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Evaluating the self-consumption potential from PV systems in 2030

A short technical study based on the PRIMES scenarios for the 28 EU countries

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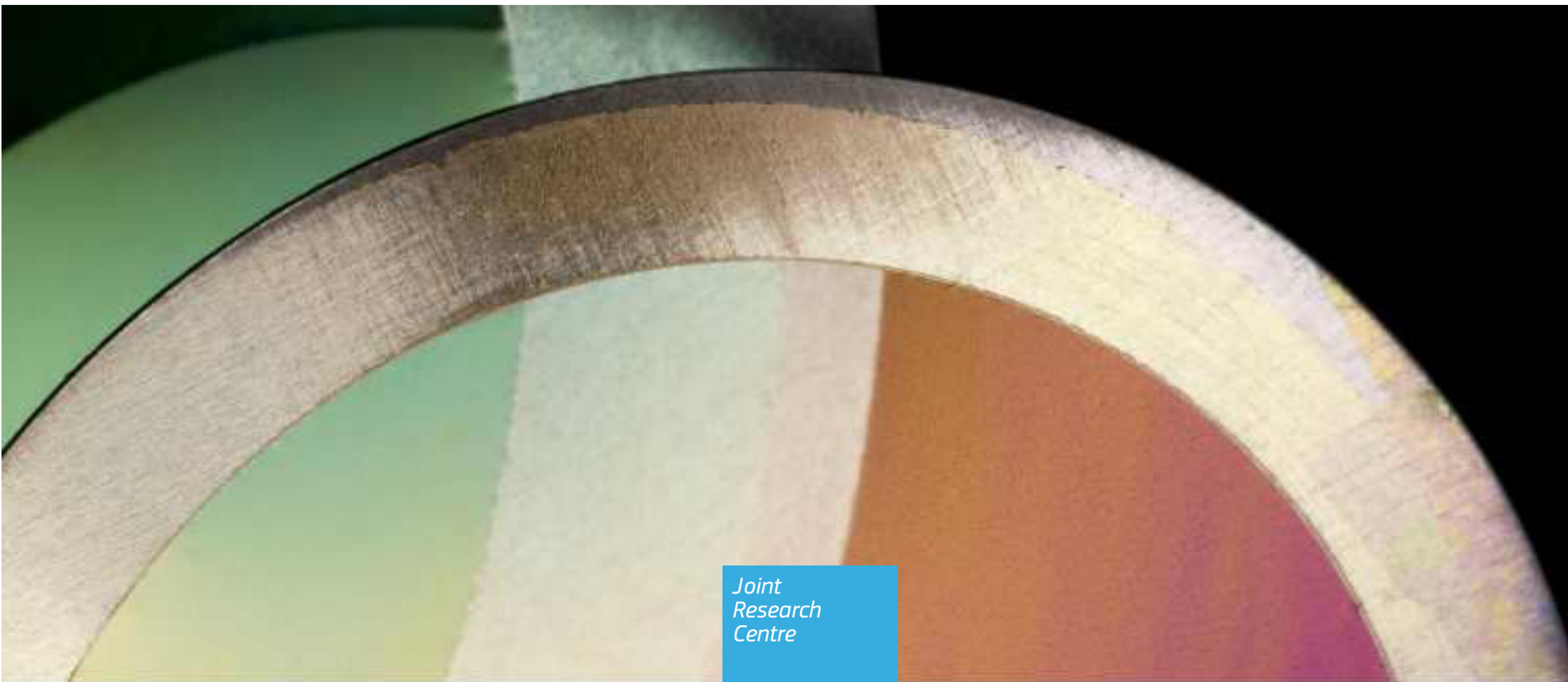

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1. Introduction

The recent development and marketing of new home battery systems, combined with significant price reductions, have been seen by many as a catalyst for a solar energy revolution and have created high expectations in the sector. Significant uptake of combined photovoltaic (PV)/battery units is now seen as a possible future, which would lead to increased decentralised generation and higher self-consumption levels. In addition, if current cost reduction trends persist, it is predicted that these systems could ultimately disconnect from the grid and lead to autonomous homes or micro-grids.

