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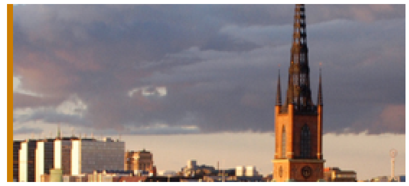

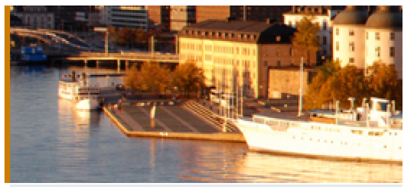

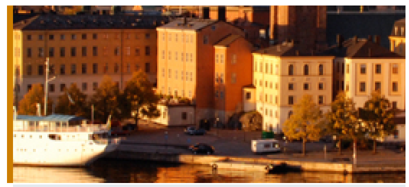

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[Multifunctional battery system – storage of renewable electricity generation]

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Overview

The discussion over the integration of renewable and decentralised generation into the distribution gird is one of the main reasons of our writing. In detail a calculation is made to analyse if it is possible to gain more revenues through providing the storage capacity - in combination with renewable generation, on the energy exchange market (EXX) in comparison to sell the renewable energy via feed in tariffs. Therefore, a Matlab based model is made. It is composed of generation and demand profiles of a photovoltaic power plant (PV), a small scale wind power plant, a household with two occupants and the charging and discharging profile of the storage unit. Based on this model two different economic assessments are evaluated: on the one hand the battery capacity is directly put on the EXX market and on the other hand the renewable generation is directly fed into the grid gaining revenues via feed in tariffs, without a storage unit. Thus, annual monetary contribution margins emerge due to the consideration of increasing household electricity prices, electricity market prices on the EXX and technical restrictions of the storage unit.

Results show, that it is possible to gain more monetary contributions from the year 2008 until 2020 in the option with the feed in tariffs, than in the version with the storage unit. Form the customer´s point of view €13.199 of profits occur over the first twelve years. After that, the other variant where a storage unit is used gets more remunerative, because the feed in tariffs expire after 12 years. With this second alternative it is possible to obtain additional €20.628 monetary contributions in comparison to sell the renewable generation directly on the EEX. The difference between the loss and the profit of the monetary contribution can finally be taken for paying off investments and are €7400 over the contemplated 22 years, if the customer decides from the beginning for the option with the storage system. If the customers first takes the option with the feed in tariffs and afterwards, after the expiration of these tariffs decides for the storage systems, then it's possible to gain monetary margins of € 20.600,-.

Methods

the handling of renewable generation's volatility is one of the biggest challenges grid operators and power suppliers have to cope with. Due to different incentives ([1],[2]) there will be an enhanced deployment of renewable generation technologies in the future and therefore more volatile electricity will be fed into the grids. To cope with this situation the introduction of alternative battery storage systems could be a possible solution. They charge the buffer storage of renewable electricity at peak generation times and easily feed back the stored energy when needed at peak consumption times. Therefore, decentralized generation and consumption is enabled, which would have a positive effect on the transmission and the distribution grid, because it may not be stressed to the maximum under such conditions. Thus, battery systems could improve the balancing of the system by grid operators using decentralized technologies. In the course of an Austrian research project, called MBS (Multifunctional Battery Storage Systems), a pilot system which is composed of a small wind power plant with 1.5kW and a photovoltaic plant with $15kW_{peak}$ as electricity generators, linked with a household customer in the role of a consumer and in combination with a 100kWh battery, is realized.

