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Energy savings by adapting consumer behavior in grid-connected photovoltaic systems with battery storage

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ABSTRACT

Today, the world faces many energy challenges that make the use of clean energy an obligation and an emergency. These challenges require changes in a wide range of sectors, including transport, industry and residential areas. At present, energy production is responsible for a large amount of greenhouse gas emissions, the main cause of climate change with its various dangerous effects on human life. Therefore, a change towards non-carbon energy is becoming a necessity. Certainly, this evolution has been underway for years and the renewable energy market has developed in a surprisingly efficient way. However, the current situation has reached an alarming state and requires the active participation of all stakeholders, especially consumers. Therefore, the main objective of this paper is to illustrate how consumer behavior can significantly influence and contribute to the optimization of renewable energy systems, especially photovoltaic systems. The paper emphasizes the beneficial integration of batteries and storage systems to achieve energy savings. The results show that with some adjustments in daily behavior, an overall energy saving of 62% can be achieved compared to the normal consumption scenario: the energy obtained from the grid and then the electricity bill is reduced.

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1. INTRODUCTION

A group of researchers has undertaken numerous studies with the aim of optimizing solar systems, delving into various components related to production, conversion, and storage. Other researchers have directed their attention towards external factors such as pollution, geographical location, and protective measures. The integration of these diverse components through management systems has also been explored. Undoubtedly, these comprehensive studies have played a crucial role in advancing the solar market. However, it is essential not to overlook the pivotal role of the primary customer particularly considering the significant electricity consumption within the residential sector. Consumers need to recognize the importance of their involvement in the installation, maintenance, management, and supervision of solar systems. Their actions must be efficient and well-considered, as their behavior directly influences these systems, impacting factors like system lifespan and electricity costs. In general, the measures to be taken by the consumer and that contribute to reduce the quantity of electricity required from the distributor can be summarized in four parts [1]: i) Measures related to consumer behavior by reducing the energy consumption of appliances while being efficient and avoiding wasteful behavior; ii) Measures related to automation by integrating intelligent electronic devices such as presence detectors; iii) Measures related to the improvement of energy conversion by moving towards more energy efficient appliances with choosing the optimal class of energy consumption; and iv) Measures aimed at the self-production of electricity and hot water by investing in solar photovoltaic systems that are amortized in a few years but ensure a certain independence.

Consumer behavior remains unknown in terms of electricity consumption, especially with the presence of a photovoltaic system (PV) [2]. The motivation and involvement of consumers to adapt their consumption is an important topic for researchers. Based on a mixed process combining survey questionnaires and qualitative, in-depth interviews with selected PV owners in Denmark, 67% of the participants claim to adapt the use of certain appliances such as the washing machine [3]. The degree of this adaptation is mainly related to billing. This will certainly change from country to country depending on daily practices.

In addition to the PV system, the presence or absence of the battery is also an element to be studied, especially the interaction with the consumer. Considering the importance of the consumer, especially when talking about households and individual consumption, a set of research has been elaborated in order to optimize consumption. Khafaf *et al.* [4] studied the impact of the introduction of storage systems on residential consumption and a case study was developed based on smart meter data. The analysis involved 5,000 consumers and showed that the presence of the battery balances the consumption at night, which contributes to the reduction of the bill. Centrally, and according to a technical-economic evaluation of different PV systems in Portugal with and also without batteries, the results showed that solar systems without storage are economically more viable in comparison with PV systems with batteries. This was the case in most of the studied configurations. Nevertheless, with a good energy management strategy, systems with storage will also be advantageous [5].

First, it is important to list the various reasons that might encourage an ordinary consumer to invest in renewable energy, particularly solar power:

a. Sustainability: availability is a guaranteed feature of renewable energy, unlike fossil fuels, which are scattered reserves that can disappear.
b. Energy independence: renewable energy is not tied to an existing stock. They can be extracted and used at any time, depending on climatic conditions.
c. Low carbon footprint: renewable energy is essentially clean energy. They produce fewer greenhouse gas emissions, which contributes to the fight against climate change.
d. Social impact: investing in renewable energy means creating various infrastructures that require installation, management, control and maintenance. This contributes to the creation of a number of jobs.

Consumer motivation to adopt this type of clean energy remains a crucial parameter. This issue cannot be resolved without real consumer involvement. A number of researchers have therefore given priority to analyzing the factors that can influence consumer motivation and interest in renewable energy. The aim of the article [6], for example, is to analyze the factors that can motivate or influence consumers to invest in renewable energy. Data for the study was collected through surveys conducted in five cities in Thailand. The results showed that self-efficacy, interest in the environment and perception of the benefits of renewable energy have a positive and significant effect on consumers' intention to adopt renewable energy. The cost of energy, on the other hand, has a negative but insignificant effect on consumer adoption of renewable energy. It is therefore important to address these factors when raising consumer awareness.

