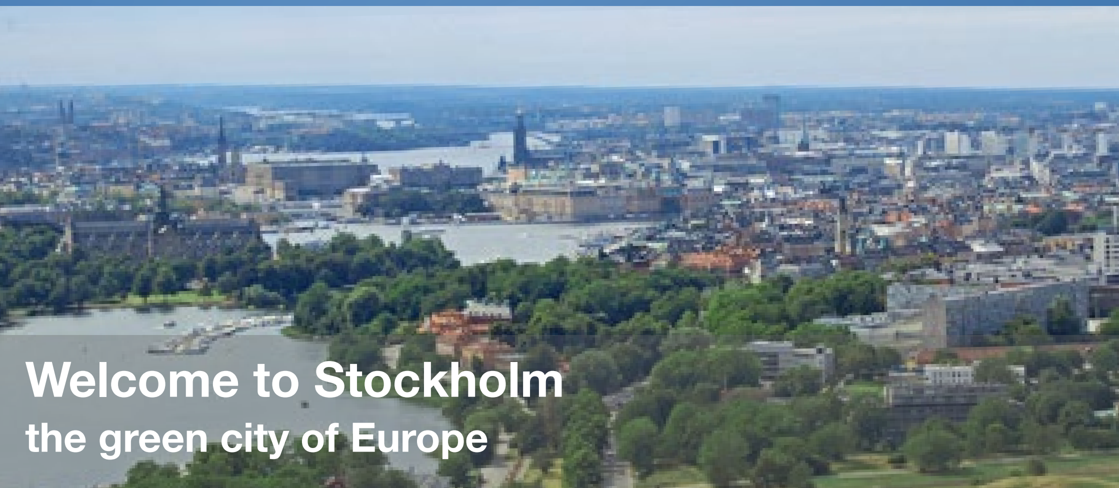
10th International Conference on the European Energy Market

27 - 31 May 2013, Stockholm, Sweden



PV COMPETITIVENESS AND PV SUPPORT SCHEMES – ECONOMIC EFFECTS OF RENT SEEKING

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***Abstract*-- In recent years, market shares of electricity generation from photovoltaics (PV) have been growing continuously. This boom in the PV market was mainly caused by previous and current support schemes, especially in Germany. As a result of that, significant cost decreases of the PV technology have been observed (technological learning). This leads to an increasing competitiveness of PV generation in comparison to remaining electricity generation technologies [1]. In some European countries current or in the next coming years in the residential and commercial/industry sector PV is competitiveness. PV competitiveness in this context means that the investment in a PV system is economic without any support schemes over the lifetime of the PV system. Despite this PV competitiveness in some European countries, policies strategies follow the funding of PV with different support schemes in the future. Most of these funding strategies guarantee a fixed remuneration of up to 20 years. Nowadays the PV industries ensure a module lifetime over 25 years and efficiency decreases at a maximum rate of up to 20% during 25 years. Also the inverter producers guarantee functionality of up to 25 years and in case of a converter exchange, this exchange is ensured and no additional costs incurred.**

***Index Terms*-- Dynamic Modeling, Levelized Cost of Electricity Generation (LCOE), Photovoltaics (PV), PV Competitiveness, Support Schemes**

I. INTRODUCTION

The significant cost decreases of the PV technology in the last years (technological learning) leads to an increased competitiveness of PV generation in comparison to remaining generation technologies (both conventional and renewable) if levelized cost of electricity generation (LCOE) are used as a benchmark. In general, LCOE describe the economics of a technology on an aggregated level (i.e. annual basis) only. Due to the variable/intermittent characteristics of PV electricity generation (e.g. day/night characteristics), however, different challenges have to be taken into account when integrating the PV technology into electricity systems where electricity generation and demand have to be met simultaneously at each point in time. Nonetheless, the gradient of LCOE development of PV generation is expected to open a wide range of different applications of this technology in different market segments in the future. In this context, the household customer always has been playing an important role when considering the implementation of decentralized PV technologies. And as a consequence of that, already in the past the retail electricity price (i.e. the end-users electricity bill/statement) always has been some comparative parameter of the LCOE of PV generation.

