Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 103 (2014) 19–27

SOLAR ENERGY

www.elsevier.com/locate/solener

# Simulation and analysis of a solar assisted heat pump system with two different storage types for high levels of PV electricity self-consumption

Richard Thygesen *, Björn Karlsson

*Mälardalen University, School of Business, Society & Engineering, Box 883, 721 23 Västerås, Sweden*

Received 27 September 2013; received in revised form 30 October 2013; accepted 4 February 2014

Communicated by: Associate Editor Elias K. Stefanakos

**Abstract**

The incentives for PV-systems in Europe is being gradually lowered or ended. This makes a higher level of self-consumption interesting for owners of PV-systems.

Sweden has an incentive of 35% of the investment cost for PV-systems. Unfortunately not all consumers can get this incentive. Therefore a high level of self-consumption will be necessary if the PV-systems are to be profitable in Sweden.

A reference system with two different energy storage technologies is investigated in this paper. One system with 48 kW h of batteries and one system with a hot water storage tank where the electricity is stored as heat.

The research questions in this paper are:

Which storage system gives the highest level of PV electricity self-consumption?

Are the storage systems profitable with the assumptions made in this paper?

What are the levelized costs of electricity (LCOE) for the reference system with different storage system?

The system with batteries has a self-consumption of 89% of the annual PV-electricity output and the system with a hot water storage tank has 88%.

The system with batteries has a levelized cost of electricity two times higher than the system with a hot water storage tank.
© 2014 Elsevier Ltd. All rights reserved.

*Keywords:* Photovoltaic; Energy storage systems; Energy system simulation; Self-consumption

## 1. Introduction

Some countries in Europe have begun to phase out the incentives which support the growth of small scale PV-systems for localized electricity production. This will shift the focus from exporting as much of the PV-system electricity to the grid to maximize the self-consumption in the building.

In Sweden the incentive is 35% of the PV system installation cost but no net metering or feed in tariff system is implemented. This makes self-consumption crucial in making the investment profitable in a 15–20 year period in Sweden.

Maximizing self-consumption is not an easy task for a single family house in Sweden where the main part of the electricity is consumed in the evening and winter. One way of storing PV electricity is to install batteries or a hot water storage tank and store the electricity as heat. Earlier research on PV electricity self-consumption in resi-

* Corresponding author. Tel.: +46 21 103182; fax: +46 21 101480.
*E-mail address:* richard.thygesen@mdh.se (R. Thygesen).

http://dx.doi.org/10.1016/j.solener.2014.02.013
0038-092X/© 2014 Elsevier Ltd. All rights reserved.

**Nomenclature**

| | |
|---|---|
| $A_i$ | anisotropy index |
| $C_t$ | net cost of project for year $t$ (€) |
| $d$ | annual degradation |
| $EP_t$ | electricity price at year $t$ |
| $i$ | inflation |
| $I_b$ | beam radiation on tilted surface |
| $I_c$ | investment cost (€) |
| $I_d$ | diffuse radiation on tilted surface |
| $I_T$ | total radiation on tilted surface |
| $r$ | nominal discount rate |
| $R_b$ | ratio of beam radiation on tilted surface |
| $r_r$ | real discount rate |
| $S_t$ | PV-system yearly energy output (kW h) |
| $T$ | life time of the system (year) |
| $t$ | year $t$ |
| $(1 - \cos\beta)/2$ | view factor to the ground |
| $(1 + \cos\beta)/2$ | view factor to the sky |

dential buildings has mainly been focused on grid issues, electricity demand management systems and batteries as can be seen in Castillo-Cagigal et al. (2011a), Purvins et al. (2013), Williams et al. (2012) and to some extent on self-consumption for residential buildings where energy and/or economics for end consumers has been studied (Castillo-Cagigal et al., 2011b; Nottrott et al., 2013; Riffonneau et al., 2011). No studies concerning PV electricity stored as heat in a hot water tank has been found.

In Sweden new buildings are often equipped with some form of heat pump for heat and hot water production which means that the electricity demand is higher than for a building equipped with a boiler or district heating.

In this article a reference building energy system which was developed and analyzed in Thygesen and Karlsson (2013) is compared with two modified reference systems, the first is equipped with a battery system and the other one is equipped with a hot water storage tank.

The building energy system and the different storage systems are simulated in Trnsys (Klein et al., 2010) which is a transient simulation program.

The focus of this article is to answer the following research questions:

Which storage system gives the highest level of PV electricity self-consumption?

Are the storage systems profitable with the assumptions made in this paper?

What are the levelized costs of electricity (LCOE) for the reference system with different storage system?

## 2. Methodology

The reference system developed and analyzed in Thygesen and Karlsson (2013) is further developed and different storage systems are added to the system. The output from the simulation program are imported to a spreadsheet program and further processed.

The reference system with storage systems added is simulated for two years in 3 min periods. This is done to get a whole winter season simulated in the program. Only year two are further processed and analyzed.