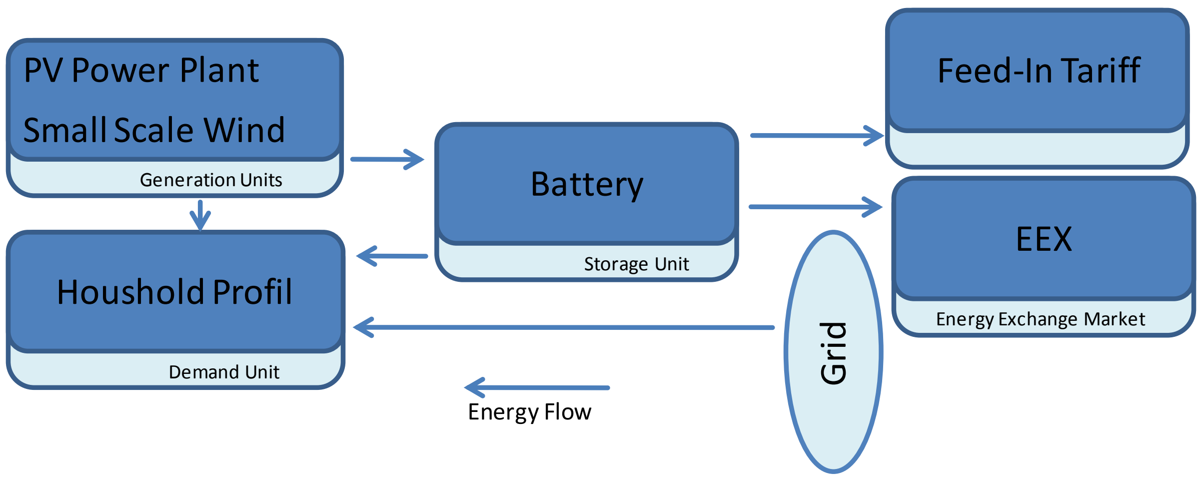

Figure 1 System overview of the investigated model components

Parameters of the model

- **The energy storage unit**
  The battery shaped in the model has a capacity of 100kWh, a maximum charging power of 12kW and a discharging power of 8kW.[3] The profile of the charging and discharging power is shown in Figure 2.The charging power decreases with an increasing SOC; because it is assumed that the charging voltage is restricted starting at a SOC of 50%. So it is possible to avoid the battery from overcharging. In the range of 25-88% of the SOC the battery can be discharged steadily with a discharging power of 10kW. Over a SOC of 88 % it is not possible to charge or discharge the battery, because this is an undefined range and the battery can only be used until a capacity of 88kWh. Moreover, after the first charge, the SOC of the battery should not go beneath 10% because there the battery can be damaged.

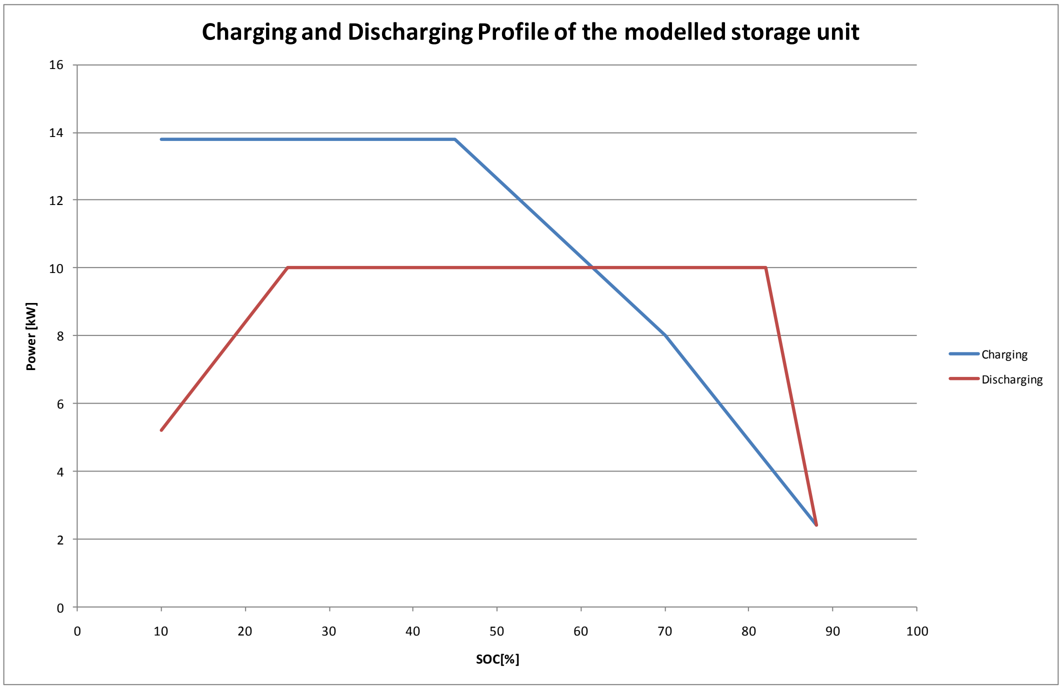

Figure 2 Description of the modelled charging- and discharging power of the storage unit

- **Renewable generation**

  The system, consisting of a household and the storage unit is fed from renewable generation units. The photovoltaic power plant has a peak generation of 15kW and it averages at least 12.700kWh per year. The modelled small scale wind power plant has an annual generation of about 3.600kWh, with a maximum power of 1.5kW.

- **The household profile**

  In the context of the MBS project different household profiles (quarter based profile) have been generated with the software PV SOL. For this work we chose the load profile "double income no kids" (DINK) to do the model iterations. The total annual demand of this amounts to 3.2MWh, with an average power of 370W.