The use of renewable energy to meet energy consumption needs remains a choice and a decision to be made by the consumer. In this sense, several factors may encourage or discourage the use of this type of energy. Masrahi *et al.* [7] sought to understand how the physical, socio-economic and behavioral demographic characteristics of consumers, especially in the residential sector in the United States, can influence their degree of adherence to renewable energy. In this sense, the theory of planned behavior and willingness to pay were considered to predict consumer intentions to use renewable energy. An estimate of the willingness to pay for renewable energy was presented for 27 different countries. Influencing factors, in particular the situation of the countries, were presented [8]. Another group of consumers would like to switch to renewable energy to help combat climate change. However, their level of vulnerability does not allow them to do so. Article [9] supports the importance of proposing support and financing measures for this type of project as part of the development of renewable energy communities. The analysis of consumer behavior can be more sophisticated depending on the field of research. Navratil *et al.* [10] assessed for example the preferences of hotel guests in terms of the energy sources used and which are environmentally friendly: Roof-mounted solar panels, ground-mounted solar panels, heat pumps, anaerobic digestion or methanation and wind turbines were analyzed in four tourist destinations in the Czech Republic. It can be concluded then that consumers are always interested in entering the renewable energy sector, provided they are encouraged by certain factors and facilities. In this sense, the aim of this article is to present the technical and consequently, economic benefits that can be achieved by adapting consumer behavior in an environment characterized by the presence of renewable energies.

Air conditioning and heating play an important role in this analysis. In Morocco, buildings account for about 25% of total energy consumption, of which 18% is in the residential sector and 7% in the tertiary sector. This consumption is increasing in the residential sector, as the use of heating and air-conditioning systems remains high [11]. Heating and air-conditioning equipment is a major energy consumer and must be taken into account when dimensioning. It is important to ensure a certain level of thermal comfort, which is linked to the well-being of the occupants. The presence of heating and air conditioning certainly contributes to thermal comfort, but it also increases energy bills.

According to the aforementioned state of the art, consumer behavior is a parameter that has been taken into account in previous articles, but in different ways. Consumers' motivations and reasons have been analyzed. In some cases, consumption has been adjusted on the basis of a few specific devices, depending on the daily life of each country. The presence of the battery has also been analyzed, but it has been shown that its presence is not so advantageous. Our article will show how consumer behavior can turn the presence of a battery into an advantage in terms of energy savings and independence. Two elements are specific and particular to our article: i) The daily life of the Moroccan consumer has been taken into account, in particular the annual use of heating and air conditioning; and ii) The current Moroccan context has been taken into account, in particular the fact that surplus energy is not sold back to the distributor and there is no economic gain in this sense.

The role of the consumer is therefore crucial in the various aspects of a PV with battery storage, from sizing to implementation and interaction. In this paper we will focus on the interaction of the consumer with this type of installation and its consequences. In this article, we will study the impact of the consumer's behavior on the optimization of the PV system, especially with the presence of battery storage. The adaptation of the consumer behavior generates energy gain and reduction of grid dependency.

In the present article, we will first present the various parameters that can influence the storage system, including the battery. Secondly, we will describe how the consumer should behave with the presence of the battery, from sizing to operation. In the third part, a concrete case study will be presented to demonstrate the impact of the user's behavior on a PV system connected to the grid with the presence of the battery and then present the energy savings that can be generated from a right consumer behavior.

2. THE DIFFERENT PARAMETERS AFFECTING THE BATTERIES

Despite falling prices, storage systems remain a major challenge for manufacturers and consumers. The aim is to ensure the longest possible battery life. Batteries have well-defined characteristics [12]: i) Capacity, which depends on operating conditions such as load and temperature; ii) The voltage, which is usually defined by the manufacturer. Depending on the case, it varies between 3, 6, 12, and 24 V; iii) Depth of discharge (DOD) and the state of charge of the battery can be considered as the difference between the full charge and the depth of discharge in percentage; iv) Battery life cycle is the number of full charge and discharge cycles the battery can undergo before its capacity is reduced to 80% of its initial rated capacity; v) Self-discharge due to the internal electrochemical process of the battery, which corresponds to the electrical capacity lost when the battery is not in use. For example, self-discharge rates for Li-ion batteries are between 5% and 10% [13]. In this part, we will present the different parameters that can affect batteries. This one remains a quite sensitive element to which it is essential to pay a particular attention in order to preserve it.

