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Autonomous Electricity Supply to German Households from Solar Photovoltaic Systems

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Abstract – *A kWh household electricity bill in Germany consists of about 60% of costs related with electricity transmission, distribution and taxes. Household has to pay grid access costs to the utilities when a house is newly built. Those costs could be avoided if a stand alone solar photovoltaic (PV) system is installed in order to fulfill the household electricity needs. This possibility has been analyzed in this paper. Daily and monthly average household electricity consumption trend has been analyzed and this, together with climate data, is used to design the PV system for Cologne, Germany. Detailed cost benefit analysis of the proposed PV system has been made. An experience curve has been extrapolated for the period 2006-2060 to project the time series PV module price decrease in the future and these values are used to calculate time series kWh PV electricity generation costs. Estimating 4% annual growth rate for grid electricity price, breakeven and grid parity years for PV system have been calculated. Results are compared with a scenario if there were no seasonal variations in available solar radiation and household electricity consumption pattern.*

Keywords – Breakeven analysis, experience curve, grid parity, seasonal variation, stand alone system.

1. INTRODUCTION

The world population highly depends on fossil fuel resources to fulfill their electricity demand. Only 3% of world electricity demand in 2006 was covered from renewable resources, the rest came from fossil fuels (68%), nuclear (14%) and large hydropower (15%) [1]. As fossil fuel prices have risen rapidly in the previous years (with an exception in recent years due to global financial crisis) and as concerns over greenhouse gases and global climate change have increased, renewable energy technologies for producing electricity are gaining more attention.

Solar radiation and other renewable energy resources are more equally distributed than oil, coal, gas, and uranium [2]. Hence, the transition from conventional sources to renewable sources for generating electricity in the future is inevitable. In addition to that, existing energy infrastructures, *i.e.* power plants, transmission lines and substations, and gas and oil pipelines, are all potentially vulnerable to natural and/or human disasters [3]. Borenstein [4] mentioned that power from central generation station requires significant investment in transmission and distribution infrastructure, investment that could potentially be reduced if more power were generated on site. Solar PV, especially the off grid types, is one of such technology that could be generated on site and hence is potential alternative to become one of sustainable energy resources of the future.

About 14% of German electricity has been generated from renewable sources by the end of 2007 [5]. However, solar PV still has a very small share of about 4% of total electricity generated from renewable sources. Other technologies such as wind-energy, bio-energy and hydropower come on top of it, with share of around 45%, 27% and 24%, respectively [1]. Nevertheless, it is expected that the application of solar PV system will increase rapidly in coming years. The price for solar PV systems have been decreasing every year because of their mass production, innovation, better efficiency, experiences of the industries, *etc*. The price decrease of solar PV system is about 20% for each cumulative doubling of its production [6]-[7]. It might be the case in near future that installing a solar PV system at own home premises could be cheaper than paying the regular electricity bills for using grid electricity plus paying the initial cost associated with grid access to house.

Germany is the world market leader for solar PV systems with an estimated cumulative installed capacity of 3.8 GW by the end of 2007 [8]. Out of all solar PV systems installed in Germany so far, about 99% are connected to the grids and only 1% is off grid types [9]. This shows that off grid system is relatively less popular. One of the obvious reasons behind this is that only the grid connected systems were addressed by feed in tariff scheme under German Renewable Energy Act. This situation has already changed and since the beginning of 2009, off grid systems also benefit from feed in tariff scheme. This might eventually help to spread more stand alone systems. Schmid [10] has suggested that solar PV systems are the most suitable solution for stand alone applications.

Electricity price for German household customer in January 2008 was 21.43 €ct/kWh [11]. Figure 1 shows the household electricity bill breakdown. It can be seen that the major part of bill does not fall under electricity production or wholesale price, but it falls under transmission, distribution and different taxes on

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electricity. If stand alone generation is opted, these major expenses of bill can be avoided. These avoided expenses can be used to invest in stand alone PV systems securing reliable and environment friendly electricity.

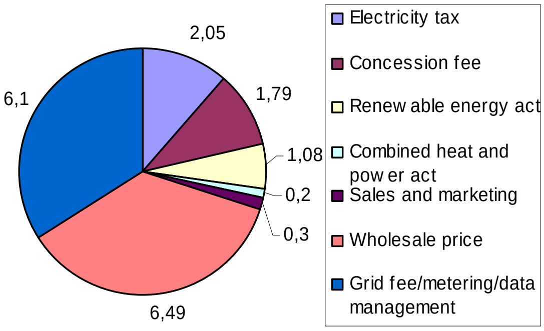


Fig. 1. Composition of German electricity bill.