At present, however, solar home battery systems are not in thermselves economically viable in most EU countries: rooftop PV panels still require subsidies in the form of feed-in-tariffs, green certificates or favourable net metering schemes [1, 2]. The benefits of battery systems are closely linked to higher levels of self-consumption and thus to exemptions from taxes and grid fees on the self-consumed part [2]. Increased self-consumption also raises concerns as regards the sharing of grid costs, taxes and levies: it tends to reallocate costs from some prosumers who can afford the necessary investment to consumers who depend fully on the grid. The fact that the latter bear a higher proportion of non-energy-related costs can raise questions on the distribution effect of self-consumption. [3].

The typical installation considered in this paper is depicted in Figure 1. It consists of a DC-coupled PV and battery system, covering part of the household consumption and feeding excess electricity to the grid. Although the scope of the study is limited to single households, the proposed approach could easily be extended to public or commercial buildings, or to micro-grids comprising several households.

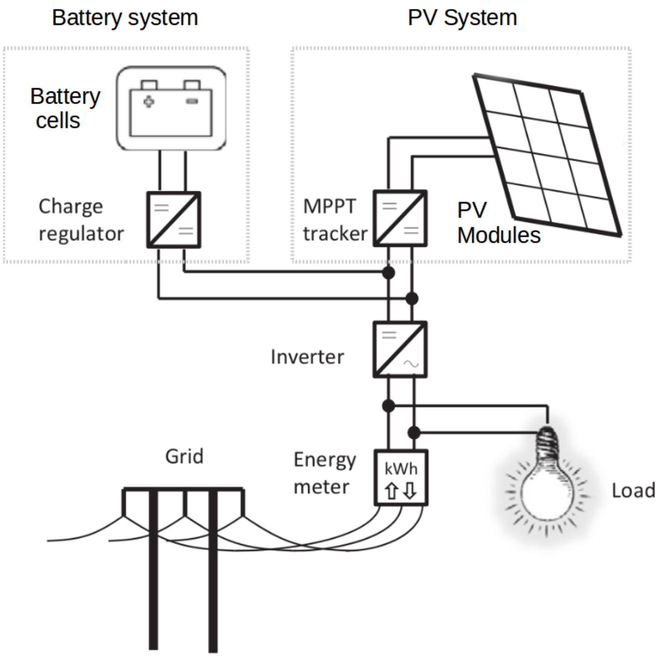

Figure 1: Conceptual scheme of the considered DC-coupled system. Adapted from [4]

2. Incentives for self-consumption, prosumer perspective

Figure 2 describes the rationale whereby a prosumer maximises self-consumption. Germany is taken as an example because its tariff structure is favourable to solar home batteries: the large price difference between buying electricity (at the retail price) and selling it (at the feed-in-price) can justify investing in self-consumption.

In such a context, households optimise their solar home battery investment by comparing the levelised cost of storage and of the PV installation with the residential electricity tariff. The latter includes network tariffs, taxes, levies and other surcharges that can be avoided when consuming self-produced PV electricity instead of purchasing from the grid. The tariff structure can thus be seen as creating an indirect financial incentive to self-consumption.

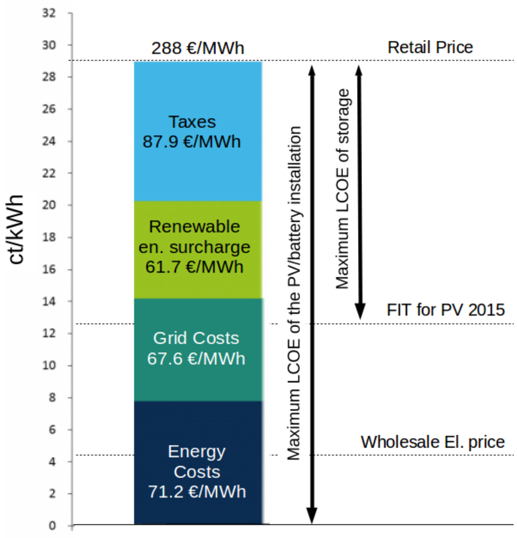

Figure 2: Average retail tariff structure in Germany (2015) and impact on self-consumption

It should be noted that this mechanism may become unsustainable in a scenario in which such systems enjoy significant uptake, since it generates revenue shortfalls for government, municipalities and system operators. These losses of revenue need to be compensated, either by increasing the network tariffs or by changing the tariff structure, e.g. switching from a volume (per kWh) remuneration to a hybrid scheme involving fixed or capacity-dependent remuneration for the grid connection. Interestingly, tariff structures are already being adjusted in this way in several EU countries. [1].

