IEA INTERNATIONAL ENERGY AGENCY

REVIEW AND ANALYSIS OF PV SELF-CONSUMPTION POLICIES

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

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Report IEA-PVPS T1-28:2016

COVER IMAGE
The Red Oak Park a neighborhood in Boulder
CO features renewable energy design
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WHAT IS THE IEA PVPS?

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organisation for Economic Cooperation and Development (OECD). The IEA carries out a comprehensive programme of energy cooperation among its 29 members and with the participation of the European Commission. The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the collaborative research and development agreements within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems."

In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct "Tasks", that may be research projects or activity areas. This report has been prepared under Task 1, which facilitates the exchange and dissemination of information arising from the overall IEA PVPS Programme. The participating countries are Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Thailand, Turkey and the United States of America. The European Commission, Solar Power Europe (former EPIA), the Solar Electric Power Association, the Solar Energy Industries Association and the Copper Alliance are also members.

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IEA PVPS TASK 1

REVIEW AND ANALYSIS OF PV SELF-CONSUMPTION POLICIES

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1 INTRODUCTION TO SELF-CONSUMPTION ANALYSIS

This report aims at providing a comparative analysis of existing mechanisms supporting the self-consumption of electricity in key countries all over the world and to highlight the challenges and opportunities associated to their developments.

Mechanisms promoting self-consumption of PV electricity are based on the idea that PV electricity will be used first for local consumption and that all this electricity should not be injected into the grid. The part of the bill that can be compensated depends on several options that are used vary, depending on countries or regions, as we will see below.

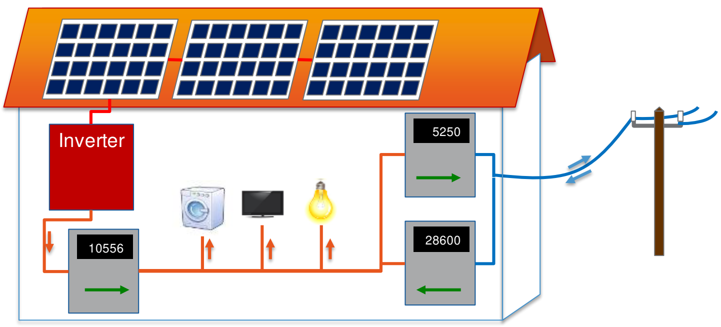
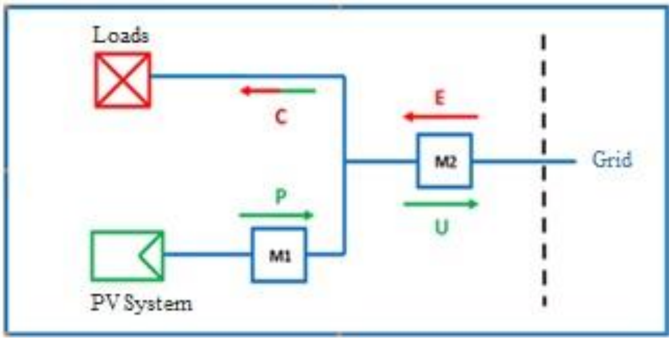


Figure 1. Example of self-consumption energy flows

We will refer to this mechanism of energy consumption in real-time (or per 15 minutes) as a "self-consumption scheme". An incentive scheme that allows compensating production and consumption during a larger timeframe (up to one year or more) is called "net-metering scheme". In case, where the compensation can be calculated on a cash-flow basis, rather than an energy basis, we will refer to it as a "net-billing scheme". Hence, some hybrid programmes exist between these two main schemes.

One of the heated debates in the market is about to identify whether compensation can apply not only to the procurement price of electricity but also to grid costs and taxes. This paper provides detailed explanation on how to classify these schemes and what their characteristics are.



The aim of this document is to define the range of existing business models that can support PV self-consumption, highlighting the difference between categories and their impacts on profitability from various perspectives.

Figure 2. Example of self-consumption metering

PROSUMERS

The neologism "prosumer" refers to an electricity consumer producing electricity to support his/her own consumption (and possibly for injection into the grid). The word is built based on the association of "producer" and "consumer" and it is used widely nowadays. In this document, the concept of "prosumer" will be used in parallel with "PV system owner" to qualify the same thing.

SELF-CONSUMPTION AND SELF-SUFFICIENCY

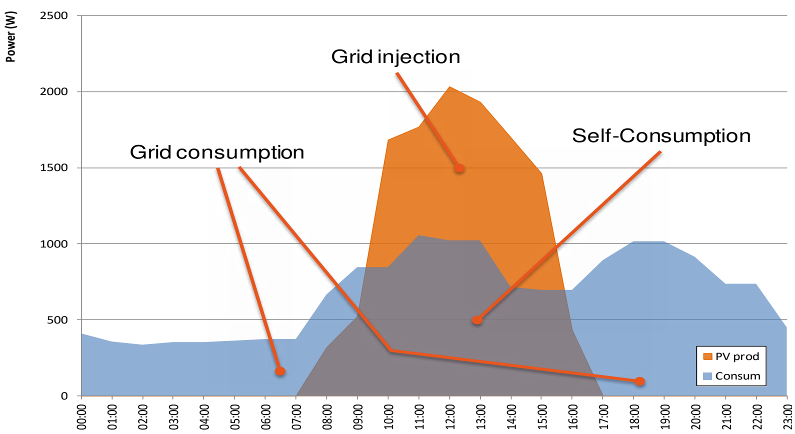


Figure 3. Comparison of production and consumption profiles

Self-consumption should not be confused with self-sufficiency. The ratio of self-consumption describes the local (or remote under some schemes) use of PV electricity while the self-sufficiency ratio describes how PV production can cover the needs of the place where it is installed. These concepts are completely different but both play important roles in the debate on the development of prosumers.

The chapter on the economy of self-consumption will go into details about current main constraints linked to the production of PV electricity for local use. Hence, in this study, the self-sufficiency ratio will not be the focus since it has little to do with this issue.

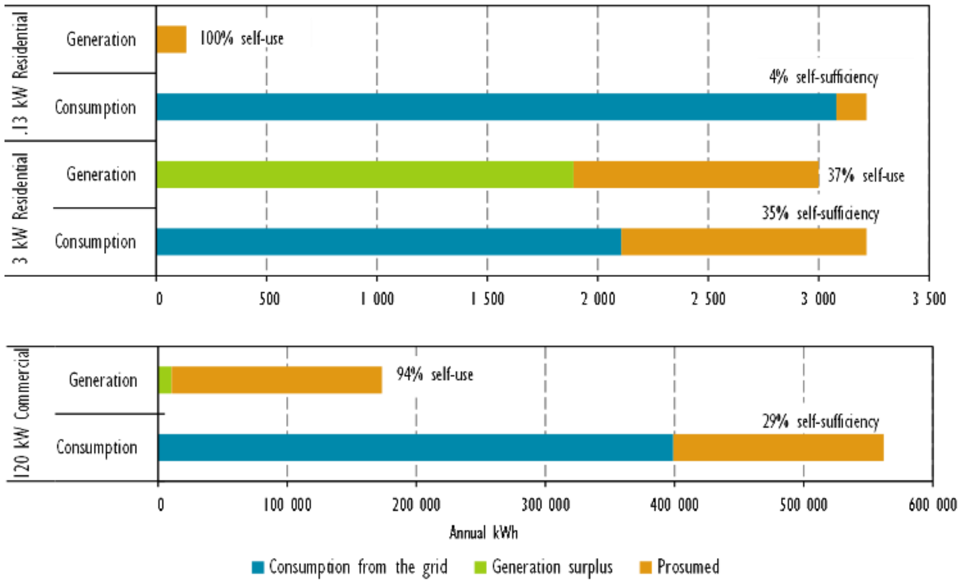


Figure 4. Self-consumption and self-sufficiency (source: IEA)

A 17.2 kW PV system on the roof offsets some of the power of the Cambria Office Building / NREL

2 CATEGORIES OF SELF-CONSUMPTION SCHEMES

Self-consumption can be described as the local use of PV electricity in order to reduce the buying of electricity from other producers. In practice, self-consumption ratios can vary from a few percent to a theoretical maximum of 100%, depending on the PV system size and the local load profile.

Onsite Self-Consumption	Right to self-consume	• Self-consumption is legally permitted
	Revenues for self-consumed PV electricity	• Savings on the variable price of electricity from the grid
	Charges to finance T&D costs	• Additional costs associated to self-consumption such as fees or taxes may exist
Excess PV Electricity	Value of excess electricity	• Net metering: energetic compensation (credit in kWh) • Net billing: monetary compensation (credit in monetary unit)
	Maximum timeframe for compensation	• Self-consumption: real time (e.g 15 minutes) • Net metering and net billing: time frame is typically one year although there are some exceptions (from credits that can be rolled over to the following billing cycle to quarterly compensation)

Key:
- Same between shemes (red)
- Main differences (dark blue)

Table 1. Self-consumption's main characteristics

Given the diversity of policies allowing for self-consumption that are being implemented worldwide, in order to classify all self-consumption schemes, several parameters have been chosen, covering all aspects of self-consuming PV electricity. These parameters aim at categorizing all kinds of policies supporting self-consumption and to clarify the wording used in several countries, especially net-metering and net-billing schemes. The table below provides detailed information about parameters and gives a comparison of existing schemes in various countries.

PV Self-consumption	**1**	Right to self-consume
	2	Revenues from self-consumed PV
	3	Charges to finance T&D
Excess PV electricity	**4**	Revenues from excess electricity
	5	Maximum timeframe for compensation
	6	Geographical compensation
Other system characteristics	**7**	Regulatory scheme duration
	8	Third party ownership accepted
	9	Grid codes and additional taxes/fees
	10	Other enablers of self-consumption
	11	PV System Size Limitations
	12	Electricity System Limitations
	13	Additional features

Table 2. Main parameters defining a self-consumption scheme

1 - Right to self-consume

This parameters identifies whether the electricity consumer has the legal right to connect a PV system to the grid and self-consume a part of its PV-generated electricity.

2 - Revenues from self-consumed PV electricity

This parameter is based on the source of revenue from each kWh of self-consumed PV electricity. It comprises not only the savings on the electricity bill but also possible additional revenues such as a self-consumption bonus/premium or green certificates.

3 - Charges to finance grid (Distribution and Transmission) costs

This parameter indicates whether the PV system owner has to pay part of the total grid costs on the self-consumed electricity.

4 - Value of excess electricity

This parameter explains which compensation PV system owner will receive when PV electricity is injected into the grid. Examples include:

- The same value as the retail electricity price or a value based on the retail electricity price but reduced through specific fees or taxes. This is the precise definition of "net-metering" with or without additional fees or taxes. Technically, this is often described as an allowance of credits that can be used during a predefined period of time to reduce the electricity bill of the PV system owner.
- Payment through traditional support schemes such as feed-in tariff (FiT) or green certificates (GC): PV electricity gets a value defined by regulation.

- Wholesale market price through some regulated or market tariff: PV gets the price of electricity when it is injected (or an average value).
- No value (it is lost).

5 - Maximum timeframe for credit compensation

This parameter refers to schemes that allow credits for all electricity injected. Such credits can in general be used during a certain period of time during which compensation is permitted. (e.g., real-time/15 minutes, credits during: a day, a month, a year, or indefinitely).

6 - Geographical compensation

This parameter indicates whether consumption and generation can be compensated in different locations. (e.g. "Virtual net-Metering", "Meter Aggregation", and "Peer to Peer").

7 – Regulatory scheme duration

This parameter, if available, indicates the duration of the compensation scheme in term of years.

8 - Third-party ownership

This parameter indicates whether policies are permitting a third-party to own the generation asset when a self-consumption scheme is in place (e.g., through structures such as leases and PPAs).

9 - Grid codes and additional taxes/fees of self-consumption

This parameter describes which additional costs have to be borne by PV system owners

- Undifferentiated costs (e.g. self-consumption fee)
- Specific costs (e.g. balancing costs, back-up costs…)

and which specific grid codes can be asked specifically to prosumers (e.g. grid code requirements such as phase balancing, frequency-based power reduction, reactive power control, voltage dips, inverter reconnection conditions, output power control, among others).

10 - Other enablers of self-consumption

Are there other additional supports to self-consumption such as a storage bonus, demand side management, or electricity rates with TOU/tiers?

11 – System Size Limitations

This parameter states which segments are considered by the compensation scheme and if applicable which capacity limit is applied (kW - MW). For instance, self-consumption can be allowed in the range of 5 to 250 kW only.

12 – Electricity System Limitations

This parameter explains whether the regulator has foreseen a maximum penetration of PV above which the self-consumption regulation does not apply anymore. For instance: above 2% of the electricity demand or above 10% of the minimum peak load.

13 – Additional characteristics

This last parameter includes all other elements not considered above. For example, rules for aggregation of renewable energy sources would be described here in case they are required when selling PV electricity on electricity market.

The above parameters will be used in the following sections to analyse the current situation in key markets and to define the most common range of self-consumption incentives.

The Red Oak Park a neighborhood in Boulder, CO features renewable energy design / NREL

3 SELF-CONSUMPTION IN DIFFERENT REGULATORY ENVIRONMENTS

After defining the set of parameters which will be used to classify different self-consumption schemes, this chapter will practically apply these parameters to describe the current state of self-consumption in 19 different countries. These countries have been selected from the IEA PVPS participating countries, as well as some additional countries presenting interesting self-consumption features.

3.1 AUSTRALIA (IEA PVPS)

- The right to self-consume is guaranteed.
- Australia has implemented self-consumption with a payment for the excess electricity. The existing scheme is rather successful and has contributed to maintain PV installations at a high level even after the end of the FiT.
- In most states/territories, the level of the FiT is much lower than the offset electricity.
- NSW and QLD: **Voluntary** FiT (much lower than the price of electricity from the grid) .
- VIC/SA/WA/TAS/ACT: **Mandatory** FiT or **Minimum** FiT (much lower than the price of electricity from the grid).
- NT: **Mandatory** FiT (similar to the price of electricity from the grid).
- These FiTs are revised annually.
- Transport and Distribution (T&D) grid costs: Disadvantageous change in tariff structure might be triggered due to addition of PV on commercial sites in South Australia.
- Additional grid codes have been implemented in some states/territories (QLD for instance): Multi-function relay are often required for non-residential systems to control and prevent export of excess electricity. Western Australia usually avoids DC-injection in commercial PV, and ramp-rate control in diesel mini-grid.

- Moreover, residential PV systems can receive subsidies through the Commonwealth Small-scale Renewable Energy Scheme to reduce the initial capital investment of the PV system via small-scale technology certificates (STC) which can be sold to electricity retailers.

			Australia
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	Tariff structure changes in some states
Excess PV electricity	**4**	Revenues from excess electricity	Feed-in Tariff
	5	Maximum timeframe for compensation	30 Minutes
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	Unlimited but FiT are revised annually.
	8	Third party ownership accepted	Yes (e.g. Solar Leasing)
	9	Grid codes and additional taxes/fees	Yes (Injection control / ramp-rate control / no DC-injection)
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	None
	12	Electricity System Limitations	None (except additional grid codes)
	13	Additional features	None

Table 3. Australia's self-consumption schemes

3.2 BELGIUM (IEA PVPS)

- Self-consumption is allowed.
- In Belgium (Brussels, Flanders and Wallonia), electricity consumers can benefit from a net-metering scheme.
- In Flanders and Wallonia, systems below 10 kW are eligible for net-metering (1 year compensation).
- Despites the net-metering scheme, the PV market in Belgium has decreased significantly with the fading-out of green certificates. It can be assumed that the transition was negatively perceived by the potential prosumers even though the conditions are profitable in some market segments and regions.
- Retroactive capacity-based grid fees have been implemented in Flanders and could be applied in other regions for net-metered installations.
- Self-consumption is allowed for all types of systems in the Brussels region while in Wallonia and Flanders, it is applied only for system above 10 kW.
- Excess PV electricity is remunerated through PPA. The PV system owner has to find a counterpart willing to buy the electricity at market price.
- Green certificates can be paid additionally for all PV production, in Brussels and Wallonia.

			Belgium residential (VL, WA)	**Belgium Commercial /Industrial all segments**
PV Self-consumption	**1**	Right to self-consume	Yes	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill
	3	Charges to finance T&D	Capacity based fee (Flanders), under discussion (other regions)	None
Excess PV electricity	**4**	Revenues from excess electricity	Retail Electricity Prices	Only if a PPA is signed. Otherwise = 0.
	5	Maximum timeframe for compensation	One year	None
	6	Geographical compensation	On site only	None
Other system characteristics	**7**	Regulatory scheme duration	Unlimited	Unlimited
	8	Third party ownership accepted	Yes	Yes
	9	Grid codes and additional taxes/fees	Capacity based fee (Flanders), under discussion (other regions)	None
	10	Other enablers of self-consumption	ToU Tariffs	ToU Tariffs
	11	PV System Size Limitations	Up to 10 kW	Above 10 kW
	12	Electricity System Limitations	None	None
	13	Additional features	Green Certificates for the PV production	Green Certificates for the PV production

Table 4. Belgium's self-consumption schemes

3.3 BRAZIL (non IEA PVPS)

A net-metering regulation (Sistema de Compensação de Energia), proposed by ANEEL, for renewable energy systems up to 1 MWp is in place since January 2013 ; with the following main characteristics:

- Users will only pay for the difference between the energy consumed and the one fed to the grid.
- Compensation will be held within the same rate period (peak - peak / off-peak - off-peak).
- Energy surpluses can be compensated during a 36-month period or in other consumption units (other buildings) as long as they belong to the same owner and are located within the geographical scope of the utility (virtual net-metering).

Apart from net metering, the relatively recent introduction of some financing options (e.g. renting) will also drive the market.

			Brazil
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	Retail Electricity Prices
	5	Maximum timeframe for compensation	3 Years
	6	Geographical compensation	On site and virtual net-metering
Other system characteristics	**7**	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	ToU Tariffs
	11	PV System Size Limitations	1 MW
	12	Electricity System Limitations	None
	13	Additional features	None

Table 5. Brazil's self-consumption schemes

3.4 CANADA (IEA PVPS)

- Self-consumption is allowed
- Across Canada, there are different incentive schemes for PV in place, varying by jurisdiction.
- The province of Ontario has had a feed-in tariff (FIT) since 2009. The province is currently transitioning from the FIT-approach to a self-consumption/ net-metering (SC/NM) program for small systems with price decrease and competitive tendering of PPAs for larger systems as two key elements of this transition.
- Most other Canadian jurisdiction currently has some form of net-metering or net-billing.
- Some federal tax incentives and a variety of utility and municipal supports are also available.

			Canada
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	Ontario: retail price (net-metering) - other systems depending on the jurisdiction
	5	Maximum timeframe for compensation	Ontario: 1 year - other systems depending on the jurisdiction
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	Yes
	10	Other enablers of self-consumption	ToU Tariffs
	11	PV System Size Limitations	Vary from jurisdiction to jurisdiction
	12	Electricity System Limitations	None
	13	Additional features	In Ontario, choice between FIT and Self-Consumption

Table 6. Canada's self-consumption schemes

3.5 CHILE (non IEA PVPS)

In March 2012 a net-billing regulation for PV installations up to 100 kW was approved (Law 20.571).

- PV electricity surpluses will be valued at an economical rate (lower than the retail electricity price) and used for later electricity consumption or, if this is not possible, the self-consumer will get the monetary value from the electricity companies.

Moreover, a potential increase of retail rates will likely improve the economics of self-consumption, both for the residential and for the commercial segment.