2.1. Effects of charging and discharging techniques and tools on solar batteries

Before investing in a renewable energy system, it is necessary to consider that the investment in the storage system varies between 30% and 45%. Thus, the number of batteries to be implemented will affect the optimization of the system and, consequently, the levelized cost of electricity (LCOE). A number of studies have been carried out on batteries, in particular on their lifetime, in order to determine it efficiently and accurately [14]. The life of the battery depends on the technology used, but this life can really be reduced if the charging and discharging is not done in an optimal way, which is the case with most solar or non-solar batteries. For example, nickel-cadmium or nickel-metal-hydride batteries are most commonly used for portable applications. For PV applications, however, batteries are subject to frequent charging and discharging. Deep-cycle lead-acid batteries are most commonly used for PV applications. Where isolated operation with less maintenance is required, lead-acid gel batteries are used. Battery life varies from 3 to 5 years and depends mainly on charge and discharge cycles, temperature and other parameters [12]. For example, in study [15], an optimal battery charging and discharging model was developed to achieve different objectives: minimizing energy cost as a function of time and minimizing carbon emissions. In study [16], an intelligent hybrid energy storage module was developed to improve the lifetime of the lead-acid battery used in off-grid PV systems, while dealing with lifetime limiting factors such as voltage surges and current fluctuations. This intelligent hybrid energy storage plug-in module can reduce annual operating costs by 53.7% and helps extend battery life. We must not forget the importance of charge controllers in protecting the battery from deep discharge and overcharge. However, some parameters are sometimes not taken into account in these controllers, such as the fluctuating energy exchange, the frequent transition between charging and discharging and other external parameters.

2.2. Battery management system and impact on batteries

The introduction of batteries in renewable energy production systems requires great attention. The storage system must be able to communicate and take into account all the components of the larger system, hence the purpose of integrating energy management systems. For example, the home energy management system (HEMS) is a suitable system for managing and monitoring energy consumption, production and storage efficiently. It is specifically designed for smart homes [17]. The first objective of this type of system is to reduce energy consumption [18]. This type of system also influences consumer behavior, in particular the use of electrical appliances, to the benefit of both the consumer and the supplier. HEMS can control certain appliances and shift their power supply to off-peak hours when electricity prices are low [19]. In order to create a beneficial and optimal storage system, other researchers recommend the creation of community facilities where the stored capacity is shared by different neighbors and especially consumers, generating economic benefits [20].

2.3. Environmental impacts on battery life time

Climatic conditions also have a significant impact on storage systems, particularly on battery life. Depending on the location and the ambient climate, the first thing to do is to protect the storage system in order to isolate the batteries. Some photovoltaic systems can even degrade over time if the storage components have not been well-chosen, especially depending on the existing climate. In the article [21], two types of batteries were compared according to climate parameters, including temperature and irradiation, and it was observed that temperature has a greater effect on lead-acid than on lithium-ion. As the ambient temperature rises, so does the internal temperature of the battery pack, which also has an effect on lithium-ion batteries. During the charging process, internal heat is generated, one related to the Joule effect, which is irreversible, and the other related to the electrochemical reactions, which is reversible. Considering these internal effects and also external effects related to the ambient temperature, it has been shown that lithium-ion batteries are more stable in areas with high temperatures and high irradiation. On the other hand, lithium-ion technologies can also overheat due to their energy density and combustibility, which is an alarming safety issue [22]. Researchers are also currently focusing on systems that optimize cost reduction and ensure self-consumption. On the other hand, there is limited research on the carbon dioxide ($\mathrm{CO_2}$) emissions generated by the operation of battery energy storage systems (BESS), which can have a negative impact on the production of greenhouse gases. A model for the optimization of BESS has been developed with the aim of reducing both the cost and the $\mathrm{CO_2}$ emissions [15]. The production of 1 Wh of storage capacity can result in greenhouse gas (GHG) emissions of 110gCO2eq [23]. We also talk about the concept of carbon footprint, which is the total amount of greenhouse gases produced directly and indirectly by human activities. It is usually expressed in equivalent tons of $\mathrm{CO_2}$. A carbon footprint is the sum of all $\mathrm{CO_2}$ emissions. It can also be calculated using solar system simulation software such as PV Syst, which is the most widely used for solar applications [24].

3. IMPACT OF THE CONSUMER BEHAVIOR ON THE BATTERY

Currently and considering all the challenges involved in producing energy. Consumers need to find alternative renewable energy solutions, especially the most affordable one for a simple user, which would be photovoltaic. As the owner of his photovoltaic system, the consumer becomes more responsible and is encouraged to control his consumption in order to obtain an economic benefit and, above all, a return on investment in the long term. Even if the grid is sometimes present, the consumer wants to ensure maximum autonomy. In this section we will show how the consumer's behavior and awareness can influence the optimization of the entire PV system, but in particular the storage system and the battery.

