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Simultaneity of consumption and solar energy production of a Hungarian household

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Abstract

Nowadays, the electricity production with renewable energy plays an increasingly important role in which photovoltaic (PV) systems play significant role as well. This kind of technology is predominant on the household level for. The reason, that a wide output range can be created, and each of the individual consumers can be customized, furthermore its aesthetic, manageability and financial characteristics are also positive. In this publication the simultaneity of the production of a household size small power plant and the quarter-hourly consumption of a household was analyzed, and the sizing of an energy store system (ESS) in the event of power supply interruption was shown. Analysis of the data shows the impact of production and consumption in individual seasons, and illustrates the extent of it. In addition the simultaneity of production and consumption was shown on diagrams in each month and season. The simultaneity has been very low, but it could be improved by using ESS. In this study the sizing methodology and the financial aspect of an ESS has been displayed.

Keywords

battery, energy storage, photovoltaic system, energy consumption, energy production

1. Introduction

In the case of household users, the electricity consumption and the production of the photovoltaic system indicates very low simultaneity. This simultaneity is increasable with the integration of energy storage system with the photovoltaic system. In this case the storage system could store the temporarily unused electricity for later use. By doing so the produced electricity is stored and used in this way, the communal electrical network is not loaded as much as if the produced energy would be fed back into the network. This ensures that the spread of renewable energy sources (in this case the PV system) have a smaller influence on the operation of the electric network, as in the case of the feedback power supply.

Recently, several national and international studies have appeared showing the development and the increasing usage of photovoltaic systems. Considerable attention was also paid to numerous energy productions in household size. These high numerous appearances have a high impact on the electricity system. In addition the balance of the electricity consumption and production is also very important, just as the flexibility of the systems. This problem can be solved with energy storage systems, which on the household level are the batteries. There is a significant financial investment for the development of batteries. Several scientific papers have been published in which it was shown which type of battery should be used and how much time should the battery systems gap. The present work shows a slightly different perspective for these energy storage problems [1], [2], [3].

Firstly, the document presents the analysis of the annual electricity consumption of the examined residential customer on monthly and seasonal levels. After that the analysis of the electricity production by user-installed solar energy systems on a similar level is presented (see section 2.2). These are used to compare the production and consumption and to test the simultaneity (see section 2.3), mainly the influence of the seasons (see section 2.4). In the third part of the work the on-sizing of the battery energy storage is presented which system can work in grid operation mode for limited time.

2. Comparison of consumption and production data

In order to compare the electricity production and consumption, both must be available in both formats of the same data set. It is preferable for the data to be available in each quarter-hour just as the time-series measurements of consumers are happening.

2.1 Consumption

For the examining the impact of production and consumption to be carried out, it is necessary to have consumption data of households. These are available between 01.01.2016. and 12.31.2016. in quarter-hour resolution.

The used database contains 1422 pieces of different-energy residential customer profiles. The individual profiles include a full year of energy consumption. It covers 366 days, since the examined year was a leap year (2016). The yearly electricity consumptions of the examined households are between 500 kWh and 9000 kWh. The investigation was made for an average Hungarian household, the average yearly electricity consumption of which was 2600 kWh.

The consumption of the household was modeled for the average of 1422 pieces of data series. In this case, the average yearly electricity consumption was 2509.27 kWh respectively. In the modeling the used dataset was "parallel" with this artificially created profile, to reach 2600 kWh per year energy consumption. If this operation is not carried out, the targeted analysis could also be performed. However if the consumption is equal to the production of the integrated PV system similar statements could be drawn from the amount of production surplus and consumption surplus.

The used monthly average dataset of the household is shown on Figure 1 in quarter-hour resolution. From this the differences between the consumption of each month could observed.

