energy and reducing CO_2 emissions, are the focus, and other building technical systems that can satisfy these basic functions are reviewed as well.	• For BAPV and BIPV, solar PV shall be compared with different building technical systems that may be used to deliver either: – a specific level of reduction in primary energy use and CO_2 emissions, or – to supply a specific proportion of a buildings energy from renewables. – To substitute the consumption on-site of a specific grade of energy e.g. heat for domestic hot water,

3.5.2.2 Indirect impacts on energy systems

Solar photovoltaic electricity generation will displace or substitute centralised, non-renewable electricity generation, thereby indirectly reducing environmental impacts. Other indirect impacts could include a reduction in transmission and distribution losses from local on-site production and, attempts to increase self-consumption. Three main types of indirect impacts have therefore been identified and are proposed to be taken into account in the modelling of base cases and scenarios in subsequent tasks. These three impacts are briefly summarised in Table 17.

Table 17. Scoping of the system boundary and approach to indirect impact modelling

Indirect impact	**Description**	**Technical implications**
Substitution effect of grid electricity	Avoided environmental impacts due to the substitution of non-renewable electricity with photovoltaic energy.	• Modelling of the substitution of the average EU impact resulting from the generation of 1 kWh of electricity • For a more accurate modelling the hourly or half hourly grid mix for a specific Member State should be used
Transmission and distribution grid losses	Transmissions and distribution losses associated with the grid transport of electricity. Ancillary grid support in order to curtail generation and adjust the grid frequency in order to manage asynchronous generation.	• Modelling of the solar PV electricity generation under low, medium and high grid penetration scenarios because of the variance in anticipated grid losses. • Consideration of the potential role of inverters which provide grid ancillary services e.g. reactive power to avoid congestion and frequency mismatches.
Demand side management and self-consumption	Demand side management in order to reshape load profiles so that there is better load matching with the supply. PV system integrated or grid level storage in order to load match within a 12-24 hour period of time	• Consideration of demand response at building level as a means of maximising self-consumption and minimising grid losses. • Measures to maximise self-consumption could comprise smart monitoring systems, the use of optimisers, smart appliances and battery storage.

System aspects in the use phase of solar photovoltaics

Stakeholder consultation points

3.5 Should the direct and indirect impacts be interpreted in any different way?
3.6 Should the scope of the direct impacts and the proposed derate factors be modified in anyway? *(see table 5, page 24)*
3.7 Do you agree with the product approaches as proposed to be addressed within the modelling of PV systems and components? *(see Table 16)*
3.8 Do you agree that a comparison of solar PV with other building technical systems that can deliver renewable energy of primary energy reductions, referred to as the 'functional approach', can be left out of the scope?
3.9 Should the scope of the indirect impacts be modified in anyway? *(see Table 17)*
3.10 For the purpose of PV system modelling 3-4 climate zones shall be defined and a location selected for each – which zones and locations would be the most representative? *(see table 6, page 29)*

3.5.3 End of life behaviour

An initial analysis has been made of actual user requirements regarding end of life aspects for PV systems. However due to the long life time of PV modules (>20 years) and inverters (>10 years), reliable and representative data for these tasks is not yet readily available. The limited evidence found today on user requirements, choices and behaviour might therefore be anecdotal and not yet representative for 2030 and beyond.

3.5.3.1 Recycling and disposal practices and the collection rate

The dismantling of photovoltaic systems and modules is typically carried out by a trained professional. Due to the long life time end-of-life of PV modules (>20 years) and inverters, and the relatively low overall deployment of the technology in the EU, only limited dismantling, recycling and disposal have taken place so far. In the framework of WEEE Directive, EU countries are setting up PV module recycling take back schemes such as PV CYCLE.

Data and estimates for Europe that are provided for each Member State have been compiled in the Commission's new WEEE calculator tool. It estimates that 2500 tonnes of solar module waste (Si based) was generated in 2016 in the EU. Estimates are only available till 2020 and suggest that 5000 tonnes of solar module waste (Si-based) will arise in 2020.