In this work, we consider the difference between the retail price and grid feed-in remuneration as the only relevant incentive for self-consumption thus defining the profitability of a potential home storage system. In the example of Figure 2, this corresponds to the difference between retail and feed-in tariffs: the levelised cost of one stored kWh over the lifetime of the battery should be lower than this difference to ensure profitability.

3. Scope of the work and selected scenarios

The goal of this short study is to evaluate possible levels of self-consumption by 2030 in various scenarios and under various hypothese. To that aim, two PRIMES scenarios are taken as reference:

- The PRIMES Reference scenario
- The PRIMES EUCO scenario

In both cases, we would like to evaluate the effects of different regulation schemes. To that end, two extreme cases are considered:

- A high self-consumption case, assuming that member state regulations are favourable to self-consumption and therefore that the average difference between buying and selling electricity prices for a prosumer is high. In this study, we assume that the buying price of electricity is the projected retail price in the residential sector by 2030 (provided by the PRIMES model). The selling price is assumed to be zero (i.e. any kWh fed to the grid is lost).
- A low self-consumption case, in which there is no incentive for self-consumption. This scenario corresponds for, example, to the case of yearly net-metering: because the balance is calculated annually, there is no incentive to time-shift the PV production or the load, and there is therefore no incentive for self-consumption. In this study this assumption corresponds to the case in which the delta between buying and selling electricity is null.

In this study, we consider that the prosumer optimises its benefits by dispatching the storage capacity in such a way as to maximise self-consumption; if the PV power is higher than the load, the battery is charged until full. As soon as the PV power is lower than the load, the battery is discharged until empty. The losses taken into account are battery round-trip efficiency and inverter efficiency. It is assumed that demand is not responsive. Figure 3 illustrates the results of the dispatch algorithm for a French historical consumption profile in a typical week in July. Battery charging and feeding to the grid are indicated as negative values.

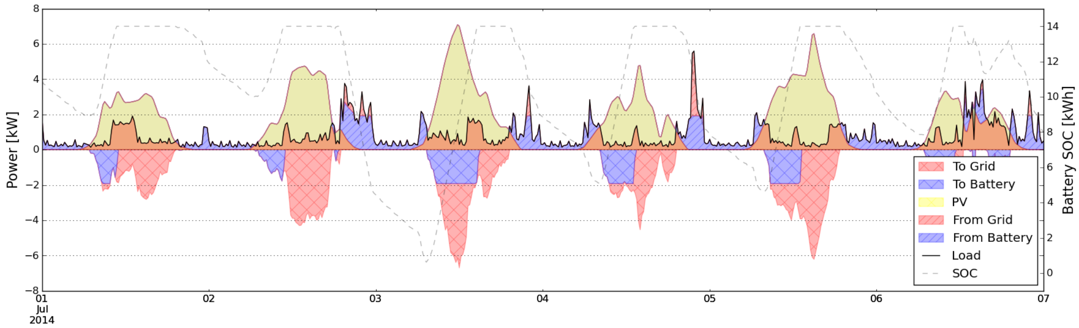

Figure 3: Power dispatch for a typical week of July

4. Input data and modeling

4.1 Hypotheses

Because the data originating from the PRIMES model is highly aggregated, various assumptions and simplifying hypotheses must be formulated. They are summarised hereunder:

- The full spectrum of possible regulations impacting self-consumption is summarised in the difference between buying and selling electricity prices. The simulations are performed in extreme cases (very favourable regulation, or unfavourable regulation).

- Self-consumption linked to demand side management or to the use of smart charging of electric vehicles is not considered. The main driver for increased self-consumption is the installation of batteries coupled to the PV installation.

- It is assumed that the largest part of self-consumption is linked to rooftop PV and not to ground-mounted PV. Because the PRIMES output do no allow disaggregating between the shares of residential, commercial, industrial and tertiary, ground-mounted PV is not considered for self-consumption (i.e. it is assumed that it is feeding directly to the grid without covering a local demand).

- Because no database of consumption profiles is available for the commercial or industrial sectors, it is assumed that the link between battery size and the level of self-consumption is the same as for the residential sector.