To implement non-economic power generation technologies in a first step into the energy system, support schemes are necessary to encourage these technologies to their future market maturity. In the last years the implementation of PV to the energy system was mainly driven by different national support schemes like fixed Feed in Tariffs (FiT), Green-Premium Tariffs and/or investment subsidies. The PV market was growing very fastly in the last years and the cost reduction was significant, so that PV becomes more and more competitive in different European countries and market segments [2][3]. PV competitiveness in this context means that PV generation partially or completely replaces the current consumption. Thus, an economic comparison with the current retail electricity price (= generation costs & grid costs & taxes) is made. The conditions for the competitiveness of PV generation are then savings on end-users electricity bill by self-consumption and revenues through feeding PV generation into the grid. A calculation over the lifetime of a PV generation plant can then be performed considering the dynamic development of different parameters, such as. self-consumption, grid,exports and price development to derive the net present values (NPV) of revenues and cost of PV generation

Regarding revenues most of the current existing support schemes guarantee a fixed remuneration of up to 20 years. Nowadays the PV industries ensure a module lifetime over 25 years and efficiency decreases maximum up to 20% till 25 years. Also the inverter producers guarantee functionality up to 25 years and in case of a converter exchange, this exchange is ensured and no additional costs incurred. Despite to changing PV competitiveness in the residential and/or in the commercial sector in some European countries nowadays or in the near future, support schemes will be still offered.

II. METHODOLOGY

A. *Definition "PV Competitiveness"*

To determine the PV competitiveness, an economic cost comparison of a market participant with a PV system and a market participant without a PV installation is made. As a

The work was supported by the "European Commission" and is part of the program "Intelligent Energy Europe". Title: PV Parity [IEE/10/307/SI2.592205]

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basis for this economic cost comparison the "Levelized Cost of Electricity" (LCOE) is considered. For systems that primarily generate electricity to be consumed elsewhere, the LCOE is compared to electricity generation costs for several different power generation technologies. For a consumer, for example a household, the LCOE is comparable to the retail electricity price. For the calculation of future LCOE of PV technologies, a variety of different boundary conditions and assumptions for the future development of several important parameters (e.g. specific cost, efficiency, etc.) is required. To carry out the economic cost comparison, the development of future Wholesale-/Retail-Electricity-Prices must be considered.

B. *Mathematical Approach*

1) *Levelized Cost of Electricity for PV*

By calculating the "Levelized Cost of Electricity" (LCOE) can be the specific costs of a PV system in €/Wp, which are common in the PV industry, transform into the usual specific costs for the energy industry in €/kWh, see (1).

$$LCOE_{PVSystem,i} = \frac{CAPEX_i + OPEX_i}{EP_i} \qquad i = 1,2,...,N \tag{1}$$

$$CAPEX_i = C_{Invet} \cdot crf \qquad for\ i > n: CAPEX_i = 0 \qquad n \leq N \tag{2}$$

$$crf = \frac{WACC \cdot (1 + WACC)^n}{(1 + WACC)^n - 1} \tag{3}$$

$$WACC = \frac{E}{E + D} \cdot k_E + \frac{D}{E + D} \cdot k_D \cdot (1 - s_C) \tag{4}$$

$LCOE_{PVSystem,i}$	Levelized Costs of Electricity per year in €/kWh
$CAPEX_i$	CAPitel Expenditure per year in €
$OPEX_i$	Operational Expenditure per year in €
EP_i	electrical energy yield per year in kWh
C_{Invest}	Investments in €
crf	capital recovery factor
WACC	Weighted Average Cost of Capital
E	equity in €
D	debt in €
k_E	return of equity
k_D	return of debt
s_C	corporate tax rate
N	lifetime of the PV-System
n	depreciation time of the PV-System

2) *Calculation of annual cost of different "PV Parity" definitions*

The special load profile of households and the specific generation profile of PV systems (day-night characteristics and difference by irradiance-winter-summer) result in three different situations for the energy system of the prosumer (= producer and consumer):

1. <u>External procurement from the grid (term 1 in (5)):</u>
During the night there will be no PV generation, therefore the required energy must be imported from the grid. However with the use of storage technologies, the share of external procurement from the grid may be reduced or substituted. The cost of this external procurement is determined by the retail electricity price (including grid cost and taxes) as well as the savings due to self-consumption on household level (incl. storage of PV generated electricity).

