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Photovoltaic Electricity Cost Maps

H. Ossenbrink, T. Huld, A. Jäger Waldau, N. Taylor

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Institute for Energy and Transport

Contact information

Nigel Taylor
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 450, 21027 Ispra (VA), Italy
E-mail: nigel.taylor@jrc.ec.europa.eu

<http://www.jrc.ec.europa.eu/>

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1. Introduction

The PV industry has experienced a compound annual growth rate (CAGR) of over 50% over the last 10 years, accompanied by a four-fold reduction of costs. In Europe, approximately 69 GW of installations provide (2012) already about 2.4% of Europe's electricity needs. To implement the Renewable Energy Directive, Member States committed in their National Renewable Energy Plans (NREAP) to install by 2020 a PV capacity of 84 GW. It is likely, that this objective will be already achieved in this year. The JRC PV Status Report 2013 (in production) will show that global PV cell production in 2012 varied between 35 GW and 42 GW. The uncertainty in these data is due to some companies' unwillingness to share data in highly competitive market and to different reporting practices.

The costs of electric energy at the output of a PV module have dropped to less than 0.05 EUR/kWh¹, making it currently the lowest cost new technology for electricity generation. However, the largest cost component in comparison with conventional electricity generators is to get the power from the module to where it is needed, and when it is needed. Therefore, new, innovative and cost effective overall electricity system solutions for the integration of PV electricity are essential to realising the vision of PV as a major electricity source. The second largest cost component which adds to the final electricity cost is the capital cost for the investment.

To highlight the implications of the recent reduction in PV prices, the JRC has performed a short study in which we compare generation costs for roof-top systems with prices for household electricity (retail prices). The method used and the results are described below.

2. Levelised Cost of Electricity for Photovoltaic Systems

2.1 LCOE Calculation

The "Levelized Cost of Energy" (LCOE) is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel and cost of capital. It can be calculated in a single formula as:

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

Where I_t = Investment expenditures in year t , M_t = operations and maintenance expenditures in year t , F_t = fuel expenditures in year t , which is zero for photovoltaic electricity, E_t = electricity generation in the year t , r = discount rate and n = investment period considered in years.

¹ PV modules can be purchased in July 2013 for 800 € / kW, and in average European sun conditions of 1000 kWh / kW / year can produce 20,000 kWh in 20 years (the typical minimum performance warranty period). The direct costs at the cable connection of the module, within this timescale would be 800 € / 20000 kWh = 0.04 € / kWh. Clearly, this does not include financing costs, mounting, conversion of the module's electricity to alternating current and costs for operation and maintenance. These would raise the actual electricity cost to about 0.18 € / kWh. The above 0.04 € / kWh value underlines the progress made in material physics and manufacturing of solar cells. There are a number of specific applications for PV, such as water pumping or desalination, where the electricity cost could be very close to this lowest figure.

For the purposes of this study the following assumptions were made:

- A system price of 1 700 EUR/kWp for a rooftop system of less than 25 kWp
- 5% cost of capital (discount rate in the formula above): this value was chosen arbitrarily to be somewhat above what a private investor could currently expect from an investment of comparable duration in government bonds, but analysis of this risk premium is beyond the scope of this study.
- 20 years of financial lifetime: this value corresponds to the current minimum performance duration warranty offered by module manufacturers
- O&M costs are fixed at 1.5% of the capital cost.
- The annual energy yield (kWh per kWp installed) is taken for each location using the JRC's PV-GIS on-line tool.

The calculations were made with the algorithm used by the National Renewable Energy Laboratory (NREL)² which is fully consistent with the JRC SETIS LCOE calculator or the BNEF method³.

The above approach provides the LCOE of a given generator and is strictly appropriate only when the electricity can be used directly at source i.e. self-consumption. It does not fully describe the cost in the context of the overall electricity supply system, since profile cost (including flexibility and utilisation effects), balancing costs and grid costs are not considered. These categories are applicable of all electricity generators in the system, whether they are conventional or renewable energy sources, and leads to a "system LCOE" for each generator. This issue is further discussed in the JRC's 2013 PV Status Report.⁴

The PV Status Report also provides more detail on the cost elements in the calculation and the sensitivity to the return on investment (ROI) value. To illustrate the former, Table 1 shows the cost breakdown for an ROI of 5% at a location with an annual insolation level of 1 000 kWh/kWp. Financing is already the largest single cost factor, and together with fees and permitting costs, contributes one third of the electricity generation costs from such a PV system over the financing period of 20 years (Fig. 1).