			Chile
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	Lower value than the retail price of electricity
	5	Maximum timeframe for compensation	1 year
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	100 kW
	12	Electricity System Limitations	None
	13	Additional features	None

Table 7. Chile's self-consumption schemes

3.6 CHINA (IEA PVPS)

- Self-consumption is allowed in China.
- Incentives have been existed since 2012 and were revised in September 2014 in order to boost the development of distributed PV in China.
- Self-consumed electricity gets a bonus (0.42 CNY/kWh) on top of the saved retail price. PV system owners can choose whether they want to use the FiT policy or opt for self-consumption with the bonus.
- Excess PV electricity injected into the grid is remunerated at wholesale price of electricity (based on coal-fired power plants' electricity prices) plus a bonus on top of it (0.42 CNY/kWh).
- This scheme has contributed to foster self-consumption as the amount consumers receive for the energy surplus fed into the grid is lower than the retail electricity price, i.e. lower than the savings from self-consumption.
- In 2014, the regulations have simplified the development of distributed PV, through easier registration, grid connection and financing procedure but the PV market is still largely dominated by large-scale installations.

			China
PV Self-consumption	1	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill + bonus
	3	Charges to finance T&D	None
Excess PV electricity	4	Revenues from excess electricity	Market price + bonus
	5	Maximum timeframe for compensation	Real-time
	6	Geographical compensation	On site only
Other system characteristics	7	Regulatory scheme duration	20 years
	8	Third party ownership accepted	None
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	20 MW - 35kV
	12	Electricity System Limitations	7 GW for distributed PV installations in 2015
	13	Additional features	None

Table 8. China's self-consumption schemes

3.7 DENMARK (IEA PVPS)

- Self-consumption is allowed.
- Before November 2012, Denmark had a full net-metering scheme for systems up to 6 kW. This was a very successful scheme as it enabled self-consumers to compensate the energy surplus throughout one year.
- In order to avoid losing tax revenue, the government decided to abolish the net-metering scheme and set an aggressive cap on total installed capacity by 2020 at 800 MW.
- The previous system was then replaced by a net-metering regulation but with energy compensation on an hourly basis only.
    - The excess generation is bought by the utility at a price that is significantly lower than the price of electricity from the grid.
    - Some 80 MW can receive a tariff of 1.03 DKK/kWh for 10 years, probably reduced.
    - Outside of these 80 MW, a reduced tariff (0.6 DKK/kWh paid for 10 years and 0.4 DKK/kWh for the 10 following years) is paid for the excess electricity. After 20 years, the tariff paid will be equal to the spot market price.

			Denmark
PV Self-consumption	1	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	4	Revenues from excess electricity	Retail price (1 hour net-metering) and above 1 hour: Lower value than the retail price of electricity
	5	Maximum timeframe for compensation	1 Hour
	6	Geographical compensation	On site only
Other system characteristics	7	Regulatory scheme duration	20 years
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	Yes (grid codes requirements)
	10	Other enablers of self-consumption	ToU Tariffs
	11	PV System Size Limitations	6kW(AC) for the high tariff
	12	Electricity System Limitations	800 MW (high tariff)
	13	Additional features	None

Table 9. Denmark's self-consumption schemes

3.8 FINLAND (IEA PVPS)

- Self-consumption is allowed.
- Finland uses a very simple self-consumption system without self-consumption incentives. The competitiveness gap is compensated with tax credits and similar incentives.
- For companies and organisations, it is possible to apply 30 % investment subsidy of the total costs of grid-connected PV projects.
- For agriculture it is possible to apply investment subsidy is 35 % of the total investment. However, only the portion of investment used in agricultural production is taken into account.
- Individual persons are able to get a tax credit for the installation work of the PV system. The sum is 45% of the total work cost including taxes. The maximum tax credit for a person is 2400 €/year. The tax credit is subtracted directly from amount of taxes that have to be paid.
- The on-site production has an exemption of electricity tax below 100 kVA or the yearly energy generation is less than 800 kWh/y.

			Finland
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	Retail electricity price (typically Finnish SPOT electricity price)
	5	Maximum timeframe for compensation	Real-time, hourly net-metering is under discussion
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	Grid code for PV plant
	10	Other enablers of self-consumption	No
	11	PV System Size Limitations	When S<100 kVA or Ea< 800 kWh/a, exemption of electricity tax
	12	Electricity System Limitations	No
	13	Additional features	No

Table 10. Finland's self-consumption schemes

3.9 FRANCE (IEA PVPS)

- Self-consumption is allowed in France.
- Due to low retail electricity price, the PV installations remain dominated by driven feed-in tariff rather than self-consumption measures.
- In case of self-consumption, PV systems can receive a feed-in tariff that compensates for the excess electricity fed into the grid.
- Given the price of retail electricity, self-consumption is not used and PV electricity is sold almost entirely through the feed-in tariffs.
- In order to be ready for the competitiveness in PV installation, it is proposed to remunerate PV systems with self-consumption using tailored self-consumption incentive.
- Discussions are still on-going in order to increase the fixed part of grid costs and decrease the variable cost. This can decrease the attractiveness of self-consumption due to lowering the revenues associated with the electricity bill. Nevertheless, this has not been implemented yet in Q1 2015.

			France
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	FiT (see detail)
	5	Maximum timeframe for compensation	Real-time
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	20 years (FiT)
	8	Third party ownership accepted	None
	9	Grid codes and additional taxes/fees	Possible move towards a higher share of fixed grid costs.
	10	Other enablers of self-consumption	ToU Tariffs
	11	PV System Size Limitations	None
	12	Electricity System Limitations	None
	13	Additional features	Projects to increase the fixed part of grid costs

Table 11. France's self-consumption schemes

3.10 GERMANY (IEA PVPS)

- In Germany, self-consumption is legally permitted under the Renewable Energy Act (EEG, acronym in German).
- Historically speaking, PV owners were encouraged to self-consume PV-generated electricity with a premium paid for each kWh of self-consumed PV electricity. This scheme was replaced by a simpler self-consumption scheme. The new incentive scheme contributes in driving a large part of the PV market.
- Excess PV electricity is paid either with a defined feed-in tariff or through the so-called "market integration model": a feed-in premium on top of electricity market prices.
- For installations between 10 kW and 1 MW, only 90% of the yearly-generated electricity is allowed to receive the tariff, which can be translated into a minimum requirement of 10% of self-consumption.
- Since 2014, the surcharge on the electricity bill that finances feed-in tariffs has to be paid for the self-consumed electricity from new PV systems. Installations below 10 kW are exempted while other installations have to pay 30% of the surcharge, increasing to 40% in 2017. The exemption is valid during 20 years, after which the full surcharge will have to be paid.
- Germany has introduced an energy storage incentive program that provides owners of systems up to 30 kW with a 30% rebate and low interest loans from KfW (German development bank).

			Germany
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	FiT or FiP
	5	Maximum timeframe for compensation	Real time
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	20 years (FiT)
	8	Third party ownership accepted	All
	9	Grid codes and additional taxes/fees	Grid codes compliance and partial EEG-surcharge
	10	Other enablers of self-consumption	Battery storage incentives
	11	PV System Size Limitations	Minimum 10% of self-consumption
	12	Electricity System Limitations	52 GW of PV installations
	13	Additional features	EEG levy must be paid anyway by the prosumer (above 10kW)

Table 12. Germany's self-consumption schemes

3.11 ISRAEL (IEA PVPS)

- Self-consumption is allowed in Israel.
- In 2013, a net-metering scheme was implemented for all RES. It established a cap of 200 MW for 2013 and the same for 2014. This was extended to 2015, and is expected to prolong into future, with some successes regarding to PV development.
- Real-time self-consumption simply reduces the electricity bill.
- Excess PV production can be fed into the grid in exchange for energy credits, which can be used to offset electricity consumption from the grid during the following 24 months. The credit is day-time dependent. Hence, a small overproduction at peak times can offset a large consumption at low times.
- All the electricity fed into the grid is subject to Grid and Services charges.
- Moreover, energy credits can be transferred to any other consumers as well as other locations of the same entity. One has the option to sell a pre-set amount of the electricity to the grid for money (not credits) at the conventional price (0,30 ILS/kWh). In which case, T&D charges shall be subtracted from the credits.
- A back-up fee aims at covering the need to back-up PV systems with conventional power plants. This fee is technology and size dependent. The fee will grow from 0,03 ILS/kWh when the installed capacity reaches 1,8 GW to double as of 0,06 ILS/kWh when 2,4 GW is installed.
- A balancing fee (0,015 ILS/kWh) for variable renewable sources has also been introduced.
- Finally, a grid fee that depends on the time of day, day of the week and connection time ranges from 0,01 and 0,05 ILS/kWh has also been used.

			Israel
PV Self-consumption	1	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	4	Revenues from excess electricity	Retail Electricity Prices (full net-metering)
	5	Maximum timeframe for compensation	2 years
	6	Geographical compensation	Credits can be transfered to other consumers (but without T&D costs)
Other system characteristics	7	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	System costs (see detail) - grid, back-up and balancing costs
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	5 MW
	12	Electricity System Limitations	No, but system costs are linked to PV penetration.
	13	Additional features	None

Table 13. Israel's self-consumption schemes

3.12 ITALY (IEA PVPS)

- Self-consumption is allowed for all PV system sizes.
- For systems below 200 kW (and even 500 kW for plants installed starting from 2015), Italy has switched in 2009 from a net-metering mechanism to the so-called "Scambio Sul Posto (SSP)". The SSP can be seen as a hybrid solution between a self-consumption system (real-time self-consumption) with some net-billing features (for the calculation of the "energy quota" and the "service quota"). After the end of the FiT law, net billing is the only scheme left. Above the 500 kW limit, a pure self-consumption scheme is used.
- In all cases, the electricity self-consumed reduces the energy injected into the grid (the self-consumed energy is never fed into the grid).
- With the SSP, the electricity fed into the grid is remunerated through an "energy quota" that is based on electricity market prices and a "service quota" that depends on the cost of grid services (transport, distribution, metering and other extra charges). Without SSP, the market prices apply for the electricity injected into the grid.
- Grid costs linked to self-consumed electricity are compensated for all plants under SSP scheme; for system bigger than 20 kW, a fee is added to the bill to compensate partially the saved grid costs.
- New rules have introduced the so-called "*Sistema Efficiente di Utenza*" (SEU), a system in which one or more power production plants operated by a single producer are connected through a private transmission line to a single end user located on the same site.

			Italy
PV Self-consumption	**1**	Right to self-consume	*Yes*
	2	Revenues from self-consumed PV	*Savings on the electricity bill*
	3	Charges to finance T&D	*Yes, above 20 kW*
Excess PV electricity	**4**	Revenues from excess electricity	*SSP, net-billing based on energy and services; market price for selling*
	5	Maximum timeframe for compensation	*Self consumption, real time; SSP, advance payment twice per year*
	6	Geographical compensation	*On site (meter aggregation is allowed for some specific SSP cases)*
Other System characteristics	**7**	Regulatory scheme duration	*Unlimited*
	8	Third party ownership accepted	*Yes, with conditions for SSP*
	9	Grid codes and additional taxes/fees	*None*
	10	Other enablers of self-consumption	*None*
	11	PV System Size Limitations	*Self-consumption, none (below 20 MW for SEU); SSP, up to 500 kW*
	12	Electricity System Limitations	*None*
	13	Additional features	*None*

Table 14. Italy's self-consumption schemes

3.13 JAPAN (IEA PVPS)

- Self-consumption is allowed in Japan.
- Below 10 kW, prosumers are allowed to self-consume part of their PV generation on site and receive a payment for the excess electricity fed into the grid through the FiT program (paid during 10 years). It can be assumed that self-consumption is not the major driver of the PV market.
- If fuel cells, storage batteries, or co-generation are used with the PV systems, a lower FiT level is applied.
- The tariff levels are currently above the retail price of electricity from the grid, therefore self-consumption is not being encouraged.
- PV systems above 10 kW can inject all the PV electricity generation into the grid in order to receive the FiT during 20 years but self-consumption is also allowed. The choice is then in the hands of the PV system owner. The level of price paid for excess electricity can be negotiated.

			Japan
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	FiT
	5	Maximum timeframe for compensation	Real-time (30 minutes)
	6	Geographical compensation	On site only
Other system characteristics	**7**	Regulatory scheme duration	10 years (FiT)
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	ToU tariffs / Storage and DSM incentives
	11	PV System Size Limitations	Below 10 kW
	12	Electricity System Limitations	None
	13	Additional features	None

Table 15. Japan's self-consumption schemes

3.14 MEXICO (IEA PVPS)

- In Mexico, a net-metering mechanism (Medición Neta) was created in June 2007 for renewable energy based systems under 500 kW.
  - It allows users to feed into the grid part of their electricity and to receive energy credits (in kWh) for it, used to offset their electricity bill.
- Furthermore, the National Fund for Energy Savings (FIDE, acronym in Spanish) finances PV systems for commercial and industrial consumers, with a 5 year repayment term, at lower interest rates than commercial banks do.
- In addition, companies can depreciate 100% of the capital investment on the first year and can benefit from a reduced rate for power transmission services.
- An increasing trend of retail tariffs and a possible stabilization of the Peso exchange rate could also drive the self-consumption market in the short term (in particular for DAC –high consumption- consumers).

			Mexico
PV Self-consumption	1	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	4	Revenues from excess electricity	Retail Electricity Prices (full net-metering)
	5	Maximum timeframe for compensation	1 year
	6	Geographical compensation	Virtual net-metering allowed
Other system characteristics	7	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes (leasing is possible)
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	500kW
	12	Electricity System Limitations	None
	13	Additional features	Additional Incentives Exist

Table 16. Mexico's self-consumption schemes

3.15 SPAIN (IEA PVPS)

- Self-consumption is allowed in Spain.
- The size of the PV plant cannot exceed the maximum power contracted.
- Two different regulations exists depending on the system size:
- Type 1: under 100 kW, self-consumption is allowed but the prosumer receives no compensation for the excess PV electricity injected into the grid.
- Type 2: Above 100 kW without limitation, self-consumption is allowed and the excess PV electricity can be sold on the wholesale market directly or through an intermediary. A specific grid tax of 0.5 EUR/MWh has to be paid together with a 7% tax on the electricity produced.
- All systems used for self-consumption above 10 kW are charged with a fee per KWh consumed. It is justified as a "grid backup toll" and is known as the so-called "Sun tax".
- At least two meters have to be installed, depending of the cases (LV or HV connection).
- Adding battery storage implies also an additional tax.
- Geographical compensation is not allowed, and self-consumption for several end customers or a community is not allowed.

			Spain	
			Below 100 kW	**Above 100 kW**
PV Self-Consumption	**1**	Right to Self-Consume	Yes	Yes
	2	Revenues from Self-Consumed PV	Savings on the electricity bill	Savings on the electricity bill
	3	Charges to Finance T&D	Yes ("solar tax")	Yes ("solar tax")
Excess PV Electricity	**4**	Revenues from excess electricity	None	Wholesale market price minus taxes
	5	Maximum timeframe for compensation	Real-time	Real-time
	6	Geographical compensation	None	None
Other system characteristics	**7**	Regulatory scheme duration	Unlimited	Unlimited
	8	Third party ownership accepted	None	Yes
	9	Grid codes and additional taxes/fees	Above 10 kW (*)	Yes (*)
	10	Other enablers of self-consumption	None	None
	11	PV system size limitation	100 kW but below or equal to capacity contracted	Below or equal to the capacity contracted
	12	Electricity system limitations	Distributor´s License	Distributor´s License
	13	Additional features	Taxes on batteries	Taxes on batteries

(*) except the Canary Islands, Baleares Islands, Ceuta and Melilla

Table 17. Spain's self-consumption schemes

3.16 SWEDEN (IEA PVPS)

- Self-consumption is allowed in Sweden under conditions.
- Net-metering has been discussed and investigated in Sweden since 2007. However, the latest investigation instead proposed a tax credit system for the excess electricity from micro producers which was implemented from the first of January 2015.
- The tax reduction works like a feed-in-tariff for the excess PV electricity fed into the grid, but the financial compensation is paid at the end of the year as a tax reduction. The tax reduction includes both individuals and businesses for buildings with a fuse of up to 100 amps. The tax credit is 0,60 SEK / kWh fed into the national grid and the maximum is 30 000 kWh.
- Furthermore, the self-consumption must be at least as large as the number of kWh the PV owner feed into the grid and get a tax credit for. On top of the tax credit the PV owner may also receive green electricity certificates and sell their surplus electricity to an electricity trading utility. Some utilities have offered different compensation schemes for the excess electricity, ranging from the spot-price, net-metering and up to 1,2 SEK/kWh.
- The continuous market development in Sweden can be at least partially associated with these regulations.

			Sweden	Sweden
PV Self-consumption	1	Right to self-consume	Yes	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill
	3	Charges to finance T&D	None	None
Excess PV electricity	4	Revenues from excess electricity	Various offers from utilities + 0,6 SEK/kWh + Green certificates	Wholesale electricity price
	5	Maximum timeframe for compensation	1 year	Real-time
	6	Geographical compensation	On site only	On site only
Other system characteristics	7	Regulatory scheme duration	Subject to annual revision	Unlimited
	8	Third party ownership accepted	Yes	Yes
	9	Grid codes and additional taxes/fees	Grid codes requirements and VAT registration	Grid codes requirements and VAT registration
	10	Other enablers of self-consumption	ToU Tariffs	ToU Tariffs
	11	PV System Size Limitations	Below 100 Amp. Maximum 30MWh/year for the tax credit.	Above 100 Amp
	12	Electricity System Limitations	None	None
	13	Additional features	None	None

Table 18. Sweden's self-consumption schemes

3.17 SWITZERLAND (IEA PVPS)

- Self-consumption has been allowed in Switzerland by law since April 1st 2014.
- PV generation and consumption from the grid are compensated in real-time, regardless of the PV system size.
- The excess PV electricity generation is bought by utilities at a price that is lower than the variable price of electricity, as it will only remunerate the energy cost.
- Provided that PV systems for self-consumption are promoted, pressure from DSO to tax self-consumption could increase, as most of grid costs are currently charged on a per kWh basis.
- Self-consumption for multi-family housing is allowed, but the regulation is not stabilized yet.
- In addition, systems up to 30 kW(DC) get direct subsidies from the FiT-fund (since April 1st 2014)
- Some (local) utilities still allow full net-metering and/or pay a higher tariff for excess energy than the minimum price fixed by law.
- The question of financing the grid is debated but no additional grid charges have been implemented for PV system owners so far.

			Switzerland
PV Self-consumption	1	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	4	Revenues from excess electricity	FiT (energy cost for the DSO minus ~8%)
	5	Maximum timeframe for compensation	Real-time
	6	Geographical compensation	Multi-family Housing
Other system characteristics	7	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	Specific grid codes
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	None
	12	Electricity System Limitations	None
	13	Additional features	Direct subsidies up to 30kW and some specific rules (see detail)

Table 19. Switzerland's self-consumption schemes

3.18 THE NETHERLANDS (IEA PVPS)

- Self-consumption is allowed in the Netherlands.
- In 2011, a net-metering scheme, with a balancing period of one year, was established for small residential consumers (3x80 Amp). That scheme was modified in 2014 and triggered a rapid market expansion.
- Prosumers could compensate a maximum excess PV generation of 5 MWh per year against electricity consumption from the grid but this rule was lifted in 2014.
- Above the net-metering limit, self-consumption is allowed but not incentivized.
- In case the excess PV electricity is higher than the consumption, the prosumer receives a smaller Feed-in Tariff. (7-9 c€/kWh for instance).