The battery system size is dimensioned based on the findings in Thygesen and Karlsson (2013) and the heat storage has the same volume as the domestic hot water tank which is integrated in the ground source heat pump. A parametric run is performed for the battery storage systems where the capacity of the storages is varied. This is done so a sensitivity analysis with regards to storage capacity, investment cost, discount rate and electricity cost can be performed. The tank volume is optimal sized for the simulated heat pump and therefore there will be no variation of the tank volume with regards to sensitivity analysis.

The battery model is based on a model developed by Shepherd. The Shepherd model which describes the battery in terms of different voltages, ohmic resistance, fractional depth of discharge and discharge current is the most used battery model and in this paper a modified model that also can describe battery behavior at low currents are used (Klein et al., 2010).

Different models for calculation of radiation on sloped surfaces can be chosen in Trnsys. In these simulations the calculation of the radiation on sloped surfaces is performed with the Hay and Davies model (Hay and Davis, 1980) as shown in Eq. (1). In Hay and Davies model the diffuse radiation consists of an isotropic and a circumsolar part. It does not however handle horizon brightening.

$$I_T = (I_b + I_d \times A_i) \times R_b + I_d \times (1 - A_i) \times \left(\frac{1+\cos\beta}{2}\right) + 1 \times \rho_g \times \left(\frac{1+\cos\beta}{2}\right) \quad (1)$$

The second part of Eq. (1) is the isotropic part and describes the diffuse part that is evenly distributed over the sky dome and the first part of the equation is the circumsolar part which describes the diffuse radiation coming from the suns direction.

The meteorology data including the solar radiation is taken from Meteonorm version 7 (Remund et al., 2013).

### 2.1. Levelized cost of electricity

The levelized cost of electricity calculations is based on the net present value method which discounts the investment and operations cost to the same reference year. The levelized cost of electricity is calculated for the reference system with the different storage systems in accordance with Eq. (2) which can be found in Branker et al. (2011) with one difference. The start time is set to year one and therefore the initial investment cost, $I_C$, must be inserted in the equation. To put it simpler the total costs of the system during its lifetime divided by the total PV output during the lifetime gives the levelized cost of electricity in €/kW h.

$$\mathrm{LCOE} = \frac{I_C + \sum_{t=1}^{T}(C_t)/(1+r_r)^t}{\sum_{t=1}^{T} St * (1-d)^t/(1+r_r)^t} \tag{2}$$

The cost given by Eq. (2) is the average cost per kW h electricity during the lifetime of the system.

The real discount rate is calculated in accordance with Eq. (3) and is 2.36% and the lifetime of the system is set to 30 years. The inflation is based on the average Swedish inflation during 1992–2011 (Statistics Sweden, 2012a) and the nominal discount rate is assumed to be 4%. As can be seen in Eq. (3) the real discount rate is the nominal rate divided with the inflation.

Every 15 years the inverter is replaced and the battery system is replaced every 7 years and the calculations are not taking the 35% Swedish incentive in account. The PV modules have an annual estimated degradation of 0.5%. This estimation is based on the findings in Ndiaye et al. (2013) and Kaplanis and Kaplani (2011).

$$r_r = \frac{1+r}{1+i} - 1 \tag{3}$$

The investment cost of 2660 €/kW$_p$ is based on the national report from IEA-PVPS task 1, 2012.

In this paper the levelized cost of electricity will be compared with the Swedish assumed annual net present electricity cost during a 30 year period to evaluate the studied systems profitability.

The annual net present electricity price calculation is given in Eq. (4).

$$\int_{t=1}^{T} EP_t \times (1+r_r)^{-t}/T \tag{4}$$

## 3. Building energy system

The building and its technical installations have been described in detail in Thygesen and Karlsson (2013). In this article the systems will be described briefly. All main components of the different configurations can be seen in Fig. 1.

The simulated building is a one story energy effective building located in Västerås, Sweden and equipped with a 3 kW ground source heat pump for the supply of heat and domestic hot water and a roof mounted PV-system for electricity production and a heat recovery ventilation system.

The living area of the building is 138 m$^2$ and four people lives in the building. *U*-values for the buildings different components are specified in Appendix A and data on the PV-system is in Appendix B.

Total building load is the sum of the heat pump electricity consumption, the ventilation heat recovery electricity consumption, the electrical heater electricity consumption and the household electricity. Total annual electricity consumption is 10,260 kW h of which domestic hot water and heating accounts for 3250 kW h and household electricity for 5155 kW h.

## 4. Photovoltaic-system

The PV-system has an installed peak power of 5.19 kW. The polycrystalline modules are oriented to the south and have a tilt of 70°. The system is unaffected by shading at all times.

The reason for the high tilt angle is to reduce the output during summer and increase it in fall and autumn. A drawback with this approach is that the total annual output is smaller than from a system with optimal tilt which affects the profitability of the system. Total annual output from the system is 5060 kW h or 975 kW h/kW$_p$.