- The average size of the PV system is defined as the one allowing to cover the yearly demand (i.e. yearly PV generation = yearly demand).

- The benefits linked to the decrease of the peak power injected to the grid are not considered.

The underlying hypothesis is that, by 2030, there is a fleet of rooftop PV systems whose peak capacity and generation are provided by the PRIMES scenarios. The goal of the analysis is to evaluate for each EU country what would be the economically optimum storage capacity linked to these systems: low storage capacities do not allow to shift significant amounts of PV generation while too high storage capacity results in a lower use of the batteries (shallow charge/discharge cycles) and therefore in a poor use of the investment.

4.2 Modelling

The main challenge when evaluating the impact of decentralised electricity storage is to establish the relationship between self-consumption and battery sizes. To that aim, we use the results of a previous study performed over more than 900 EU household profiles [5].

The main result of the study is summarised in Figure 4, which maps the Self-Sufficiency Rate (SSR) as a function of the relative PV and battery sizes.

SSR is defined as the ratio between the self-consumed energy and the total yearly energy demand:

$$SSR = \frac{E_{SC}}{E_{load}} = \frac{\sum_{i=1}^{N} (P_{dis,i} + P_{SC,DC,0,i}) \cdot \eta_{inv}}{\sum_{i=1}^{N} P_{load,i}} \tag{1}$$

where E refers to an annual energy flow and P to an instantaneous power. N is the number of time steps in one year and $P_{SC,DC,0,i}$ is the DC PV generation directly self-consumed (i.e. without passing through the battery)

The Self-Consumption Rate (SCR) is defined in a similar manner, but the reference is the PV generation instead of the demand:

$$SCR = \frac{E_{SC}}{E_{PV,DC}} = \frac{\sum_{i=1}^{N} (P_{dis,i} + P_{SC,DC,0,i}) \cdot \eta_{inv}}{\sum_{i=1}^{N} P_{PV,DC,i}} \tag{2}$$

In the particular case considered here, the PV generation is equal to the yearly demand, and therefore $SSR = SCR$.

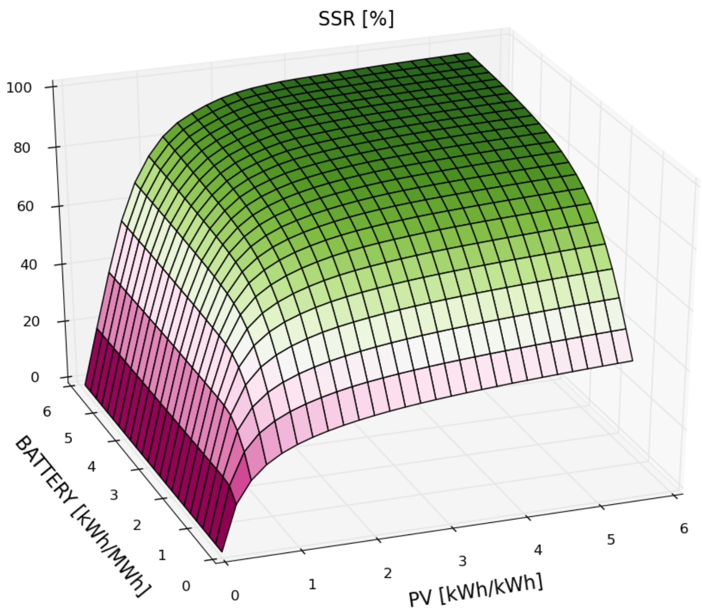

Figure 4: Influence on SSR of the relative PV size (PV generation per unit of yearly electricity demand) and of the relative battery size (battery capacity per unit of yearly electricity demand)

It is worthwhile to note that the SSR mapping is highly non-linear: increasing the PV and/or battery sizes increases the self-sufficiency, but this effect becomes marginal at high PV/battery capacities. In other words, it is not possible to be completely self-sufficient (i.e. go off-grid), even with an oversized solar battery home system.