An off-grid PV system, however, is not without any demerits. The first problem with having no grid is a need for electricity storage system because there is no coincidence in time of household electricity demand and time of solar PV electricity generation. The avoided expenses by avoiding grids have to be transferred to an electricity storage device, generally a big battery bank, to ensure the household supply in no sunshine hours. The second problem is a need for an oversized PV system due to seasonal variation in available global radiation in the countries like Germany, which lie at high latitude. As PV generator is the most expensive component of PV systems, it will increase overall system cost significantly, making a kWh electricity generation cost very expensive.

The question becomes, is it economically feasible to eliminate the grids (and hence to avoid grid associated costs) while allowing the need of storage system as a consequence of using stand alone solar PV systems? This question has been analyzed in this paper with the help of experience curve analysis and benefit cost analysis. For reference purpose, climate and economic data for Cologne, Germany, are used in calculations.

2. HOUSEHOLD ELECTRICITY DEMAND IN GERMANY

A reference household (four-person household) has an annual electricity consumption of 3,500 kWh [11]. In fact, household electricity consumption depends on a large number of factors such as, number of persons living, their usage habits, number of electrical appliances in use, *etc*. BMU [1] argues that a four person household that is well equipped with efficient appliances may nevertheless keep its annual consumption down to as little as 2,000 kWh. Figure 2 shows the daily electricity consumption profile of a reference household having an annual consumption of 3500 kWh [12]. Not surprisingly, there is seasonal variation in consumption profile, with the highest consumption in winter and the lowest consumption in summer times. Variation in consumption profile is high not only in different seasons, but also in different hours of a day. There are peaks in weekends, most likely this is because people stay at home and consume more electricity than in working days.

Figure 2 also shows the daily average solar radiation for Cologne (data were taken from PVSOL 2.6). If a household is supposed to be supplied with electricity from stand alone solar PV system, a big problem exists due to seasonal variations. In summer time, when there is high potential for PV electricity generation, household demand is less. On the contrary, in winter time, when household demand is high, potential for PV electricity generation is unfortunately very low.

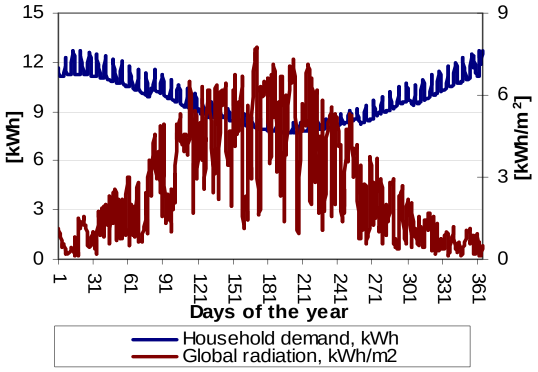


Fig. 2. Daily average household electricity consumption profile and daily average global radiation.

3. EXPERIENCE CURVE ANALYSIS

Experience curves describe how cost declines with cumulative production, where cumulative production is used as an approximation for the accumulated experience in producing and employing a technology. PV modules experience curve learning rate for the period before 1980 up to beyond 2015 will follow 20% [6]. Worldwide cumulative installed capacity of PV modules doubled more than ten times, from 95 kWp to over 950 MWp between 1968 and 1998, while costs were reduced by an average rate of 20.2% for each doubling [13]. If the progress ratios (PR) for PV modules are calculated for a single country, the results vary very much. Countries that have installed more PV capacity than average will show less favourable PR (*e.g.* case of Germany), because the price will decline with same pace in other countries, but the number of doublings will be higher than in average. Schaeffer *et al.* [7] found PR for PV modules around 90% for Germany, whereas the global PR was found in the range of 75-80%. For grid connected systems, they found the BOS experience curve sustained a progress ratio of 78% during 1992–2000. System oriented learning is equal to or even greater than that of module [13]. The similar results are found in a study from Wiser *et al.* [14].