2. <u>Self-consumption and storage (term 2 in (5)):</u>
By fluctuating PV generation during a day, the external procurement from the grid can be replaced partially or even completely by the PV generation. If the PV generation is higher than the load, the energy surplus can be fed back into the grid (see term 3 in (5)) or be saved, if a storage technology is available. The cost for their self-consumption without storage is determined by the LCOE of the PV system and the energetic self-consumption. If a storage technology is used, the LCOE of the PV system and the LCOE of the storage system should be considered general, leading to significantly higher LCOE of the combined PV and storage system. These higher LCOE and the resulting changes in self-consumption (additional reduction of the external procurement in the night) then determine the overall costs.

3. <u>Feed into the grid (term 3 in (5)):</u>
The higher the capacity of the installed PV power system, the higher is the maximum of the PV generation. If the PV generation is higher than the possible self-consumption or storage potential, the surplus PV generation is fed into the grid, assuming that this is always possible. By feeding into the grid revenues can be gained following the existing market price. Market prices can be fixed feed-in tariffs, green premium tariffs or the "wholesale" price. A reduction of the total cost of the energy system for the prosumer thus can only be achieved, if the LCOE of PV system or rather the LCOE of PV and storage system is lower than the available market price.

The net present values of annual cost of a market participant who had installed a PV system or alternatively PV and storage system is described in (5).

$$\begin{aligned} NPVof\ C_{PVSystem,i} = {} & p_{Retail,i} \cdot (Demand_i - Selfconsumption\,\&\,Storage_i) + \\ & + LCOE_{PVSystem,i} \cdot Selfconsumption\,\&\,Storage_i + \\ & + (LCOE_{PVSystem,i} - p_{Market,i}) \cdot Feedin_i \end{aligned} \tag{5}$$

$NPVof\ C_{PVSystem,i}$	Net Present Value of the cost of the PV system per year in €
$Demand_i$	annual electricity demand in kWh
$Selfconsumption\&Storage_i$	annual self-consumption and storage of the PV generation in kWh
$Feedin_i$	feed into the grid in kWh
$p_{Retail,i}$	annual retail electricity price in €
$p_{Market,I}$	annual market price of the feed into the grid PV generation in €/kWh

The net present value of annual costs for market participants without a PV system are calculated from the annual retail electricity price and the annual consumption, see (6).

$$NPVof\ C_{withoutPVSystem,i} = p_{Retail,i} \cdot Demand_i \tag{6}$$

Fig. 1, shows an example of the comparison of a typical household load profile compared to a PV generation profile for a summer day without additional storage technology. On winter days, the PV generation by the lower irradiation intensity and the shorter hours of sunlight is correspondingly low, so only a small share of PV generation can to be feed into the grid, see Fig. 2.

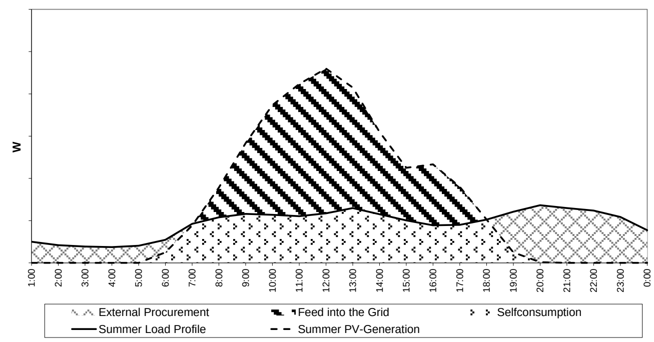

Fig. 1. Example of household electricity profile relative to the PV generation in the summer WITHOUT storage technology