The module is the second largest contributor, but in this example contributes to just 19% of the LCOE (and 35% of the system cost). This underlines the need to also target the whole range of technological and non-technological items for further significant cost reductions to maintain the high growth rate of the industry. These "soft costs" mainly consist of financing and permitting costs, as well as installer/system integrator margins.

Operation, maintenance and repair costs (O&M) are the third largest cost factor. At 2.5 EURct/kWh these cover the foreseeable repairs and exchange costs of components like the inverter, as well as the annual degradation of the solar modules as specified by the manufacturers. O&M costs have a special significance in relation to operation beyond the period of 20 years used to pay back the initial capital investment in this model. If one adds a conservative "safety" margin of 1.5 EURct/kWh on top of the 2.5 EURct/kWh used over the financing period, a highly attractive electricity price of 4.0 EURct/kWh is obtained.

² http://www.nrel.gov/analysis/tech_lcoe_documentation.html

³ Bloomberg New Energy Finance, Levelised cost of electricity update: Q2 2013

⁴ A. Jäger-Waldau, PV Status Report 2013, EUR 26118 EN, Publication Office of the European Union, ISBN 978-92-79-32718-6 (pdf), September 2013

Table 1: LCOE of PV generated electricity for residential systems with a system price of 1 700 EUR/kWp ex. VAT, 1.5% operation, maintenance and repair (O&M) cost, an annual generation of 1 000 kWh/kWp/y installed and financial lifetime of 20 years.

Item	Contributions to LCOE				LCOE Total [EURct/kWh]
	Cost [EUR/kWp]	Item [EURct/kWh]	Capital for ROI 5% [EURct/kWh]	O&M 1.5% [EURct/kWh]	
PV Module	600	3.00	1.60	0.9	5.5
Inverter	150	0.75	0.35	0.2	1.3
Balance of Systems	420	2.10	1.10	0.6	3.8
Engineering Procurement & Construction	370	1.85	0.95	0.6	2.8
Other (fees, permitting, Insurance..)	160	0.80	0.40	0.2	1.4
Total	1,700	8.50	4.40	2.5	15.4

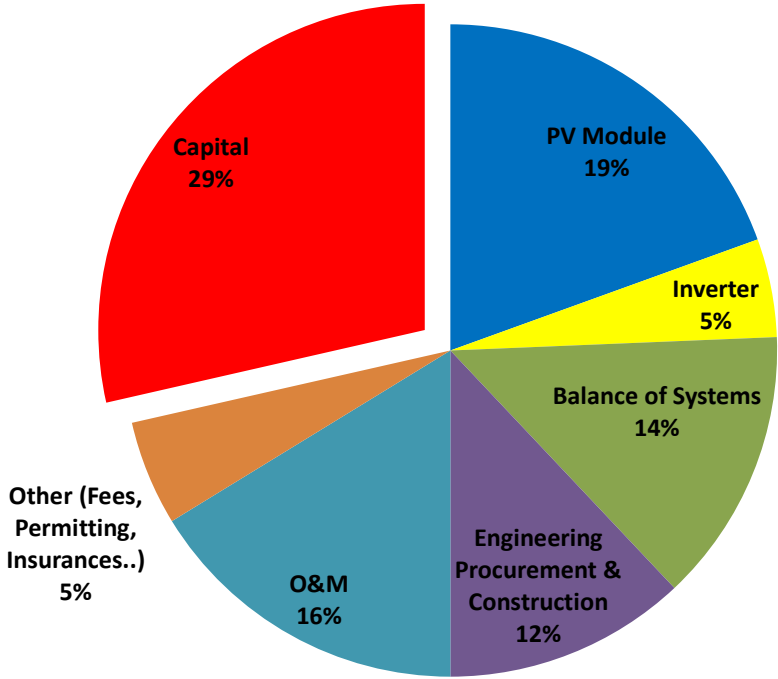


Fig. 2: LCOE cost breakdown for locations generating 1,000 kWh/kWp/y

2.2 PV LCOE Distribution in Europe

Using the approach described above, LCOE values for each 10 km x 10 km grid-cell (the resolution of the insolation database in PVGIS) over all of Europe can be calculated as shown in Fig. 1.