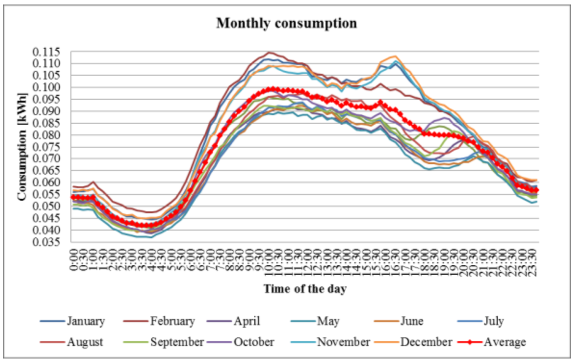

Fig. 1: Monthly consumption profiles

It is observable on the chart, that in each month the approximation of average in the night (20:45 to 04:45) was better (average MAPE (Mean Absolute Percentage Error) = 17:11%) than in the daytime (5:00 to 20:30) period (average MAPE = 35.41%). In the daytime period the difference between these values are greater. This was calculated on the basis of prior expectations, as consumer habits in the night of each month and seasons do not affect, only the electricity usage of heating system installation. However, it could be relatively surprising that the biggest consumption occurred during the winter months. This is shown on Figure 2 to be more perceptible. On the diagram, the average seasonal consumption is presented.

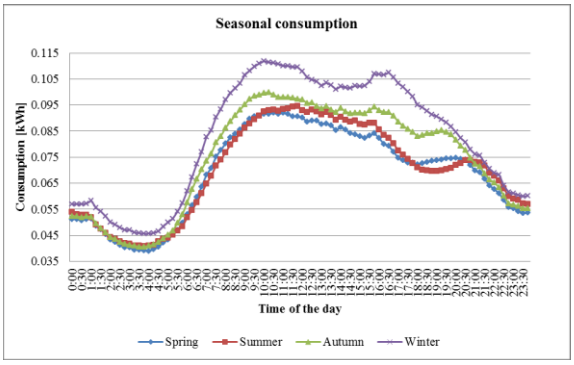

Fig. 2: Seasonal consumption profiles

On the figure the low seasonality in electricity consumption of residential consumers can be seen. The reason for this was the use of lighting trend for the autumn and winter months and the electricity need of heating installation. The latter demand led to an increase in electricity consumption in the night time. On the chart the quarter-hourly low energy content of seasonal deviation also can be seen.

2.2 Production

The analyzed PV system is a Hungarian household size small power plant, which was installed to cover the annual electricity consumption of households with renewable energy source. In the PV system there are 11 pieces of polycrystalline PV modules placed with 250 Wp/piece output power. The type of the modules was Sharp ND-R250A5. The rated power of this PV system is 2.75 kWp. The PV modules were mounted on a tent roof with 40° inclination. The orientation of the PV system was SW (South-West) 45°. The system was operating on shady location because of the higher voluminous trees surrounding the house. Because of this a major loss has to be expected. The PV system was connected to the network via a 3 kVA inverter. This type of the inverter was Sunny Boy 3000TL-21. Data on the solar system and the production was available on a website (www.sunnyportal.com) operated by the company SMA Solar Technology AG. The data herein can state that the production is a little bit more than the required 2600 kWh (2834.285 kWh). The production of each quarter-hour has been modified to achieve the desired goal number. During the modification each quarter-hour production value has been multiplied with 0.917339 (2600/2834.285). This modification would not cause a big mistake the nature of the production was not affected.

According to preliminary expectations and knowledge major differences were experienced in the production characteristic of the individual seasons, as it has been experienced in the consumption. For the examination of the production the average production of each month was compared to the average production of seasons. These comparisons are shown in the following figures (Fig. 3, Fig.4, Fig.5, Fig.6).