## 5. Storage systems

The selected types of storage technologies are lead acid batteries and hot water storage tank. The reason for selecting this type of storage is that lead acid batteries are a well-known, mature and widespread technology and many heating systems in small buildings in Sweden consists of a hot water storage tank.

### *5.1. Battery system*

The simulated battery system consists of several secondary valve regulated lead acid batteries connected to a charge controller and an inverter. The regulator controls the flow of electricity in four different ways. The first way is that all PV-electricity is fed to the batteries, the second way is that part of the PV-electricity is fed to the building load and the rest is fed to the batteries, the third way is that a part is fed to the building load a part is fed to the batteries and the rest is fed to the electricity grid and the fourth way is that all electricity is fed to the electricity grid. In this way the building load can be supplied with electricity from the batteries, the PV-system and the electricity grid at the same time.

The total capacity of the system is 48 kW h and the depth of discharge is limited to 50%. The battery system nominal voltage is 12 V.

The valve regulated lead acid battery type with a gelled electrolyte is one of the most common lead acid battery types in renewable energy systems today. In this battery type the liquid electrolyte is mixed with silica to get a gelled electrolyte. The advantages with this battery type are that it is maintenance free and have a relative low cost in relations to other battery technologies. The disadvantages are amongst others that it should not be stored discharged for longer periods of time and that it is sensitive to high temperatures.

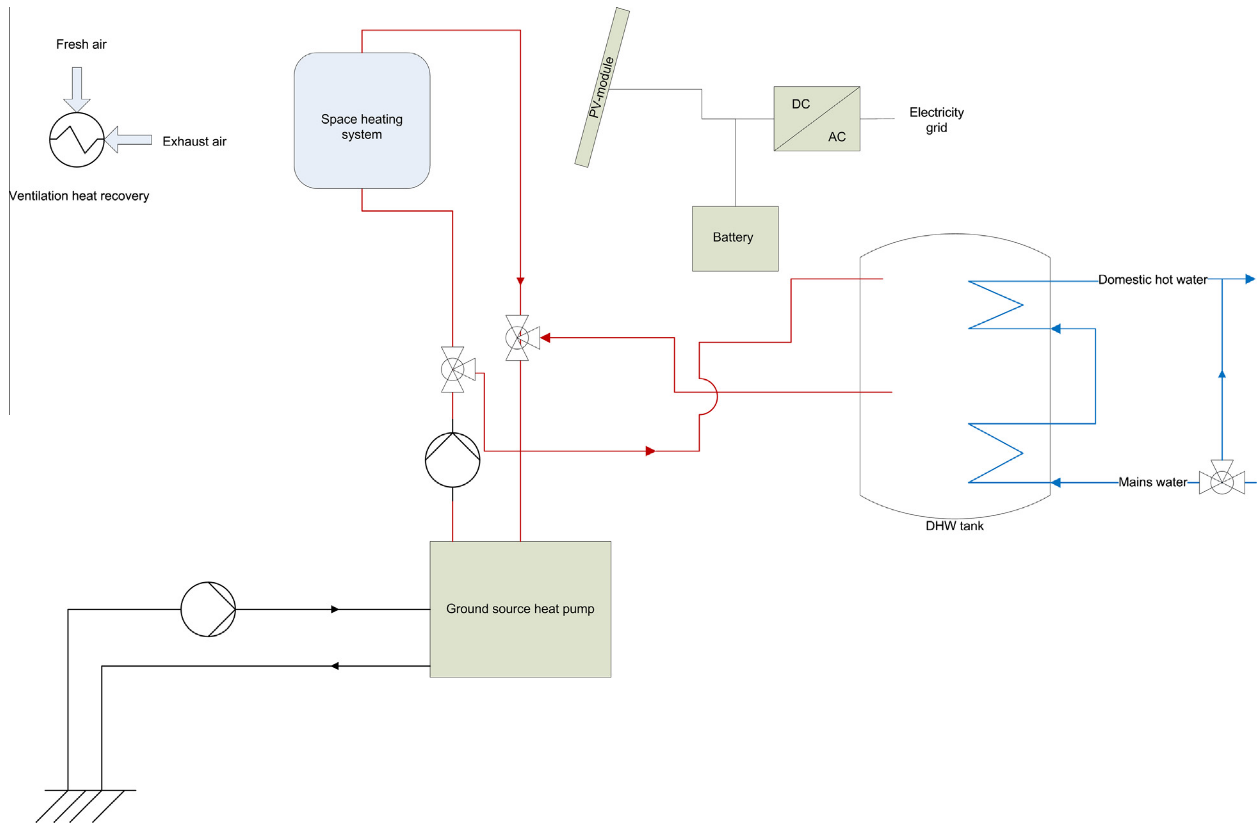


Fig. 1. System schematic.

A battery system with a capacity of 48 kW h would be able to store one day surplus of PV electricity. This is because the maximum daily surplus of the PV-system is approximately 24 kW h and the battery can only put out 24 kW h because of the depth of discharge restriction.