3.5.3.2 Module and inverter technical lifetime, degradation and failure mechanisms

The following key aspects of a solar PV system technical lifetime have been analysed in order to derive initial assumptions which can be used for modelling purposes. These largely focus on mechanisms that can lead to a decrease in yield or performance, or else a complete loss of function that cannot in all cases be recovered by repair or replacement:

- *Name plate module lifetime and degradation rates:* An annual degradation rate (power loss) of 0.5 – 0.6% in performance appears to be achievable in the short term, which would allow a module to still provide 80% of its initial yield after at least 25-30 years.
- *Life expectancy as a function of failure rate:* For modules and inverters this is taken to represent the theoretical technical lifetime of these components, as a catastrophic failure would mean that the module or inverter stops functioning and/or cannot be installed or operated safely.
  - *Module technical lifetime*: Major causes of failure are linked to the junction box and cabling, glass breakage and cell and interconnection damage. Failures can also occur during shipment, installation and operation. The means of protection against mechanical stress during transport is an important factor. A damage rate of 5% per annum has been identified. Other potential performance testing aspects are referenced in the main body of the report.
  - *Inverter technical lifetime*: Inverters have shorter life times (5-20 years) and are comparable to other electronic products. The very limited number of independent reviews of inverter failure rates suggest 1%-15% yearly failure rate. These are related to their electronic component reliability, and mainly include the DC bus capacitors, IGBT power module solder joint life time, the main DC contactor (if any) and cooling fans (if any). The potential downtime is important to consider, with reports citing an average of 20 days/year downtime for string inverters and 3 days/year for central inverters. In this context the focus has been on Design for Serviceability (DFS) to reduce the "Mean Time To Repair".
- *Additional system components failure*: In a PV system the clamps, railings, cabling, and increasingly trackers should be considered. Trackers in particular may be subject to failure due to their mechanical nature.

3.5.3.3 Repair, refurbishment and second hand use of PV systems

When considering life time it is also important to look at the potential for repair and refurbishment, possibly leading to extension of the first service life or a second-hand service life. Upon maturity of the PV industry, in some EU Member States with a large PV deployment (such as Germany) several companies are now offering services for the repair and re-powering of PV modules. The following type of damage can typically be repaired:

- faulty bypass diodes and connectors,
- punctured backsheets,
- damaged frames.

The 'healing' of PV modules affected by Potential Induced Degradation (PID) is also offered by some companies. The most common failures that cannot be repaired are cited as being linked to damaged cell connections, delamination of the encapsulant and glass breakage to cite. Most repair companies provide a 2 year warranty on their repair work. Beyond repair or replacement of the damaged PV modules, adjusting the PV system design and eventually re-cabling of the PV string is necessary for optimal performance.

In general inverter repair in the field appears to be less common, with faulty inverters mostly replaced. In order not to invalidate the (relatively expensive) inverter warranty only the inverter providers or a company commissioned by them is allowed to intervene for repair.

End of life behaviour

Stakeholder consultation points

3.11 Does the analysis of technical lifetime, degradation and failure reflect current feedback from the field?
3.12 Does the analysis of technical lifetime, degradation and failure reflect current assumptions used in business cases?
3.13 Are there any other aspects of performance that should also be addressed? If yes, please cite your supporting evidence.
3.14 To what extent are these repair practices and services available 1) in other Member States, 2) available to consumer PV system owners?

Requests for information and case studies

- Further examples of repair, remanufacturing and repowering practices and companies are requested.