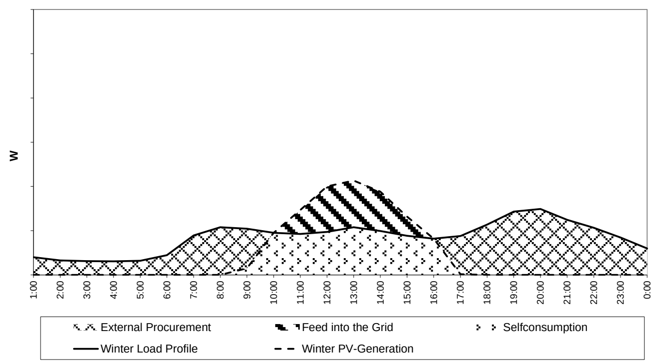

Fig. 2. Example of household electricity profile relative to the PV generation in the winter WITHOUT storage technology

C. *Monte Carlo Simulation of PV Competitiveness*

In order to model a possible range of different input parameters and finally to derive results for PV competitiveness on household level a Monte-Carlo simulation approach is used. All parameters are generated by specifying a mean value as well as a defined standard deviation of a normal distribution function (in this case derived by implementing 1000 values). Those different input parameters are divided in static and dynamic ones. The static parameters are constant over the lifetime of the PV system and also in the coming years, unless the PV system cost, the retail price and the market price are changing in the coming years with an annual dynamic parameters rate. An overview about all different input parameters for calculation of the future PV competitiveness for all target countries are shown in chapter 3.

III. Status Quo and Price Development

Due to the natural heterogeneity of the suns' irradiation, the evolvement of heterogeneous markets in Europe and thus widely varying electricity prices (retail and market prices = revenues for selling PV generated electricity) and of PV system prices in the analysed target countries, the starting point in 2012 for achieving PV competitiveness at household level is very diverging, see Fig. 3.

Fig. 3. Overview of the status quo 2012 of the retail price, market price, avg. energy yield and the avg. PV system costs for different European countries

The most important influence parameters for the dynamic PV grid parity are the PV system price, the PV system size (directly affects the share of self-consumption), the retail and the market price. Thus, the future development of these parameters, shown in Fig. 4 and for the Austrian case in Fig. 5, is the crucial factor regarding the time horizon for achieving PV grid parity in different European countries. Exception the PV system size is depending of the PV installer. Fig. 4 shows the assumption that the European PV market is harmonised to uniform PV system prices until 2018. From 2012 to 2018 in some target countries the PV system prices are lower as the experience curve for the PV. Therefore, the annual decreasing rate is different in the target countries and does not follow the experience curve, which is confirmed by the EPIA study "Solar Generation 6" [4]. After the harmonisation of the whole European PV markets the reduction of the PV system prices are following the experience curve, with a learning rate of about 20% (based on a worldwide cumulative installed PV capacity based on the "Accelerated" scenario from EPIA). The assumed development of the retail and market prices are based on historical data from the last decade. The annual average growth rate of the last years is extrapolated to the coming years and the energy economic singularity of each country is considered. For example the energy-turn ("Energiewende") in Germany will possibly affect (increase) the retail prices more significantly than the more or less static electricity supply situation in France, with a high share of nuclear power plants and non-existing discussions for changing this energy policy. Furthermore, the choice of the value of the different parameter for calculation of the LCOE of the PV system and the calculation of the PV competitiveness approach has a very large impact of the results (see e.g. [5]).