A battery size of 48 kW h is chosen according to the findings in Thygesen and Karlsson (2013) which shows that a system with at least daily net metering is profitable. Net metering can be described as a metering system where the electricity grid is acting as the battery and in this case has a capacity to store one day of PV electricity. Therefore the battery system is able to store one day of PV electricity output.

The battery system is charged by the electricity from the 5.19 $kW_p$ PV-system when the building load is lower than the PV-output and will discharge as soon as the building load is greater than the contribution from the PV-system and the battery depth of discharge is above 50%.

The lifetime of the batteries is assumed to be 1700 full cycles down to a depth of discharge of 50%. This assumption is based on data sheets from manufacturers of valve regulated lead acid batteries.

The investment cost of lead acid batteries is estimated to be 225 €/kW h (Helder et al., 2013).

### 5.2. Hot water storage tank

The hot water storage tank in the simulated system is a 225 l double jacketed tank with an inner volume of 185 l. The tank is equipped with an electrical heater placed at the bottom of the tank below the heat pump in- and outtake ports.

#### 5.2.1. PV electricity controller

The controller has current transformer clamps installed at the incoming grid supply cable and on the cable from the inverter. The controller is continuously monitoring the building load and PV electricity output via the CT clamps.

The electrical heater is then connected to the controller which switches it to on if the PV electricity output is larger than the building load and switches it off if the output is smaller than the building load or zero or if the temperature in the top of the tank has reached 95 °C. PV overproduction is only feed to the grid if the PV production is higher than the building load and the temperature in the tank is above 95 °C.

The cost of the controller is 350 € which is an average price based on five different commercial available products.

### 5.3. Total cost of electricity in Sweden

The total cost of electricity in Sweden is divided into two parts. These parts are the electricity price and the electricity grid cost. The electricity price consists of the electricity price itself, an electricity tax and a value added tax. The grid cost consists of the grid fee and value added tax.

During the period 2001–2011 the electricity price itself increased by an average of 4.7% each year and the electricity tax increased by an average of 4.3% (Statistics Sweden, 2012b).

The average electricity price for a 30 year period in relations to annual price change can be seen in Fig. 2. This figure is used in the sensitivity analysis presented in Section 6.4.

## 6. Results

### 6.1. Reference system

The solar energy fraction of the reference system is 28% and the solar electricity self-consumption is 56%.Total annual need for purchased electricity is 7350 kW h.

Levelized cost of electricity for the reference system is 0.16 €/kW h. This means that the average price of the electricity saved and feed into the grid need to be above 0.16 €/kW h if the system is to be profitable. As can be seen in Fig. 2 the annual average electricity change over a 30 year period needs to be just above 1.5% with the chosen assumptions. When the electricity price change is just above 1.5% the average electricity price over 30 years is just above 0.16 €/kW h. The average electricity price is calculated with the net present method as shown in Eq. (4).

### 6.2. Reference system with batteries

With the 48 kW h battery system the annual self-consumption of the system is increased from 56% or 2900 kW h in the reference system to 89% or 4600 kW h. This gives a total annual need for 5660 kW h of purchased electricity.

Only 14 kW h is annually exported to the electricity grid and the battery system losses are 11% or 546 kW h. The losses are not included in the above 4600 kW h.

The solar energy fraction of this alternative is 44.5% and the levelized cost of electricity is 0.4 €/kW h.

The simulation shows that the battery system will be subjected to 220 full charge/discharge cycles per year which gives an estimated lifetime of just below 8 years. Fig. 3 shows the self-consumption fraction in relations to the battery storage size i.e. the part of PV electricity used in the building in relations to installed battery size. This figure indicates that the most efficient battery system must be smaller than 10 kW h for this system. As can be seen in the figure the self-consumption fraction increases linear to 10 kW h and this means that all kW h of battery capacity contribute to the same amount of self-consumption i.e. all battery capacity is used as optimal as possible. After 10 kW h the incline of the line in the graph is decreasing. This means that the battery capacity larger than 10 kW h contribute less to the self-consumption when compared with the battery capacity installed up to 10 kW h i.e. the additional battery capacity is not used optimal in regards to increasing self-consumption.

A 48 kW h system has a state of charge of 100% during 14 h during a year and a 10 kW h system has a state of charge of 100% charge during 310 h.