The values range from a minimum of 0.08 EURcts/kWh in southern Mediterranean to 32 EURcts/kWh in the most northern regions. This takes into account only the differences in annual insolation. The impact of variations in other parameters in the LCOE calculation (such as interest rates or system costs) from country to country or from region to region is beyond the scope of the current study.

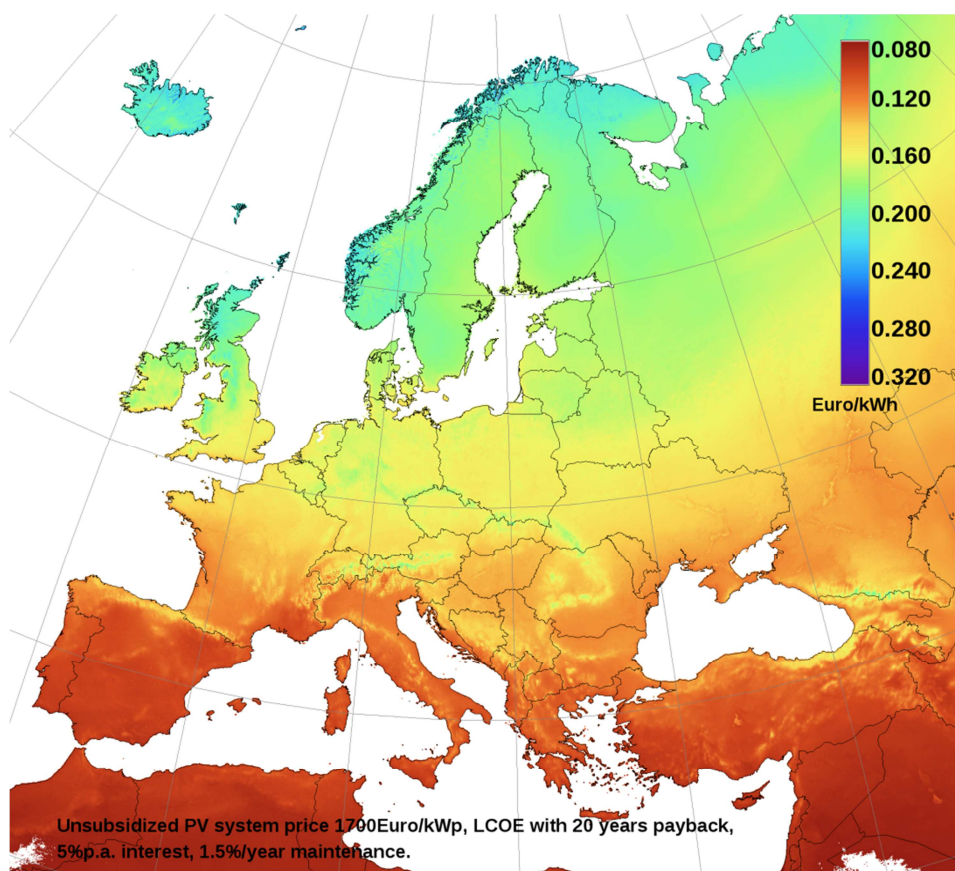


Fig. 1 Distribution of the levelised cost of PV electricity in Europe.

3. Comparison of PV LCOE with Retail Electricity Prices

3.1. Results

The analysis is based on a straightforward comparison between the PV LCOE value for each 10 km x 10 km grid-cell in Europe (as described above) and the residential electricity price. EUROSTAT provides electricity prices in the EU member states, for industrial and residential users, and with and without taxes. Here the data for 2012 for residential users including taxes are used (see Table 2).

Fig. 2 maps the results of subtracting the PV LCOE from the household retail price. The colour scale is the difference in Euro: red colours indicate that the PV LCOE is less than current residential electricity and blue the reverse.

As an example, in Vienna the electricity retail price in 2012 for households was 0.202 EUR/kWh, while the LCOE for a PV system costing 1 700/kWp is 0.154 EUR/kWh, resulting in a difference of -0.048 EUR/kWh in 2012.

This comparison does not include any incentive or subsidy scheme for the PV system. However it does assume cost-free exchange with the grid i.e. net metering, whereby the electricity meter runs "backwards" during sunny hours, and forward while consuming electricity during bad weather and at night-time. No such scheme is currently available in the EU.