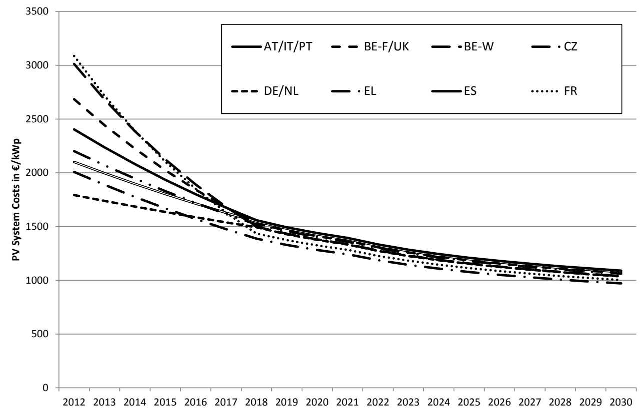

Fig. 4. Development of the future PV system prices in different European countries

IV. Modeling of PV Competitiveness

A. Parameter settings

Table 1 provides an overview of the different variable input parameters for calculation of the PV competitiveness.

For example in Fig. 5 and Fig. 6 the simulation results for the Austrian case illustrate the development of the bandwidth of LCOE of PV and the retail price and in Fig. 7 the distribution of the bandwidth of the share of self-consumption, PV system size and the Weighted Average Costs of Capital (WACC) are shown.

Table 1 Variable Input Parameters

Demand (kWh)	Income Tax (% of the Energy Income)
Sytem Lifetime (Year)	Capital Gains Tax (%/year)
Depreciation Time (Year)	Cost of Equity (%/year)
System Size (kW)	Share of Equity (%)
Efficiency annual decrease (%)	Debt Cost (%/year)
System Cost (€/kW)	Share of Debt (%)
Public Financing (€/kW)	WACC (%/year)
Connexion Cost (€)	Retail price Household (EUR/kWh)
Income Tax Credit (% of the Investment)	Market price Household (EUR/kWh)
Annual Cost of Insurance, Operation and Maintenance (% of the System Cost/Year)	
Decrease of the PV System Price Rate up to 2018 (%/year)	Average increase of the Electricity Market Price Rate (%/year)
Learning Rate of the PV System Price from the year 2018	Average increase of the Electricity Consumer Price Rate (%/year)

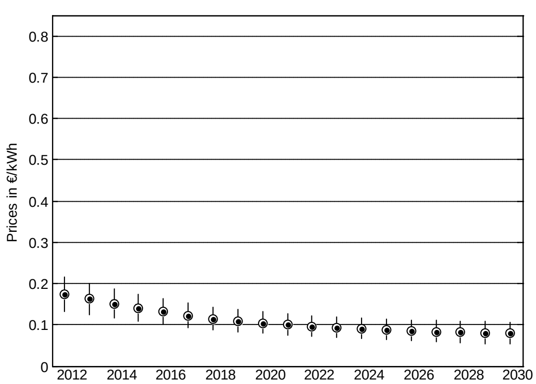

Fig. 5 Development of the bandwidth of LCOE in Austria

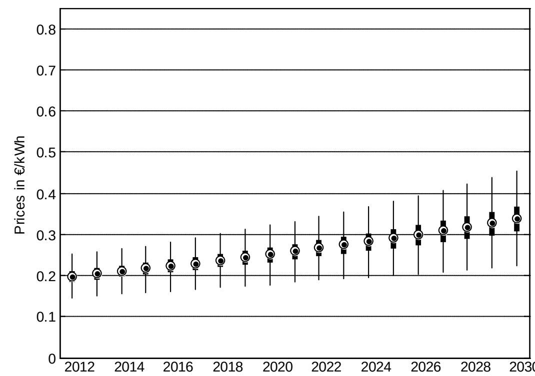

Fig. 6 Development of the bandwidth of retail price in Austria

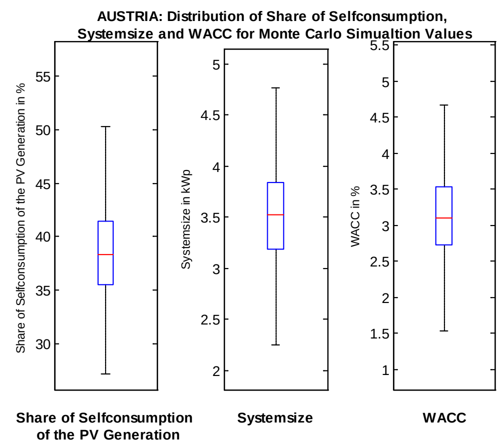

Fig. 7 Distribution of the share of self-consumption, PV system size and WACC for the simulation