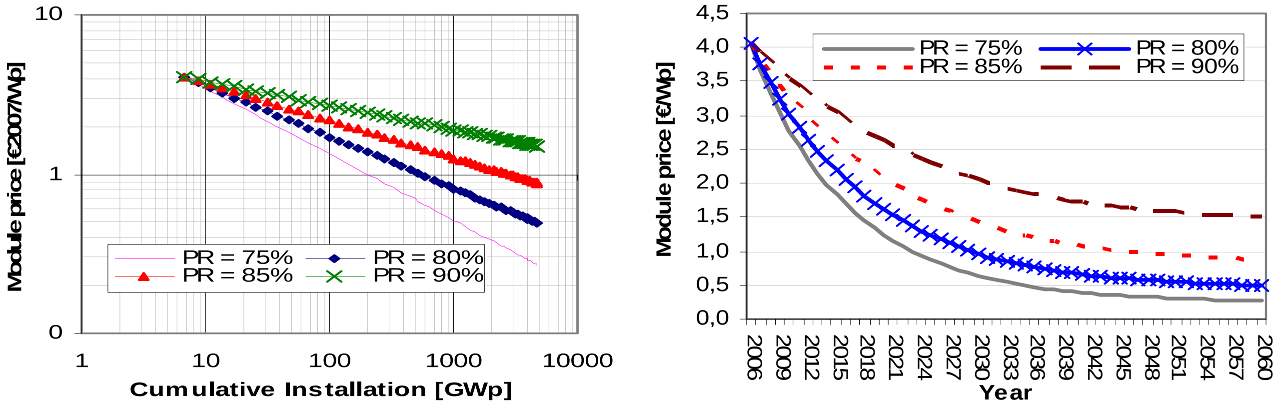
The learning at PV module level makes no distinction between global and local learning, since most of the module manufacturing is done by internationally operating companies and there is extensive exchange of scientific and technological information on module technology. This is why an experience curve for world module price has been extrapolated and the values are used in calculations for Germany in this paper.

In Figure 3, experience curves are plotted for different progress ratios (75%, 80%, 85% and 90%) and different annual growth rates for PV installations worldwide. For the calculations of economic analysis, a module price decrease at PR of 80% has been used.

4. ECONOMIC ANALYSIS

In this study, household energy demand is considered to be solely met by PV system. Solar PV system basically consists of two components – module and balance of system (BOS) components. BOS components include two cost intensive components *i.e.* batteries and inverters, as well as other accessories, *e.g.* charge controllers, cables, electronic components, system installation and management, *etc*. Equations for benefit cost analyses and breakeven analyses of proposed PV system have been developed and the following default values of variables (Table 1) are used in calculation.

Annual degradation in energy yield is not considered in the calculation, and it is thought to be compensated with the use of energy efficient devices in coming years. Effect of this degradation in imputed revenue is neglected to avoid complexity in the calculations. Avoided grid access cost as revenue can be excluded for the houses which are already connected to grids, but this must be considered for the new houses to be built. Other local factors such as value added taxes or any existing subsidy schemes that influence the investment in PV systems are excluded. No salvage value or disposal cost after system life time is over has been considered.



(a) (b)

Fig. 3. Experience curves for PV modules (2006-2060).

Table 1. Parameters default values.

Description	Value
Electricity demand, E_d (kWh/yr)	3500
Global radiation, G (kWh/m^2.yr)	994
Quality factor (performance ratio), Q (%)	40
Energy consumption days, D (days/yr)	365
Number of autonomous days, D_a (days)	4
Maximum depth of discharge, DOD (%)	80
Overall power conversion efficiency, η_b (%)	80
Module price, C_m (€$_{2007}$/kW$_p$)	3238
Balance of systems (BOS) cost factor (excluding battery), k_{bos} (%)	30
BOS replacement cost factor, $k_{mbosrpl}$ (%)	70
Battery price, C_b (€$_{2007}$/kWh)	100
Battery replacement cost factor, k_{brpl} (%)	100
Discounting rate, d (%)	4
Real interest rate, i (%)	6
Variable cost factor, k_v (%)	1
Electricity price from grid, p_{el} (€$_{2007}$/kWh)	0.2143
Annual Pel growth rate, gr (%)	4
Cost for grid access (up to 10 m), C_{ga} (€$_{2007}$)	1180
System life time, N (year)	25
BOS (excluding battery) replacement year, N_r (year)	12
Battery (lead acid type) life time, n_b (year)	5

System Sizing

Sizing of stand alone PV systems represents an important step in their design and basically, it can be done using analytical method or simplified method [15]. The analytical method needs relatively complex input data set for statistical analysis, but it gives the information about supply reliability. The level of supply reliability is expressed in terms of loss of load probability (LLP). LLP is the ratio of the energy deficit to the total energy demand for a period of time in question [16]. The zero LLP means 100% reliable supply. LLP affects the system size and thereby per unit electricity generation cost. If all the energy produced in the system is used either to satisfy the load demand or used in another application (*e.g.* supply into the grid), the unit cost of electricity is the least at *LLP=0* [17], but the unit cost varies considerably for different location with different climate and market data. However, if the excess energy after satisfying the load has to be dumped (the case of stand alone PV systems in most of cases), the unit cost of electricity is least at the particular LLP level, and not necessarily at zero LLP. For example, Celik *et al.* [17] have found this level between 0.16 and 0.21 for five different cities in Turkey.