At this EUR 1 700/kWp level, the PV LCOE is still above the retail electricity price in FI, ES, LT, LI, RO and BU, as well as for some less sunny parts of UK, F, PL and CZ. In the other Member States the population benefit from a situation where the PV LCOE is below the residential electricity price. As shown in Table 2, this amounts to 57% of EU citizens.

3.2. Discussion

The maps shows those locations where either a pricing for a feed-in tariff can be lower than the household electricity price (colours from white to red), or where some form of subsidy would be required to provide an investor with a sufficient rate of return on a PV system investment (colours from white to blue).

In favoured locations, with colours from yellow to red, the price difference could be used to invest into local battery storage. The advantage of such local storage is on one hand to relieve the grid distribution system from excessive PV supply, as it is the case during sunny weekends and holiday periods, and on the other hand to allow the PV owner to increase self-consumption at a net cost below the retail electricity price.

One can also identify locations where a "stand-alone" PV system could be cost effective; that is either single user or mini-grid systems which can either be disconnected from the grid or are entirely independent of it. Such a calculation depends strongly on battery prices, and as these are expected to decline in the coming years, the maps provide also an useful tool for designing and operating smart-grid systems.

Table 2 EUROSTAT data for retail electricity prices and for EU Member States and populations

EU Member State	Residential electricity price, EUROSTAT 2012 EUR/kWh	Population	PV LCOE < electricity price (see Fig. 2)	Population with PV LCOE < electricity price
AT:Austria	0.2024	8443018	Y	8443018
BE:Belgium	0.2223	11094850	Y	11094850
BG:Bulgaria	0.0955	7327224	N	0
CY:Cyprus	0.2909	862011	Y	862011
CZ:Czech Republic	0.1501	10505445	N	0
DE:Germany	0.2676	81843743	Y	81843743
DK:Denmark	0.2972	5573894	Y	5573894
EE:Estonia	0.1123	1294486	N	0
EL:Greece	0.1418	11290067	Y	11290067
ES:Spain	0.2275	46196276	Y	46196276
FI:Finland	0.1559	5401267	N	0
FR:France	0.1450	65327724	N	0
HR:Croatia	0.1384	4398150	Y	4398150
HU:Hungary	0.1557	9932000	Y	9932000
IE:Ireland	0.2289	4582707	Y	4582707
IT:Italy	0.2297	59394207	Y	59394207
LT:Lithuania	0.1268	3003641	N	0
LU:Luxembourg	0.1706	524853	Y	524853
LV:Latvia	0.1369	2041763	N	0
MT:Malta	0.1700	417546	Y	417546
NL:Netherlands	0.1895	16730348	Y	16730348
PL:Poland	0.1529	38538447	N	0
PT:Portugal	0.2063	10542398	Y	10542398
RO:Romania	0.1075	21355849	N	0
SE:Sweden	0.2083	9482855	Y	9482855
SI:Slovenia	0.1542	2055496	Y	2055496
SK:Slovakia	0.1722	5404322	Y	5404322
UK:United Kingdom	0.1785	63456584	N	0
Total		507021171		288768741 (57%)