3.1. Interest of the consumer behavior

Consumer behavior and intervention can influence the operation of renewable energy systems, particularly photovoltaic systems, at all stages from design and sizing to operation and maintenance. The choice of batteries is based on three main parameters: price, safety and size. Even if the price is the first interest for the consumer, its impact is not really visible in the first period of its implementation. In the paper [22] it has been shown how residential consumers are motivated by the choice of appropriate storage parameters to ensure autonomy and independence from the grid in the first place. Surveys have also been carried out showing that the majority of consumers want storage systems to meet their needs to the maximum with less involvement in the grid. They also want systems that are fairly autonomous and require less intervention. The aim is also to guarantee a certain level of comfort for the user. Before investing in a PV system, it is necessary to carefully consider which components to introduce and which would not be efficient, especially the integration or not of the storage system, and this should be analyzed according to the energy and economic impact. It has been shown that PV storage in combination with PV generation would be more beneficial and cost-effective compared to PV generation alone [25]. The consumer will also have to adapt to the operation of these systems by adjusting the use of different appliances and especially the time of their use, and this will not have a significant impact on the loss of comfort, even if there are appliances whose time of use cannot be changed [25]. Electrical systems in general face a number of challenges in terms of efficiency, reliability and energy losses. Consumers do not always have an interest in adapting their use to costs, so a number of solutions are proposed as an alternative, such as demand response (DR) programs. These have proven to be effective in reducing a number of problems, such as the high cost of electricity supply, especially at peak times, but they need to be implemented optimally. In this sense, DR has been the subject of a number of studies, especially for its optimization [26].

3.2. Sizing optimization

Sizing is also an element that has a strong impact on the operation of the battery and its lifetime, as well as on the economic benefit. While it is important to ensure maximum autonomy, it is also important to avoid over-sizing by choosing larger batteries. For example, in the presence of the grid, smaller storage systems should be chosen [22]. Smaller and decentralized solutions are also more important [20]. Battery sizing should be based on the following characteristics [12]:

a. Low cost: The life of the battery has an important influence on the cost of the whole system. The battery will be the most expensive part when its life is less than 3.5 years.
b. Energy efficiency: The generation of losses in the three stages of charging, discharging and self-discharging should be as low as possible. This also increases with temperature. Energy efficiency = charged energy (kW)/discharged energy (kW).
c. Lifetime: the longer the lifetime, the better the choice of the battery.
d. Maintenance: The more our installations, especially the battery, require less intervention, the more efficient it is, especially in rural areas.
e. Reliability and less self-discharge.
f. Temperature: The battery is supposed to be able to work in higher temperature ranges.

In general, the first step is to determine the size of the PV system, followed by optimizing the battery size if we want to size a storage system in conjunction with a grid-connected PV system [27]. The introduction of batteries can in some cases increase the profitability of PV if the size of the battery is large [28]. However, this is not at all feasible due to various conditions and limitations, either economic or physical, related to the roof or the space that will host this type of installation. Therefore, and contrary to what is generally done, some results recommend starting with the sizing of the storage system, followed by the PV power supply. The storage system also depends on other parameters such as load and price [25]. The presence of batteries can also be important to improve grid stability, flexibility, reliability and resilience [22].

In fact, the integration of photovoltaic sources in the electrical distribution network is developing more and more, but it has both positive and negative effects, which are still the subject of a number of studies. Techniques have been used to define the optimal reconfiguration of the network [29], [30]. In this sense, and more specifically, an optimization of the distribution network configuration has been proposed, which varies according to the increase of the PV production, with the aim of reducing the total active losses [31]. In the same sense, a mixed integer linear program (MILP) has been developed to identify the optimal PV and battery size for a well-identified site under time of use and demand tariff structures. The results favor systems without batteries or with small storage systems. However, these battery-free systems remain very limited compared to the energy planning options [32].

3.3. The right choice of location and protection

Before embarking on a project for a PV system or any other renewable energy installation, it is necessary to know whether we have the space and conditions necessary for its implementation. In this sense, and in order to optimize the space, some consumers have turned to energy communities. For example, in the article [33], an advanced study was carried out to define the impact of these communities, especially based on renewable energy with the presence of the battery on the distribution network. It has been shown that the location of the battery mainly affects the voltage. In particular, when the battery is located at the end of the distribution line, we can observe large differences, but when it is located at the beginning of the line, the community has no impact on the minimum and maximum voltage observed. A real case study in Cambridge, USA, showed that the optimal battery capacity at the community level is lower compared to the implementation of storage systems for individual households and the exchange with the grid remains reduced [34]. The optimization of the placement and size of a PV system integrated into a real distribution network has been presented, taking into account consumption, PV production and also meteorological conditions [35]. Others have relied on algorithmic solutions and methods for optimizing the appropriate location of the distributed PV source for its introduction into the power system. The objective is specifically to improve the line voltage stability index (LVSI) [36]. The performance of the battery is also related to the performance of the PV system, including its geographical location, solar irradiance, types of PV modules and their orientation [24].

3.4. Rationalized consumption depending on peak hours

Electricity prices vary according to the time of day but are highest during peak hours. Therefore, and with the presence of PV energy, it would be ideal to mobilize this clean energy more during these peak hours. Obviously, a BESS system would be more cost-effective if it is as self-sufficient as possible, but also if the load supply is well distributed throughout the day [20].