If the reference system was fitted with a 10 kW h battery system the levelized cost of electricity would be 0.21 €/kW h and the self-consumption of the PV electricity would be 74% or 3810 kW h. This means that 790 kW h more of electricity is feed into the electricity grid with the smaller battery system. This also means that the cost for increasing the self-consumption with 790 kW h from 3810 kW h to 4600 kW h is 9675 €. This should be put in

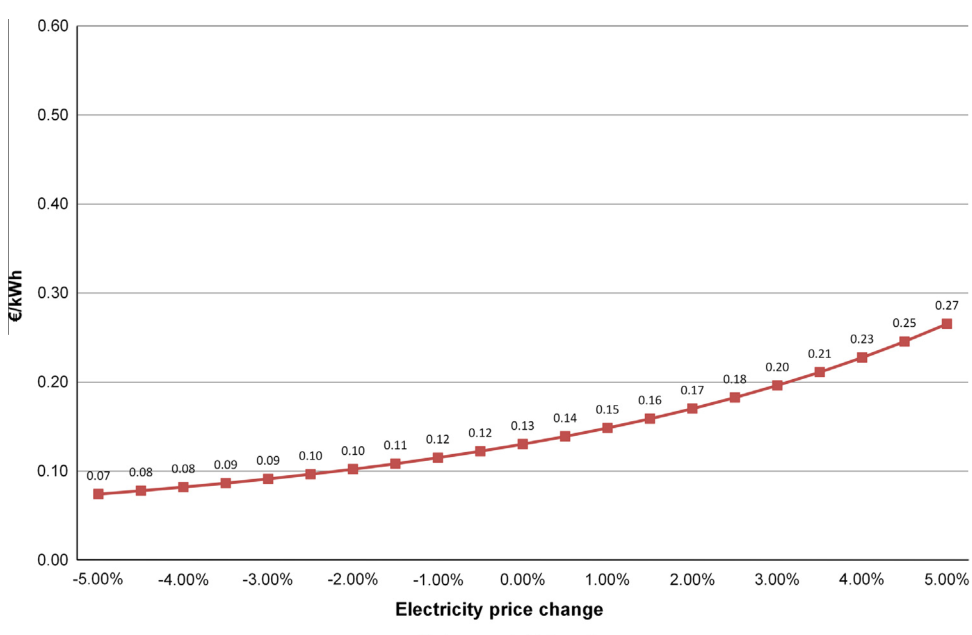


Fig. 2. Installed battery capacity in relations to self-consumption.

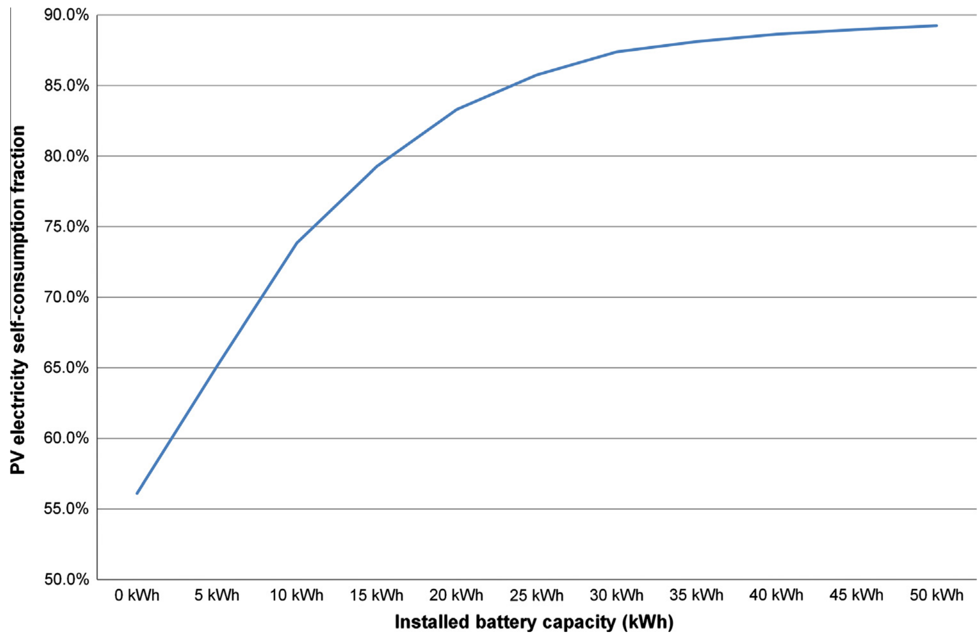


Fig. 3. Installed battery capacity in relations to PV electricity self-consumption.

relation to the investment cost for the 10 kW h battery system which is 2250 €.

### 6.3. Reference system with hot water storage tank

PV electricity self-consumption in the system with the hot water storage tank is 88% or 4555 kW h and the difference between hot water storage tank losses in the reference system and in this system is 175 kW h. This can be related to the increased hot water temperature due to the increased storage of energy in the tank hence the PV electricity losses due to storage is 3.4% or 175 kW h and is not included in the 4555 kW h of self-consumption. The solar energy fraction of this system is 44.4%.

Annual need for purchased electricity is 5700 kW h.

In this system configuration 12% or 605 kW h of the PV electricity is exported to the grid.

The levelized cost of electricity for this system is 0.2 €/kW h.

### 6.4. Sensitivity analysis

Sensitivity analysis should always be performed when using the LCOE method. This is because the model is sensitive to changes in the discount rate and investment cost.