  For this DINK profile the following assumptions were made; two people live in the household, who are out of their home during the day, 5 weeks of the year they are away on holidays, separated in 3 weeks in the summer and two weeks in the winter. The resulted profile is shown in Figure 3.

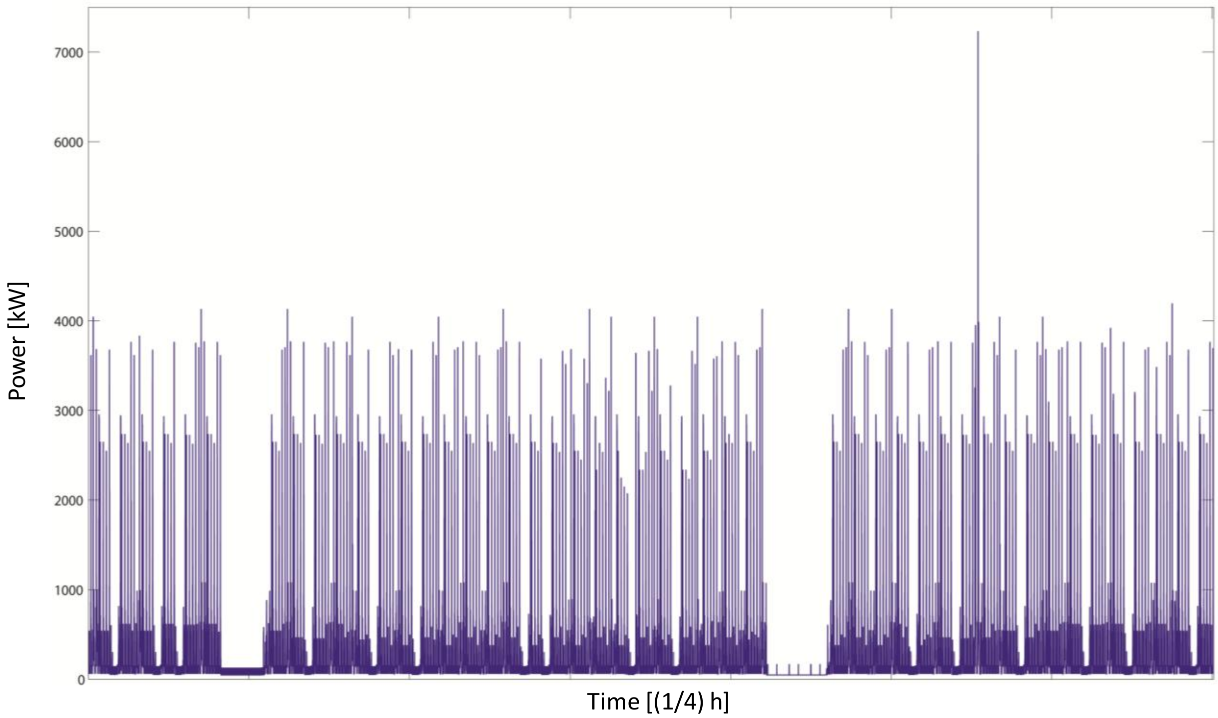

Figure 3 Household profile over a year

- **The household electricity price**

  In the model the median energy prices for the year 2000 until the year 2030 are used, like predicted in [5] This associated energy price build up only 36% of the household electricity price [6]. These values are used as input parameters for the electricity price prediction.

Methodology

- **Coverage ratio for household requirements**

  For an economic use, the battery capacity is split into two different capacity parts. The energy from part X is used for covering the domestic requirements and the other energy part Y for selling on the EEX. To estimate the X/Y ratio, the part for covering the domestic requirements is gradually increased, starting at a capacity of 10 kWh until 100kWh and for each step the coverage ratio CR is calculated.

$$CR = \frac{E_{discharge}}{CSP} * 100 \qquad (1)$$

CR... Coverage ratio of the household profile %
$E_{discharge}$...whole discharged energy kWh
CSP... total annual consumption MWh/a

These calculations lead to Figure 4, where the incrementally calculated values are shown.