4.3 Yearly performance indicators

To compute all energy flows, we first need to determine the 'self-sufficiency without battery' value. We do this through the SSR_0 variable, defined as:

$$SSR_0 = \frac{E_{SC,0}}{E_{load}} = \frac{\sum_{i=1}^{N} P_{SC,DC,0,i} \cdot \eta_{inv}}{\sum_{i=1}^{N} P_{load,i}} \tag{3}$$

The relative battery size is defined as input of the simulation since it influences the different energy flows and the volume of self-consumption. It is normalised to the annual electricity demand:

$$R_{bat} = \frac{CAP_{bat}}{E_{load}} \quad \left[\frac{kWh}{MWh}\right] \tag{4}$$

where CAP_{bat} is the accessible battery capacity (i.e. the total battery capacity multiplied by the maximum depth of discharge).

The total amount of energy provided by the battery is self-consumption minus the self-consumption in the case without battery:

$$E_{Stored} = E_{SC,DC} - E_{SC,DC,0} = \frac{E_{SC} - E_{SC,0}}{\eta_{inv}} \tag{5}$$

The amount of electricity sold to the grid is what remains from the PV production after removing the self-consumed energy flows:

$$E_{WithGrid} = \eta_{inv} \left(\cdot E_{PV,DC} - E_{SC,DC,0} - \frac{E_{FromBat}}{\eta_{bat}} \right) \tag{6}$$

From the above equations, it appears that all the yearly energy flows can be deducted from the relative battery size and from the SSR function. They can then be used to evaluate the profit (or losses) originating from the investment in a storage system.

The investment in the battery system is taken into account as a constant annuity:

$$A = I_{bat} \cdot (CRF + OM) \tag{7}$$

where A is the annuity and I stands for investment. It is assumed that there is a second investment in the battery after N_{bat} years. OM is the fraction of annual operation and maintenance. CRF denotes the capital recovery factor calculated by:

$$CRF = \frac{i \cdot (1+i)^{N_{bat}}}{(1+i)^{N_{bat}} - 1} \tag{8}$$

where i is the weighted average cost of capital (WACC) and N_{bat} is the battery system lifetime in years.

The benefits of the storage system are equal to the difference between the electricity exchanged with the grid, with or without battery, multiplied by the selling/buying electricity price differential. The profitability rate is defined as:

$$PR = \frac{E_{Stored} \cdot \Delta P_{sell/buy} - A_{bat}}{E_{Load}} \tag{9}$$

where A_{bat} denotes the annuities linked to the battery investment and re-investment (cfr. Eq. 7). $\Delta P_{sell/buy}$ is the price difference between buying and selling electricity from/to the grid.

4.4 Model inputs and parameters

The final model inputs selected for the present simulation are summarised in table 1

Table 1: Main model hypotheses

Variable	Unit	Battery
Lifetime (N)	years	10
Round-trip efficiency (η_{bat})	%	92
Inverter efficiency (η_{inv})	%	96
Investment (I)	EUR/kWh	200
O&M	EUR/year	$1.5\% \cdot I$
Discount Rate	%	4

A very sensitive parameter is the specific cost of the battery system. According to [6], a yearly drop of 8% can be expected, starting from EUR 1167/kWH in 2015. This would yield a cost of EUR 168/kWh by 2030. In [7], a cost of EUR 150/kWh is predicted for 2030 for the battery pack (i.e. not including installation and balance of plant). In this work, a value of EUR 200/kWh is selected as a conservative hypothesis.

5. Influence of the incentives for self-consumption

The incentives for self-consumption are largely linked to the local regulations, such as the tariff structure, the level of taxation, the grid fees, the presence of capacity-based grid fees, of taxes on self-consumption etc. In this analysis, this diversity is summarised into a simple numerical indicator, i.e. the price difference between buying and selling electricity for prosumers. This indicator can realistically vary between 0 (i.e. no incentive for self-consumption) to the value of the retail price in the given country (thus assuming that the selling price is zero).

Figure 5 shows the optimal deployment of battery storage as a function of the incentives for self-consumption. Each point of the curves results from an optimization in which the profit of the prosumers (Eq. 9) has been maximised using a non-linear optimization algorithm (Nelder-Meade method). The vertical lines indicate the projected retail prices of electricity in each country by 2030. They can be considered as a maximum value for the incentives each country can provide for self-consumption.