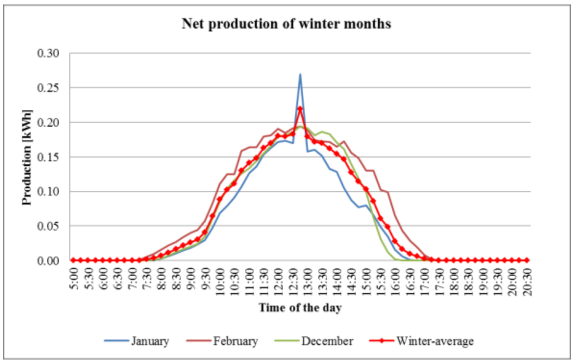

Fig. 3: Net production of winter months

For the winter months the nature of the curves were considered to be nearly identical. The major difference was in the January curve, since there was a significant outlier in the middle of the day. The reason for this was the short period cleaning of a cloudy, darker day of January (2016.01.08.). On this day, the production was only of a small degree, but during this period a significant drift was caused (time of day: 12:45). Before this time of day the production 0.07 kWh, at this time (12:45) 0.552 kWh, after this time of the day below 0.098 kW was measured. This can be seen graphically in both January and average winter production curves. This deviation was caused from the weather features. In February, the orbit of the Sun was higher than in the other two months. Because of this in February the beginning of production was shifted for an earlier time, and the curves slope of the ramp was greater. In February the production was higher than the winter average.

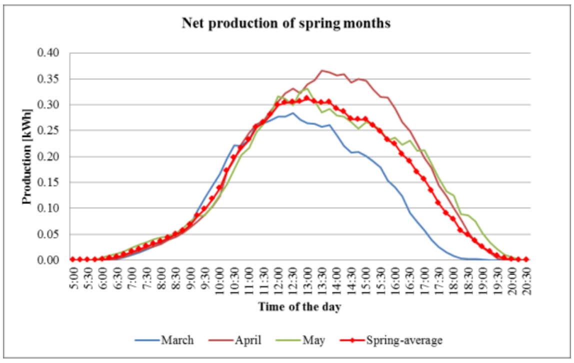

Fig. 4: Net production of spring months

In the spring months of the curves were of a significantly different nature, as it can be seen on Figure 4. The start-up phases of the curves were considered approximately identical. Large differences in the amount and the time of maximum value of production was registered. It was observable that the volume and the maximum value of a quarter-hour electricity production in April were significantly higher than the volumes in May. According to preliminary expectations it was not fully developed as expected. However, this could be due to large change in temperature. In April, the average temperature of Budapest linearly increased between 10 °C to 20 °C, and in May also linearly increased from 19 °C to 23 °C. In May, the higher temperatures on the PV modules could their efficiency decreasing, and the angle of incidence of the irradiance could be different from the desired 90°.

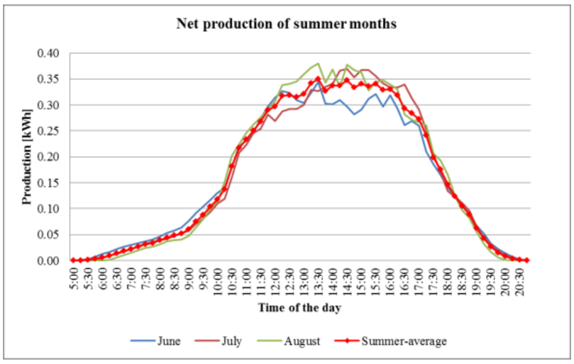

Fig. 5: Net production of summer months

On Figure 5 the net production of summer months and the summer average is shown. The curves depicting the months the starting, rising and falling section of the curve shows a good approximation of the average. Larger differences are only around the global maxima, on the top of curves. This can be caused by clouds in the sky, and the radiation and temperature fluctuations.