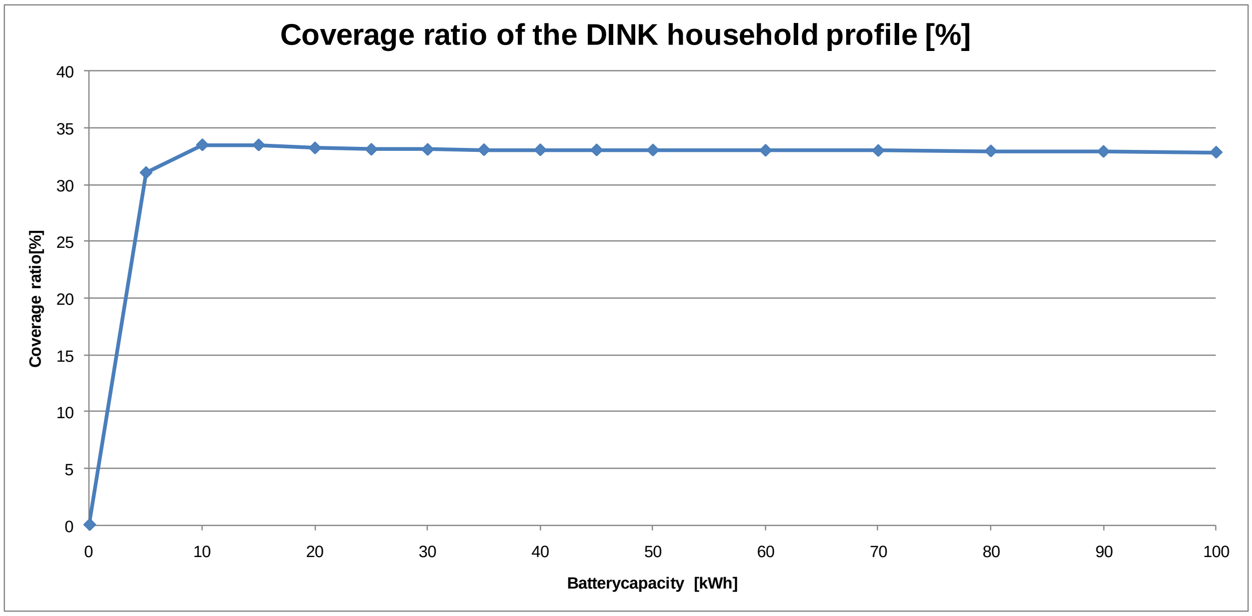

Figure 4 Coverage ratio of the DINK household profile in combination with a battery system

In Figure 4 the behaviour of the coverage ratio is shown. At 5% of the whole capacity the curve showing the coverage ratio turns downwards the first time, the gradient gets smaller and after 10% the gradient gets negative, a turning point appears. Therefore no more advantages exist after this value of 10% SOC because of a bigger battery capacity. Thus a battery capacity of 10kWh is computed for the optimal coverage ratio. To this 10kWh additional 10kWh are added, because the battery should not be operated under the 10% SOC boundary (see The energy storage unit). Consequently the final boundary lies at 20kWh. So these 20kWh are used for the coverage of the household demand and the other 80kWh for the participation of the battery storage system on the EEX market.

- **Electricity price prediction**

For the used electricity price prediction, historical energy price data sets from the years 2003-2009 of the Austrian EEX have been analysed. The electricity price profiles on an hourly basis are separated in defined timeslots; weekdays, weekends and official Austrian holidays. For each of this profiles in the time slots, a quantitative profile has been made, which exists of the typical behaviour of the considered time slots. As an exogenous parameter for this model of the EXX electricity prices serves the future energy price, see the chapter “The household electricity price” and [5]. This predicted energy prices correspond to the area under the found qualitative curves and thus set the altitude of the curves and therefore the prospective time variant electricity price curve on the EEX.
These curves have been extrapolated for the years 2015, 2020, 2025 and 2030 and consequential the monetary coverage of the variant with the storage unit calculated.

- **The charging strategy**

Different parameters influence the optimal charging strategy of this model. On the one hand the energy prices on the EEX have to be taken into consideration, on the other hand the wind and photovoltaic generation and the actual battery energy level are important. In a first attempt in this work the charging strategy is optimized on the PV generation, without considering the other parameters. In a next step it will be possible to optimize the charging strategy with linear optimization under consideration of the other constrains too.

Through the linkage of the charging strategy with the photovoltaic generation, three different areas for charging and discharging occur for each day. The storage unit is daily charged in the time from 10am until 5.30pm, because then the maximum generation is produced from the photovoltaic cells. The remaining time, before and after this time interval the battery is discharged, with a discharging power dependent on the SOC.
So the storage unit is charged over midday and when there is peak demand in the grid, and thus peak prices on the EEX occur, the storage unit is discharged.