Electricity is generally charged according to the time of use, at night when the tariff is low and during the day when the tariff is high. The presence of the battery will contribute to the reduction of this bill by limiting the demand at peak hours and by moving from high tariff to low tariff through its storage system. In this sense, a series of studies have been carried out to optimize the energy of the system and, in particular, the capacity of the battery suitable to reduce the payment of electricity bills and to identify the optimal investment in battery storage (kW and kWh) in order to reduce the total operating and investment costs [37].

Three categories of consumers can be identified: domestic, commercial and industrial. The supplier formulates a tariff system for the different consumers based on the peak load, the quantity and quality of the electricity, the voltage level of the consumer and other characteristics [37]. In order for the battery to be profitable, it must ensure maximum power supply during peak hours and optimal discharge during this period [38].

4. CASE STUDY

4.1. Description of the site and the load

A good availability of solar energy encourages autonomous or grid-connected photovoltaic solar installations to guarantee a healthy, clean and free electricity supply. In our case, we have chosen to study a grid-connected site with a storage system in Errachidia, one of the sunniest regions in Morocco. The aim is to analyze the impact of consumer behavior on the optimization of photovoltaic systems, in particular the battery. The general irradiation is represented in Figure 1.

We considered a family of 4 persons, different appliances were taken into consideration (lamps, television, computers, domestic appliances, fridge, washing machine and dishwasher) as well as a reversible air conditioner whose number of hours of use changes during the year depending on the climate. Thus, the needs of users is susceptible to change depending on the climate and the season. Nevertheless, and to ensure the adequate sizing for the installation, we have considered an average of 3.5 hours of use of the air conditioner over the year. The user requirement is approximately 22,825 kWh/day. In order to make our study accurate, we will adjust the number of air conditioning hours per month according to the following distribution as shown in Figure 2.

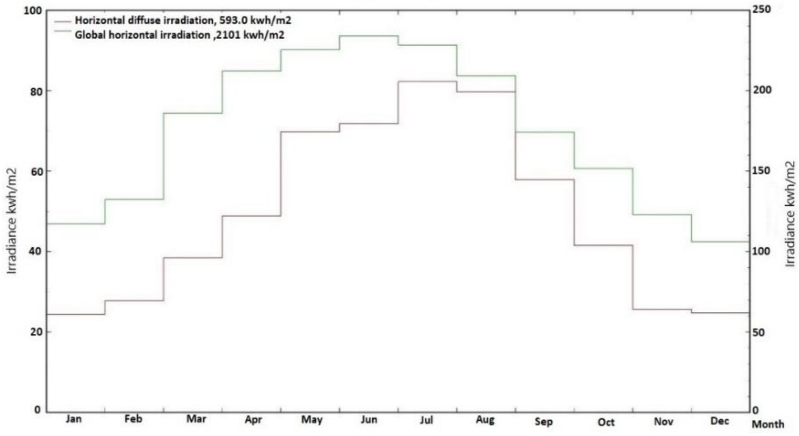

Figure 1. Horizontal diffuse irradiation and global horizontal irradiation (kWh/m^2)

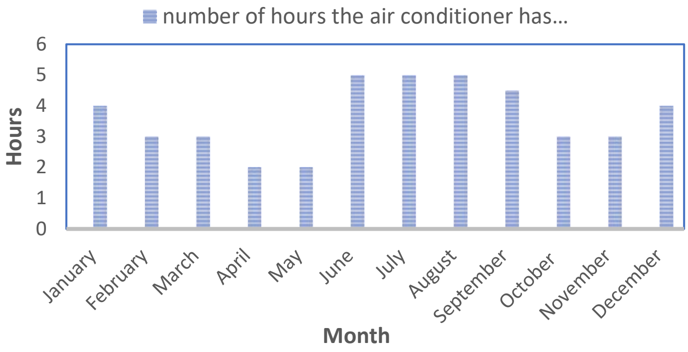

Figure 2. Number of hours using the air conditioner

The photovoltaic array has also been sized according to the identified need of use and corresponds to a power of 5.2 kWp. In order to make the installation as independent as possible, we opted for a storage system with a lithium-ion battery with a capacity of 1,130 Ah and a number of days of autonomy of 1 day since our system would be connected to the grid. Thanks to their high efficiency and long life time, Li-ion batteries are the main solution for residential energy systems [25]. In our present study, we will opt for the PV Syst simulation software, which is widely used to design, optimize and evaluate the energy performance of its systems [39]. It deals with grid connected systems, stand-alone systems and solar pumping systems. Figure 3 shows the production time of the PV system according to the number of hours.