B. Results

Fig. 8 shows the modeling results with the self-developed simulation tool MITHRAS for the Austrian case. The probability distribution when the economic trade-off criterion is fulfilled. Under the constraint that over 90% of the model runs achieve the PV competitiveness, for Austria the PV competitiveness in the residential sector is likely in 2015.

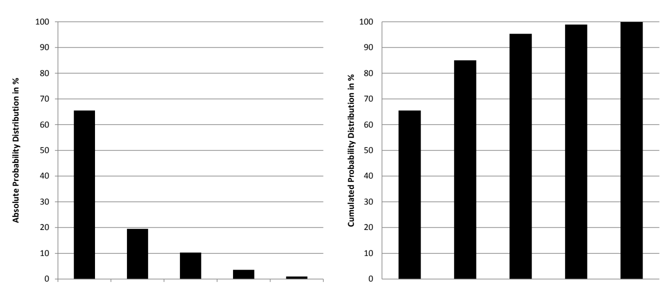

Fig. 8 Absolute and cumulated probability distribution when occur PV competitiveness in Austria

In accordance with the heterogeneity of the European electricity market, especially in case of retail prices, also the situation to achieve PV competitiveness in the different European countries is diverse. One important assumption for

the simulation of the PV competitiveness is that the PV system size is maximized for the share of self-consumption in order to address the best economic performance. The current trend is contra dictionary to that, as due to the current situation of high feed in tariffs the PV operators will maximise their profits with as large PV systems as possible.
An overview for different European countries and the calculated year for achieving PV grid parity in the residential sector are shown in Fig. 9.

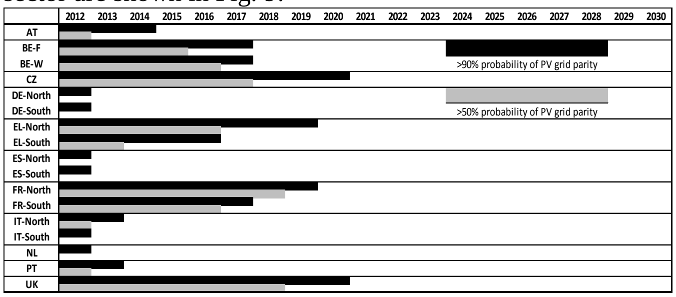

Fig. 9 Overview of achieving the dynamic PV grid parity in different European countries

V. PV COMPETITIVENESS AND PV SUPPORT SCHEMES

The main driver that made PV more and more competitive are support schemes. Due to the significant decrease of PV system costs and increasing electricity retail prices the PV competitiveness is already achieved or close to it mainly in countries with support schemes. How far these support schemes are still necessary or even enhance the profit margins of PV systems is shown by examples for different countries below.

A. Austria

In Austria the PV support scheme for the residential sector for systems up to 5kWp is based on an investment subsidy. Currently this investment subsidy is 800 €/kWp [8]. The analysis results with the simulation tool MITHRAS for different PV system sizes is shown Fig. 10. The implemented cost data for several PV systems account to 2600€/kWp for a 2 kWp, 2450 €/kWp for a 3.5 kWp and 2300 €/kWp for a 5 kWp system size. Yearly residential consumption is implemented at 3500 kWh. The operational and maintenance (O&M) costs are 25€/kWp/year, the inflation rate is 2.5%/year and a WACC of 4%/year has been chosen. The electricity retail price is 20 ct/kWh with an increasing rate of 3%/year. In Austria you can sell your PV generation surplus (feed into the grid) to the execution office for green electricity it is called "OeMAG" for around 5ct/kWh or to a local utility at an assumed 8 ct/kWh rate (fixed for 10 years and afterwards also to the OeMAG-Tariff for 5 ct/kWh).