- **Economic evaluation: Storage usage strategy on the EEX**

The monetary margin, earned through the disposal of the 80kWh storage unit, composed of revenues of the sold energy on the EEX, the saved costs of the household demand through the coverage of the household requirements, minus the costs for the grid receipt. (See equation 2) The costs for the grid receipts cannot be neglected, because the household demand is not covered through the renewable generation at the beginning of the year, due to high demand and less PV generation.

$$MM_{EEX} = GEN_{tot} * P_{EEX} + DM_{H_{tot}} * P_H - C_{GR} \qquad (2)$$

MM_{EEX}... monetary margin of the storage unit [€/a]
GEN_{tot}... total generation of PV and wind [kWh/a]
P_{EEX}... EEX electricity prices [€/kWh]
DM_{Htot}... annual household demand of the DINK profile [kWh/a]
P_H... Household electricity price [€/kWh]
C_{GR}...Arising costs through electricity grid receipts [€/a]

- **Economic evaluation: Disposal strategy of the whole renewable generation with feed-in tariffs**

The remuneration for the feeding in of PV facilities on free spaces with a power between 5 and 20 kW_{peak} in Austria is about 35c€/kWh. For small scale wind one can get 9.7c€/kWh, see also [7]. With the before described household electricity price, like described in the chapter "The household profile", the household electricity price for the considered time period is taken for calculation of the costs, occurring because of the DINK demand. The revenues compound of the energy fed-in into the grid, produced through PV and wind.

$$MM_{FT} = T_{Feed,PV} * GEN_{PV} + T_{Feed,Wind} * GEN_{Wind} - P_H * DM_{Htot} \qquad (3)$$

MM_{FT}... monetary margin of the feed in tariffs [€/a]
$T_{Feed,PV}$... Feed in tariffs for PV generation [€/kWh]
GEN_{PV}... annual generation of the PV facility [kWh]
$T_{Feed,Wind}$... Feed in tariffs for wind generation [€/kWh]
GEN_{Wind}... annual generation of the small scale wind plant [€/kWh]

- **Comparison of the two different options**

In a first step the intersection points between the monetary margins is calculated. Therefore the particular courses are equated and the intersection is calculated. The area between the curves is computed from equation (4) and demonstrated in Figure 5.

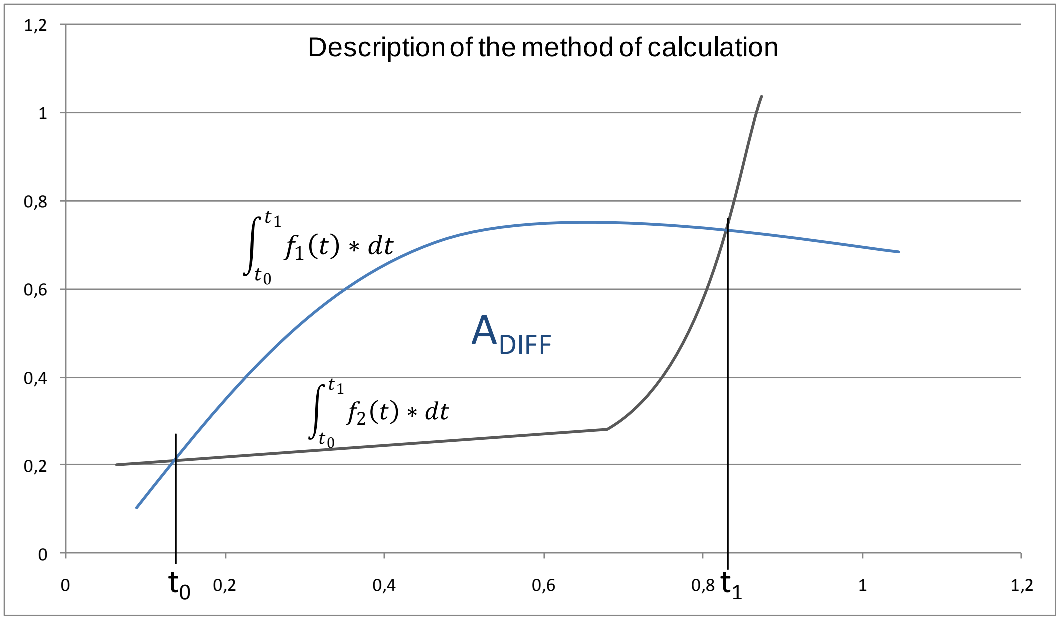

Figure 5 Description of the general computation of the remaining difference of the monetary margins

$$A_{DIFF} = \int_{t_0}^{t_1} f_1(t) * dt - \int_{t_0}^{t_1} f_2(t) * dt \quad (4)$$

A_{DIFF}... is the area between the functions
$f_{1(t)}$ ... function 1
$f_{2(t)}$ ... function 2

This approach, as exemplarily shown in equation (4) is made for the areas before and after the intersection, dependent on the period under consideration, and the two areas ADIFF1 and ADIFF2 are put into relation. Based on these results a comparison from the customers' point of view is made.
If ADIFF1>ADIFF2, the option described with function f1(t) is not profitable form the customers' point of view. The customer will decide for the other option, described with function f2(t).
Nevertheless, if ADIFF2>ADIFF1 the customer will get more revenues with function f2(t) and therefore will give preference to this option.