Simplified method generally uses energy balance equation for the worst month (least production, highest demand) and average meteorological data [18]. However, designing the system for the worst month does not necessarily mean a LLP of zero, *e.g.* for Turkey, Celik [19] has calculated LLP value of 0.93 for a PV system with battery storage, whose design was based on worst month and corresponding ratio for average monthly energy production to load was 1.53. Sizing based on energy balance is probably the simplest of the sizing methods but, because of its transparency, it is widely used [18]. This method has also been used in this paper using the energy balance equation for the worst month (December). The average monthly ratio of production to load has been calculated as 6.35 (ranging from 1.0 in December to 12.8 in July). This high ratio means an enormous system size, but relatively low LLP level. However, if the energy balance equation for the second worst month (January) is considered in design, the average monthly production to load ratio would have been reduced to 4.98, requiring a smaller system size. This would have, however, increased the LLP level making system less reliable, but unit cost for PV electricity generation would have been also less.

System size is calculated by using the following equations:

$$P_{peak} = \frac{E_d I_{stc}}{Q.G} \tag{1}$$

$$B_c = \frac{D_a E_d}{DOD.\eta_b.D} \tag{2}$$

Thus obtained values for module size is 51.6 kW$_p$ and for storage battery is 71.8 kWh. Figure 4 shows average monthly household electricity demand and PV electricity generation from 51.6 kW$_p$ PV generator. System design would be more accurate when considering daily values of electricity consumption and solar radiation data, but it leads to an enormous system size if done so. This is why, monthly average data are used in this calculation.

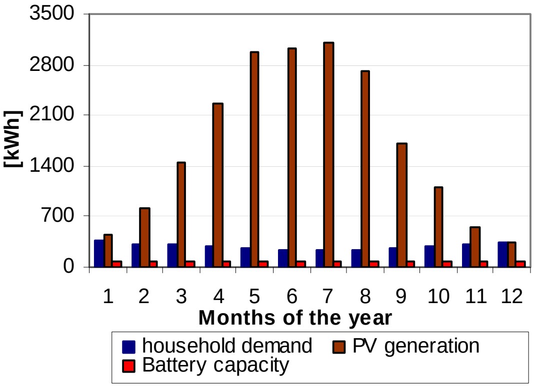


Fig. 4. Monthly PV electricity yield and household demand.

It can be seen in Figure 4 that the electricity generated is more than the energy demand in most of the months. If values are summed up for one year period, about 20,516 kWh electricity will be generated and out of which only 3500 kWh will be utilized. In other words, only 17% of the generated electricity will be consumed and rest 83% will be lost. This is because the system has to be designed for the worst month, *i.e.* December, to ensure sufficient electricity supply throughout the year. Battery is designed to meet household electricity demand for four autonomous days.

In an unrealistic scenario for Germany (though it is true for tropical countries), if there were no seasonal variations (NSV) in available global radiation and average daily electricity consumption throughout the year, system size would have been quite small. The comparison of module and battery size to fulfill the same electricity demand has been made and the calculated values for module and battery size are found as 8.8 kW$_p$ and 59.9 kWh, respectively. There is a big difference in module size and relatively small difference in battery size. The effect of seasonal variation in climate will be very high for available global radiation that determines the PV system size. The autonomous energy supply days that determine the battery size are considered to be the same (*i.e.* four days) for both cases and seasonal variation has less impact in average monthly electricity consumption than in average monthly solar radiation.