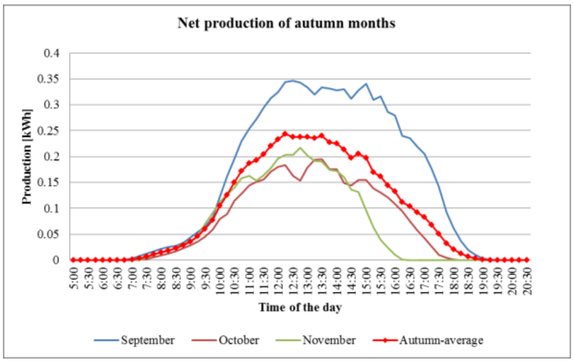

Fig. 6: Net production of autumn months

For the autumn months, it can be seen with the approach of winter, the amount of relative production largely decreased. This production was in September 9.1942 kWh, in October 4.2893 kWh and in November 3.9606 kWh. The production in October was the 46.65% rate of the September value. The average production moved between the October and November, as well as the September production curve. The global maximum of each month took place ever earlier in the winter was delayed. This is because the days were shortening, and in Hungary, the clock adjustment took place at the end of October. The beginning of the rising phase of the curves for the three-month average was well approximated. At the middle of the rising phase of the curves there is a little difference to be seen. However, the falling phases of the curves show a higher difference. It is because of both the weather, the length of the days and the Hungarian clock adjustment. Also, it should not be overlooked that in autumn the air pollution can grow significantly due to the beginning of the heating season and the green waste incineration. This amount of impurities was deposited on the surface of the PV modules increased significantly.

During the research of simultaneity of the production and consumption the impact on production was examined in some seasons. In order to compare the production for some seasons, the described means of the seasons were plotted on the same figure. This comparison is shown on the Figure 7 In this chart the meteorological seasons are shown, so the effects of the September production is taken into account with the autumn average.

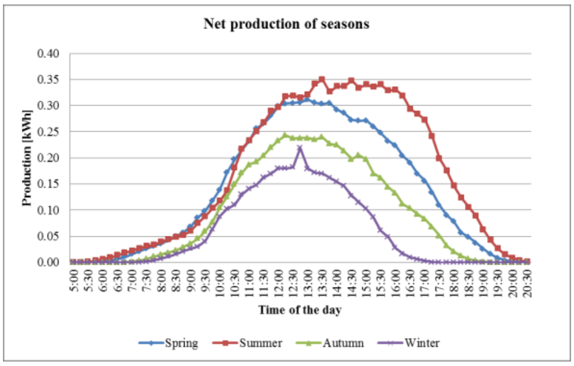

Fig. 7: Net production of seasons

It is seen from the diagram that in some seasons the quantity and nature of the electricity production is significantly different from each other. The rising phase of spring and summer curves were the same with a very good approximation. The curves are nearly identical to that time of the day until the spring curve reaches its global maximum. The different length of day can be observed in certain seasons. A significant difference is experienced in the evening. The high temperatures generated by the efficiency-reducing effect can be seen, because if it were not, the curve would be different from the spring to summer period should be better both in the maximum and the rising phase.

2.3 Simultaneity of consumption and production

In the comparison of production and consumption [6] the basic concept was used in the sizing of the PV system to produce an average self-consumption of a Hungarian household. In this case, the annual electricity use, which was established in 2600 kWh, and electricity generated production of the PV system, which is also due to 2600 kWh. Because the two values are the same, the household would be able to operate without communal utility power plants theoretically. But this can not be determined in this case, since the simultaneity of the production of the PV system and electricity consumption is so bad. This simultaneity is shown in the Figure 8.

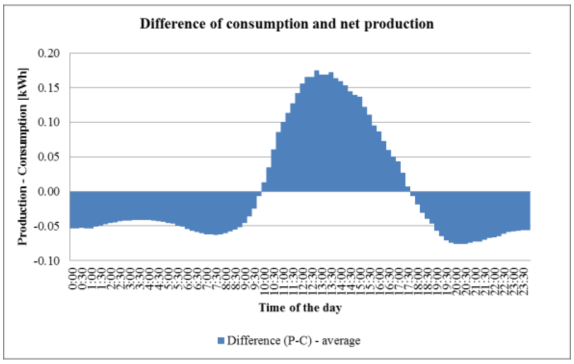

Fig. 8: Difference of the consumption and net production

On the chart the difference between the average electricity consumption of the household and the average amount of PV systems production can be seen in quarter-hour resolution [6]. The differentiation of consumption and production can be carried out without problems, since both data for the consumption and production available in quarter-hour resolution. On the quarter-hours where the resulting difference is negative (the coordinate system is in the negative range), there is surplus consumption, where the gap is positive (the coordinate system is in the positive range), there is surplus production. Since the model of the system is produced in self-consumption, the average daily amount of the surplus production and consumptions are not exactly the same.