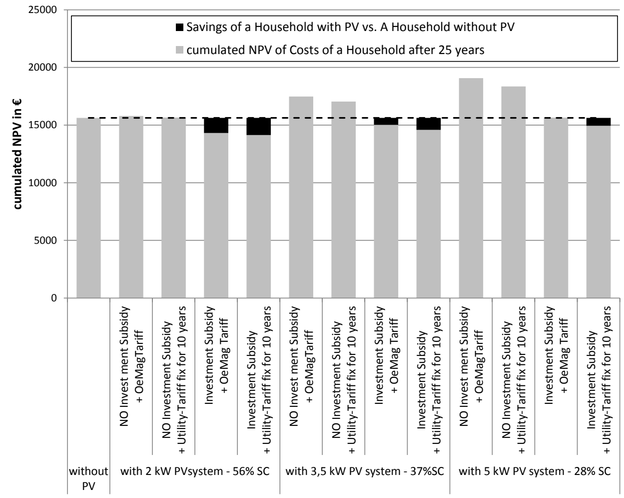

Fig. 10 Comparison of cumulated NPV of Costs of a Household with and without a PV system after 25 years in Austria

Fig. 10 shows that a 2 kWp PV system size with a high share of self-consumption (SC) is already economic without the investment subsidy. On contrary, a 3.5 kWp (SC~37%) and 5 kWp (SC~28%) PV system still needs the invest subsidy to be economic.

B. Germany

Germany's PV support scheme is based on a Feed in Tariff (FiT) for 20 years. The parameter settings for demand, O&M costs, WACC, inflation rate and increasing rate are the same as in the Austrian case. The PV system costs in Germany are one of the lowest in Europe due to the highly developed PV market and the PV boom driven by the FiT support scheme. The assumed PV system costs[1] are 1800 €/kWp for a for 2kWp, 3.5 kWp 1750 €/kWp, 5kWp 1700 €/kWp and 10kWp 1600 €/KWp. The limit of 10 kWp for households can be explained due to the average maximum roof size and the current maximum FiT of 16.59 ct/kWh for up to 10 kWp PV system sizes. If no FiT support scheme in Germany is assumed the PV generation which is fed into the grid is remunerated with an energy market (EM) price of 5 ct/kWh. The electricity retail price in Germany for households is assumed at 25.5 ct/kWh.
The model results in Fig. 11 show that Germany achieves the PV competitiveness in the residential sector. Here the 10kWp is not economic as of the low share of self-consumption or the high assumed PV system prices. In Germany there is no possibility to use PV generation for self-consumption if the household claimed the FiT. With this constraint the PV system becomes more economic with higher PV system sizes. This means that a FiT promotes no self-consumption but high PV capacities. From a technical point of view is this detrimental for the grid, because there is procurement and feed in at the same time.

[1] This assumed PV system costs are on the upper level in Germany.

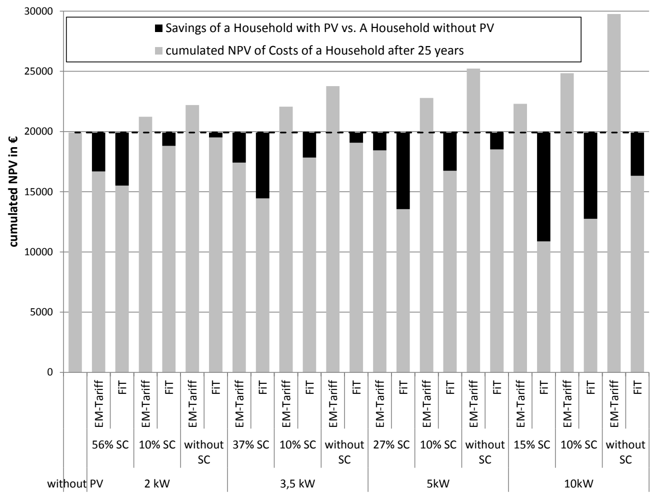

Fig. 11 Comparison of cumulated NPV of Costs of a Household with and without a PV system after 25 years in Germany