			The Netherlands
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	Retail Electricity Prices (full net-metering)
	5	Maximum timeframe for compensation	1 year
	6	Geographical compensation	Multi-family Housing / or through private line
Other system characteristics	**7**	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	Experimental ToU
	11	PV System Size Limitations	15 kW
	12	Electricity System Limitations	None
	13	Additional features	None

Table 20. The Netherlands' self-consumption schemes

3.19 UK (non IEA PVPS)

- Self-consumption is allowed.
- Self-consumption for small systems (<30 kW) is being encouraged through a generation tariff and an export tariff, applicable to the electricity fed into the grid.
- The prosumer gets the generation tariff for all PV generated electricity.
- Moreover, for the energy fed into the grid, the user also receives an export tariff (~5,5 c€/kWh).
- Since the total amount consumers receive for the energy fed to the grid is lower than the total revenues (or savings) from self-consumption, this scheme can be seen as an indirect incentive for self-consumption.
- In October 2015, the UK government announced a change in its self-consumption scheme with a major decrease of the generation tariff.

			UK
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill + Generation Tariff
	3	Charges to finance T&D	None
Excess PV electricity	**4**	Revenues from excess electricity	Generation tariff + Export Tariff
	5	Maximum timeframe for compensation	Real-time
	6	Geographical compensation	On-site
Other system characteristics	**7**	Regulatory scheme duration	20 years
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	None
	10	Other enablers of self-consumption	None
	11	PV System Size Limitations	30kW
	12	Electricity System Limitations	None
	13	Additional features	None

Table 21. The UK's self-consumption schemes

3.20 USA (IEA PVPS)

- In the USA, various regulatory policies for self-consumption have been implemented.
- The most popular scheme is net-metering, since 41 states have adopted it already (plus DC and 4 territories). Hence, the characteristics of each regulation differ from one to another (some States such as Arizona charge a monthly fixed fee, others allow utilities to charge a fixed month fee). The nature of the fee is determined by the utility rather than the state.
- A small number of cities or jurisdictions have adopted a remuneration of injected PV electricity that could be considered as a “FiT” or “Value of Solar” tariff. The value of these tariffs vary across jurisdiction and have compensated solar both above and below the retail rate. Certain states allow PV systems to sell directly into the wholesale market.
- On top of net-metering, other programs have offered generous cash rebates for solar installations. Simplified interconnection procedures and accelerated interconnection timelines exist for self-generation renewable energy systems in some jurisdictions. California allows virtual net-metering for certain utility customers and aggregation of customers (i.e. credits for exported excess electricity produced by a single system are distributed across more than one self-consumer within the generating unit). Other states offer credits (SRECS) for solar production. Generally these credits reward generation that is both consumed on sight or exported to the grid, and are traded in a market structure.
- ToU tariffs exist in several states.

			USA
PV Self-consumption	**1**	Right to self-consume	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill
	3	Charges to finance T&D	In specific states
Excess PV electricity	**4**	Revenues from excess electricity	Retail Electricity Prices (full net-metering)
	5	Maximum timeframe for compensation	Vary by state
	6	Compensation	On-Site
Other system characteristics	**7**	Regulatory scheme duration	Unlimited
	8	Third party ownership accepted	Yes
	9	Grid codes and additional taxes/fees	Vary by state. E.g. In Mass, NEM energy is calculated monthly with a mínimum bill. Arizona utilities have implemented fixed charges to account for grid costs
	10	Other enablers of self-consumption	ToU Tariffs in some states
	11	PV System Size Limitations	Yes, but depends on the state: from 10 kW to 10 MW (or no limit)
	12	Electricity System Limitations	In some states
	13	Additional features	Multiple other policies depending on the state or at federal level

Table 22. The USA’s self-consumption schemes

3.21 SUMMARY OF COUNTRY POSITIONING

In all 20 countries analysed, self-consumption is allowed one way or another but the regulations in place differ significantly.

1. Self-consumption is accepted everywhere, sometimes with an ad hoc legal framework, sometimes without. The very principle of self-consumption is always the same: the electricity that is produced by the PV system and locally consumed reduces mechanically the electricity bill of the consumer. But this reduction is not implemented in the same way in all countries.
2. It is generally accepted that variable grid costs on the part of electricity bill that is saved thanks to self-consumption should not be paid. Spain applies an additional tax that recovers a part of these grid costs. In a more general way, several countries have either modified the structure of the grid tariffs (to increase the fixed part and reduce the variable part linked to the consumption), such as some Australian grid operators, or are discussing it (France). In Belgium a grid tax will have to be paid in several regions to repay a part of saved grid costs (but since the net-metering allows full compensation of the PV consumption, these additional grid costs could be attributed only to the injected part).
3. The financial compensation for injecting excess PV electricity into the grid is extremely different from one country to another. Several trends exists:
    a. The excess PV electricity is not paid at all. This is the Spanish case. In that situation, it is considered that the PV electricity has no value on the market and prosumers are expected to self-consume all their production.
    b. The excess PV electricity gets a value linked to the wholesale electricity market price, in some cases with a bonus (or a penalty since trading on the market has a price). This is the case in China (with bonus), in the Brussels region in Belgium (most probably with a penalty), in Germany (for customers choosing the market integration, in that case, a bonus is paid), in Italy (with a bonus for grid services), in Sweden (with a bonus), in Switzerland (with a penalty), etc. The penalty refers in general to costs incurred by the trader to put the PV electricity on the market, while the bonus could be seen as a feed-in premium that incentivizes PV injection. In some cases, it is up to the PV system owner to find a counterparty that will trade the electricity on the market.
    c. The excess PV electricity gets a feed-in-tariff, between the wholesale and the retail price of electricity. This is the case in Denmark.
    d. The excess PV electricity gets the retail price of electricity (that is the usual definition of net-metering with credits). This is the case in Belgium (FL, WA), Brazil, some Canadian jurisdictions, Israel, Mexico, the Netherlands and several states in the USA.
    e. The excess PV electricity gets a higher value than the retail price of electricity: this is the case in the UK.
4. By definition, self-consumption occurs in real-time. For practical reasons, the “real-time” measure becomes a quarter of an hour. Above that threshold, the self-consumption in real-time becomes a compensation of the PV production and electricity consumption during a longer period of time. Denmark considers netting during one hour when the most common net-metering schemes are netting production and consumption

during one year. In several cases, the netting officially occurs during one month with credits transferable during one year, sometimes up to two years.

5. While most countries accept self-consumption or net-metering schemes for PV systems installed on the consumption sites, some specific cases exist in various parts of the world:
    a. Virtual net-metering between distant sites is a reality in Mexico or Brazil, under specific conditions of ownership.
    b. Multi-family housing implies to net production in one site with production split between several consumers. This has been implemented for instance in the Netherlands.
6. While the principles of self-consumption have no time limit, the excess PV electricity remuneration schemes can have a limit in time: feed-in tariffs are limited in time (China, Denmark, France, Germany…). After the 10 or 20 years, the question remains of the remuneration of the excess electricity.
7. In most countries, the ownership of the PV system could differ from the electricity consumer. This is a complex situation with national regulations and no clear pattern appears today with regard to third party ownership.
8. Two aspects have to be mentioned:
    a. Some countries impose specific grid codes to PV system owners who are self-consuming electricity. In Australia for instance, grid injection limits exists in some states. Denmark asks specific grid codes. Germany requires specific compliance with specific grid codes for all PV systems. Other countries have imposed specific grid codes as well.
    b. Specific grid taxes are starting to be implemented in some countries, with the aim to compensate for saved grid costs due to net-metering policies (in Belgium for instance). The Spanish grid tax is the only example of a specific tax for pure self-consumers. In Australia and France, the shift from variable to fixed grid costs is debated actively and could lead to a change in the electricity tariff structure that could be detrimental to PV development. In the USA, an intense debate on the cost of net-metering policies led to small grid costs increases for prosumers in some states.
    c. The case of Israel is more specific, with dedicated taxes for balancing and back-up.
9. Storage is incentivized in Germany but without a direct link to self-consumption. While it is not easy to identify whether Time of Use billing could be an asset or an issue for self-consumption, it exists in many countries where higher day prices could favour self-consumption.
10. In many countries, net-metering schemes are limited to small-scale residential PV applications. Self-consumption schemes are used in general without a limit size or with limits close or above the MW.
11. In most cases, PV systems are not envisaged within the electricity system as a whole. Few countries have defined limits for PV penetration that apply specifically to self-consumption. China defined annual targets for distributed PV; Denmark has defined a cap for incentivized net-metering policies; Germany has defined a cap for incentivizing PV development; Israel has defined specific limits that frame the additional system costs.

12. While until recently decentralized PV installations were remunerated automatically, the Brussels region in Belgium could implement a system that would force the prosumer to find a counterpart to sell this excess electricity. This quest for a PPA is rather new for prosumers and could see the establishment of energy aggregators.

Residence with PV panels; Gardner, Massachusetts / NREL

4 ECONOMIC ANALYSIS OF SELF-CONSUMPTION BUSINESS MODELS

This chapter aims at identifying the main business models associated with self-consumption and similar schemes. By comparing these business models with the classical tariffs applied for PV electricity fed into the grid, it shows how effective these business models could be in boosting PV market development and achieve a certain level of PV competitiveness. The details of these business models will be provided in the beginning part of this chapter while the latter will focus on the reality of the self-consumption ratios in different countries.

4.1 DESCRIPTION OF BUSINESS MODELS

Five business models have been identified and described below. There exist other alternative models but these five are believed to be representative and well-fitted with above case studies mentioned in the previous chapter.

			A Self-consumption with constraints	B Self-consumption with a FiT	C Net-billing	D Net-metering	E Self-consumption with premium
PV Self-consumption	1	Right to self-consume	Yes	Yes	Not compulsory	Yes	Yes
	2	Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill	Production revenue minus consumption costs	Savings on the electricity bill	Savings on the electricity bill + premium
	3	Charges to finance T&D	Yes	No	No	No	No
Excess PV electricity	4	Revenues from excess electricity	No remuneration	Feed-in Tariff	Feed-in tariff	Retail electricity prices	Feed-in Tariff
	5	Maximum timeframe for compensation	Real-time	Real-time	Could be > 1 year	Could be > 1 year	Real-time
	6	Geographical compensation	-	-	Could be virtual	Could be virtual	-
Other system characteristics	7	Regulatory scheme duration	Unlimited	Limited (e.g. 20 years for the FiT)	Could be limited	Unlimited	Limited (e.g. 20 years for the FiT)
	8	Third party ownership accepted	-	-	-	-	-
	9	Grid codes and additional taxes/fees	-	-	-	-	-
	10	Other enablers of self-consumption	-	-	-	-	-
	11	PV System Size Limitations	-	-	-	-	-
	12	Electricity System Limitations	-	-	-	-	-
	13	Additional features	-	-	-	-	-

Table 23. Summary of Self-consumption Business Models

These five business models cover:

A – Pure self-consumption with constraints

Self-consumption is allowed but the savings from the electricity bill are reduced by some additional fees or taxes. In addition, the electricity injected into the grid is not remunerated and thus lost for the prosumer. In order to be competitive, the PV system must produce electricity significantly below grid parity to compensate for the additional costs. Such business models will also promote local self-consumption through demand side management, storage and/or a decrease in system size.

B – Pure self-consumption with a feed-in tariff for the excess electricity

This situation is the classical definition of self-consumption, as implemented for instance in Germany (in some market segments). Self-consumed electricity allows savings on the electricity bill of the prosumer while excess PV electricity is bought at a predefined tariff. Such feed-in tariff can be fixed, or based on the average wholesale price of electricity thanks to aggregators.

C – Net-billing

While self-consumption assumes an energy netting (kWh produced are locally consumed and reduces the electricity bill naturally), net-billing assumes two different flows of energy that might have different prices associated with. The costs related to these two flows are netted to calculate the reduction for the prosumer electricity bill. In this business model, we will consider that the compensation for the excess electricity will be below the price of electricity. Grid-parity is considered to be reached.

D – Net-metering

Net-metering is the business case in which the excess PV electricity is remunerated at the same price of the wholesale price of electricity. Some countries have adopted net-metering systems where prosumers have to pay some additional grid charges or taxes but this will not be considered in this business model. Grid-parity is considered to be reached. In some countries, if this is not yet the case, an additional incentive can be paid on top of the net-metering system.

E – Pure self-consumption is the case in countries where grid parity has not been achieved yet.

In case grid parity has not been reached yet, self-consumption could be incentivized using two following ways: by awarding an incentive on top of the retail electricity price for part of electricity that is self-consumed or through a certain value for excess electricity injected into the grid, higher than the market price (possibly higher than the retail electricity price as well).

		Production based: classical "FiT" - style. No self-consumption	Self-consumption with constraints	Self-consumption + FiT	Net-billing	Net-metering	Self-consumption + Premium
1	Right to self-consume	Not Allowed	Yes	Yes	Yes	Yes	Yes
2	Revenues from self-consumed PV	N/A	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	N/A	No	No	No	No	Premium
3	Charges to finance T&D cost	N/A	Yes	No	No	No	No
4	Revenues from excess electricity	N/A	Zero	< retail price	<= retail price	= retail price	> retail price
5	Maximum timeframe for compensation	N/A	Real-time	Real-time	Long period	Long period	Real time

Table 24. Range of business models from the perspective of the prosumer

4.2 ECONOMIC ANALYSIS OF SELF-CONSUMPTION BUSINESS CASES

This section provides the analysis of the economic impact of different compensation methods. Each method is demonstrated in detail in the following graph with the aim to present readers a clear explanation regarding the cash flows associated with on-site PV self-consumption, excess PV generation and consumption from the grid.

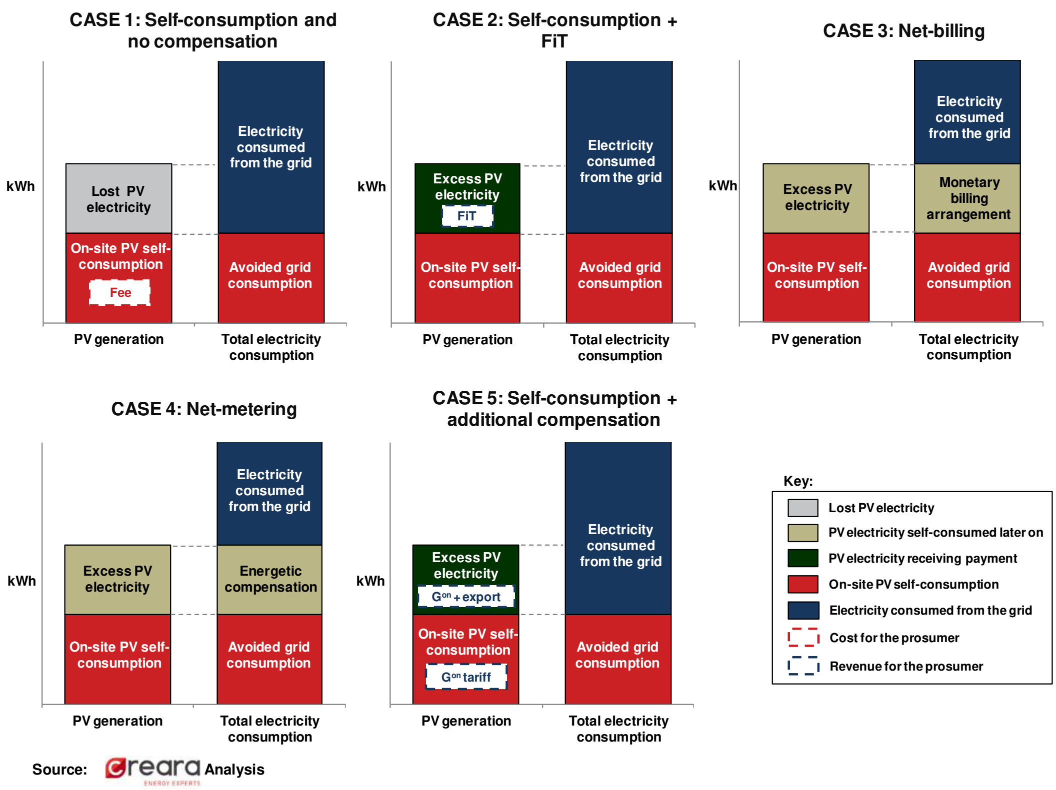


Figure 5. Illustration of annual PV generation and electricity consumption per Business Case

A financial model was created to estimate the economic impact in each case on the prosumer, the electricity market (including TSO, DSO and electricity consumers), and the government (as Tax Collector). The following figure summarizes the framework used:

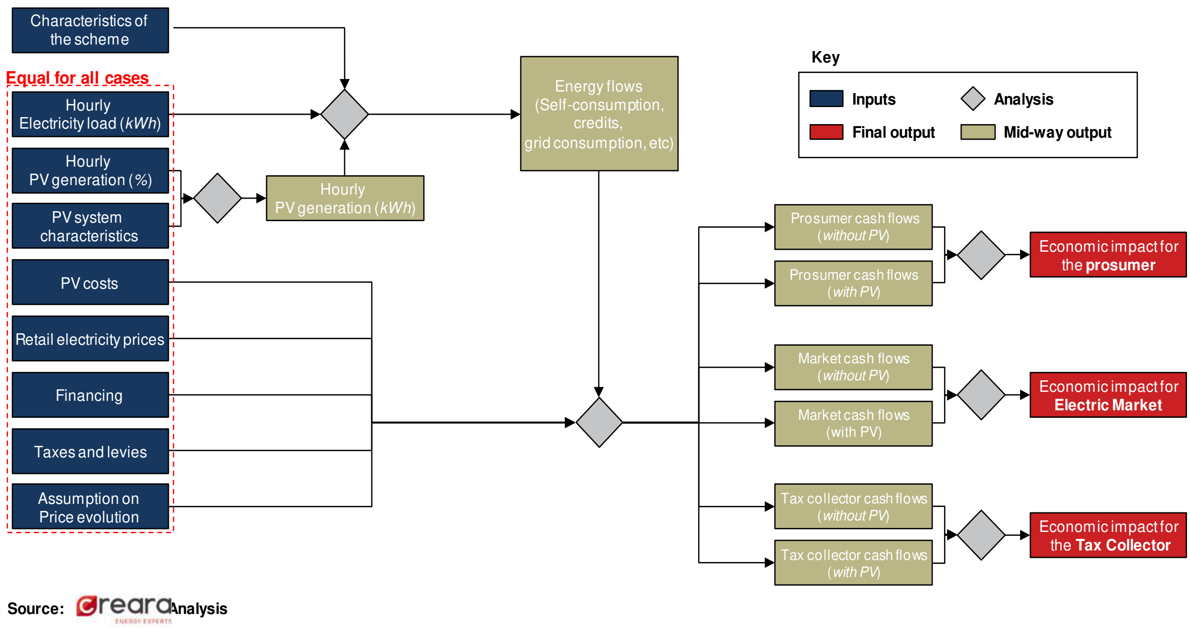


Figure 6. Framework of the analysis

4.2.1 PARAMETERS FOR THE REFERENCE CASES

All the cases are analysed **assuming identical economic and environmental conditions**, so as to **isolate the effect of the regulatory framework** for self-consumption on the economics of the stakeholders. This analysis focuses only on the **residential segment**, as it is the most constraining segment from a self-consumption perspective (low self-consumption ratio under nominal conditions, highest system costs). But commercial and industrial segments possess similar characteristics (the self-consumption ratios will be higher). In addition, only the most direct (and easily quantifiable) differential cash flow components associated with PV self-consumption are included in the economic analysis. It is assumed that the LCOE of PV is established below the retail price of electricity in the business cases A, B, C and D. In the case E, the LCOE of PV remains higher than the retail price of electricity and will require additional incentives to become competitive.