The attention has been focusing on the individual seasons, not each month. A more detailed examination is made on the basis of this criterion. To do this the difference between seasonal average production and consumption has been formed and shown. The representation is shown on Figure 9.

The findings proceeding from Figure 7 on the diagram it can be observed, that in the individual seasons the different nature of the curves are significantly vary.

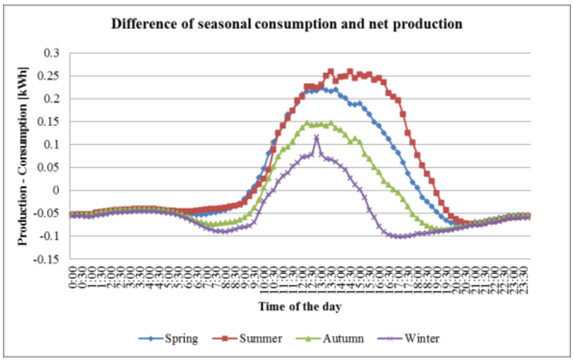

Fig. 9: Seasonal difference between consumption and net production

2.4 Seasonal simultaneity of consumption and production

The evaluation of the data obtained by focusing on the following issues occur:

Production and consumption charts-course influenced by the examined seasons

During the evaluation of the first consideration in a comparison examination in which the difference between production and consumption curves are representing the influence of the studied seasons only the falling phases of the seasonal curves, shown in Figure 9 were analyzed. This period can be put between the global maximum of curves (always in the different time of day) and the end of the falling phase (always 20:30). It is concluded that the different characteristic nature of the seasons is also greatly affected. In summer, the maximum before the falling phase is much higher than in the spring, the autumn and for the winter too. The declining sections of the slope of the falling phase are different in each season. In the summer, the slope is steeper as in the other three seasons. This is due to the significant size of the surplus production aroused. The pre-curved section of a maximum amount of falling and the Sunset, the Sun's career is changed in the seasons (perceived height) and the curved characteristic features are affected by time of darkness too. The maximum value is higher because the high number of sunny hours and the sun high arc trajectory (sun inclination) experienced. However, this maximum would be much greater if the efficiency of solar cell can not be decreased by high temperature.

Summer surplus production and the goodness of temporality relations

In the evaluation, the following criteria were also casted. Whether we can state that in summer the temporality of production surplus is better (the production of the photovoltaic system follows better the load growth in morning), or this association can not be stated. The examined interval (morning increasing load) can be made for the period from 00:06 to 09:00. The assessment during this aspect focused on this interval. The simultaneity of spring temporality is not, or only imperceptibly better than in summer. Therefore, from this point of view the load increase of spring and summer can be considered to be identical. During the summer time the simultaneity of the system is also better than in the autumn and winter seasons, as load increases in the morning followed by more production of the solar system. This is confirmed by the morning average of summer of the curve although the increasing load has not fallen as much as in this phase of the autumn and winter curve. The rising of the graph is shown at an earlier time of day (7:15) than in the other two cases (8:00 in autumn, 8:30 in winter). In spring and summer the load increase in production is more easily compensated for, such as in autumn and winter, caused by a mismatch between the times of sunrise. In the course of everyday life in the late autumn and winter months the morning activity begins before sunrise. In this case the PV system has not yet produced electricity. After sunrise the production is significantly lower (0.0884 kWh) than in the spring (0.3706 kWh), summer (0.4059 kWh) and early autumn (September) (0.1970 kWh) months. The morning load growth so difficult to be compensated for the winter months.