System Cost

The source of initial investment for modules, BOS components and batteries is a bank loan. This has to be paid back in form of annual instalment and interest on loan. Individual component costs are summed up to calculate the total system cost and it is given by:

$$C_t = C_{mt} + C_{mbos} + C_{bt} + C_{mbosrpl} + C_{brpl} + C_v \tag{3}$$

The present value of overall system cost is calculated by using standard net present value equation:

$$NPV = NFV\left(\frac{1}{1+d}\right)^{n} \tag{4}$$

The present value of component cost is given by:

$$C_{mt} = C_m P_{peak}\left\{\sum_{n=1}^{n=N}\frac{(1+i(N-n+1)}{N(1+d)^n}\right\} \tag{5}$$

$$C_{mbos} = C_m P_{peak} k_{bos}\left\{\sum_{n=1}^{n=N_r}\frac{(1+i(N_r-n+1)}{N_r(1+d)^n}\right\} \tag{6}$$

$$C_{bt} = \frac{E_d D_a C_b}{DOD.\eta_b.D}\sum_{n=1}^{n=n_b}\frac{(1+i(n_b-n+1)}{n_b(1+d)^n} \tag{7}$$

BOS components (all other than batteries) are supposed to last for twelve years (15 and 20 years for longer module life times of 30 and 40 years, respectively) after the installation and they will have to be replaced at the end of twelfth year. The present value of BOS replacement cost is given by:

$$C_{mbosrpl} = C_m P_{peak} k\left\{\frac{k_{bos}k_{bosrpl}}{(1+d)^{N_r}}\right\},\ k = \frac{C_{m(n+N_r)}}{C_{m(n)}} \tag{8}$$

Batteries are supposed to have shorter life time than system life time, and therefore they have to be replaced periodically (5, 6 and 10 years for system life times of 25, 30 and 40 years, respectively). The present value battery replacement cost is given by:

$$C_{brpl} = B_c C_b k_{brpl}\left\{\frac{b_1}{(1+d)^{r_1 n_b}}+\frac{b_2}{(1+d)^{r_2 n_b}}+\frac{b_3}{(1+d)^{r_3 n_b}}+\frac{b_4}{(1+d)^{r_4 n_b}}\right\} \tag{9}$$

Cost needed for BOS and battery replacement could be covered by own savings that would be made from forgone electricity bills, which would have been paid to electricity supplier if stand alone system was not installed.

Variable cost is assumed to be a certain portion (1%) of initial investment. The present value of variable cost is given by:

$$C_v = C_m P_{peak}\left\{k_v(1+k_{bos})\sum_{n=1}^{n=N}\frac{1}{(1+d)^n}\right\}+\frac{E_d D_a C_b}{DOD.\eta_b.D}\sum_{n=1}^{n=N}\frac{k_v}{(1+d)^n} \tag{10}$$

Thus calculated net present cost of individual PV system (N=25 years) components is shown in Figure 5.

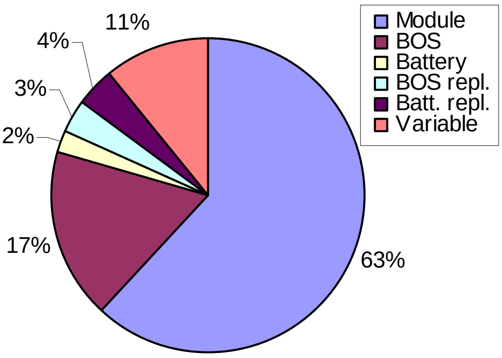


Fig. 5. PV system cost breakdown.

Figure 5 shows that the most expensive component is solar module, and it is obviously resulted by enormous module size and its high cost.

Grid Access Cost

Grid access cost includes the cost charged by utilities for the grid infrastructure between house and nearby grid node (connecting wires, accessories and construction work) in order to make electricity access to the house. The cost is different from place to place. An example of those costs for three German cities is given in Figure 6 [20]. The grid access cost increases proportionally with the distance between house and nearby grid access node.

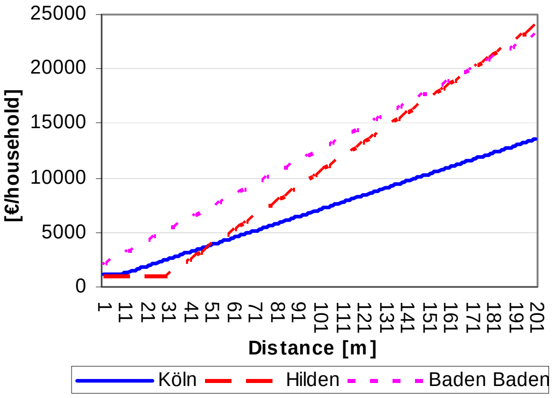


Fig. 6. Grid access cost.