References

4-noks. (2018). Solar Photovoltaic. Retrieved from https://www.4-noks.com/product-categories/solar-photovoltaic-en/?lang=en

Abbasi, M., Monazzam, M. R., Akbarzadeh, A., Zakerian, S. A., & Ebrahimi, M. H. (2015). Impact of wind turbine sound on general health, sleep disturbance and annoyance of workers: a pilot- study in Manjil wind farm, Iran. *Journal of Environmental Health Science and Engineering*, *13*(1), 71. https://doi.org/10.1186/s40201-015-0225-8

ACCIONA, NOBATEK, C. (2016). *European regulatory framework for BIPV*.

Adhikari, R. S., Aste, N., Pero, C. D., & Manfren, M. (2012). Net Zero Energy Buildings: Expense or Investment? *Energy Procedia*, *14*, 1331–1336. https://doi.org/10.1016/j.egypro.2011.12.1097

Attia, S. (Ed.). (2018). *Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmap for Project Analysis and Implementation*. Butterworth-Heinemann.

BVES, & BSW Solar. (2017). *Effizienzleitfaden für PV-Speichersysteme*.

Carlsson, J., Fortes, M. del M. P., Marco, G. de, Giuntoli, J., Jakubcionis, M., Jäger-Waldau, A., … Weidner, E. (2014). *ETRI 2014 - Energy Technology Reference Indicator projections for 2010-2050. JRC Science and Policy Reports*. https://doi.org/10.2790/057687

D'Agostino, D., & Parker, D. (2018). A framework for the cost-optimal design of nearly zero energy buildings (NZEBs) in representative climates across Europe. *Energy*, *149*, 814–829. https://doi.org/10.1016/j.energy.2018.02.020

Doyle, C., Truitt, A., Inda, D., Lawrence, R., Lockhart, R., & Golden, M. (2015). *Best Practices in PV System Installation*. Retrieved from http://www.nrel.gov/docs/fy15osti/63234.pdf

Dufo-López, R., & Bernal-Agustín, J. L. (2015). A comparative assessment of net metering and net billing policies. Study cases for Spain. *Energy*, *84*, 684–694. https://doi.org/10.1016/j.energy.2015.03.031

Dunlop, S., & Roesch, A. (2016). D4.4 EU-wide Solar PV Buiness Models. Guidelines for implementation, (646554).

Ecofys. (2016). Prices and Costs of EU Energy.

Frantzis, L., Graham, S., Katofsky, R., & Sawyer, H. (2008). *Photovoltaics Business Models*.

Fthenakis, V. M., Frischknecht, R., Raugei, M., Kim, H. C., Alsema, E., Held, M., & de Wild Scholten, M. (2011). *Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity*. *Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity* (Vol. IEA PVPS T). https://doi.org/IEA-PVPS-TASK 12

GfK Belgium Consortium. (2017). *Study on "Residential Prosumers in the European Energy Union" - JUST/2015/CONS/FW/C006/0127*. Retrieved from https://ec.europa.eu/commission/sites/beta-political/files/study-residential-prosumers-energy-union_en.pdf

Global Capital Finance, & Clean Energy Pipeline. (2014). *The European Renewable Energy Investor Landscape*.

Golnas, A. (2013). PV System Reliability: An Operator's Perspective. *IEEE Journal of Photovoltaics*, *3*(1), 416–421. https://doi.org/10.1109/JPHOTOV.2012.2215015

Huawei. (2018). FusionHome Smart Energy Solution. Retrieved from http://solar.huawei.com/eu/Residential

Huisman, J., Leroy, P., Tertre, F., Söderman, M. L., Chancerel, P., Cassard, D., … Emmerich, J. (2017). *Prospecting Secondary Raw Materials in the Urban Mine and mining wastes (ProSUM) - Final Report, ISBN: 978-92-808-9060-0 (print), 978-92-808-9061-7 (electronic), December 21*. Brussels.