The following figure illustrates the main elements that are considered in the study and also present factors that are excluded from the analysis.

	Included in the analysis	Excluded from the analysis
Prosumer	(+) Savings from consumption of electricity from the grid (+) Revenues/Savings from PV electricity injected to the grid (if applicable) (-) Costs associated to the PV system (-) Taxes or fees on self-consumed PV (if applicable)	(+) Potential savings from reduced variable charges under tiered rates (if applicable) (+) Potential savings from reduced capacity charges (if applicable)
Electricity System Actors	(+) Fees over on-site self-consumption (if applicable) (-) Reduced revenues associated to self-consumed PV (-) Subsidies on PV generation (if applicable)	(+) Benefits such as avoided T&D investment, reliability benefits and energy cost reduction (-) Needed investments such as grid reinforcements (-) Increase in balancing costs
Public Authority	(+) VAT of PV investment (+) VAT of operating costs (+) Taxes over insurance cost (+) Corporate tax rate of installer (-) Taxes and levies over electricity	(+) Other benefits such as indirect tax collections resulting from increased revenues in other economic sectors (e.g. equipment manufacturers)

Key: (+) Positive impact; (-) Negative impact

Note: *The Electricity Market encloses generators, suppliers, TSO, DSO, regulators, and electricity consumers
Source: Creara Analysis

Figure 7. Cash flow components considered in the analysis

In order to assess the economic impact of different business models and compare the results, a realistic reference case has been created: a nominal power capacity of 3 kW located on the rooftop of a standard household with an annual electricity demand of 7,3 MWh located in an area with annual irradiation of 1 611 kWh/m^2 (Rome was used as reference). It is assumed that the prosumer will try to maximize savings by installing a relatively large PV system (as long as it remains a profitable decision) and to minimize the difference between PV generation and total electricity consumption, to avoid losing energy credits. In reality, the prosumer will adapt its investment decision to the regulatory environment.

The following figure shows the PV generation curve and household electricity load as well as the consumption ratios.

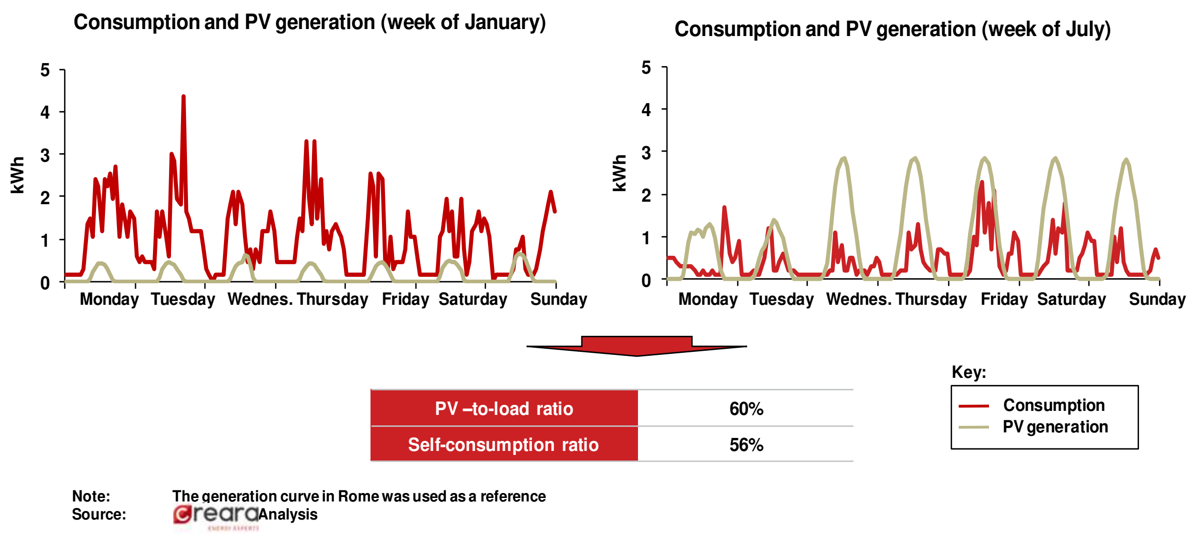


Figure 8. Generation curve and electricity load (winter and summer)

Structure of the variable component of the retail electricity tariff

It should be noted that the variable component of the electricity tariff is in many cases not only designed to cover variable costs (per kWh) but also fixed costs of the system (e.g. grid utilization charges). Therefore, the tariff structure is considered as an important determinant in relation with the level of revenue reduction in the Electricity Market as well as the savings of the prosumer.

Based on current practices, the below tariff structure is chosen to be used for our reference case.

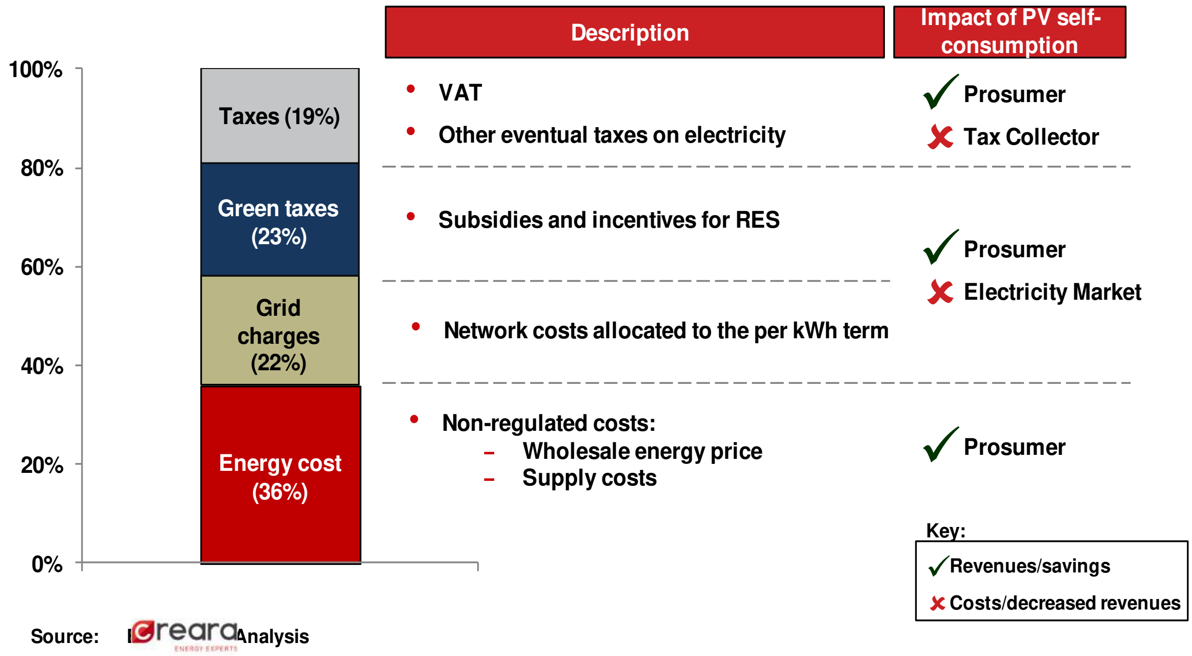


Figure 9. Segmentation of the variable components of the retail electricity tariff

Regarding to variable tariffs, the approach varies significantly among countries. In countries such as Germany, Spain, and The Netherlands, the weight of grid charges within the tariff is relatively similar to what is illustrated above. However, countries such as the United Kingdom present a lower weight of grid charges within the variable component of the tariff. This situation is evaluated through sensitivity analysis in the next section.

Parameters used for the calculation (not linked to a specific country)

Parameter	Unit	Value	Comments
Retail rate with taxes			
Peak	EUR/kWh	0,23	-
Off peak	EUR/kWh	0,19	-
Standard	EUR/kWh	0,22	-
Annual fee per meter	EUR	13,00	Meter charge (scenario without PV)
Estimated annual price increase of grid electricity	%	2%	Conservative estimate (the higher the price increase, the better the profitability of the investment for the prosumer)
Annual solar irradiation	kWh/m2/yr	1 611	
Performance Ratio (PR)	%	0.8	-
Size	kW	3	-
Turnkey cost	EUR/Wp	2	-
Annual degradation rate	%	0,5%	-
Lifetime of the investment	years	30	-
Operating costs	EUR/(kWp.yr)	20	Includes annual O&M and insurance costs (5 Currency Unit/kWp per year)
Tax on insurance	%	6%	Based on average market values
CPI	%	2%	It is assumed that operating costs grow according to the CPI
Inverter replacement	EUR/W	0,26	The inverter is replaced once during the lifetime of the PV system
Financing			
Leverage	%	50%	-
Interest rate	%	7%	A tenure of 10 years is assumed
Discount rate	%	7%/ 5%	Prosumer/ Tax Collector and Electricity Market
kWp/kW ratio	-	1,15	-
Installer margin	%	20%	-
Corporate tax rate	%	30%	-

Table 25. Parameters used in the analysis

The results of the analysis are based on **a specific set of assumptions** and only include the cash flow components as shown in table above. To the extent that these parameters tend to vary in reality, the actual results might be different from the one presented here. Therefore, it should be noted that these results cannot be generally applied to all other cases (instead, a case-by-case analysis is recommended).

4.2.2 IMPACT FOR THE PROSUMER

To assess the attractiveness of a PV investment from the prosumer point of view under five different business cases, the following metrics are used:

- **Net Present Value (NPV):** a positive (negative) NPV indicates that the project is profitable (unprofitable) and allows comparing between different cases.
- **Simple payback period:** under the same parameters, a project is more (less) attractive if the payback period is lower (higher) than a specific desired term[1].

The following figure shows the results for each business case:

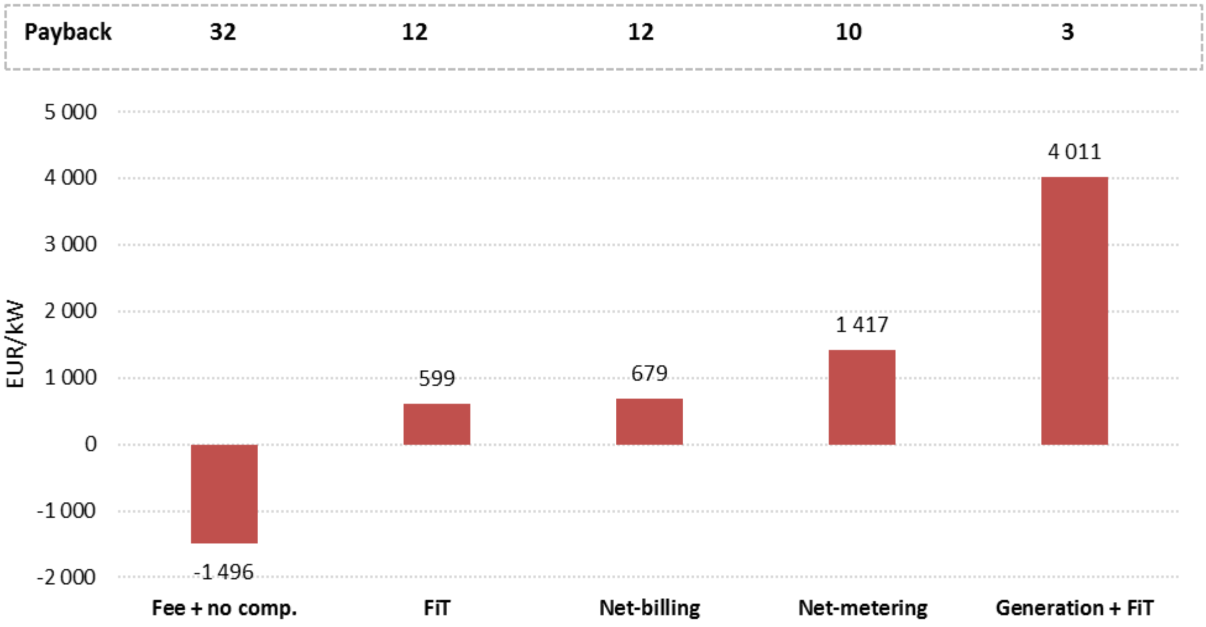


Figure 10. NPV per installed kW (30 years) for the prosumer per Business Case

The above results came out as expected due to the following reasons:

A. The "Self-consumption with constraints" Case: there is a charge on each kWh of PV on-site self-consumption and there is no compensation whatsoever for the excess PV electricity fed into the grid. The only saving the prosumer achieves is the part associated to the reduction of consumption from the grid, due to on-site PV self-consumption. However, such saving is not enough to compensate for the costs associated with the PV system and self-consumption, i.e. the fee. This case could become profitable with PV LCOE significantly below the retail price of electricity and a higher self-consumption ratio. In any case this situation is the least profitable. The same situation without additional fees to be paid would be less negative and would approach the case D with self-consumption ratios close to 100%.

[1] This indicator should be used only in conjunction with other metric.

B. The “Self-consumption with Feed-in Tariff” Case: for each kWh of PV on-site self-consumption, the prosumer saves on the full variable cost of electricity from the grid (plus taxes), and excess PV generation exported to the grid is valued at a price that is lower than the retail price of electricity. The economic viability depends on the LCOE of PV with regard to retail electricity prices and the level of the feed-in tariff for the excess PV electricity.
C. The “Net-billing” Case: since net-billing is about netting cash flows instead of netting energy flows, its profitability depends on the value given to the cash flows. It could be compared to the “FiT” case or the net-metering case from a profitability point of view. In general, the value associated with the excess PV electricity can be smaller than the retail price of electricity and some grid costs or taxes could be taken out of the netting process.
D. The “Net-metering” Case: for each kWh of PV on-site self-consumption, the prosumer saves on the full variable cost of electricity from the grid (including taxes), and excess PV generation exported to the grid is valued at a price that is equal to the retail price of electricity. In some cases, a part of the grid costs has to be paid anyway.
E. The “Self-consumption with premium” Case: This case corresponds to a situation where the LCOE of PV is still higher than the retail price of electricity. But self-consumption is incentivized by given a higher value to the self-consumed electricity. For each kWh of PV on-site self-consumption, the prosumer not only saves on the full variable cost of electricity from the grid (plus taxes) but also receives an additional payment (a generation tariff). Moreover, excess PV generation exported to the grid is valued at a price that is higher than the retail price of electricity.

Under the hypothesis considered here, the worst case (Fee + no compensation) is compared below to the best case (Generation + FiT) from the perspective of the prosumer, the annual cash flows under each scenario are illustrated below:

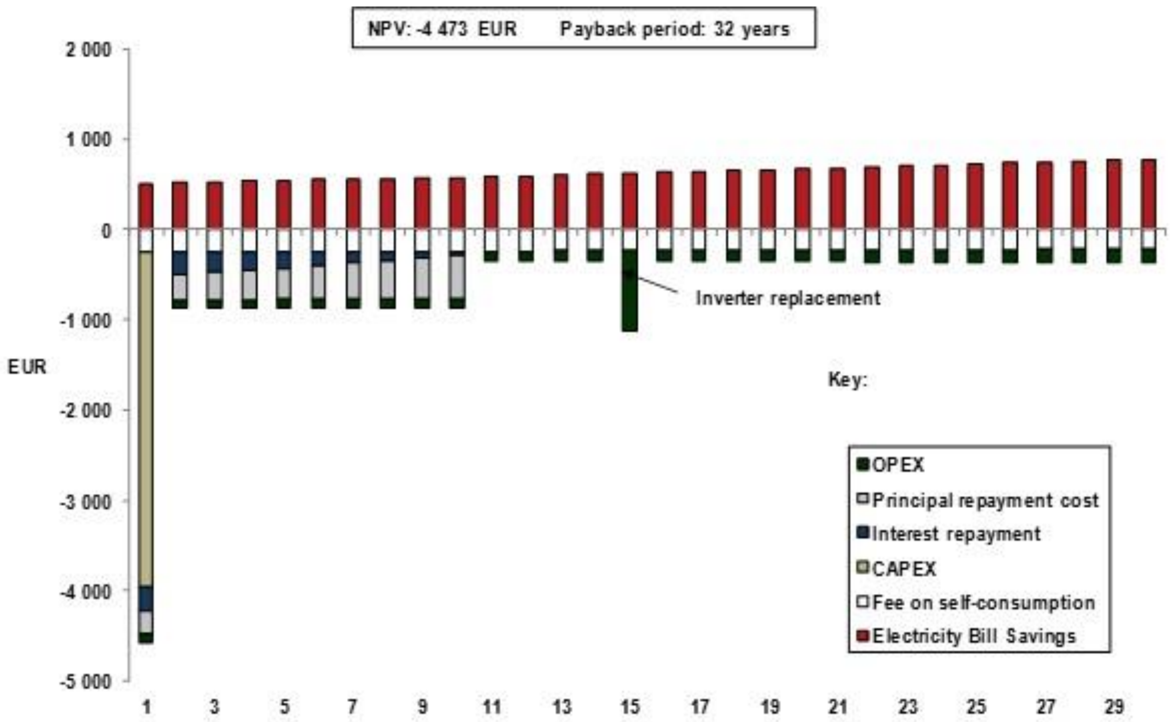


Figure 11. Annual cash flows for the prosumer under "Fee + no comp"

Under "Fee + no comp", apart from the general relevant cost flows from the perspective of the prosumers, a fee on on-site self-consumption (coloured in white in the Figure above) is also included, which has a negative impact on profitability.

In contrast, within "Generation + FiT", not only is there no such cost associated with on-site PV consumption, but there is a revenue associated with total PV generation, as well:

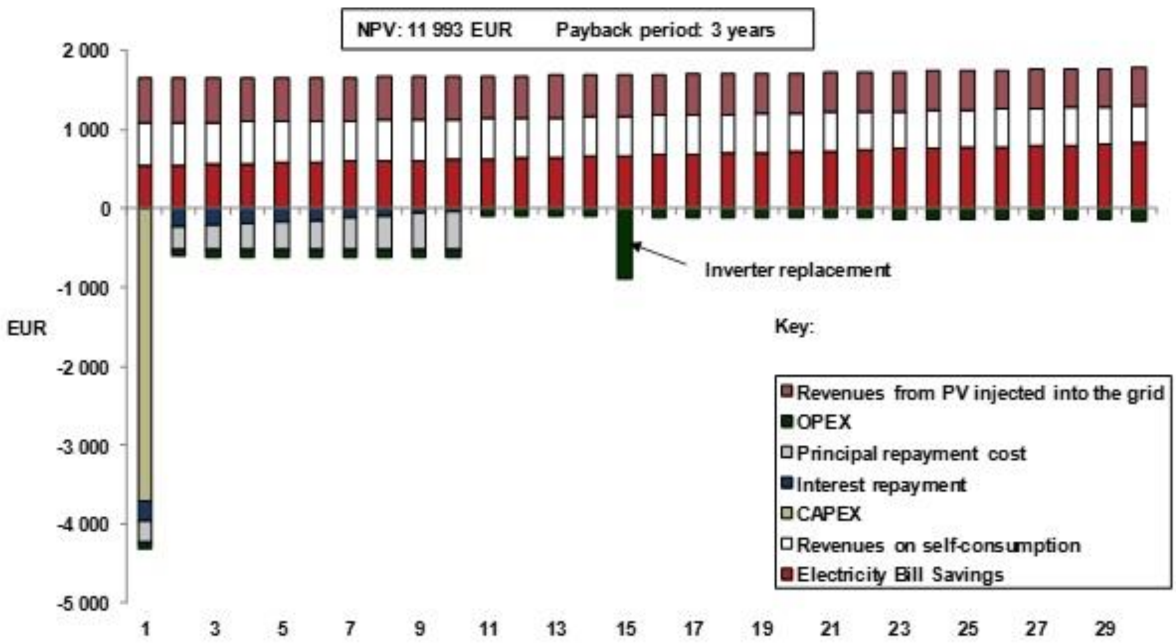


Figure 12. Annual cash flows for the prosumer under "Generation + FiT"

Under the specific assumptions made mainly about current costs of PV and retail rates, the following conclusions can be extracted:

- The more the LCOE of PV goes below the retail price of electricity, the more the target model of self-consumption and remuneration of excess PV electricity with wholesale market prices becomes a reality.
- Additional grid fees and taxes are shifting in time when self-consumption becomes competitive all other things being equal. This applies to taxes on top of net-metering schemes as well. Such fees and taxes imply it is required to keep higher level of the incentives to reach the same profitability.
- Additional remuneration on top of self-consumed electricity might be necessary before grid parity is reached.
- Net-metering should be considered as a normal self-consumption scheme where the value of injected PV electricity is simply equal to the retail price of electricity.
- In a self-consumption scheme, the variable to adjust profitability is the value of the excess PV electricity. This adjustment is therefore not possible for net-metering schemes unless additional fees and taxes are imposed.