The sensitivity analysis suggest that the investment cost for the reference system must be below 1800 €/kW$_p$ if the system is to be profitable with the used assumptions. The systems with a battery storage is not profitable even with an investment cost as low as 50 €/kW h battery capacity as seen in Fig 4.

Fig. 4 describes the LCOE, on the $y$-axis for two battery system sizes and battery investment costs per kW h installed battery capacity on the $x$-axis.

A sensitivity analysis of the discount rate and the different studied systems configurations shows that it needs to be 1% or below if the reference system is to be profitable. The battery system cannot be profitable by lowering the discount rate as seen in Fig. 5.

The average electricity price need to be 4.5% or above and the real discount rate needs to be 2.0% or below during the lifespan of the system if the 10 kW h battery system is to be profitable. The 48 kW h system is not profitable even with a electricity price change of 5% and a real discount rate of 0%.

Of the analyzed parameters it is concluded that changes in the investment cost of the system has the highest impact on the levelized cost of electricity.

### 6.5. Summarized results

Table 1 summarizes the result for all the different system alternatives and Fig. 6 displays the self-consumption level for the reference system and the different storage technologies.

## 7. Discussion and conclusions

The levelized cost of electricity is a simple method for assessing different systems production cost for electricity production. On the other hand it is not a good model for assessing if a system is profitable. For that the method has to be supplemented with the assumed future electricity cost when purchasing and selling electricity and the level of self-consumption.

The high tilt angle of the PV system gives a lower annual electricity yield which affects the profitability of the system. The reason for having a high tilt angle is to lower the yield

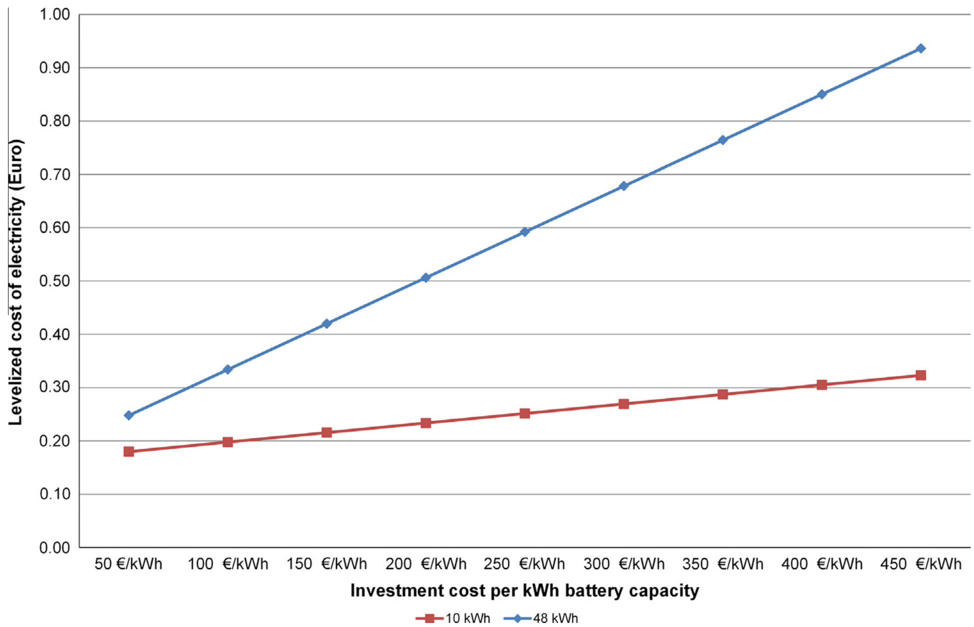


Fig. 4. LCOE in relations to investment cost.

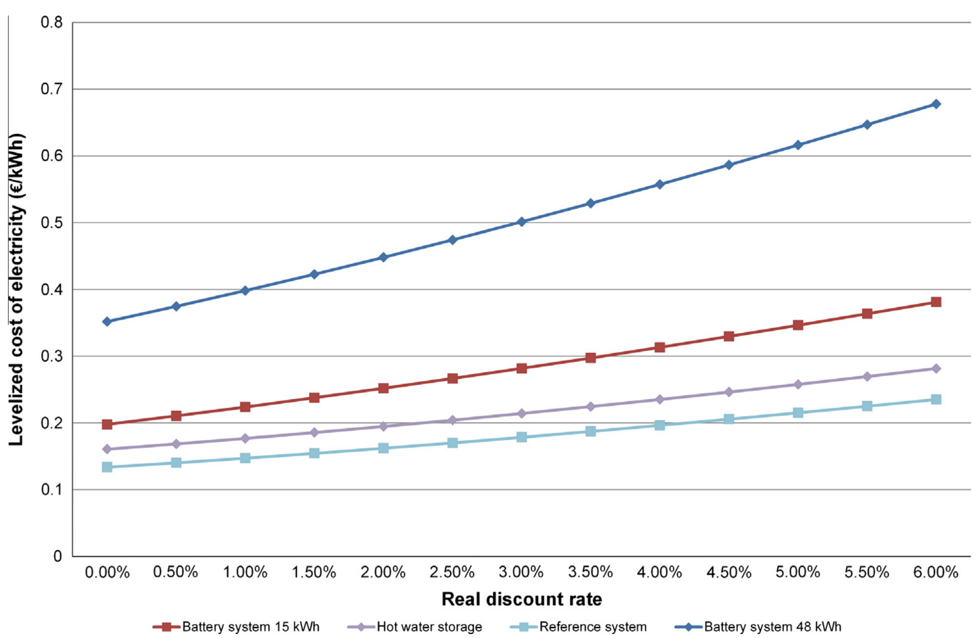


Fig. 5. LCOE in relations to real discount rate.