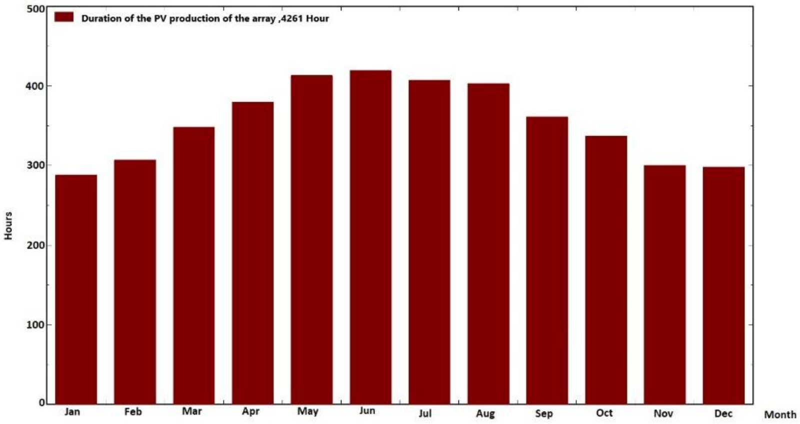

Figure 3. Duration of the PV production of the array during the year

4.2. Description of consumer behavior

In this section we will analyze the impact of the consumer's behavior on the optimization of his solar system. The aim is to be as independent of the grid as possible. In a more advanced case, if we have to get energy from the grid, it must be at a lower cost. If the aim is to reduce the energy bill, the consumer is encouraged to reduce his energy consumption and to shift it to the hours when the price of electricity would be cheaper [19]. For the purposes of this article, the priority is to reduce grid dependency as much as possible, but this indirectly has a very positive effect on the energy bill. In this part we will study two different cases. The first will be related to the random and normal use of different electrical appliances by the consumer. The second is related to an adaptation of the use of the appliance with the guarantee of a certain comfort. Since the system is connected to the grid, the user should only turn to the grid if the PV system cannot supply the required energy and the battery is also empty. In addition, they should request energy from their PV system or from the grid whenever possible, preferably at a low price that does not correspond to peak hours. There are some electrical appliances that we cannot adapt or change their hours of use, such as the fridge, laptops and lamps. Others, such as the washing machine and dishwasher, can be controlled. The use of air conditioning is on a specific side. We only have to act on the number of hours of use depending on the climate and the month. The ordinary daily global consumption is represented in Figure 4.

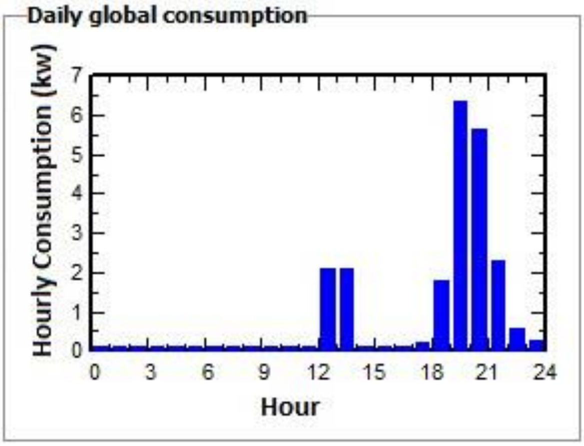

Figure 4. Daily global consumption scenario 1

4.3. Impact of the consumer behavior

In order to keep the comfort of the consumer, we have tried to act only on some appliances by adapting the use timing when it is logical and convenient for the consumer. In some cases, like Demand Response operations, the timing of electricity is adapted to switch off electric heating during peak hours generating then a loss of comfort to the consumer [19]. Below we present two possibilities for the hourly distribution, avoiding the concentration on one hourly interval and ensuring distribution over the day, avoiding as much as possible the demand of electricity from the network. Two adapted scenarios are possible as shown in Figure 5 and Figure 6. Nevertheless, scenario 3 generates a high energy demand as well compared to the ordinary scenario as shown in Figure 4 despite ensuring consumption distribution. This is justified by the fact that in the time interval [6am, 9am] the PV field is not always functional, and this depends on the month. In addition, this generates a peak energy demand in this interval and requires a more complicated adaptation from the user. Therefore, we will keep for the following study scenario 2, which will be compared with the ordinary scenario based on the missing energy that is especially provided by the network. In both cases, the comfort of the consumer is always taken into account, in particular the variation of the number of hours of use of the air conditioner that it is in summer or in winter as shown in Figure 2.

Below are graphs comparing the energy supplied by the grid in the normal case and the optimal case, Scenario 1 and Scenario 2. In both cases, the number of hours the air conditioner is used is already taken into account. The comparison is made on a monthly basis, as the impact of the air conditioner and its use changes from month to month. The even figures of Figures 7 to 25 represent the provided energy from the network in the different months in the year related to scenario 1. The odd figures of Figures 8 to 26 represent the provided energy from the network in the different months in the year related to scenario 2.