4.2.3 IMPACT ON THE ELECTRICITY SYSTEM ACTORS

Self-consumption mechanisms are by definition reducing the electricity bill and therefore, under current conditions, the revenues from several actors linked to the electricity system. This revenues decline comes from two origins that have the same source: first prosumers consume less electricity produced by utilities, which reduces de facto their turnover. But in addition, by reducing the volume of electricity produces, prosumer indirectly impact the prices on the wholesale markets: this effect that will not be studied here is often mentioned as the Duck curve, since it transforms the wholesale prices during the day in a curve with a low mid-day price and a high evening price. This effect reduces also the revenues of utilities since the lower demand implies lower wholesale prices at times where utilities are selling electricity on the market. The positive effects from the integration of several percentages of PV generation into the distribution grid are not considered here.

The same five business cases have been analysed with that perspective and the results are presented below.

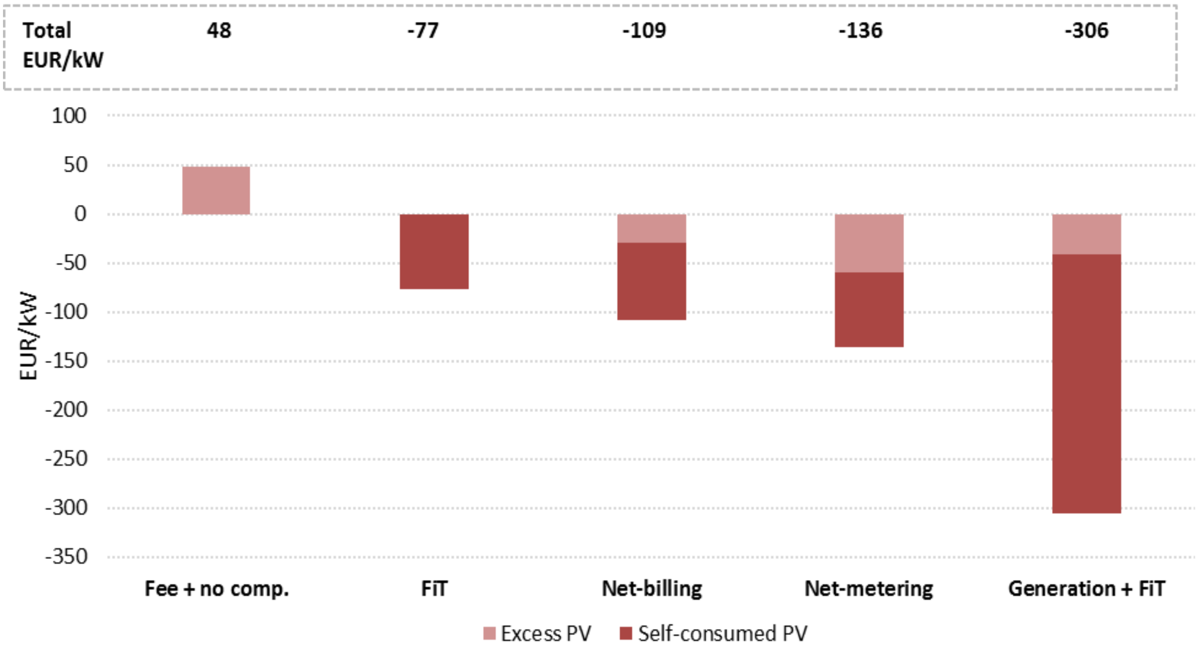


Figure 13. Annual impact per installed kW for the Electricity Market per Business Case

The main results are as follows:

- The “A” case “self-consumption with constraints” yields a positive annual impact for the electricity stakeholders. As there is no compensation for the PV excess fed into the grid, the electricity market actors receive it for free. In addition, the fee compensates at least partially for the losses related to the self-consumed part and grid costs continued at least partially to be covered.
- The “B” case “self-consumption with FiT”, the negative impact results solely from the decreased revenues associated with on-site self-consumption: losses for the utilities and the grid operators are coming from the reduced revenues associated to self-produced and consumed electricity.
- “Net-billing” and “Net-metering” include an additional negative impact, which accounts for the remuneration granted to the consumer for the excess generation.
- Finally, the Electricity Market is most affected in “self-consumption with premium” case as a generation tariff is paid for each kWh of PV generation, and an additional export tariff is given for every kWh of PV injected into the grid.

4.2.4 IMPACT FOR THE PUBLIC AUTHORITY INCOME (TAXES)

From the perspective of the public authority, several taxes can be collected that are linked to the production and consumption of electricity. Different taxes should be considered: taxes on electricity consumption or similar taxes; but also VAT on the CAPEX investment (residential PV systems), the corporate income tax for the installer company, OPEX related taxes, etc.

During the year of the PV system installation, the taxes collected will raise significantly while the taxes linked to electricity consumption will be reduced later during the lifetime of the PV plant.

The cash flow components that have an impact on the revenues of the Tax Collector differ under each case as follows:

		A Fee+ no comp	B FiT	C Net-billing	D Net-metering	E Generation + FiT
+	VAT of PV investment	✓	✓	✓	✓	✓
+	Corporate tax rate of installer	✓	✓	✓	✓	✓
+	VAT of operating costs	✓	✓	✓	✓	✓
+	Taxes over insurance cost	✓	✓	✓	✓	✓
+	VAT from fee on self-consumption	✓	✗	✗	✗	✗
-	Taxes from on-site self-consumption	✓	✓	✓	✓	✓
-	Taxes from compensated PV electricity	✗	✗	✓	✓*	✗
-	VAT from meter rent	✓	✓	✓	✓	✓

Key: + Positive impact; - Negative impact; ✓ Has an impact; ✗ Has no impact

Note: * Under Net-Metering the impact is higher than under Net-Billing, as in the former the prosumer saves on 100% of the taxes associated to compensated electricity, whereas under the later the prosumer saves on part of the taxes

Source: Creara Analysis

Figure 14. Impacting elements on the Tax Collector for each Case

These results of the analysis are illustrated in the following figure[2] by comparing the best and worst case for the Tax Collector:

[2] Cases "FiT" and "Generation + FiT" are practically identical from the view point of the Tax Collector. Cases "Fee + no comp." and "Net-metering" represent extreme results, so only these have been illustrated.

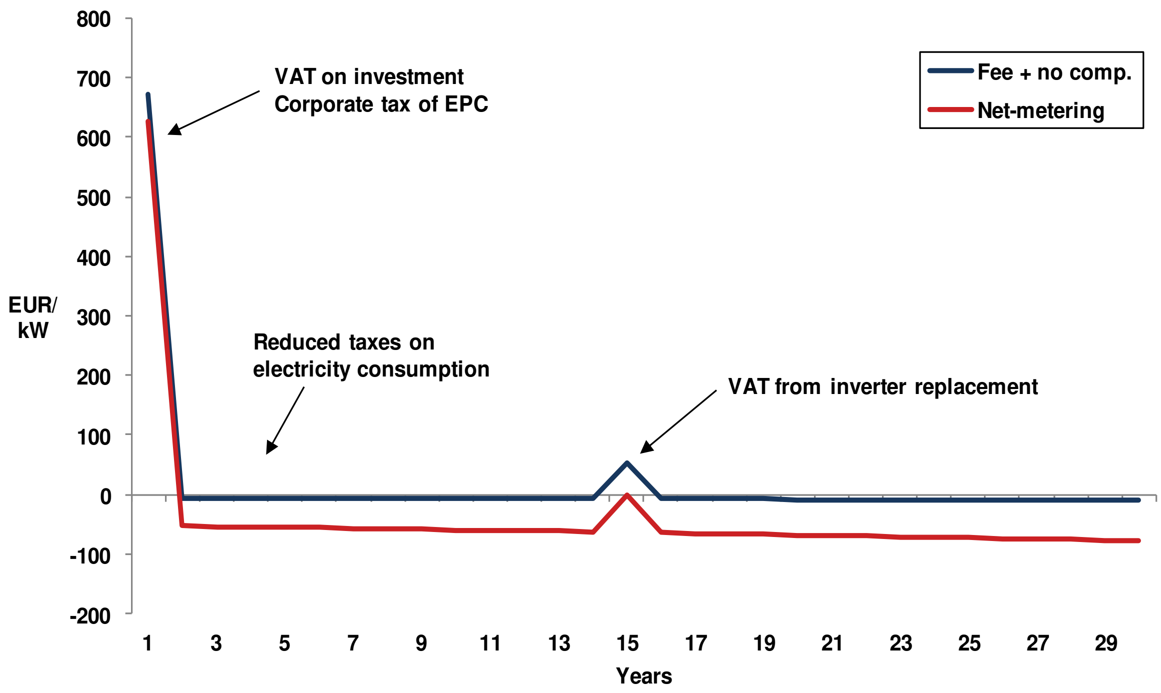


Figure 15. Annual cash flows for the Tax Collector ("Fee + no comp" and "Net-metering")

As a result of the above pattern, self-consumption has a positive impact for the Tax Collector during a significant period of time. The following figure shows the resulting accumulated cash flows from the perspective of the Tax Collector:

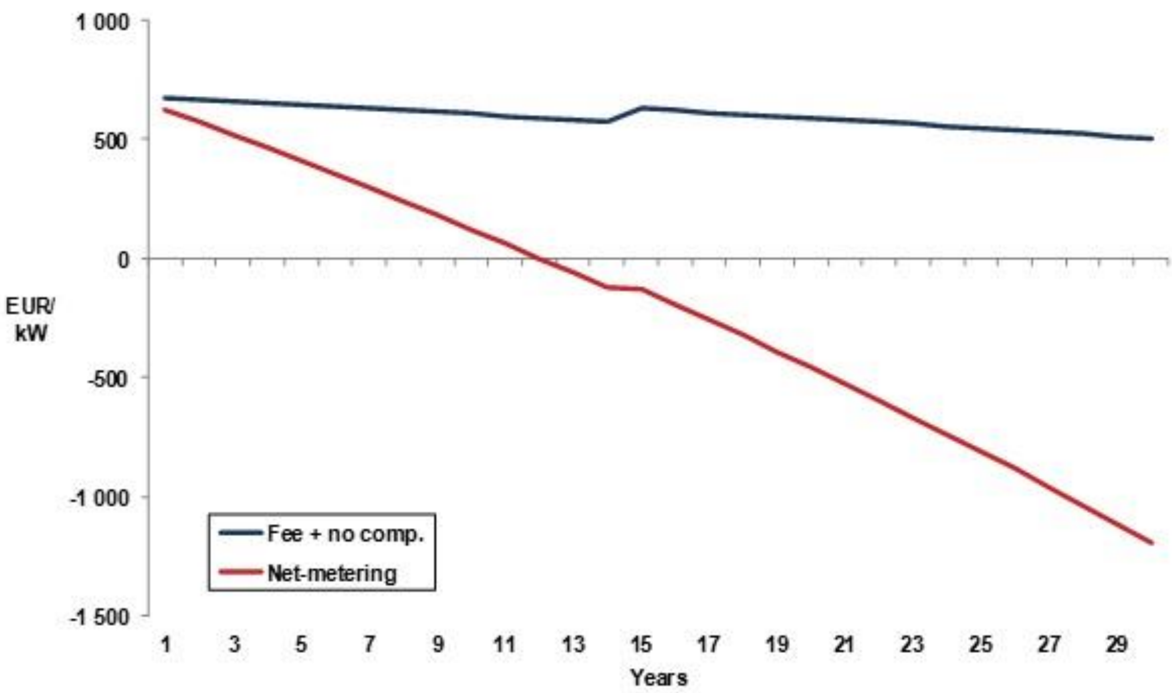


Figure 16. Accumulated cash flows for the Tax Collector ("Fee + no comp" and "Net-metering")

The impact over 30 years on the Tax Collector of the analysed cases varies as follows:

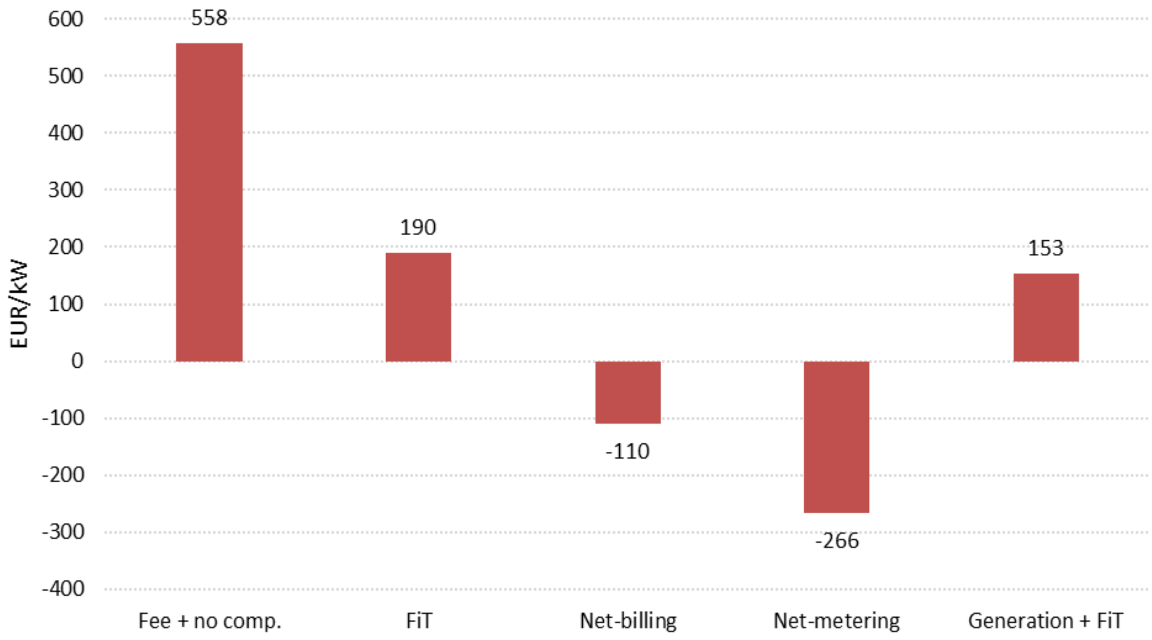


Figure 17. NPV per installed kW (30 years) for the Tax Collector

Except for "Net-metering", in all other cases the NPV of the Tax Collector is increased by the VAT obtained from the investment in PV and by the corporate taxes collected from the installer but diminished by the reduction in the energy purchased from the grid by the prosumer. Additionally, Case 1 provides the Tax Collector with an extra income from the taxes associated with the self-consumption fee.

While conceptually "FiT", "Net-billing" and "Generation + FiT" are identical from the point of view of the Tax Collector, the difference in the NPV lies in the fact that "FiT" has TOU rates and "Net-billing" and "Generation + FiT" do not.

Moreover, the above figure clearly shows how "Net-metering" results in the most detrimental impact on the Tax Collector. The segmentation of this output is presented below:

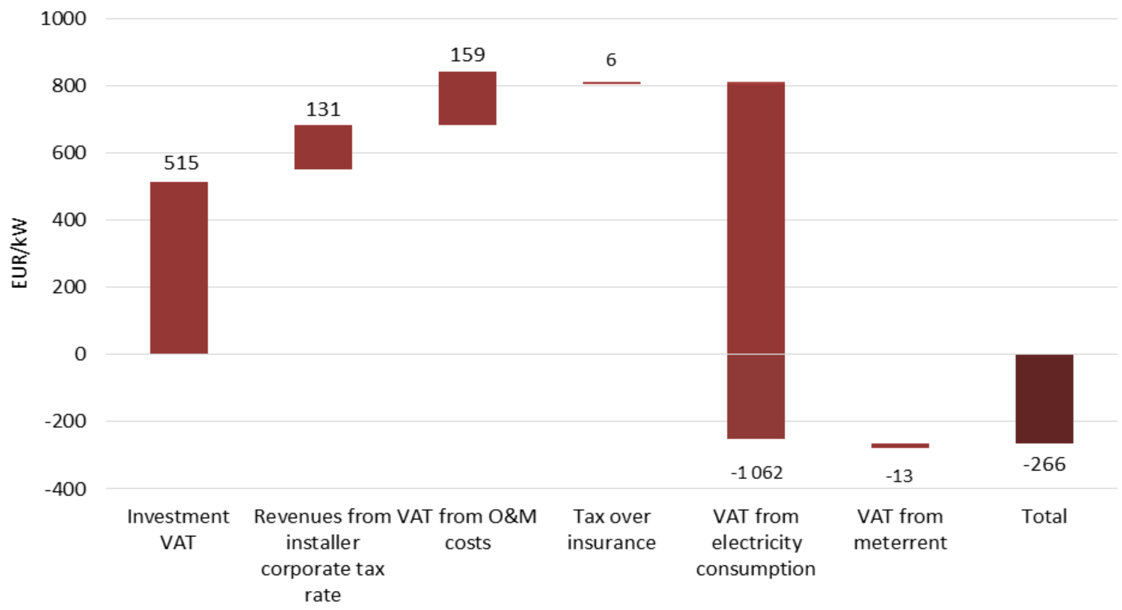
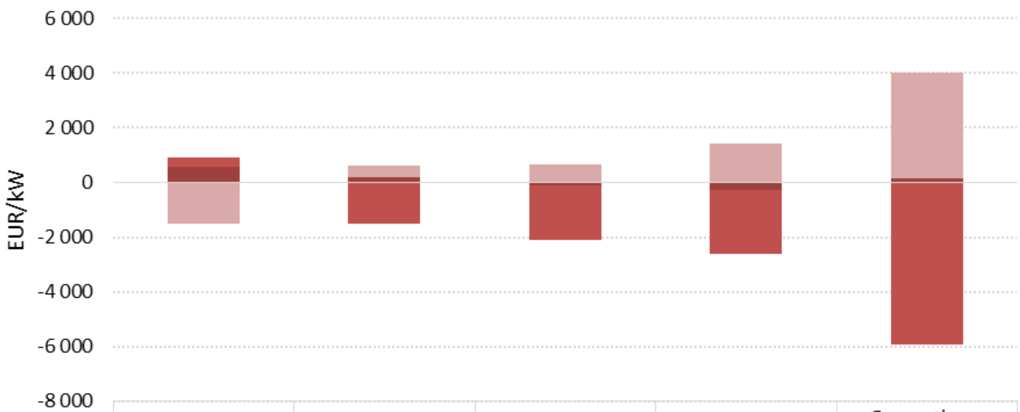


Figure 18. Segmentation of impact for the Tax Collector (example "Net-metering")

Under Net-metering, the Tax Collector is more negatively affected than under the other cases, since the prosumer purchases the lowest amount of energy from the grid, as excess PV generation is netted against energy consumption from the grid. Therefore, taxes associated with electricity purchases decrease accordingly.