Figure 5 indicates that for low incentives (differential lower than EUR 80/MWh), investment in battery storage is not profitable. The value of self-consumption corresponds to the value of a typical PV system without storage (aroung 30%). Increasing the incentive leads to a higher optimal storage capacity and to higher self-consumption rates, although the latter seem to saturate around 70%. Countries such as Germany and Denmark have high retail prices of electricity and could therefore possibly be of high interest for battery self-consumption. It should finally be reminded that the vertical bars correspond to a theroretical maximum, each member state being free to set the cursor of self-consumption incentives between 0 and this maximum, by adusting the tariff structure, the fixed grid costs, or the taxes on self-consumption.

Figure 6 presents the same analysis as before, but in the hypothesis in which the battery costs remain high (a cost of EUR 600/kWh is assumed). In this case, battery storage can only be profitable in the few countries with high retail prices, and in the case in which the incentives for self-consumption are high.

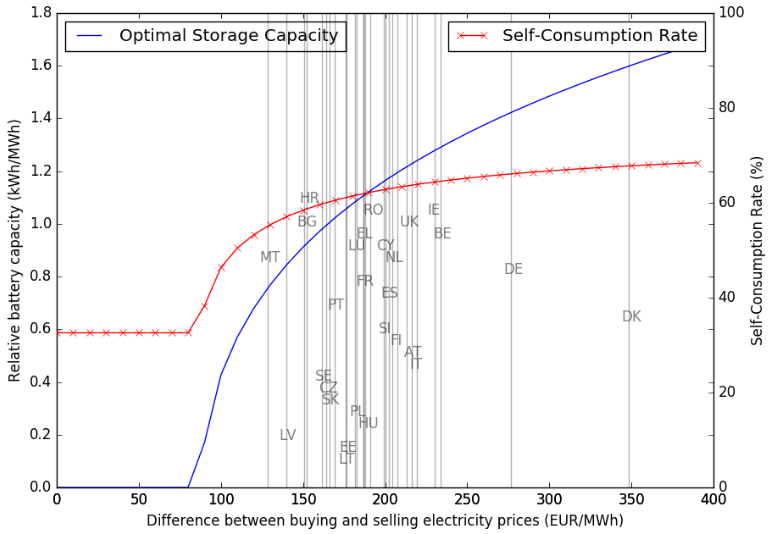

Figure 5: Influence of the incentives for self-consumption (seen as the sell/buy price differencial) on the deployment of storage and on the overall self-consumption level. The vertical lines indicated the projected retail prices of electricity in each EU country by 2030

6. Levels of self-consumption in various scenarios

The optimization of the battery capacity presented above is repeated for each country in the two considered scenarios (reference scenario and EUCO 40/27/27 scenario). The cases with no incentives for self-consumption and high incentives are differentiated by setting the price differential to zero and Pretail, respectively.

The following indicators are computed:

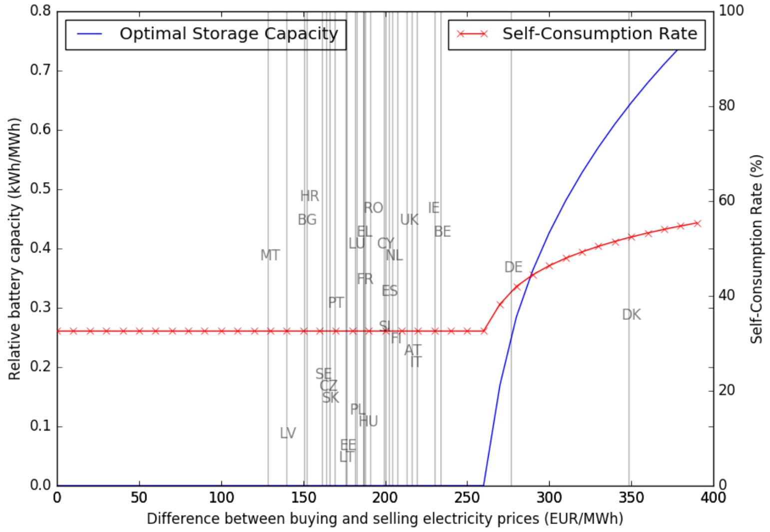

Figure 6: Influence of the incentives for self-consumption (seen as the sell/buy price differencial) on the deployment of storage and on the overall self-consumption level. The vertical lines indicated the projected retail prices of electricity in each EU country by 2030. Battery cost is assumed to be EUR 600/kWh.