The night period is considered as "discharging"

If the night period is considered as "discharging", does the period or the energy content show any deviation in seasons?
On Diagram 9 the negative range can be seen, where there is surplus consumption, for a period of discharge cycles, as well as in the energy content there was significant changed between seasons. Significant differences can not be observed during the night between 20:30-05:30. In this period the curves run together. Significant differences are seen in the morning and in the afternoon, in the early evening period. In summer (19:00), this time of the day is extended considerably, compared to the autumn (17:00) and winter (15:15) times. In contrast to the previous experience in the afternoon, early evening period, not only in autumn and winter, but in spring there is a significant difference (18:15). The shifting of time of surplus consumption demand is caused by the difference between the days, months, seasons in daytime period. In summer the days are much longer than in winter. This difference is also perceptible in the morning period, although not as markedly seen as the early evening period. This difference is also reflected in the energy content. The energy is the integration of the area under the curve obtained. In winter the area under curve has been much larger, hence the surplus demand for energy consumption even more. Notable differences in the morning (spring: 0.6279 kWh; summer: 0.5660 kWh; autumn 1.0438 kWh; winter: 1.3348 kWh), and in the early evening period there is (spring: 0.4660 kWh; summer: 0.2661 kWh; autumn 0.9015 kWh; winter: 1.7798 kWh), however during the night in winter between 20:30-5:30 there is appreciably higher energy demand (spring: 1.8901 kWh; summer: 1.9682 kWh; autumn: 1.9513 kWh, winter: 2.1287 kWh). In autumn period both simultaneity and energy demands is vary between the winter and summer values both in the morning and in the early evening period. A slight shift is perceptible towards the winter. The morning period did not show any gross deviation as the afternoon, because in the household level the change of the daily routine of the season is nearly independent, only the electricity used for lighting or the associated electrical equipment of the heating system have energy on demand. From all three aspect it can be seen that the season has a significant influence on production and a slight influence on the consumption.

3. Energy storage system (ESS)

As previously mentioned, in the case of residential consumers the simultaneity of production of PV system and energy consumption is low. To increase the simultaneity of the production of the PV system should be integrated, ESS provided, where the surplus production could be storage.

In many parts of the world research into the development pilot energy storage systems is being carried out. However, the industry is not uniform at the assessment of them, because the financial returns of new developments respond to the changing environment, the effectiveness and the territorial applicability is constantly expanding.

In Hungary, large-scale energy storage is difficult to be implemented because of the topography of the country. Therefore, it is justified by the need for the electricity, produced with decentralized renewable energy sources, stored in the place of production. In the investigated model the goal is not the storage of all electricity produced only the amount by which, in case of power interruption for a predetermined time, the system is remains in operation. The technology used to store electricity from household level, the battery energy storage method is the most appropriate and practical. The space requirements and design of the batteries in household level made them useable, aesthetically acceptable [4], [5].

3.1 Batteries

The battery is a type of energy storage device used to store chemical energy. It can be loaded for a long time with good efficiency, kept in charged state and discharged up to 20% of storage capacity. The long charge-load cycle life of the solar batteries can be ensured with heavier lead, so their weight is much greater than that of the same storage capacity motor starter lead-acid batteries. The modern lead-acid solar batteries can be operated much longer than the traditional ones. The lifetime of them is approximately 6-10 years (thanks to advanced technology can operate without problems 9-10 years). In case of isolated operating systems in addition to lead-acid batteries gel the use is also the spread of gel batteries, whereas these type of batteries are maintenance-free, able to operate without widespread for a longer time, but the costs are significantly higher than that of the lead-acid ones [7].

3.2 Related calculations of the examined system

It is expected that the system remains isolated from communal network in operation. Therefore, it is necessary that the electricity production is at least equal to the electricity consumption of the system if it remains disconnected. In this case, the difference between the average production (the four seasons of the average production curve) and the average consumption must be examined. This can be seen in the Figure 7. Looking at the daily rate of the surplus production and surplus consumption the two values are equal, and it can be stated that if the total energy produced would be stored for years, the consumer's total electricity needs would be covered. The question is to be examined, whether there is a possibility today for energy storage technology in addition to electricity to be stored over several days, weeks efficiently (without batteries self-discharge) stored. The realistic period of power supply from batteries ESS is up to a few hours, days, maybe a week of the order of time (short- and medium-term storage) [3]. A few days of a period as an example a weekend or long weekend might (3-4 days) be taken, because when there is any breakdown in this period in communal networks the improvement which may take a longer time than the prescribed time, the user can remain without electricity supply for a considerable time. When sizing the system is done in this period, the security of supply of electricity can be significantly increased. In the ESS maintenance-free (lead-gel batteries) solar batteries are used (for example Sonnenschein A 600 SOLAR-type) with 12 V output voltage and 300Ah capacity. The batteries have a high cycle resistance (3500 load-charge cycles (the remaining capacity is 50% of the nominal value)).