4.2.5 OVERALL COST OF PV FOR SELF-CONSUMPTION

To assess the total impact of each Business Case on the three stakeholders, the NPV (30 years) per installed kW for each party has been added up.



	Fee + no comp.	FiT	Net-billing	Net-metering	Generation + FiT
NPV/investment	-0,2%	28,7%	-62,4%	59,7%	-71,5%
Prosumer	-1 496	599	679	1 417	4 011
Electricity Market	932	-1 498	-2 110	-2 626	-5 930
Tax Collector	558	190	-110	-266	153

Figure 19. Costs associated with each Business Case (NPV per kW)

The results show that, taking into consideration the elements in Figure 5, in all cases except for "Generation + FiT", the costs (or reduced revenues of self-consumption) exceed the benefits (or savings).

Moreover, the worst overall results occur under "Generation + FiT" where the NPV of the investment for the stakeholders analysed is close to 72% of the initial investment in absolute terms. In addition, within each case there is a trade-off between the benefits for the prosumer and the benefits for the Electricity Market.

It is worth highlighting that an in-depth quantification of costs and benefits is required to properly assess the overall (including all stakeholders) profitability of PV for self-consumption. Moreover, this analysis could be extended to include the cash flows associated with the alternative generation sources (e.g. conventional fuels), allowing for a more complete analysis of the relative overall attractiveness of PV self-consumption.

Essential caveat

It is worth highlighting that the economic assessment is not comprehensive as it does not include many of the benefits associated with PV, regarding the following parameters, among others:

GHG emissions

Moderated energy prices

Natural resource management

Development goals

Job creation

Reduced energy-related public expenditures

Energy security

Macroeconomic effects

Industrial productivity and competitiveness

Energy provider and infrastructure business

Increased asset values

Health and wellbeing

Poverty alleviation (energy access and energy affordability)

Increased disposable income

4.2.6 SENSITIVITY ANALYSIS

It is interesting to evaluate to which extent the impact of the business cases analysed changes as the input parameters vary. This section examines the sensitivity of the results in the previous section to the following parameters:

PV system size: PV capacity from 1 kW up to 7 kW (self-consumption ratio from 81% to 33%).[3]

Tariff structure: retail electricity price (with taxes) from 22 c€/kWh to 15 c€/kWh, where "Grid Costs" plus "Green Taxes" account for 46% and 28% of the total price respectively (see Figure 20 below).

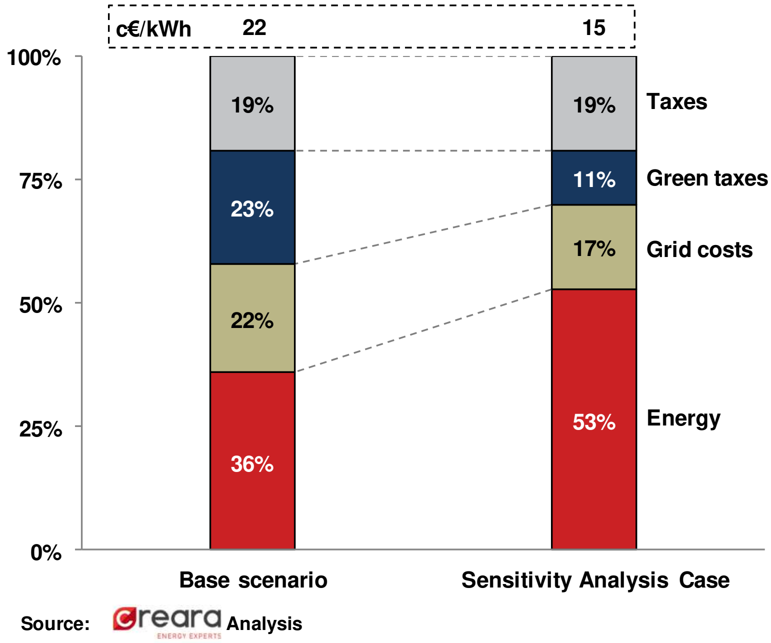


Figure 20. Retail tariff structure for Base-Case and Sensitivity Analysis Case

While the base scenario is believed to reflect the most common situation (e.g. that in countries such as Germany, Spain, and The Netherlands), the sensitivity analysis case reflects the tariff structure in UK.

[3] Recall that under the Base Case, 3 kW of installed PV results in a self-consumption ratio of 56%.

The following table gathers the economic results for the prosumer as the installed capacity is changed:

NPV (€/kW)	1 kW SC ratio 81%	3 kW SC ratio 56%	7 kW SC ratio 33%	Optimum capacity (kW)
Fee + no comp.	-1,014	-4,494	-14,515	0
FiT	911	1,794	1,281	~3,8
Net-billing	1,133	2,030	-444	~2,6
Net-metering	1,254	4,253	1,854	~3,8
Generation + FiT	4,698	12,024	22,731	∞

Keys

Better than Base Case

Worse than Base Case

Source: Creara Analysis

Table 26. NPV for the prosumer when different values of the PV installed capacity are applied

The above table demonstrates the fact that for each case, the one that yields the highest NPV for the prosumer (the optimum installed capacity of the PV system under the general assumptions described in Table 22):

- Under "Fee + no comp" case the project is unprofitable (for any installed capacity).
- Under "FiT", "Net-billing" and "Net-metering" cases, the optimum capacity lies between 1 kW and 7 kW.
- Under "Generation + FiT" Case, the higher the installed capacity, the more profitable the investment. Therefore, the user has an incentive to be a net-generator of electricity.

The following table shows the impact on the output when the retail tariff structure is changed:

NPV (EUR/kW)	Prosumer		Electricity Market		Tax Collector	
	Base	**S.A.C***	**Base**	**S.A.C***	**Base**	**S.A.C***
Fee + no comp.	-1 496	-1 698	932	932	558	537
FiT	599	-498	-1 498	-599	190	413
Net-billing	679	-199	-2 110	-1 033	-110	168
Net-metering	1 417	-317	-2 626	-1 012	-266	151
Generation + FiT	4 011	2 683	-5 930	-3 078	153	331

Keys

Better than Base Case

Worse than Base Case

**Sensitivity Analysis Case*

Source: Creara Analysis

Table 27. NPV per installed kW (30 years) for all stakeholders per Business Case and Scenario

The following conclusions can be extracted from the above table:

- The prosumer obtains higher revenues/savings in the Base Case, given that the tariff is higher.

- All else equal, the Electricity Market is better off under the sensitivity analysis case (i.e. a tariff with a low weight of fixed costs - grid charges plus green taxes), where the lower retail electricity price results in lower reduced revenues.
- From the point of view of the Tax Collector, tax collections associated with PV self-consumption (i.e. VAT of the investment) remain unchanged, but the reduced revenues from PV self-consumption are lower under sensitivity analysis case.


The DeSeve House in Chestnut Hill; 8 kW solar PV system/ NREL

5 MAIN CHALLENGES FACING SELF-CONSUMPTION

As we have seen before, the self-consumption of PV electricity could offer a way for PV to develop without financial incentives. However, the development of self-consumption-driven PV installations raises numerous questions that are presented below:

5.1 IMPROVING THE COMPETITIVENESS OF SELF-CONSUMPTION BUSINESS MODELS

We will see below that an increased self-consumption ratio increases the competitiveness of the PV system. Since wholesale electricity prices will always be lower in average than the retail ones, this will imply to maximizing self-consumption ratio to optimize the revenues of a PV system and its amortization.

We will also identify that reducing the PV system size brings the self-consumption ratio up. Hence, this solution satisfies only the question of increasing self-consumption ratio and absolutely not the question of delivering electricity for the consumption during high seasons of the year.

The increase of the self-consumption ratio can thus be achieved with either a change in the pattern of the load curve at the consumption point (this is called “Demand Side Management” or DSM, or “Demand Response” or DR), or by storing electricity when the PV production exceeds the consumption and use it when the cost of electricity is the highest.

5.1.1 SELF-CONSUMPTION AND GRID PARITY

Self-consumption of PV electricity presupposes that the cost of producing PV electricity is cheaper (at the time of investment or during the lifetime of the PV system) than the price that the consumer pays for his electricity. Without having reached this threshold, self-consumption will require additional financial incentives as we will see below. Meanwhile, the indication that grid parity is reached could mean that producing electricity rather than buying it from the grid is attractive. This is not the case due to several reasons that will be explained below and that explains why grid parity is a milestone but not the guarantee of PV competitiveness.

Grid (or socket) parity is the moment when the LCOE of PV becomes smaller than the retail prices of electricity. If some grid costs and fees are not compensable (because of a larger fixed part of grid costs for instance), the grid parity does not exist when PV becomes cheaper than the retail electricity price: PV prices have to decrease even more to reach that first benchmark of competitiveness (the red arrows below).

Moreover, since a part of PV electricity is exported, and valued potentially at a lower price (linked to wholesale electricity prices), the PV LCOE must decrease in order to ensure the competitiveness of the PV electricity not only with retail prices but also in total, including the excess PV electricity (the orange arrow below). Of course the question of grid costs that are not compensable remains the same.

Finally, trading PV electricity on the wholesale market could be more complex and costly than estimated. This value of solar PV on the wholesale market is logically expected to be lower than the market price itself (because of delivery uncertainty and management costs); and the real competitiveness of PV will be achieved when the LCOE of PV will be lower than the revenues (electricity bill savings and sales on the market through intermediaries). In that respect, it can be considered that only the variable part of electricity can be compensated, the fixed part of the electricity will always have to be paid, which will imply to shift competitiveness further in time.

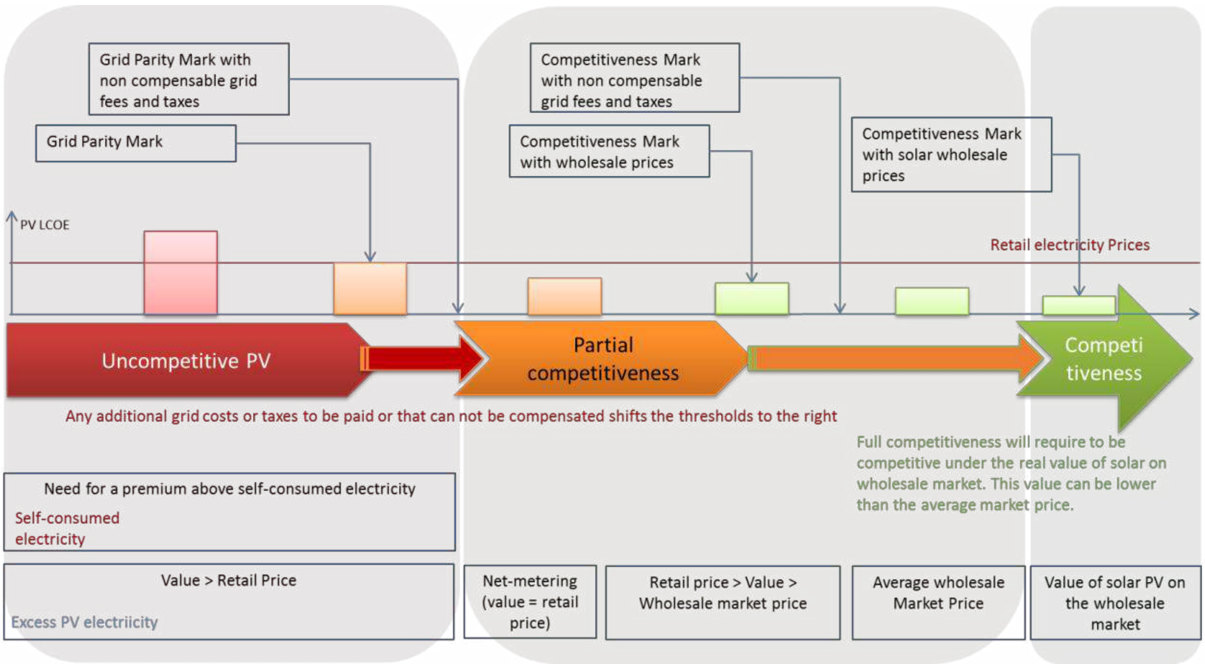


Figure 21. Steps toward Competitive PV Systems using Self-consumption

5.1.2 SELF-CONSUMPTION RATIOS

The question of the self-consumption ratio is at the core of the business model. The higher the self-consumption ratio, the higher the profitability of the entire system since retail electricity prices are by definition higher in average than wholesale prices for electricity.

In households, net-metering policies have pushed for systems producing the same amount of energy every year as the local consumption. But the real-time consumption depends on the pattern of the load curve. The more the load curve centralizes on the mid-day and the summer, the higher the compatibility between the production and the consumption will be.

The two main ratios that can describe self-consumption are:

- Self-consumption ratio (SCR): This ratio is calculated by dividing PV energy produced which is consumed locally to the total PV production. The complement to this ratio is the energy that is injected into the grid divided by total production.
- The consumption coverage or self-sufficiency ratio (SSR): it is the ratio between the PV energy produced which is consumed locally and the total consumption of the site.

The link between these energy amounts can be illustrated by these equations:

Total PV production = PV energy produced which is consumed locally + PV energy produced which is injected to the grid.

Total site consumption = PV energy produced which is consumed locally + energy drawn from the grid

These calculations are normally done on a full year basis. These ratios depends on:

- On the customer side:
  - The load profiles linked to the segment and the type of users: small/large family household, commercial, industrial etc.
  - Local climatic factor: cold (electrical heating), hot (air conditioning)
  - Consumption behaviour: cheap energy (strong consumption) or strict energy saving
- On the producer side:
  - The PV production profile linked to the size of the PV system
  - The location (irradiation)
  - The orientation will affect both the level of power and the bumps shifts

The ratios can be calculated as a function of the PV size as shown in Figure 22 below. For small PV systems, the SCR is high and the power produced is instantly locally consumed. On the other hand as the amount of energy is small, the SCR ratio is small too: it covers a negligible part of the total consumption. In the case below, a plateau of 100% SCR can be seen until 700Wp PV system size. When the PV system size increases, the consumption coverage increases as well but in parallel the SCR starts decreasing. More and more energy is injected into the grid as the PV system produces more energy than when the consumption increases frequently.

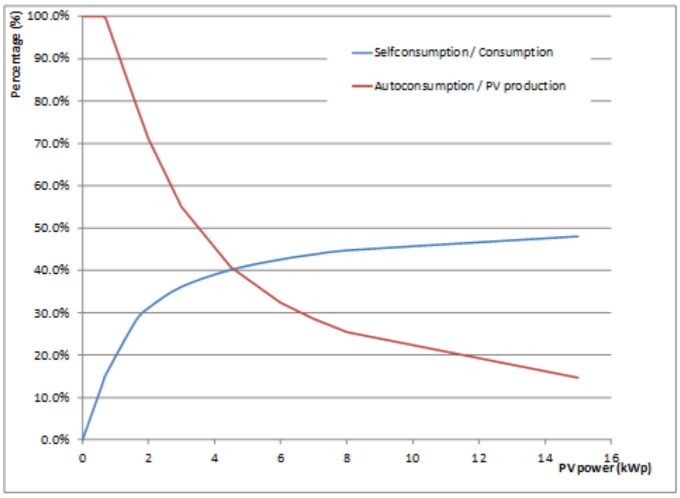


Figure 22. SC and SS ratios for residential case in Germany (consumption 4,5 MWh/year) (Source: Total, V. Cassagne)

It is commonly acknowledged that a standard household running a PV system in central France or Germany can naturally reach around 20 to 30% of self-consumption without any specific measure being put in place. This example shows higher shares but the final ratio depends on the precise load curve of the house and which electricity equipment is used.

In buildings with a high consumption of electricity during the day, whatever the period of the year, such as commercial or industrial buildings, the size of the PV system will not always allow to produce enough electricity to cover the annual consumption. The consequence will be, in most cases, an increase in the self-consumption ratio. In that respect the industrial buildings and some commercial ones could reach higher self-consumption ratios, possibly close to 100%.

Oppositely, the larger the system with regard to the local consumption, the lower the level of self-consumption ratio. These relatively low levels can be explained by the low consumption during week days in the summer and high consumption in the winter at times when PV produces less electricity. In countries with high irradiations and different load curves (such as Australia, the southern part of the USA, Spain, etc.) the better compatibility between production and consumption could lead easily to higher self-consumption ratios.

Figure 23 below illustrates the difference in Germany between households and commercial buildings' consumption at various moments of the year. The concentration of consumption for commercial buildings during the day explains partially why higher self-consumption ratios can be reached in that segment.

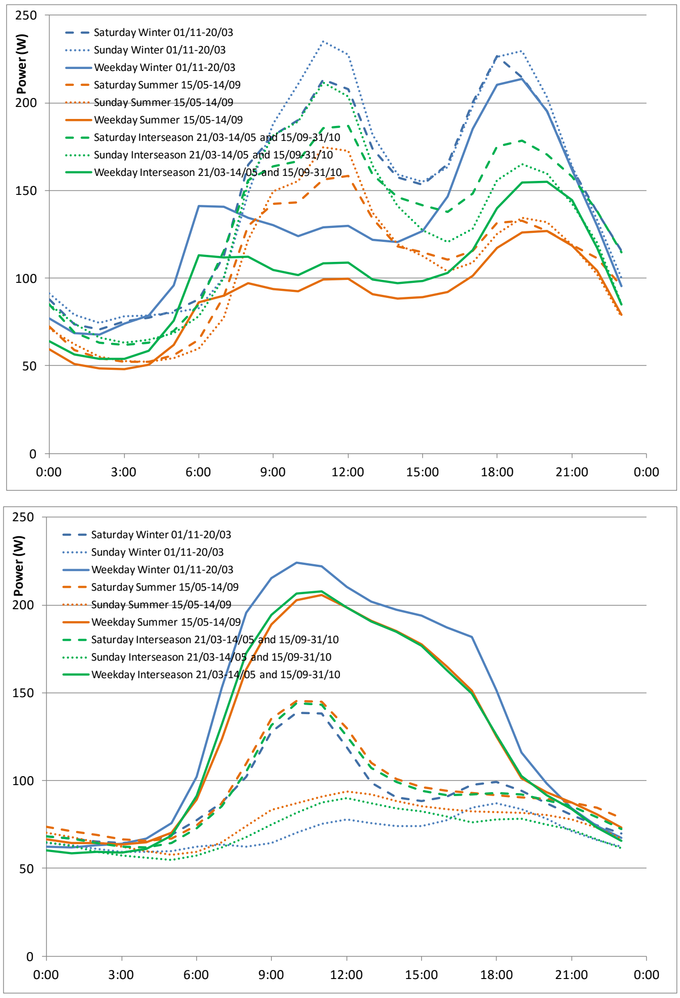


Figure 23. Consumption profiles of household (first) and commercial (second) activity in Germany (source E-On)

In general, the optimization of system size (annual production and consumption equalized) and the use of demand side management tools, such as heat-pumps, direct water heating or decentralized storage systems can increase the ratios.

This shows that reaching 100% of self-consumption without battery storage is technically feasible, under conditions of size limitation for instance. Ratios of 100% for self-consumption could be considered as equivalent to net-metering schemes.