Results

Figure 6 shows the monetary margins for the storage usage strategy on the EEX, like described in equation (2), shown for the years 2008 until 2030. The enveloping curve shows the behaviour of the total monetary margins, starting with €2280,in 2008 and pending to €3060 in the year 2030. In 2010 the spot market prices have been rather low, due to the Great Depression;. Hence the peak in the course of the curve of the monetary margins appears in the year 2008. After that the prices went down to a normal level, reflected in higher monetary margins. After that the margins increase steadily with the predicted EEX energy prices.

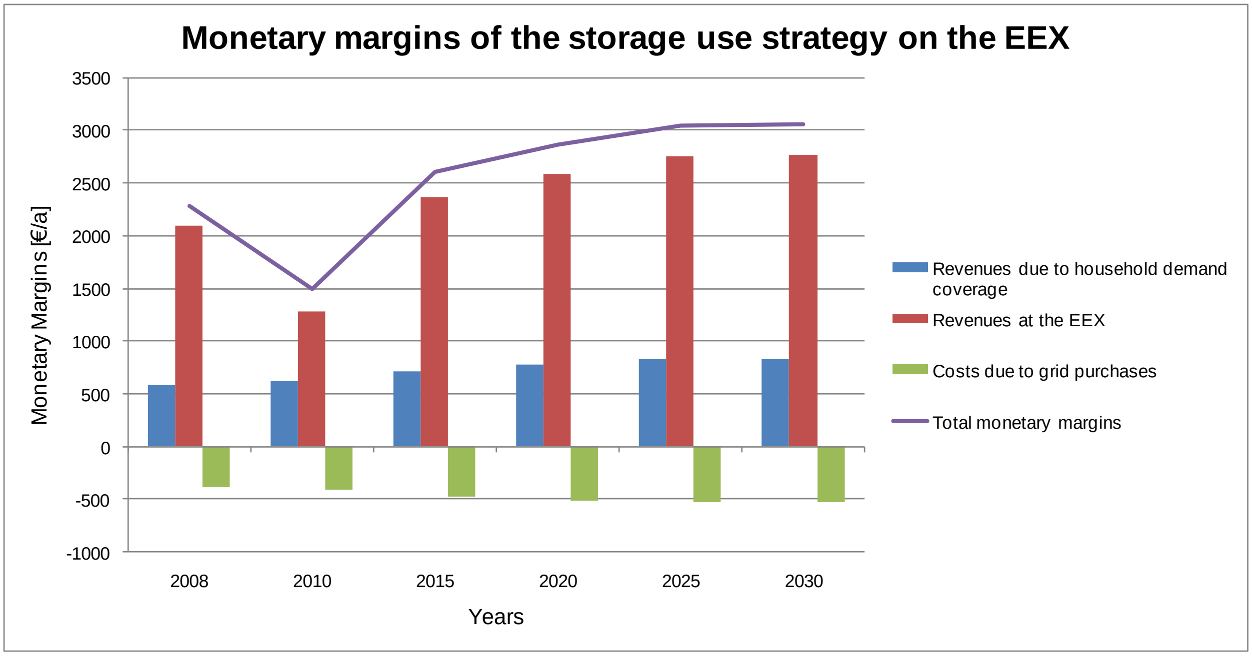

Figure 6 Revenues of the storage unit at the EEY electricity market, incl. the revenues due to the household coverage

Figure 7 shows the monetary margins of the second option, where the produced energy is directly feed into the grid with feed in tariffs. In the year 2008 starts the feeding-in with the guaranteed feed in tariffs for PV and wind and ends after 12 years in 2020. Monetary margins lie at about €3400 with guaranteed feed in tariffs. After that the monetary margins rapidly drop down, because now the renewable generation is feed into the grid without the use of a storage unit, so less monetary margins can be achieved, and this ordinary achieved margins lie at €900,- per year.