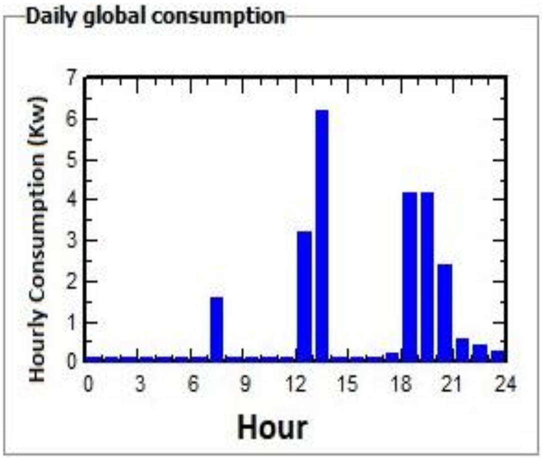

Figure 5. Daily global consumption scenario 2

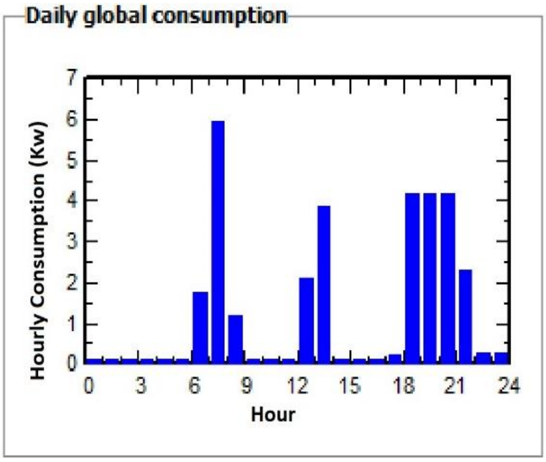

Figure 6. Daily global consumption scenario 3

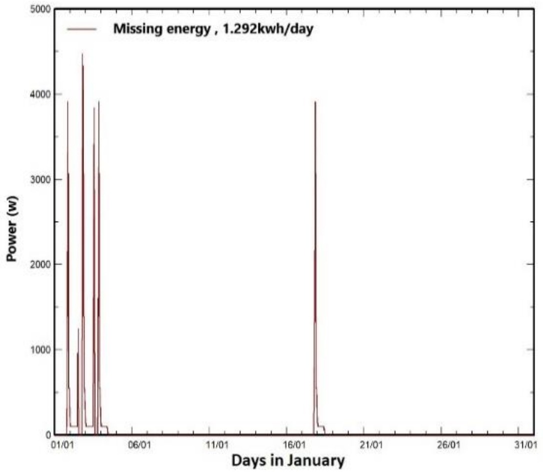

Figure 7. Provided energy from the network in January scenario1 (kWh)

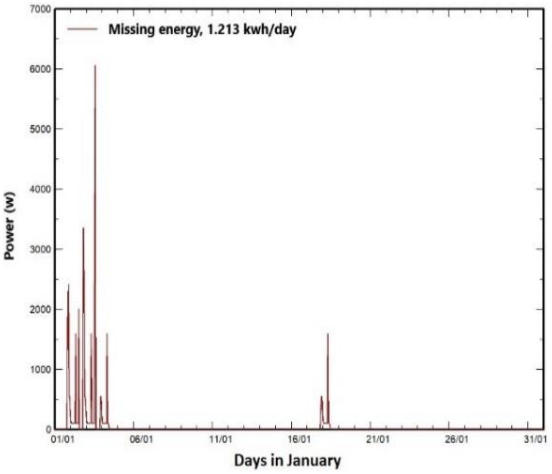

Figure 8. Provided energy from the network in January scenario 2 (kWh)

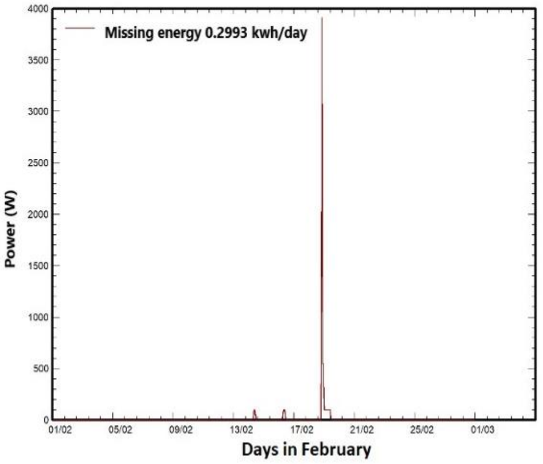

Figure 9. Average provided energy from the network in February scenario1 (kWh/day)

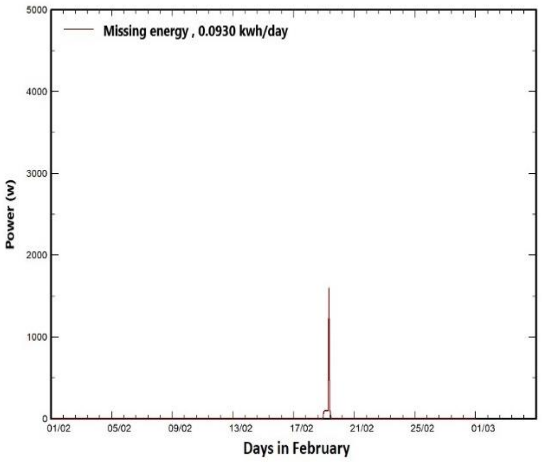

Figure 10. Average provided energy from the network in February scenario 2 (kWh/day)