- Total PV Capacity (GW): Installed PV capacity in each country and for each scenario
- Total PV Generation (GWh): Yearly PV generation in each country and for each scenario
- Rooftop PV Generation (GWh): Yearly PV generation, limited to rooftop
- Battery Capacity (MWh): computed optimal battery capacity to maximize the profit
- Profit (EUR/MWh): Self-consumption profit compared to the case without storage
- SCR (%): Self-consumption rate in the case of high self-consumption incentives
- Total self-consumption (GWh): Total self-consumption in the case of high self-consumption incentives
- Total self-consumption without battery (GWh): Total self-consumption in the case of low self-consumption incentives
- Avoided exchanged with the grid (GWh): Decrease in the total yearly energy exchanged with the grid due to the use of storage

A sample of the simulation results is provided in Table **??**. For the sake of clarity, the tables comprising the detailed simulation results are included as electronic annex of this report in the form of excel sheets.

7. Conclusions

The future deployment of batteries for self-consumption is subject to two main conditions:

- The decrease in battery costs should remain steady in the coming years
- Local regulations should provide sufficient (direct or indirect) incentives for self-consumption

Self-consumption incomes largely depend on the amount of the indirect subsidies originating from the tariff structure. Countries with high retail prices of electricity are particularly interesting because of the high difference between buying and selling prices. In a case of high incentives, it can be expected that self-consumption roughly doubles in most EU countries compared to the case without incentives.

Because incentives for self-consumption can be seen as an exemption on taxes and grid fees, scenario of high penetration of self-consumption might lead to an unfair distribution of network charges, taxes and levies, to which self-consumers contribute less. Member states

Table 2: Yearly Energy flows (in GWh) in the two considered scenarios: PV generation, Self-consumption (low hypothesis) and Self-consumption (high hypothesis)

	Reference scenario			EUCO scenario		
	Gen_{PV}	SC_{low}	SC_{high}	Gen_{PV}	SC_{low}	SC_{high}
AU	3312.18	450.18	879.782	6466.96	708.327	1384.28
BE	4012.93	1257.2	2488.84	6732.11	1783.62	3530.97
BG	3322.96	342.658	615.006	4024.38	358.675	643.752
CP	978.671	87.5889	168.574	1029.63	103.24	198.697
CZ	2276.24	536.462	987.413	2517.99	598.609	1101.8
DK	768.107	257.308	534.87	768.107	257.308	534.87
ES	0.839018	0	0	0.839018	0	0
FI	14.2475	3.20402	6.21505	14.2475	3.20402	6.21505
FR	41048.3	9702.49	18435.6	47817.5	11097.9	21087
GE	60511.6	11250.2	22803.6	75783.5	13444.6	27251.6
GR	9251.72	1571.35	2984.67	12161	1955.82	3714.94
HR	974.321	120.482	216.917	1803.48	185.223	333.477
HU	96.7082	21.9451	41.7404	1873.24	306.903	583.742
IR	15.55	2.25769	4.45897	15.55	2.25769	4.45897
IT	33957.4	7843.49	15369.2	52012.8	9949.1	19495.1
LA	1.56565	0.473015	0.828272	1.56565	0.473015	0.828272
LI	63.6917	19.0258	35.6477	63.6917	19.0258	35.6477
LX	122.048	39.0959	73.7949	320.041	94.0498	177.522
MA	350.743	72.5216	122.504	369.18	72.5216	122.504
NL	5004.28	1500.01	2901.38	5304.22	1586.61	3068.88
PD	84.3486	16.2825	30.7752	84.3486	16.2825	30.7752
PL	4147.2	616.871	1144.63	4905.95	633.134	1174.81
RO	2770.28	116.393	222.145	4051.42	315.729	602.592
SK	619.236	38.8437	71.715	619.236	38.8437	71.715
SN	848.893	150.548	276	1484.7	228.377	418.684
SP	35203	3062.54	5911.78	51028.1	3132.04	6045.94
SV	74.9543	23.2875	44.8792	74.9543	23.2875	44.8792
UK	8985.42	909.628	1773.29	8985.42	909.628	1773.29

should therefore carefully balance the opportunity to incentivize self-consumption over alternative technologies contributing to power system flexibility such as grid reinforcement, centralised storage, dispatchable power plants or demand side management.

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