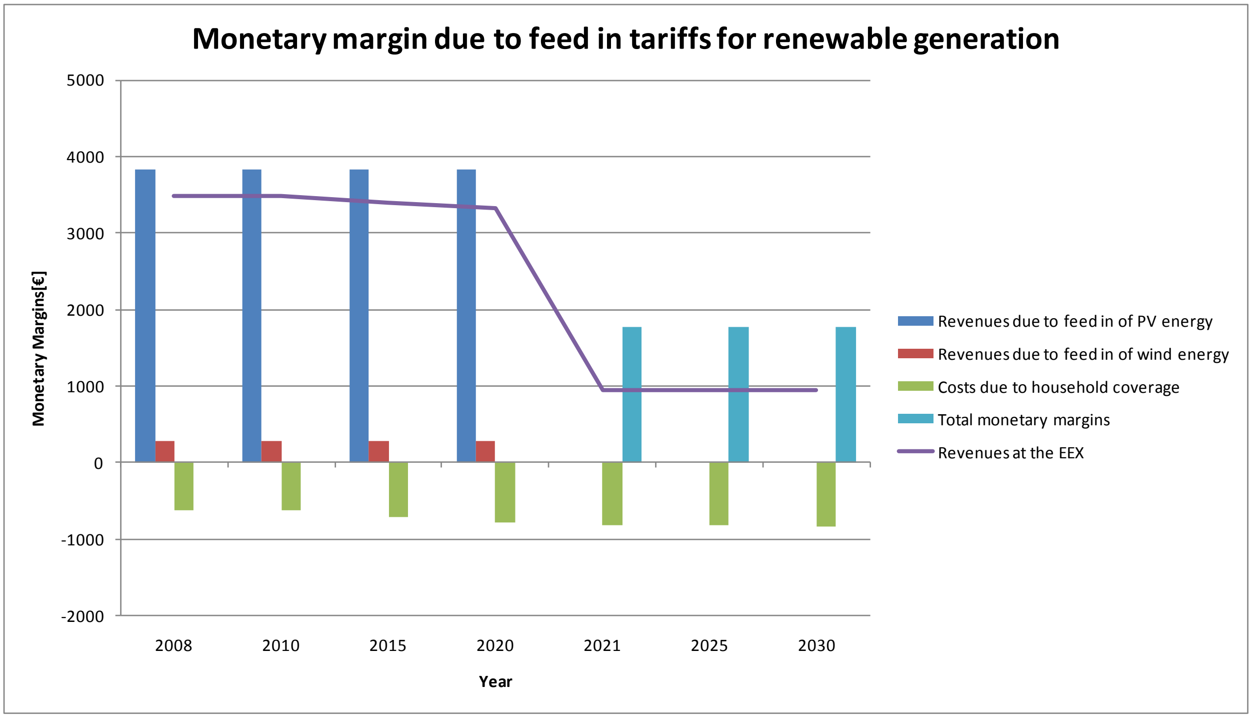

Figure 7 Monetary margins due to feed in of the renewable generation into the grid

Figure 8 shows the direct comparison of both storage usage strategies. The courses of curves intersect in the year 2020. Before 2020 the option of feeding in via feed in tariffs is more economic and afterwards the option with the storage unit turns out to be more profitable.
In this work only the monetary margins are evaluated, therefore the investment- and maintenance costs of the storage system are not be taken into consideration. Due to allowance of these additional costs, the blue curve would decrease by the value of the annuity cost of the installed systems. These have not been considered here to have the possibility to derive potential revenues for a battery storage unit.

First the discrepancy between the year 2008 and 2020 is computed, which is equal to losses of the monetary margins, because the option with the storage usage strategy is not economic. Equation (5) shows the exact calculation. It leads to total monetary margins of €78.911 in 12 years.

$$\begin{aligned} A_{DIFF1} = &\int_{2008}^{2010} (-394{,}05t + 793531)dt \\ &+ \int_{2010}^{2015} (222{,}14t - 445011)dt + \int_{2015}^{2020} (51{,}48t - 101131)dt \\ &- \left[\int_{2008}^{2010} (3479t)dt \right. \\ &\left. + \int_{2010}^{2015} (12{,}43t + 28435{,}6)dt + \int_{2015}^{2020} (-13{,}8t + 31199)dt \right] = 13.199 \text{ €} \end{aligned} \tag{5}$$

By comparison the second area after the intersection is calculated, from the year 2020 until the year 2030. From the customers' point of view this area is equal to profits of the monetary margins. The calculation is shown in equation (6), the resulting total monetary margin profits in the reconsidered 10 years are €20.628.

$$A_{DIFF2} = \int_{2020}^{2025} (36{,}94t - 71760{,}4)dt + \int_{2025}^{2030} (3{,}72t - 4489{,}9)dt - \left[\int_{2020}^{2025} (0{,}4t + 128)dt + \int_{2025}^{2030} (t - 1087)dt\right] = 20.628€ \quad (6)$$

In a last step, both areas are compared. Because here the case of $A_{DIFF1}<A_{DIFF2}$ is valid, the customer has in this case €7429 additional monetary margins, to invest in a storage battery unit. This €7429 can be generated with the storage usage strategy and now can be compared with actual battery prices.