5.1.3 OPTIMIZATION OF PV SYSTEM SIZE

In order to maximize the profitability of the PV installation, the self-consumption ratio has to be increased as much as possible, at least to the point where the costs of increasing self-consumption overcome the gains.

The optimization of the system size (annual production and consumption equalized) and the use of demand side management tools, such as heat-pumps or decentralized storage systems could increase the ratio but still this depends on several other factors. For example, moving loads to production peak (around noon) like washing machines or dish washers, increases the ratio by 5%. Reaching higher levels would require long term local storage. These relatively low levels can be explained by the low consumption during week days in the summer and high consumption in the winter at times when PV produces less electricity.

On commercial or industrial rooftops, the self-consumption ratios is expected to be high due to better correlation between consumption and production: they consume electricity mostly during daytime and often using air conditioner. As commercial companies can have very different sizes, we then use the metric kWp installed by MWh consumed as variable to study the PV system size effect. The curves in figures 5 shows the higher self-consumption rates compared to residential. Meanwhile the size of commercial roofs could also be an obstacle to reach high self-sufficiency ratios. This is rather obvious in large condominium buildings for instance, especially in sunny countries where the size of the roof (and even the façades) can be too small to provide a high self-sufficiency ratio.

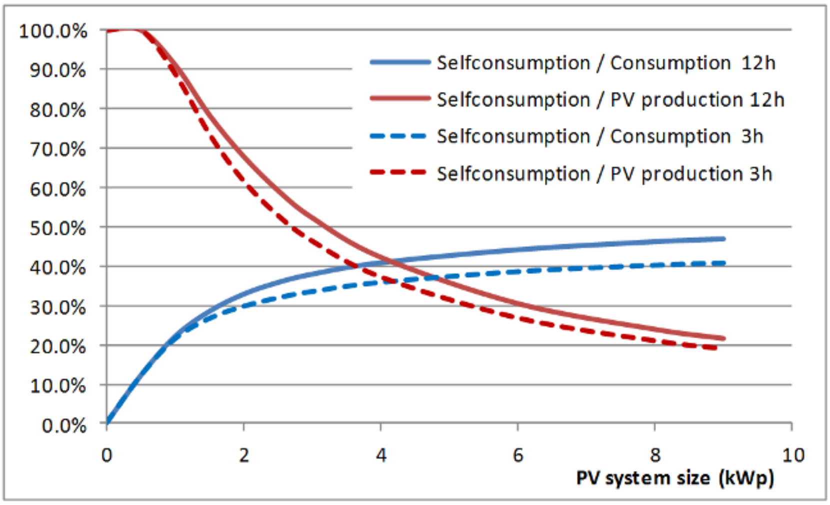


Figure 24. Effect of moving a washing machine or a dish washer from night to noon on self-consumption ratios (source: Total, V. Cassagne)

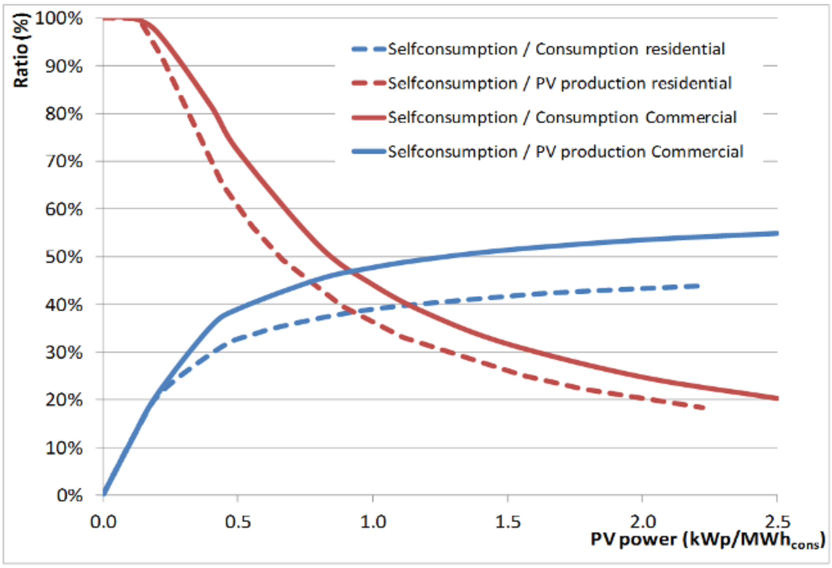


Figure 25. Self-consumption ratios comparing residential and commercial application in Germany (source: Total, V. Cassagne)

5.1.4 SELF-CONSUMPTION AND STORAGE

At first sight, the storage of electricity can appear as an interesting solution: if all PV electricity not locally consumed could be stored and used later, PV could theoretically provide the entire annual consumption of a prosumer.

However, due its very nature, PV is producing during the day and mostly during the sunniest seasons of the year. Depending on the weather conditions, storage could help to compensate not only for night times but also for some cloudy days. Nevertheless, due to their cost, storage systems need to be used as much and as quickly as possible to decrease the cost of stored electricity. In that respect, seasonal storage implying to store electricity during several months for a later use would therefore reduce the financial attractiveness of storage.

Since the cost of storage relates directly to the amount of energy to be stored, long-term storage will be much more expensive than short-term storage. In that respect, daily storage has been explored by many studies as a way to enhance self-consumption ratios.

Storage of electricity can theoretically offer important benefits not only to the prosumer but also to the grid, by solving issues coming from the injection of electricity into the distribution grid.

- Generation adequacy: due to a higher production in the summer, with high penetrations of PV in the electricity mix (>10-15%), there will be times when a huge amount of electricity is generated and if there is no storing system in place this energy would be lost: instead of curtailing PV production, it could be stored and therefore used later during the day, not only for self-consumption but to provide cheap electricity to the grid.
- T&D investment deferral: by storing the excess energy, generation peaks can be smoothed, and therefore the existing distribution grid will be able to absorb PV electricity at higher penetration levels. In the same way, by limiting the injection during peak production times (all generation sources together), the need for reinforced transmission lines can be shifted away in time.
- Ancillary Services: while some ancillary services such as reactive power production can be generated with a standard PV system, storage allows PV to deliver other ones such as black-start capability or islanding management for instance.

Moreover, storage technologies could assist the prosumer in several ways.

- In countries where self-consumption is permitted but there is no support mechanism to compensate prosumers for the excess electricity injected to the grid, prosumers should analyse whether they are better off investing in a battery to store excess PV generation than losing that electricity or modifying their load curve by shifting consumption according to PV production times.
- In countries with a regulatory incentive to self-consumption (e.g. FiT lower than the price of electricity from the grid), prosumers should assess whether it is more economical to store their excess PV

generation with a battery than to sell their PV electricity and receive the FiT. Storage may also have beneficial implications for customers on TOU rates or with high demand charges

Some battery manufacturers design specific systems for PV, particularly from Lithium-ion and lead-acid based technologies, which are the most commonly used.

- Lead-acid batteries have a few disadvantages such as low potential for future cost reduction, high volume and weight, short lifespan, and high toxicity.
- On the other hand, investments in the development of the Lithium-ion technology have recently increased, in particular for their use in electric vehicles (EV). Their high energy density makes them more suitable for installations with space limitations.

Ultimately, the impact of storage on electricity market will be determined by the economics of storage solutions. The use of batteries to store PV will become a reality if, and only if, the decision of investing in batteries is more profitable for the prosumer than that of not doing so (at the point of "storage-parity"). In analysing the alternatives, the user should also account for the possibility of attaining bill savings not only from the variable components of the electricity tariff but also from the fixed components.

5.1.5 SELF-CONSUMPTION AND HEAT-PUMPS OR DIRECT HEATING/COOLING

Demand Side Management implies to shift consumption to different times when the PV consumption is the highest in order to optimize the complementary between both production and consumption. Since demand can hardly be shifted from one season to another, DSM will be applied mostly intraday changes which are easier to standardize.

In that respect, heating and cooling technologies offer some already available options for shifting consumption intraday. Since the demand of heating does not happen at the highest PV production peak, cooling will be favoured while heating will be focused on sanitary water. Various solutions have already existed to drive the heaters or coolers with PV electricity. Heat-pumps used for hot water production or direct heaters (such as PV-powered resistances in the hot water boiler) are already technically available options.

More information can be found in the documents produced by the IEA-SHC Task 53 research program.

5.1.6 SELF-CONSUMPTION AND ELECTRIC VEHICLES (EV)

Electric vehicles (EV) can be seen as both a DSM option and a storage option, under conditions. They do not require the prosumer to invest particularly in storage. However, the use of an enabler of self-consumption will naturally be more complex to manage than a standard battery pack.

If it is assumed that prosumers who decide to buy an EV will use it for their daily drives, then during daylight hours (i.e. when the PV system generates electricity) the EV will be used or will not be plugged at home (in the case of residential prosumers). This situation could be easier for commercial applications. In all configurations where the EV is used during the mid-day production peak, the mismatch between the typical using time of EV and PV generation makes using the EV to store excess PV impossible.

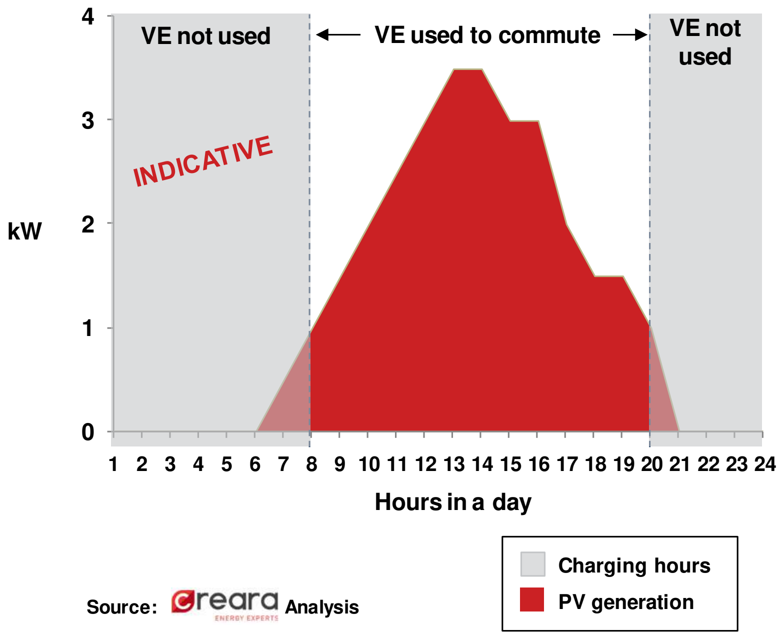


Figure 26. Daylight hours and EV charging hours

Under the above case it would still be necessary that a regulatory scheme compensate the prosumer for the excess generation injected to the grid. Meanwhile, EVs used to commute to neighbouring work places could be considered as mobile storage units: PV production will be injected into the grid and consumed in a reasonably close area and could be used to charge the EVs at the work place.

If the EV is not intended for daily use (or if the prosumer has an extra battery at home), the prosumer could use the EV to store excess PV generation (or use PV to charge the EV). The user will choose the option that results in the higher savings.

- Under a scenario such as that of Spain (i.e. no compensation for excess PV), the prosumer will be better off by charging the EV with the excess PV in order to avoid losing that electricity.
- However, under net-metering (Belgium case for instance), the prosumer will probably prefer to inject the excess PV into the grid (receiving energy credits in exchange) and to charge the EV at night, when the price of grid electricity if cheaper[4].

[4] Assuming that there are TOU rates available.

Another business model could appear, since the one that was announced by the US company Tesla in 2014: a charging station powered by PV would charge batteries when the sun is available and exchange empty batteries from EVs with charged ones. In that respect, a perfect combination between PV for charging and EVs could be realized.

In all cases, the complementarity between EVs charging needs and PV (or other variable RES) should be considered as a way to develop storage capacities and a possibility to enhance self-consumption.

5.1.7 FINANCING ALTERNATIVES

Lack of suitable financing alternatives could hinder the development of the self-consumption market. In general, if the self-consumer wishes to finance his investment, there are two main financing alternatives to equity:

- **Personal/Corporate Loan**: banks lend money on the basis of the creditworthiness of the company or the investor.
- **Leasing**: a long-term contract is signed between the investor and the financier, where the financier pays the upfront costs of the project and the user pays back the financing through a series of payments via a lease. For TPO in the USA, the host is purchasing the electricity, not paying back the owner. The host is typically given the option to purchase the system at the end of the lease. Under this arrangement the owner would also pay O&M costs.

This alternative is not always feasible, as some countries enforce that the self-consumer must be the owner of the PV system.

Well-known examples of leasing business models in the USA are those of SolarCity, Vivint and Sunrun, who offer a comprehensive service portfolio for PV systems under the net-metering model. They take over all the installation process of the PV system and in exchange, the user commits to a monthly pre-fixed payment throughout the entire length of the PPA (Power Purchase Agreement) contract.

When deciding to invest in a PV system, the prosumer will consider the available financing options and its impact on profitability. If the prosumer has neither equity available nor access to attractive alternatives, then the investment will not succeed.

5.1.8 VIRTUAL NET-METERING AND METER AGGREGATION

It is a regulatory challenge to increase the flexibility of self-consumption support schemes in order to take full advantage of self-consumption opportunities.

Virtual net-metering and meter aggregation open up a broader array of services to electricity consumers that make PV self-consumption much more flexible, attractive, and inclusive.

For instance, enabling self-consumption in multi-housing buildings (virtual net-metering) increases the target market of PV self-consumption, which can bring the following benefits:

- Offer the opportunity to lower-income electricity consumers who own/rent affordable housing to self-consume PV electricity to cover part of their energy needs.
- Contribute to reduce the energy costs of families, positively affect their disposable incomes.
- Seize the benefits of PV (environmental advantages, energy securities, etc.) to a greater extent.

Meter aggregation could foster EV usage by enabling the user to use credits from net-metering to charge the EV in locations other than the generating units.

5.2 SELF-CONSUMPTION AND THE ELECTRICITY MARKET

Self-consumption's impacts can be seen as twofold. First, the locally consumed electricity has the same impact on the electricity market as any energy efficiency measure that would take place when PV is producing. The impact on electricity markets comes from a decrease of the demand at times of PV production which can naturally trigger a price decrease at that time. Second, the excess PV electricity is injected into the grid. The impact on the market depends on the way it is valorised. In case of a feed-in tariff guaranteed and paid by electricity consumers through their electricity bills, or if PV electricity is not valued, it will impact the prices through the so-called merit-order effect: it will shift the supply curve to the right and reduce the price at which electricity from conventional producers will be sold. In case PV can be traded directly on the market, it will integrate the supply curve.

In all cases, PV is expected to reduce market prices at the time it is injected. The main impact lies therefore on conventional electricity producers that experience a lower market price due to a combined decrease of demand and lower prices.

Finally, Germany has put in place a theoretically PV market price that is used to remunerate PV electricity producers that select the "direktvermarktung" or direct selling on the electricity market. This price was rather low in 2014, down from 2013 and 2012, around 4 EUR cents per kWh of PV.

Aggregation

Due to the various size of PV systems used for self-consumption, not all of them will be able to trade electricity directly on the electricity market. This raises the need for intermediaries that will play on the market on behalf of PV producers. These intermediaries could be traditional utilities or specific electricity services companies (ESCO).

5.3 SELF-CONSUMPTION AND THE GRID

The question of the impact of self-consumption on the distribution and transmission grids has to be divided in several aspects: the technical aspects and the financial ones.

5.3.1 GRID COSTS

T&D fixed costs are recovered with both the capacity (per kW) and energy (per kWh) component of the electricity tariff. An estimation of total energy consumption is used to determine the retail electricity rates, such that revenues of T&D businesses are ensured. However, in many cases the revenues associated with the energy (variable) component to cover T&D fixed costs will likely decrease with the penetration of PV self-consumption. The following figure illustrates the effects of high penetration of PV self-consumption on annual revenues from an electricity bill:

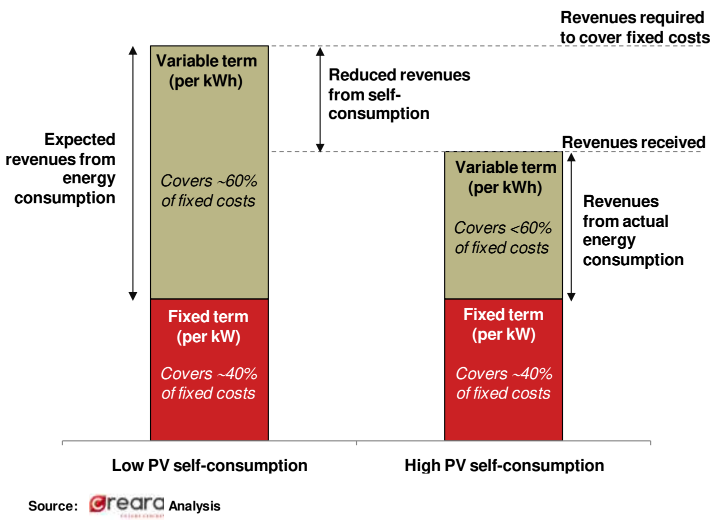


Figure 27. Illustration of T&D revenues with low and high penetration of PV self-consumption

As a result, to cover the fixed costs of DSO, some countries have imposed (or are discussing the introduction of) specific fees per kW of installed PV or per kWh of self-consumption. It is necessary that new revenue streams be designed to make the business model of utilities compatible with that of prosumers.

5.3.2 DISTRIBUTED GENERATION AND GRID OPERATION

As PV self-consumption levels increase, so does the penetration of distributed generation in the grid. While distributed generation presents some clear benefits (e.g. environmental), at high penetrations it may also complicate system operation.

In general, PV systems for self-consumption will be located near consumption areas. However, self-consumption systems for larger electricity consumers (e.g. industrial consumers) will not necessarily be located near consumption areas and as such can create large power flows that may cause congestion in some transmission lines. In order to successfully integrate those power sources it may be necessary to increase grid transmission capacity. The solution can partly be found in increasing the self-consumption ratios and reducing the injection of PV into the grid. Local consumption close to the injection point could also avoid huge flows of PV electricity into the transmission grid.

In addition, since PV is a variable source of electricity, the question of generation adequacy becomes essential. In order to supply the load at all times, additional sources of electricity will be necessary to supply PV. The "back-up" capacity has been studied in European conditions by the Intelligent Energy Europe project "PV PARITY" and has led to some costs calculations that remains rather low in European market conditions. Israel has implemented a back-up fee that will increase with the PV penetration in order to cover such costs.

Finally, PV can also contribute to grid services by providing for instance reactive power. In order to leverage these capabilities, a way to monetize theses services will have to be found for prosumers, perhaps through aggregation contracts with more than just energy-only services.

5.3.3 SELF-CONSUMPTION AND SMART GRIDS

In current grids, electricity consumers do not actively participate in the market: communication is unidirectional and information on prices and consumption is not fully disclosed.