Table 1
Summarized results.

| System alternative | LCOE (€/kW h) | Self-consumption fraction (%) | Solar energy fraction (%) |
|---|---|---|---|
| Reference system | 0.16 | 56 | 28 |
| Reference with battery (48 kW h) | 0.4 | 89 | 44.5 |
| Reference with storage tank | 0.2 | 88 | 44.4 |

during summer and be able to install larger systems without having overproduction in the system. This also gives slightly more PV electricity in fall and spring when compared to a system with optimal tilt.

A system that stores PV electricity in the form of hot water is almost as effective as a battery system when it comes to maximizing the self-consumption and limits the import of electricity to the grid. A battery system with a

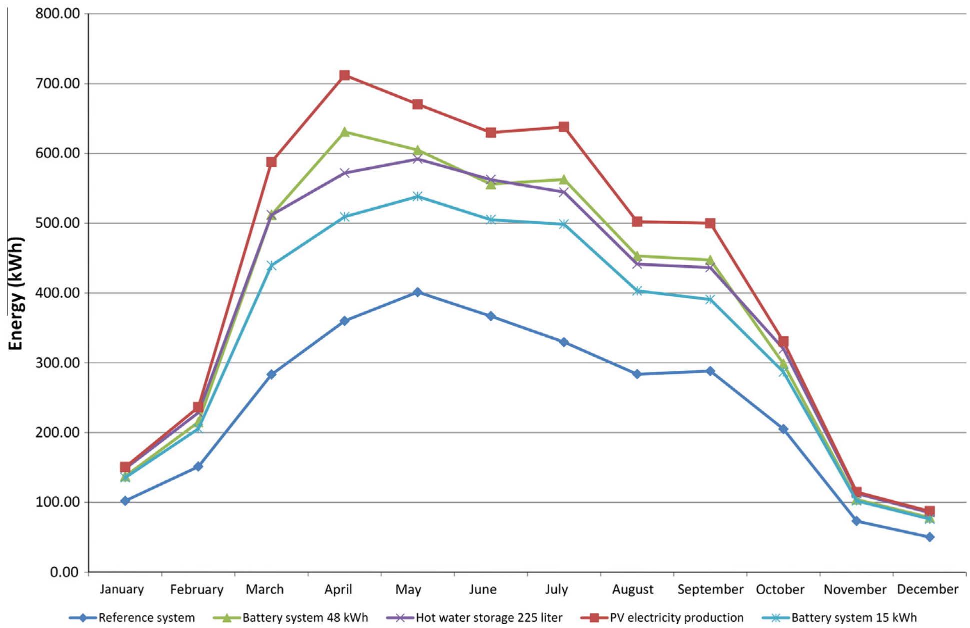


Fig. 6. Self-consumption in the different system configurations.

capacity of 48 kW h has a levelized cost of electricity that is two times higher than for a system with a hot water storage tank but the two systems has almost the same level of self-consumption. It is however thermodynamically questionable to convert electricity directly to heat. The electricity should for example be used to power different machines and lights.

There is one problem with combining heat pumps that produce hot water for heating and domestic hot water production with other systems that also produce hot water. Heat pumps utilize energy from air, ground or water sources which means that only approximately 1/3–1/5 of the energy needed to heat a building and domestic hot water consists of purchased energy. This means that a large part of the PV electricity stored in the tank saves energy taken from the ground.

Because of this the electricity output from for example a PV system that is used to directly heat water via an electrical heater only saves the energy purchased for operation of the heat pump. If the PV electricity output is 1 kW h for example and this is used for heating water the purchased energy saved in the building energy system is 0.33–0.20 kW h.

This affects the profitability of the system and needs to be taken into consideration.

In this paper no consideration has been taken to the fact that the batteries are subject to long periods of a low state of charge. This promotes sulfation and negatively affects the battery life (Linden and Reddy, 2011). If taken into consideration the electricity grid would have to supply electricity for charge during periods of low or no PV electricity. This would negatively affect the amount of purchased electricity in the building energy system.

The fact that only 14 kW h of electricity is annually exported to the grid gives a good indication that the battery system works as expected and that the sizing is right from an energy perspective.