C. Italy

Italy prefers also like Germany a FiT support scheme. The difference to Germany is that Italy has two FiT schemes, one without self-consumption and another consodering self-consumption. The assumed PV system costs are the same as in Austria and for 10kWp at 2200 €/kWh. The electricity retail price is assumed at 20.1 ct/kWh and the energy market price is 6 ct/kWh for feeding into the grid. A FiT without self-consumption is between 19.6-20.8 ct/kWh and with self-consumption 11.4-12.6 ct/kWh depending on the PV system size.

Results show that the situation in Italy is almost the same as in Germany but even better for residential PV owners. Despite higher PV system costs in Italy has similar LCOE like Germany, because of the higher solar irradiation and thereby higher energy delivery. Another positive effect is the better correlation of PV generation and demand. Fig. 12 shows this effect on the right bar, where can be interpreted that a FiT without considering self-consumption maximize private profits as higher capacities lead to higher profits.

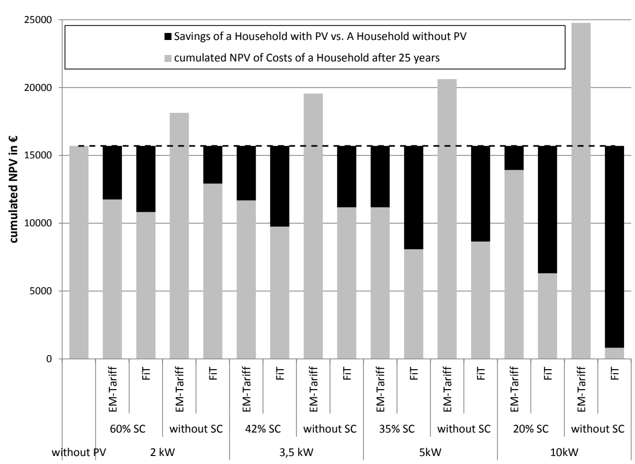

Fig. 12 Comparison of cumulated NPV of Costs of a Household with and without a PV system after 25 years in Italy

VI. Conclusion

Support schemes are necessary to enable the market entry of immature technologies and even more to lead to competitiveness in technology providing industries. PV achieves the competitiveness first of all as a decentralized electricity generation technology. The possibility that generation is used locally and may reduce household peak demand positive effects for the grid can be observed, especially in the southern regions of Europe. For larger PV system size without any self-consumption there will be no competitive in next couple of years and a supporting FiT is still necessary. How useful these large PV power plants are is matter of opinion. A future problem of PV to be competitive on the electricity wholesale market is the merit order effect of PV [9]. This effect reduces the PV competitiveness with a growing share of PV in the electricity system.

Investment subsidies do not burden future support schemes as FiT up to 20 years. An important factor is also the level of the FiT so there is no private profit maximizing and high rates of return. "Rent seeking" in this relation will be a future problem.

Self-consumption of PV generation leads to lower revenues for the grid operators and reinforcement of the grid can determine additional costs driven by PV. New market rules might be created and can postpone PV competitiveness but not stop.

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VIII. Biographies

Georg Lettner was born in Braunau (Austria), on May 9, 1978. He is an electrical engineer. Since February 2009 he has been working as a junior researcher at Vienna University of Technology, Energy Economics Group (EEG). His major fields of research are grid and market integration of DG/RES-E technologies and the development of tailor-made simulation software models.

Hans Auer was born in Schmirn (Austria) on March 26, 1969. He is senior researcher at Vienna University of Technology, Institute of Energy Systems and Electrical Drives - Energy Economics Group (EEG). He joined EEG in 1995. Hans' main research interests are electricity market analyses in general and grid and market integration policies of DG/RES-E technologies in this context in particular. In the last 16 years, Hans has been involved in many international and national projects in the renewable field for a variety of different clients.