In contrast, smart cities have been defined by the European Commission as *"systems of people interacting with and using flows of energy, materials, services and financing to catalyse sustainable economic development, resilience, and high quality of life; these flows and interactions become smart through making strategic use of information and communication infrastructure and services in a process of transparent urban planning and management that is responsive to the social and economic needs of society."*[5]

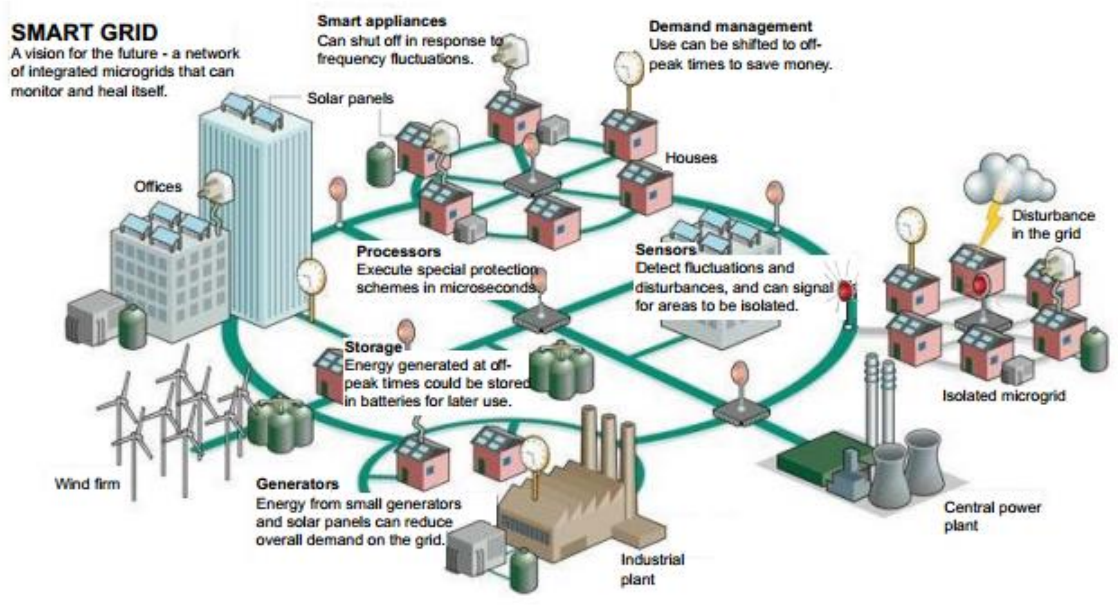


Figure 28. Smart Grid Illustration [6]

[5] European Commission (*http://ec.europa.eu/eip/smartcities/files/sip_final_en.pdf*)

[6] Source: Smart Grid 2030 Research Associates, as cited in ECLAREON SMART CITY LIGHTHOUSE CASES.

In the long term, smart grids will therefore enable a higher interaction between the main stakeholders of the electricity market (generators, TSO, DSO, and consumers). Through smart meters, the electricity consumers will be able to adjust his/her load to minimize spending.

In addition, the prosumer will be able to manage the load in order to increase the self-consumption ratio as much as possible. In this way, the profitability of the investment in a PV system for self-consumption will probably increase with a smarter grid. Apart from everything else, with a smarter grid it is expected that the number of PV systems for self-consumption will increase as the investment will be more attractive for the prosumer.

A hybrid PV/diesel generator system/ NREL

6 MARKET STATUS

The following figure illustrates the penetration of compensations schemes with regard to the PV market development until the end of 2014. The percentages are rather low compared to other incentives and especially Feed-in Tariffs. It must be noted that in this case, the percentages refer to installations where the compensation schemes have driven the market (and not all installations where self-consumption has been involved). For instance, if the net-metering system is complemented with green certificates, it makes harder to identify which of the net-metering and the certificates really drives the market.

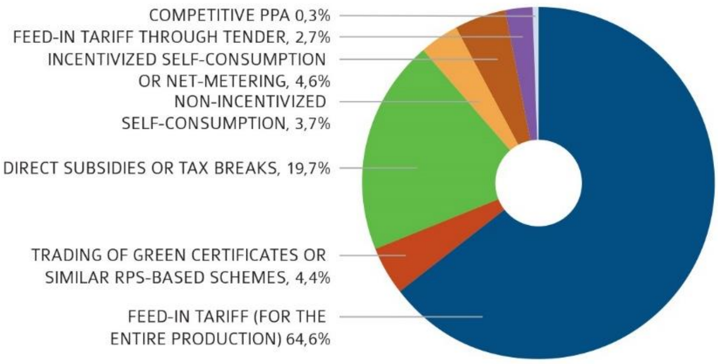


Figure 29. Historical Market Incentives And Enablers (IEA PVPS Trends 2015)

The second figure illustrates the situation in 2014. Categories have been adapted to take into consideration the evolution of the PV market in 2014. However, if self-consumption driven installations have increased, they remain a minority with less than 16% of the global PV market.

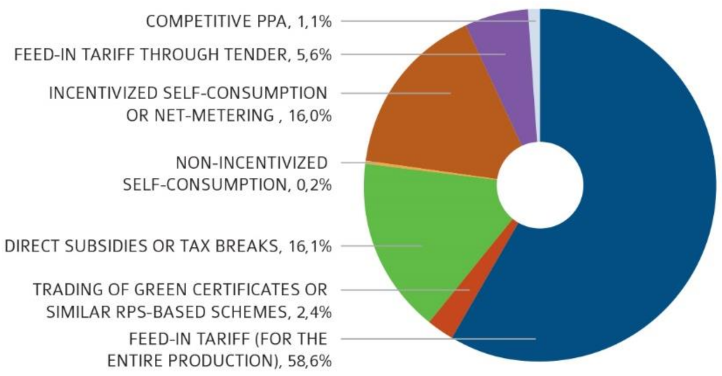


Figure 30. 2014 Market Incentives And Enablers (IEA PVPS trends 2015)

The same situation occurs in several countries. Meanwhile some countries are using compensation schemes with small additional incentives in such a way they can be seen as secondary to the compensation scheme to drive the market.

In Germany self-consumption drives the market in some segments where the price of PV is lower than the retail price of electricity. Self-consumption is completed by a FiT for the excess PV electricity but it can be seen that a very large part of the rooftop segments in Germany are driven by self-consumption.

Net-metering and similar compensation schemes are driving the market in Denmark, the Netherlands, as well as a part of Belgium and in Italy. In the USA, more than 41 states plus the District of Columbia and Puerto Rico have implemented net-metering policies. It is not an easy task to identify whether the net-metering policies or state or federal incentives are the main drivers of PV development in the rooftop segments in the USA, but together, they are responsible for USA market development and have facilitated the growing residential PV market we see today.

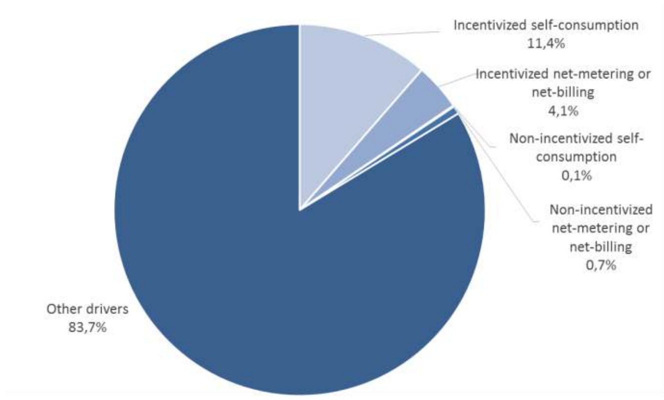


Figure 31. Share of different types of Self-consumption schemes for the entire PV market in 2014

In a nutshell, 84% of the market in 2014 (compared to 77% in 2013) was driven by other support schemes than self-consumption ones. The share of PV installations driven by self-consumption, with or without incentives accounts to around 12% of the world market while net-metering (or net-billing) schemes can be considered as having driven less than 5% of the global market.

This can even be refined by considering that most large-scale PV installations inject 100% of their production on the grid. According to IEA PVPS, the share of distributed PV in 2014 corresponded to around 43% of the PV market (or 17 GW). The previous figure can then be interpreted in a different way that in 2014 self-consumption schemes represented more than 35% of the decentralized PV market.

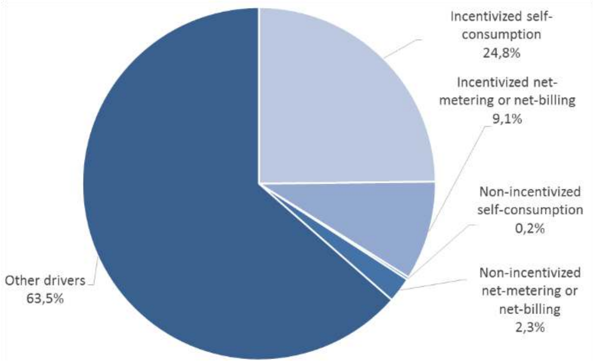


Figure 32. Different types of self-consumption schemes for distributed applications in 2014

It is foreseeable that this trend will continue in a near future with many countries discussing about compensations schemes in order to replace or complement their current policies. Canada, France, Spain, and others will influence more and more the evolution of the drivers of PV in the decentralized PV segments.

4,8 kW rated peak array capacity; Belmont, California/ NREL

7 CONCLUSIONS

As we have seen in this report, the transition from incentivized PV systems to self-consumption-driven PV systems has led to different business models and regulatory frameworks. The five cases above have been analysed and the conclusions as follow:

In places where the LCOE of PV in a defined segment is still higher than the retail price of electricity, self-consumption will require additional incentives to be competitive. This has been achieved in some countries with some premium on top of the retail electricity price and/or a FiT for the excess electricity.

When the LCOE starts reaching the retail cost of electricity, net-metering systems become attractive, although when the penetration of PV increases significantly, grid operators might have problems to recover their costs.

The more the LCOE of PV goes below the retail price of electricity, the more options are available for the prosumer and the regulator. Net-metering can be replaced with normal self-consumption and a FiT (or similar schemes) for the excess PV electricity. The FiT can be decreased for new systems together with the decline of the LCOE of PV. The more the LCOE decreases, the more it becomes easier to recover some grid costs in order to maintain grid financing at a sufficient level. In this case, it also becomes possible to define the FiT paid to the prosumer for the excess PV electricity on the wholesale price of electricity: a premium (fixed or variable) can then be tuned to cope with the decreasing LCOE until a reasonable profitability can be reached without premium.

The PV system will be considered as really competitive when the revenues from the savings on the electricity bill (the self-consumed part) and the revenues from the sales of excess PV electricity will cover on the long-term the cost of installing, financing and operating the PV system.

This allows to sort countries with regard to their positioning as shown in the figure below.

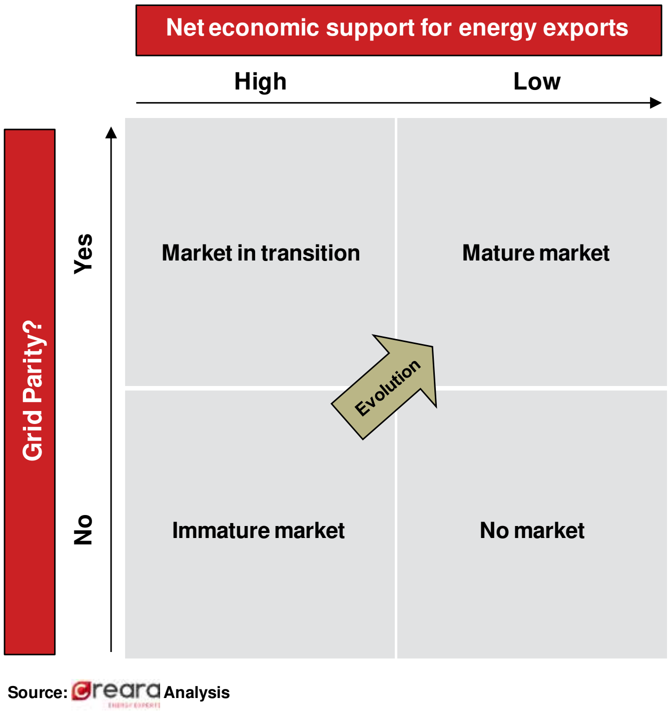


Figure 33. Illustration of market types according to market characteristics

Some conclusions can be drawn easily:

Net-metering is a temporary scheme that does not favour energy efficiency and does not push the prosumer to adapt his load curve to his PV production. Moreover it does not allow to fine-tune to revenues of the prosumers once the LCOE of PV decreases. As shown in the US or Belgium, the debates on the financing of the grid in net-metering systems have led to either additional taxes or a complete reset of the system.

In most cases, the price of retail electricity will be higher than the wholesale price: the logical conclusion is that the prosumer will have to increase the revenues of his installation by increasing the self-consumption ratio and therefore the share of self-consumed electricity. In the best case, reaching close to 100% of self-consumed electricity will be the optimal situation.

Since the supply of PV electricity is a given, DSM appears as the most logical way to adapt the local consumption to PV production and therefore to increase the self-consumption ratio. DSM can be reached by shifting consumption or by storing PV electricity. Shifting consumption could be done by displacing loads or by storing energy in a different way (heat and cold storing are already available options, for instance for hot water through heat pumps).

Another way to increase the self-consumption ratio consists in decreasing the system size. Of course, the total energy produced by the PV system will hardly reach the annual local consumption but could ease grid integration in weak grids.

Virtual net-metering between distant users can find its physical justification if grid costs remain being paid. Depending on the network on which the electricity will have to be transported, the grid costs could be finally invoiced or not.

Self-consumption of PV electricity can be assimilated to energy efficiency. In that respect the question of grid financing becomes a question on how to spread the costs on remaining users. Most countries are going in the direction of non-recovering grid costs associated to self-consumption since studies are also showing the benefits of PV for the distributing grid. However, additional grid taxes are shifting away the competitiveness of PV solutions in some countries already. A global solution to the evolution of the grid should be taken into consideration in order to cope with the increased share of self-consumed electricity, distributed generation, possible storage units and new uses of electricity that will require changing the topology and the use of the grid, The current solution that has been chosen in some countries to tax the prosumers in order to recover some decrease in grid financing doesn't appear as a logical solution since it doesn't consider the benefits that PV brings to the distribution grid. This point has not been treated here but is largely developed in the recent literature.

As a temporary conclusion, self-consumption is only in its infant stage, with most countries probing regulations to frame its development. Most essential questions remains to be considered in order to ensure its smooth development. And the most important one could be to identify whether the optimization of self-consumption locally should remain as the driver or system stability could be the answer, including generation adequacy as part of the equation, using in the case the PV system, not for local optimization but for a system optimization.

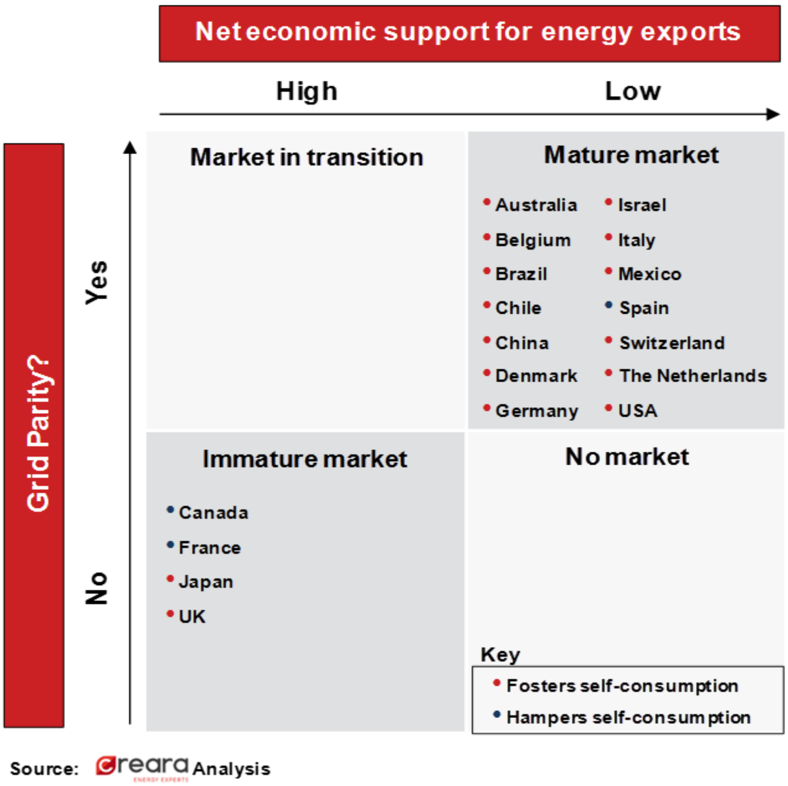


Figure 34. Country positioning according to PV market characteristics

This furniture factory in Gardner, Massachusetts incorporates PV panels into its design/ NREL

ANNEX

ACRONYMS

Acronym	Meaning
ANEEL	Agência Nacional de Energia Eléctrica (acronym in Portuguese)
c€/kWh	Euro Cents per Kilowatt Hour
CSI	California Solar Initiative
DSO	Distribution System Operator
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Act)
EUR/(kWp.yr)	Euro per Kilowatt Hour per Year
EUR/kWh	Euro per Kilowatt Hour
EUR/W	Euro per Watt
EUR/Wp	Euro per Watt Peak
EV	Electric Vehicle
FiT	Feed-in Tariff
GC	Green Certificate
GHG	Greenhouse Gas
IEA	International Energy Agency
IEA PVPS	International Energy Agency Photovoltaic Power Systems Programme
kW	Kilowatt
kWh	Kilowatt Hour
kWh/m2	Kilowatt Hour per Square Meter
kWh/m2/yr	Kilowatt hour per Square Meter per Year
MW	Megawatt
MWh	Megawatt Hour
MWp	Megawatt Peak
NPV	Net Present Value
NSW	New South Wales
PPA	Power Purchase Agreement
PV	Photovoltaic
PVPS	Photovoltaic Power Systems Programme
RES	Renewable Energy Sources
SEU	Sistema Efficiente di Utenza (acronym in Italian)

SSP	Scambio Sul Posto (acronym in Italian)
STC	Small-scale Technology Certificates
T&D	Transmission and Distribution
ToU	Time Of Use
TSO (or TNO)	Transmission System Operator
UK	United Kingdom
USA	United States of America
VAT	Value Added Tax

TERMINOLOGY EMPLOYED

The analyses are based on the following definitions[7]:

- Feed-in tariff: an explicit monetary reward is provided for producing PV electricity; paid (usually by the electricity utility business) at a rate per kWh that may be higher or lower than the retail electricity rates being paid by the customer
- Bill savings: the difference between the value of an electricity bill without a PV system for self-consumption and with it.
- Avoided costs: costs that should be borne by consumers or utilities in the absence of self-consumption.
- Net load: the difference between electricity demand from the grid without PV self-consumption (gross load) and with it.
- Real-time compensation: compensation between PV generation and electricity consumption at the exact same time, or in some cases, by 15 minutes.
- Virtual net-Metering: a characteristic of a net-metering scheme that allows the distribution of credits across more than one meter (e.g. in multi-tenant properties).
- Meter Aggregation: a characteristic of a net-metering scheme that allows a particular self-consumer with multiple meters to elect whether to use the credits associated to the excess electricity in locations other than the generating unit.
- Peer to Peer: a characteristic of a net-metering scheme that allows a prosumer to transfer credits to other electricity consumers.
- Third-party ownership: financing arrangement that allows a self-consumer to host a PV system that is owned by a separate investor, who can take advantage for instance of available incentives, such as tax credits and depreciation deductions.
- Electricity market: market place where electricity is traded and where wholesale electricity prices are formed.
- DSO/TSO: Distribution Grid System Operator (also referred to in some countries as DNO) in charge of managing the low and often medium voltage grids. Transmission Grid System Operator (or TNO) in

[7] Souce: Solar Power Europe, IEA PVPS.

charge of the high voltage grid and in some rare cases a part of the medium voltage one. TSO's are responsible for organizing the balancing of demand and supply of electricity.

LIST OF FIGURES

[8] Source: Smart Grid 2030 Research Associates, as cited in ECLAREON SMART CITY LIGHTHOUSE CASES.

LIST OF TABLES

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