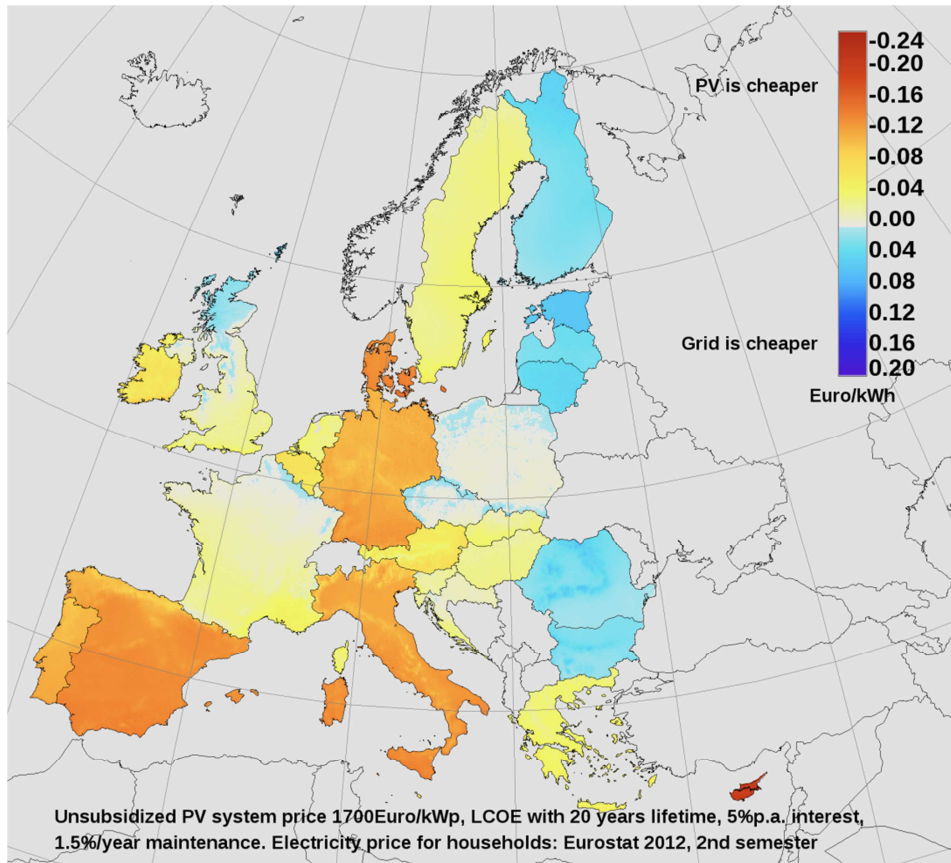


Fig. 2 Price difference between PV levelised electricity cost and household retail prices.

4. Conclusions

Maps have been generated comparing the levelised cost of PV electricity with residential prices in European countries. The analysis assumes that full and free net metering but does not include any feed-in tariff or subsidy scheme.

On this basis and assuming a PV system price of EUR 1 700/kWp (considered representative in the EU residential market in 2013), the PV LCOE is equal to or less than residential electricity prices for more than half of Europe's population.

For a more rigorous assessment of the margin between PV LCOE and the residential electricity price at any location, it would be necessary to consider a range of factors, including interest rate and system price variations, self-consumption patterns and grid access mechanisms. A detailed study of these is beyond the scope of the present report.

For those locations where the PV LCOE is less than the residential electricity price, the price margin may be diminished by a "system LCOE" cost, i.e. the additional costs for any generator accessing the grid. Part of the difference could however be used to invest into local battery storage. The advantage of such local storage is on one hand to relieve the grid distribution system from excessive PV supply, as it is the case during sunny weekends and holiday periods, and on the other hand to allow the PV owner to increase self-consumption at a net cost below the retail electricity price.

These results have several implications for the further development of the photovoltaic solar electricity.

- With increasing shares of PV electricity in the grid, the economics of integration becomes more and more important and it is urgent to focus the attention on issues such as:
 - Development of new business models for the collection, sale and distribution of photovoltaic electricity, e.g. development of bidding pools at electricity exchanges, virtual power plants with other renewable power producers and storage capacities.
 - Adaptation of the regulatory and legal procedures to ensure a fair and smart access to the electricity grid and market.
 - Development of an appropriate smartgrid and ICT infrastructure.
- To maintain the high growth rate of the industry, different technology pathways have to be pursued at the same time. The LCOE breakdown example shows that the cost of modules in a PV system has declined below 40% of the system cost for a residential system, so non-technology costs have to be targeted for further significant cost reductions.
- In countries where PV contributes already to more than about 5% of annual electricity production, it can be observed that the grid operators have difficulties in matching demand to supply. The extent depends on availability of local storage, back-up capacity and the demand pattern. Therefore measures will be increasingly required to manage such situations. An example would be capping grid access at some fraction of nominal power, i.e. if the PV generated power exceeds this limit, it cannot feed into the grid. This would be expected to stimulate market solutions to utilise the excess power, for instance by introducing battery systems which would favour self-consumption, as well as opening the possibility to store electricity and sell it back into the grid when the demand is higher.

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Author(s): H. Ossenbrink, T. Huld, A. Jäger-Waldau, N. Taylor

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Abstract

The study assesses the generation costs for residential photovoltaic systems and prices for household electricity. The results are presented as maps comparing the levelised cost of PV electricity with residential prices in European countries. The analysis assumes net metering but does not include any feed-in tariff or subsidy scheme. On this basis the PV LCOE is now below the residential electricity price for more than half of Europe's population. These results have several implications for the further development of the photovoltaic solar electricity.

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