Revenue

Although there is no direct revenue gained from PV system, however, PV electricity will help saving the money that would have been paid to utilities in the absence of PV system. This saving is named as opportunity revenue and it is given by:

$$R_t = R_i + C_{ga} \tag{11}$$

Imputed revenue is calculated by multiplying electricity demand and end user electricity price. Grid infrastructure has longer life time (about 50 years) than PV system life time and therefore a proportionate value of grid access cost (for the equal period to that of PV system life time) is included in total imputed revenue calculation. Hence, present value of overall opportunity revenue is given by:

$$R_t = E_d p_{el}\sum_{n=1}^{n=N}\frac{(1+gr)^{n-1}}{(1+d)^n}+C_{ga}\sum_{n=1}^{n=N}\frac{(1+i(N_g-n+1)}{N_g(1+d)^n} \tag{12}$$

5. RESULTS

Two different aspects, an actual case and a hypothetical case (with no seasonal variation in available solar radiation and electricity demand), have been analyzed and thereby obtained results are discussed here.

Benefit Cost Analysis

The calculated values for benefit cost analysis (BCA) are given in Table 2. Since the system size is very big compared to household electricity demand, the losses from the system will be definitely very high if the system is installed. As can be seen in Table 2, the systems are not economically feasible under existing market conditions, even under hypothetical case of no seasonal variations, as characterized by the negative values of benefit (loss).

Table 2. BCA of stand alone PV system.

	Actual case		
	N=25	*N*=30	*N*=40
Total cost (€$_{2007}$)	320,079	324,807	331,275
Total revenue (€$_{2007}$)	19,283	22,983	30,310
Benefit (loss) (€$_{2007}$)	-300,795	-301,824	-300,964
	No seasonal variation case		
	N=25	*N*=30	*N*=40
Total cost (€$_{2007}$)	69,091	68,930	67,028
Total revenue (€$_{2007}$)	19,283	22,983	30,310
Benefit (loss) (€$_{2007}$)	-49,808	-45,946	-36,717

Breakeven Analysis

Breakeven scenarios have been calculated by equaling the Equations 3 and 12. The breakeven values for module price, electricity price, battery price, and grid access cost, which would have been required to make the PV system economically feasible under existing market conditions, are presented in Table 3.

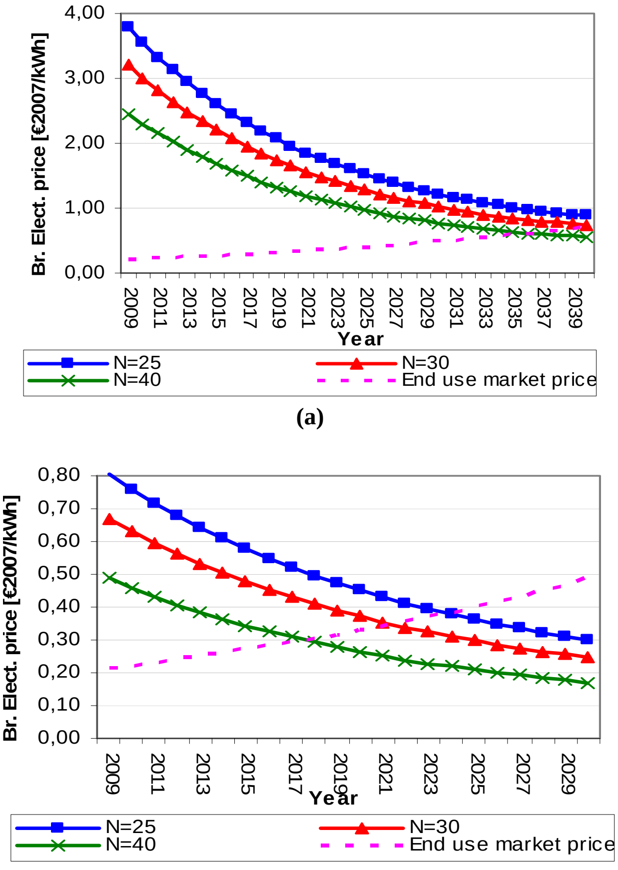
Table 3. Breakeven conditions for stand alone PV system.