Huld, T., Gottschalg, R., Beyer, H. G., & Topič, M. (2010). Mapping the performance of PV modules, effects of module type and data averaging. *Solar Energy*, *84*(2), 324–338. https://doi.org/10.1016/j.solener.2009.12.002

Huld, T., Waldau, a J., Ossenbrink, H., Szabo, S., Dunlop, E., & Taylor, N. (2014). *Cost Maps for Unsubsidised Photovoltaic Electricity. European Commission.*

IEA-PVPS, R. (2017). *Guideline to Introducing Quality Renewable Energy Technician Training Programs Guideline to*

Introducing Quality Renewable Energy.

IEA PVPS. (2017a). *Technical Assumptions Used in PV Financial Models. Review of Current Practices and Recommendations*. Retrieved from http://www.iea-pvps.org/index.php?id=426

IEA PVPS. (2017b). *Trends 2017 in Photovoltaic Applications - Report IEA PVPS T1-32:2017*.

IRENA. (2012). Renewable Energy Technologies: Cost Analysis Series. Solar Photovoltaics, (4).

Jordan, D. C., Silverman, T. J., Wohlgemuth, J. H., Kurtz, S. R., & VanSant, K. T. (2017). Photovoltaic failure and degradation modes. *Progress in Photovoltaics: Research and Applications*, *25*(4), 318–326. https://doi.org/10.1002/pip.2866

Komoto, K., & Lee, J.-S. (2018). *End-of-Life Management of Photovoltaic. Panels : Trends in PV Module Recycling Technologies. Report IEA-PVPS T12-10:2018*.

Köntges, M., Kurtz, S., Packard, C. E., Jahn, U., Berger, K., Kato, K., … Van Iseghem, M. (2014). *Review of Failures of Photovoltaic Modules*. *IEA-Photovoltaic Power Systems Programme*. https://doi.org/978-3-906042-16-9

Köntges, M., Siebert, M., Morlier, A., Illing, R., Bessing, N., & Wegert, F. (2016). *Impact of transportation on silicon wafer-based photovoltaic modules*. *Progress in Photovoltaics: Research and Applications* (Vol. 24). https://doi.org/10.1002/pip.2768

Kraftwerk. (2013). *Case Study : Photovoltaic for commercial The path to more independence*.

Kröger-Vodde, A., Armbruster, A., Hadek, V., Heydenreich, W., & Kiefer, K. (2010). Distributed vs. Central Inverters - A Comparison of Monitored PV Systems.

La Monaca, S., & Ryan, L. (2017). Solar PV where the sun doesn't shine: Estimating the economic impacts of support schemes for residential PV with detailed net demand profiling. *Energy Policy*, *108*(December 2016), 731–741. https://doi.org/10.1016/j.enpol.2017.05.052

Labastida, R. R. (2017). The Battle for the End Consumer: Residential PV and Battery Business Model Innovations in Germany. Retrieved from https://www.navigantresearch.com/blog/the-battle-for-the-end-consumer-residential-pv-and-battery-business-model-innovations-in-germany

Luque, A., & Hegedus, S. (Eds.). (2012). *Handbook of Photovoltaic Science and Engineering*. John Wiley & Sons, Ltd.

Luthander, R., Lingfors, D., Munkhammar, J., & Widén, J. (2015). Self-consumption enhancement of residential photovoltaics with battery storage and electric vehicles in communities. *Proc. of Eceee Summer Study on Energy Efficiency*, 991–1002.

Make the most of your solar panels - Which? (n.d.). Retrieved from https://www.which.co.uk/reviews/solar-panels/article/best-solar-panel-brands/make-the-most-of-your-solar-panels

Meisel, A., Mayer, A., Beyene, S., Hewlett, J., Maxwell, K. N., Coleman, N., … Mayo, E. (2016). Photovoltaic Modules with 35 Year Useful Life, 1–22.