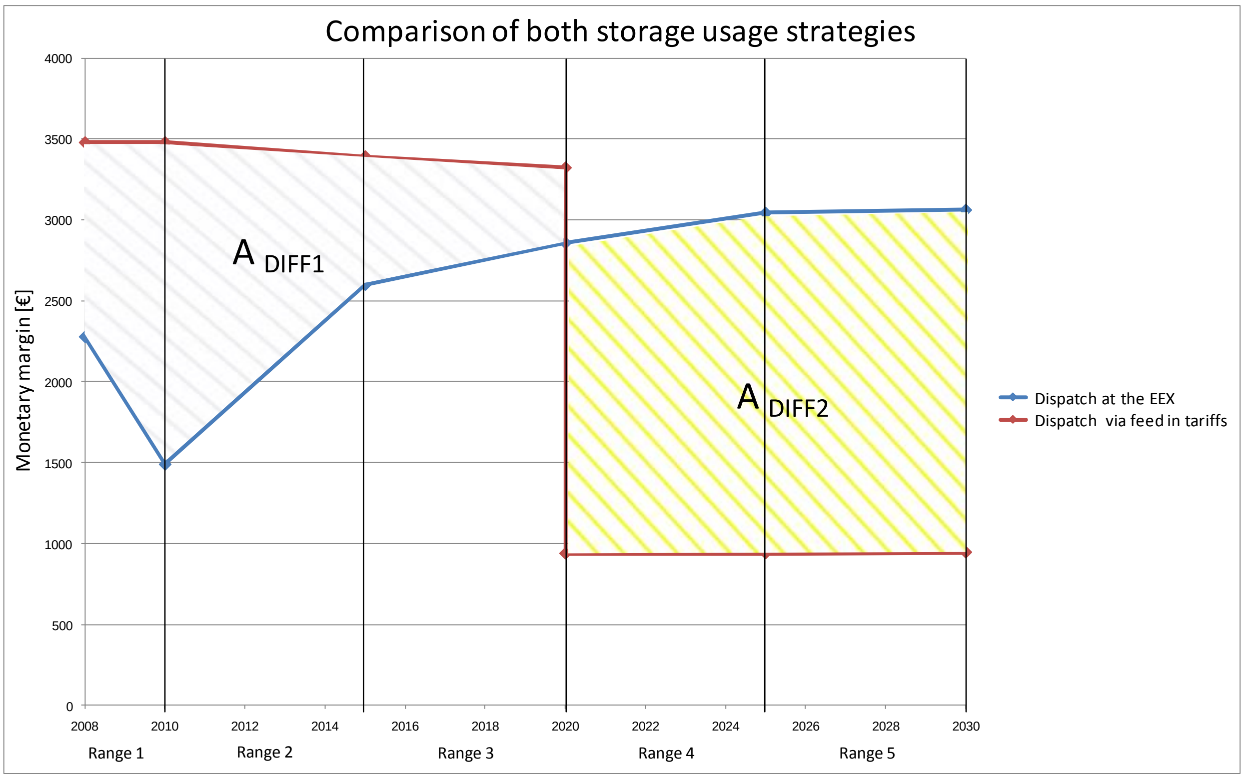

Figure 8 A direct comparison of both storage usage strategies

Conclusions

The profits of the monetary margins exceed the losses of the monetary margins in the considered time slot and for the storage usage strategy on the EEX. For the return of capital of a storage unit, only €7.400, - are available. This amount is actually not enough for the investment in a battery storage system with the before defined parameters and restrictions.

From the customers' point of view, there is a better solution feasible. First the customer has to decide for the option with the feed in tariffs, and after the expiration of the guaranteed feed in tariffs, it should be invested in a battery storage system. With this strategy it is possible for the customer to have €20.628, - for the return of capital. Thanks to technological learning and a higher market penetration of storage systems in the future, the invest costs for storage systems can decrease. But on this topic additional research is needed. Moreover alternative storage usage strategies will be explored in the course of the MBS project in the near future

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