	Actual case		
Breakeven Values	*N*=25	*N*=30	*N*=40
C_m, €$_{2007}$/kW$_p$	-27.48	27.94	148.64
p_{el}, €$_{2007}$/kWh	3.79	3.20	2.45
C_b, €$_{2007}$/kWh	-1,278.85	-1,382.64	-1,801.10
C_{ga}, €$_{2007}$/hh	302,049.17	303,171.72	302,427.61
	No seasonal variation case		
Breakeven Values	*N*=25	*N*=30	*N*=40
C_m, €$_{2007}$/kW$_p$	68.40	373.55	1028.77
p_{el}, €$_{2007}$/kWh	0.81	0.67	0.49
C_b, €$_{2007}$/kWh	-173.54	-170.40	-177.86
C_{ga}, €$_{2007}$/hh	51,061.94	47,294.56	38,180.14

The negative signs for module and battery price indicate that the system would only worth if those negative signed amount were rewarded to the owner of PV system in form of subsidy or similar scheme for generating electricity from PV. The grid access cost given in Table 3 for system life time of 25 years reflects a distance of 4.638 km between nearby grid node and a house in Cologne. In no seasonal variation case, this distance would have been only 777.4 m.

Breakeven Year

Under the case of module price decrease in accordance with the values given in Figure 3, and end user electricity price increase at annual growth rate of 4% from base year price of 21.43 €ct/kWh, stand alone PV system will not be economically feasible within next decades as shown in Figure 7. If the assumptions made in this study come true, stand alone solar PV systems with system life time of 30 years will be economically at breakeven point in the year 2040. But this will come earlier (2036) if the system life time is improved to 40 years. However, the results are very optimistic for the hypothetical case of no seasonal variations. The breakeven years calculated in this case lie between 2024 and 2017 for the systems with life time between 25 and 40 years, respectively.



(a)

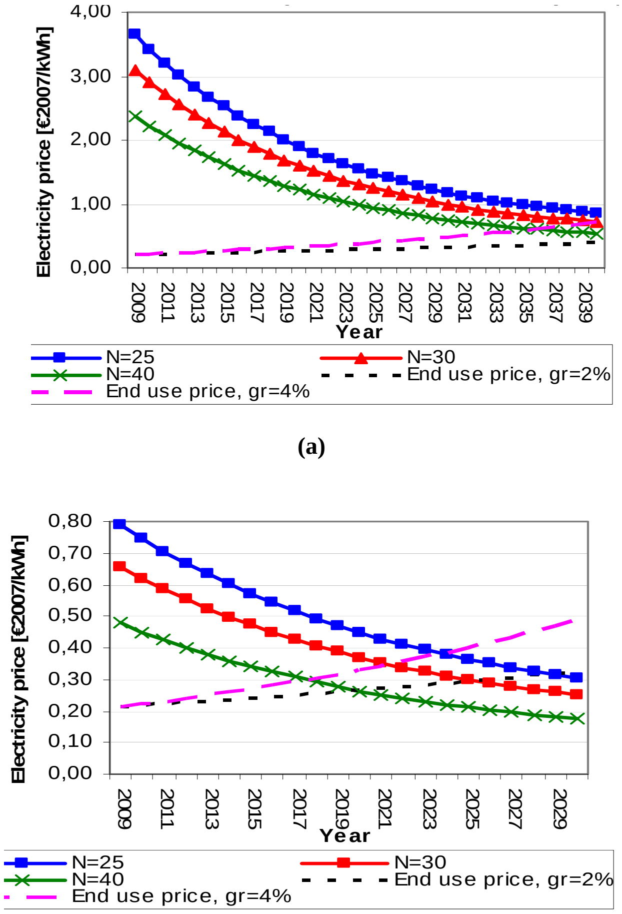
(b)

Fig. 7. Breakeven year – actual case (a) and NSV case (b).

Grid Parity

Grid parity between a kWh PV electricity generation price and a kWh grid electricity price for household customers has been analysed. Two different annual electricity price growth rate scenarios of 4% and 2% are presented for each case representing optimistic and pessimistic scenario. Figure 8 shows the grid parity years for market with and without seasonal variation conditions. Under market as usual conditions, it can be seen that even if system life time is as long as 40 years, grid parity will not occur before the year 2036. For shorter system life time of 30 and 25 years, the grid parity year will be 2040 and beyond 2040, respectively. The results for grid parity looks very positive if there were no seasonal variations, *i.e.* between years 2018 and 2024 for systems having life time between 40 and 25 years. In case of low annual grid electricity price growth rate of 2%, grid parity years will not occur in next decades.