Since the average daily energy demand is approximately 7.2 kWh evaluated, this amount of energy must be able to be supplied by the battery system. The backup time is 4 days it is assumed that the isolated system is even able to operate without mains supply for a long weekend. (Back-up time is the period, during which the ESS must provide the total consumption demand of the user.) The amount of energy storage can be calculated ability from the output voltage and capacity of the battery. In this case 3.6 kWh is aroused. Since the remaining charge in the selected battery is 50%, therefore the depth of discharge is 50%. This means only 50% of the stored electricity can be used in a discharge cycle, which in this case is 1.8 kWh. From these data it can be calculated to cover the 7.2 kWh per day energy demand 4 batteries are needed. To allow the system to remain operable for 4 days, 16 pieces of batteries are needed. The financial costs of the selected piece of battery 274.2 EUR + VAT (=27%) (348.234 EUR), which is for 16 pieces 4387.2 EUR + VAT (=27%) (5571.744 EUR). The additional cost of the development of energy storage that amount of which can reach 50% (2786 EUR). [3] Taking into account the average annual cycle of the battery, which is approximately 300 cycles / year, the batteries should be replaced every 10-12 years. These batteries can be used in the half of PV system life (20-25 years). If the energy storage price (2 x 5571.744 EUR + 2786 EUR = 13929.488 EUR) the price of the PV system is compared to that of about 3870 EUR + VAT (= 27%) (4914.9 EUR) (approx. 3 kWp * 1290 EUR + VAT (= 27%) / kWp), a significant difference can be seen. In this case the ESS is the price of 283.42% of the PV system, which is very significant. A conclusion to be drawn that for a residential user the isolated operation such for a long time (4 days) is not worth since ESS costs are now so high that the investment will not be recoverable over the life of the solar system. However, the cost of energy storage in the coming years and decades will decrease significantly [6]. Yet if the aim is to increase the security of supply for shorter times, then a battery system is available at affordable prices ensuring the continuous power supply despite the breakdown.

4. Conclusion

This study demonstrates that seasonality? both in the production of PV systems and the energy consumption of the PV system pays important roles, which were shown in Figure 2 and 7. The produced energy of the whole year can produce only 50% (6 months in the middle of the year: April to September) of the whole need of energy. In order for the monthly average production to totally compensate the consumption through a whole year, the PV system should be significantly oversized (>=260%, which equals to 7.15 kW). But still/ even so there will be days when extra consumption is needed. Examining the afternoon and early evening period has been shown that the seasons had a larger /higher impact on the time of the extra production and the appeared energy need (spring: 0.4660 kWh; summer: 0.2661 kWh; autumn 0.9015 kWh; winter: 1.7798 kWh).Therefore during the sizing of the systems should be paid attention for these requirements. Uninterruptible power supply can be provided by the usage of energy storage systems in the short term (for minutes or hour periods) which is also financially acceptable. In this case, one or two batteries, with investment costs of 870.593 EUR (considering the exchange) are suffficient. However this involves a significant financial investment (13929.488 EUR) in medium and long term (day, several days). The price of a 4-day time interval may be three times higher than the price of the PV system. The usage of such systems is also useful if the user has an electric car. Then the surplus production during the day can be stored in batteries, and the batteries of electrical vehicles can be charged from these, not using the communal network. That could have positive effects on the distribution system operator and the electricity producer too. Then the necessary amount of electricity is predictable, and also the communal network usage is not so high. The usage of this kind of energy storage will play a significant role in the achievement of the smart grid conception in the future.

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