Meydbray, J., & Dross, F. (2017). *PV Module Reliability Scorecard Report 2017*. *Dnv Gl*. Retrieved from https://www.dnvgl.com/publications/pv-module-reliability-scorecard-2017-93448

Mora, D., Kitzing, L., Soysal, E. R., Steinhilber, S., del Río, P., Wigand, F., … Woodman, B. (2017). *Auctions for renewable energy support - Taming the beast of competitive bidding Final report of the AURES Project. Report D9.2*. Retrieved from http://auresproject.eu/sites/aures.eu/files/media/documents/aures-finalreport.pdf

Moser, D., Del Buono, M., Bresciani, W., Veronese, E., Jahn, U., Herz, M., … Richter, M. (2016). Technical risks in PV projects. *Solar Bankability Project*, *1*, 1–109. Retrieved from http://www.solarbankability.org/results/technical-risks.html

Panasonic. (2018). Aquarea + PV PANELS.

Pena-Bello, A., Burer, M., Patel, M. K., & Parra, D. (2017). Optimizing PV and grid charging in combined applications to improve the profitability of residential batteries. *Journal of Energy Storage*, *13*, 58–72. https://doi.org/10.1016/j.est.2017.06.002

PVTRIN. (2013). *Training of photovoltaic installers in Europe: The PVTRIN training and certification scheme*. Retrieved from https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/final_report_pvtrin_en.pdf

R2M, Onyx Solar, Flisom, BEAR-iD, & Acciona. (2016). *PVSITES: BIPV market and stakeholder analysis and needs*.

Rasker, E. (2017). Belgian BIPV-Workshop. REYNAERS.

REMODECE. (2008). Retrieved from http://remodece.isr.uc.pt/

REnnovates. (n.d.). Retrieved from http://www.rennovates.eu/

Salom, J., Marszal, A. J., Candanedo, J., Widén, J., Lindberg, K. B., & Sartori, I. (2013). *Analysis of Load Match and Grid Interaction Indicators in Net Zero Energy Buildings with High - Resolution Data*.

Service Public Wallonie. (2015). contrattypeversion311decembre2015. Service Public Wallonie.

Stolz, P., & Frischknecht, R. (2017). *Life Cycle Assessment of Photovoltaic Module Recycling*. Retrieved from http://www.iea-pvps.org/index.php?id=275

Test-Achats/Test-Aankoop. (2015). Zonnepan e elen, (september), 62–66.

Test-Achats/Test-Aankoop, DECO, Altroconsumo, OCU, Consumentenbond, ICRT, … APERe. (2015). Clear - Consumers Learn Engage Adopt Renewable Energy Technologies. Retrieved March 20, 2018, from http://www.clear-project.eu/home/the-project/reports

Tichelen, P. Van, Ectors, D., Stevens, M., Chung, L. W., & Peeters, K. (2015). *Preparatory Studies for Product Group in the Ecodesign Working Plan 2012-2014 : Lot 8 - Power Cables Task 1 -7 report*. Retrieved from www.erp4cables.net

Tichelen, P. Van, Peeters, E., Goovaerts, L., Stevens, M., Geerken, T., Vercalsteren, A., … Faninger, T. (2011). *LOT 2: Distribution and power transformers. Tasks 1 – 7*. Retrieved from https://transformers.vito.be/sites/transformers.vito.be/files/attachments/EuP_TransformersTask_1_7_V60.pdf

Tsoutsos, T., Tournaki, S., Gkouskos, Z., Masson, G., Holden, J., Huidobro, A., … Charalambous, A. (2013). Training and certification of PV installers in Europe. A transnational need for PV industry's competitive growth. *Energy Policy*, *55*, 593–601. https://doi.org/10.1016/j.enpol.2012.12.048

Weckend, S., Wade, A., & Heath, G. (2016). *End-of-life management - Solar photovoltaic panels*. Retrieved from http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

Yordanov, G. H., Smolders, F., Olaerts, A., Verbeek, G., Baert, K., & Driesen, J. (2017). A 368-kWp Grid-connected PV System : Known and Hidden Losses. In *EU PVSEC Programme Planner* (pp. 1909–1914). Amsterdam.