Sooner or later occurrence of grid parity year is determined by the variables used in cost and revenue calculation equations. Not surprisingly, some variables have major influence than the others. For example, in case of Germany, if the progress ratio for solar modules is varied between 75 % and 90 %, the grid parity year will vary between 2037 and beyond 2040 for the systems with life time of 25 years, between 2034 and beyond 2040 for systems with life time of 30 years, and between 2030 and beyond 2040 for systems with life time of 40 years. Similarly if the cost for battery is varied between 75 and 125 €/kWh, the grid parity year will vary between 2035 and beyond 2040 for systems with life time of 40 years, and even later for the systems with shorter life time. Those years are far farther than the years shown for NSV case in Figure 8. This shows that even if there are drastic reduction in solar modules costs (*e.g.* at PR of 75%), or of batteries in the coming years, stand alone PV system can not be competitive in the coming decades. Therefore only way to make a kWh PV electricity cheaper is to reduce the system size. Other variables used in the calculations, *e.g.* bank interest rate, discounting rate, monthly average solar radiation, *etc.* are site specific, and therefore solar PV sector (or users) have no influence in altering their values.



(a)

(b)

Fig. 8. Breakeven year – actual case (a) and NSV case (b).

6. CONCLUSION

The study shows that stand alone solar PV systems are not economically feasible to German households at present. Household customers will benefit by buying the electricity from grids instead of installing a solar PV system for the next more than two decades. This is mainly because of high investment costs needed for a big system size that is required to ensure electricity supply in all seasons of the year.

Since the costs for PV modules are decreasing at the rate of 20% for each cumulative doublings in their production since commercialization of PV systems, this cost reduction trend is supposed to continue for coming decades as well. Other noble developments in PV cell technology are also expected. In this case, PV systems will be economically feasible earlier than presented in this study. Also, if the PV system life time could be increased up to 40 years, it will ultimately reduce a kWh PV electricity costs. This is because PV system needs negligible operating costs and if the same system can generate electricity for many years, it will increase imputed revenue.

The biggest problem for stand alone systems in the countries like Germany is seasonal variations that cause major fluctuations in monthly average solar radiation. This will ultimately result an enormous PV system size in order to ensure continuous electricity supply to households in all months of the year. However, if the system is designed to cover the full electricity demand of only 11 or 10 months and the partial demand of one or two months, the system size will decrease significantly and thereby a kWh PV electricity generation cost could also be very less. This is not impossible to do so by compromising certain welfare for the period of one or two months and by applying different household energy management measures.

Due to seasonal variations in available solar radiations in Germany, only 17% of generated electricity can be used and 83% of generation is a loss. This loss can be avoided in grid connected PV systems, where 100% of the generated electricity can be fed into the grids and thereby revenue can be generated making grid connected systems economically more attractive. This is why replacing or avoiding grid is not possible in German context. Another problem of stand alone PV systems is there is no coincidence in time of electricity generation and household electricity demand. A storage system solves this problem, but it constitutes a big cost component of total system cost.

Once a kWh PV electricity cost is decreased, it will bring breakeven and grid parity years sooner. If low latitude locations of the world are considered, there is less or no seasonal variation in monthly average solar radiation, which leads to a smaller module size and the costs for a kWh electricity generation are less.

At present, interruption in electricity supply is not a question in Germany, but it can not be ruled out in coming decades and in that case stand alone PV systems might be the only reliable and popular sources of electricity supply. Moreover, stand alone PV systems might be the right choices as of today in the locations without any existing grids, for example in black forests of south Germany. If the distance between a house and nearest grid in Cologne is more than 4.7 km, installing a stand alone solar PV system will be cheaper than extending the grid. However, even in today's scenario, there is no argument that stand alone PV system has no other better alternative to provide electricity in the rural areas of many countries in the world.

NOMENCLATURE

$b = \frac{C_{b(n+rn_b)}}{C_{b(n)}}$	battery price reduction factor
B_c	storage battery size (kWh)
C_{brpl}	battery replacement cost (€$_{2007}$)
C_{bt}	battery expenditure (€$_{2007}$)
C_{ga}	grid access cost (€/household)
C_{mbos}	BOS expenditure (excluding battery) (€$_{2007}$)
$C_{mbosrpl}$	BOS replacement cost (excl. battery) (€$_{2007}$)
C_{mt}	module expenditure (€$_{2007}$)
C_t	total system cost (€$_{2007}$)
C_v	variable cost (€$_{2007}$)
I_{stc}	standard test condition radiation (kWh/m^2.yr)
NFV	net future value
N_g	grid life time (years)
NPV	net present value
P_{peak}	module size (kW$_p$)
$r_{1...}r_4$	replacement numbers $(=1.4)$
R_i	imputed revenue (€)

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