Analysis of the simulation data shows that the self-consumption of the PV electricity per kW h of battery storage starts to decline at 10 kW h as shown in Fig. 2. This means that a system larger than 10 kW h becomes less efficient, in regards to self-consumption per kW h of battery storage, than smaller systems. This also means that the revenues increase slower per kW h with more than 10 kW h of battery storage. This is because of the selling price for the electricity is far lower than the price when a consumer purchases electricity. So even though the sizing seems to be right it is questionable to install systems larger than 10 kW h from a techno-economic point of view.

A lead acid battery system is unable to be profitable with the used assumptions and that is mainly because of the short lifespan and the relative high price.

The conclusion of this work is that the battery system gives the highest level of self-consumption but also has the highest levelized cost of electricity. The hot water storage tank is not far from the battery system when it comes to the level of self-consumption and has a levelized cost of electricity more than two times lower than the battery system.

Another conclusion is that the lifespan of lead acid batteries is too short in relations to the battery investment cost for battery systems to be profitable.

## 8. Further work

The reference system with the hot water storage tank will be further studied and an alternative where the heat pump is controlled so it is in operation when there is PV electricity surplus instead of the electrical heater will be

Table A1
*U*-values for the different building components used in the simulation.

| Building component | *U*-value (W/m$^2$, K) |
|---|---|
| Ceiling | 0.106 |
| Outer walls | 0.102 |
| Ground floor | 0.103 |
| Windows | 0.81 |

Table B1
Data for PV-system.

| | |
|---|---|
| Maximum power per module | 230 W |
| Tilt angle of modules | 70° |
| Open circuit voltage | 36.9 V |
| Voltage at maximum power point | 30.2 V |
| Short-circuit current | 8.31 A |
| Current at maximum power point | 7.62 A |

studied. The system model will in the future be validated against a laboratory system at Mälardalen University.

## Acknowledgement

The work was funded by the Swedish Effsys+ Program, which is in turn primarily financed by the Swedish Energy Agency and private companies.

## Appendix A

See Table A1.

## Appendix B

See Table B1.

## References

Ndiaye, Ababacar et al., 2013. Degradations of silicon photovoltaic modules: a literature review. Sol. Energy 96, 140–151.

Branker, K. et al., 2011. A review of solar photovoltaic levelized cost of electricity. Renew. Sustain. Energy Rev. 15, 4470–4482.

Castillo-Cagigal, M. et al., 2011a. A semi-distributed electric demand-side management system with PV generation for self-consumption enhancement. Energy Convers. Manage. 52, 2659–2666.

Castillo-Cagigal, M. et al., 2011b. PV self-consumption optimization with storage and Active DSM for the residential sector. Sol. Energy 85, 2338–2348.

Hay, J.E., Davis, J.A., 1980. Calculations of the solar radiation incident on an inclined surface. In: Hay, J.E., Won, T.K. (Eds.), Proc. of First Canadian Solar Radiation Data Workshop, 59. Ministry of Supply and Services, Canada.

Helder, L.P. et al., 2013. Characterisation of electrical energy storage technologies. Energy 53, 288–298.

International Energy Agency, Photovoltaic Power systems Programme task 1. <http://www.iea-pvps.org/index.php?id=146>.

Kaplanis, S., Kaplani, E., 2011. Energy performance and degradation over 20 years performance of BP c-Si PV modules. Simul. Model. Pract. Theory 19, 1201–1211.

Klein, S.A. et al., 2010. TRNSYS 17, A transient system Simulation Program. User Manual Solar Energy Laboratory, University of Wisconsin-Madison.

Linden, D., Reddy, T.B., 2011. Handbook of Batteries, Fourth edition. McGraw-Hill.

Nottrott, A. et al., 2013. Energy dispatch schedule optimization and cost benefit analysis for grid-connected, photovoltaic-battery storage systems. Renew. Energy 55, 230–240.

Purvins, A. et al., 2013. Application of battery-based storage systems in household-demand smoothening in electricity-distribution grids. Energy Convers. Manage. 65, 272–284.

Remund J. et al. 2013. Meteonorn Global Meteorological Database Version 7.

Riffonneau, Y. et al., 2011. Optimal power flow management for grid connected PV systems with batteries. IEEE Trans. Sustain. Energy 2 (3), 309–320.

Statistics Sweden, 2012a. Annual inflation. <http://www.scb.se/Pages/TableAndChart33832.aspx>.

Statistics Sweden, 2012b. Prices on electricity and transmission of electricity (network tariffs). <http://www.scb.se/Pages/PublishingCalendarViewInfo259924.aspx?PublObjId=552>.

Thygesen, R., Karlsson, B., 2013. Economic and energy analysis of three solar assisted heat pump systems in near zero energy buildings. Energy Build. 66, 77–87.

Williams et al., 2012. Demand side management through heat pumps, thermal storage and battery storage to increase local self-consumption and grid compatibility of PV systems. In: 3rd IEEE PES Innovative Smart Grid Technologies Europe, ISGT Europe.