Zanetti, I., Bonomo, P., Frontini, F., Saretta, E., van den Donker, M., Vossen, F., & Folkerts, W. (2017). BIPV Status Report 2017, 76. Retrieved from https://www.seac.cc/wp-content/uploads/2017/11/171102_SUPSI_BIPV.pdf

List of abbreviations and definitions

BAPV	Building attached photovoltaics
BAT	Best available technology
BAU	Business as usual
BIPV	Building integrated photovoltaics
BOS	Balance of System
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
CPC	Contract performance clauses
Derate factors	Factors that quantify individual sources of loss with respect to the nameplate's DC power rating
DRcapture	Factor representing combined array capture losses
DRshading	Factor representing shading losses
DRsnow	Factor representing snow cover losses
SL	Factor representing soiling losses
DRarraywr	Factor representing DC array cable losses
DRMISM	Factor representing array mismatch losses
DRrefl	Factor representing optical reflection losses
DRcap-mod	Factor representing other module level capture losses
DRtherm	Factor representing module thermal capture loss
DRdegrad	Factor representing module degradation capture loss
DRrefl	Factor representing optical reflection losses
Drspect	Factor representing spectral effects
DRBOS	Factor representing balance of system (BOS) efficiency
DRacwire	Factor representing AC wiring losses
Drtrafo	Factor representing AC transformer losses (if available)
DRcurt	Factor representing losses due to network availability (curtailment)
DRinv-fail	Factor representing losses due to inverter failures (drop out)
DRinv	Factor representing inverter losses (= DRinv-ns x ninv)
DRinv-ns	Factor representing derating non standard inverter total
DRinv-load	Factor representing derating non standard inverter loading
DRinv-MPPT	Factor representing derating non standard MPPT transients
nt-inv	Factor representing total inverter efficiency standard conditions
nconv	Factor representing static inverter converter efficiency
DFS	Design for Serviceability
DN	Distribution network
DHW	Domestic hot water

Diffuse radiation	Solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or particulates in the atmosphere
Direct sunlight	Also called "beam radiation" or "direct beam radiation". Used to describe solar radiation traveling on a straight line from the sun down to the surface of the earth
DRM	Demand response management
EoL	End of Life
EPBD	Energy Performance of Buildings Directive
EPC	Companies that are prepared to provide services linked to the Engineering, Procurement and Construction disciplines of a project
ErPs	Energy-related Products
ESCO	Energy service company
FiT	Feed-in tariff
GEC	Green energy certificates
GHG	Greenhouse gas
GIS	Geographic information systems
GPP	Green public procurement
GWP	Global-warming potential
HSW	Hot sanitary water
HVAC	Heating, ventilation, and air conditioning
IEA	International energy agency
IEC	International electrotechnical commission
IGBT	Insulated-gate bipolar transistor
IPP	Independent power producer
LCA	Life cycle analysis
LCC	Life cycle cost
LCOE	Levelized Cost of Electricity: net present value of the unit-cost of electricity over the lifetime of a generating asset allowing the comparison of different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, different capital cost, risk, return, and capacities
MEErP	Methodology for the Ecodesign of Energy-related Products
MFI	Monetary financial institutions
MPP	Maximum power point
MPPT	Maximum power point tracking
NZEB	Nearly zero energy buildings
PHS	Pumped hydro storage
PPA	Power purchase agreement
RES auction	Procurement auction, acting as a RES support allocation instrument, and in which power or energy are offered up for bidding
SRI	Smart readiness indicator
STC	Standard test conditions

TFPV	Thin film PV
TN	Transmission network
VAT	Value added tax
WACC	Weighted Average Cost of Capital
WEEE	Waste Electrical and Electronic Equipment

XX-NA-xxxxx-EN-N

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:xx.xxxx/xxxx

ISBN xxx-xx-xx-xxxxx-x