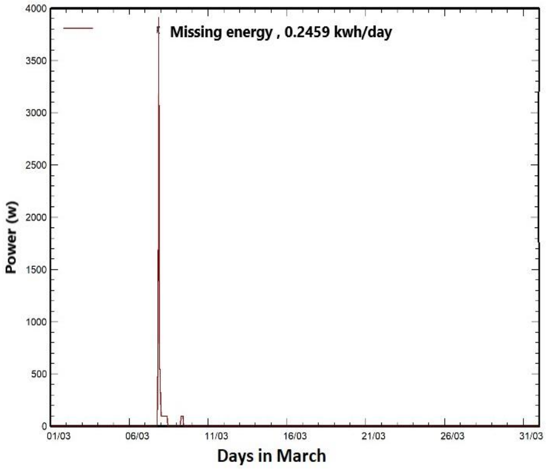

Figure 11. Average provided energy from the network in March scenario 1(kWh/day)

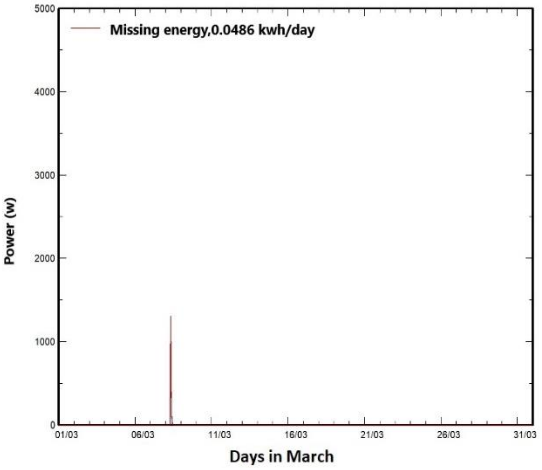

Figure 12. Average provided energy from the network in March scenario 2 (kWh/day)

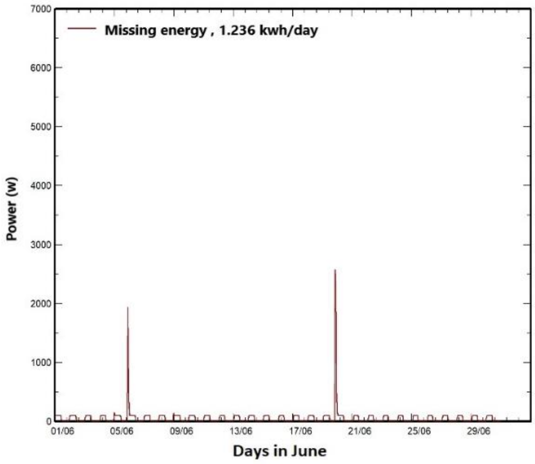

Figure 13. Average provided energy from the network in June scenario 1 (kWh/day)

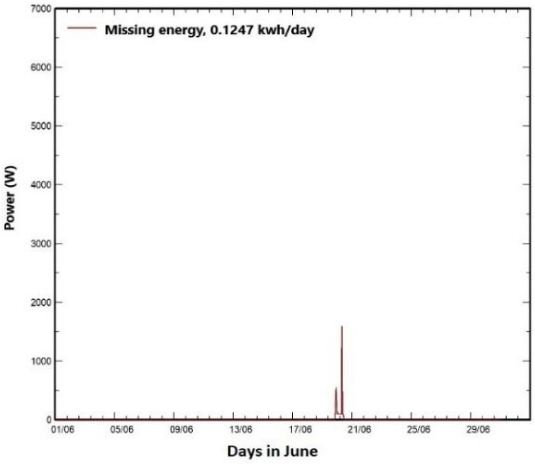

Figure 14. Average provided energy from the network in June scenario 2 (kWh/day)

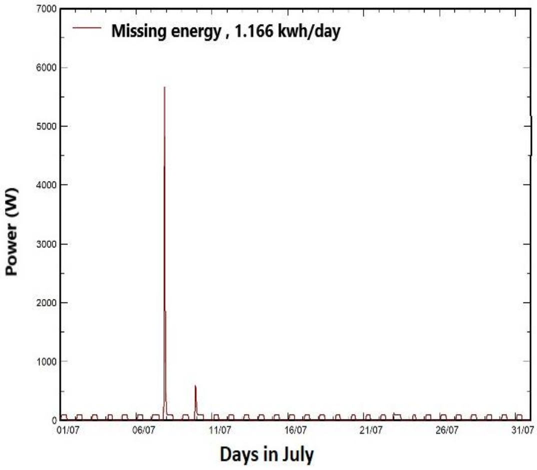

Figure 15. Average provided energy from the network in July scenario 1 (kWh/day)

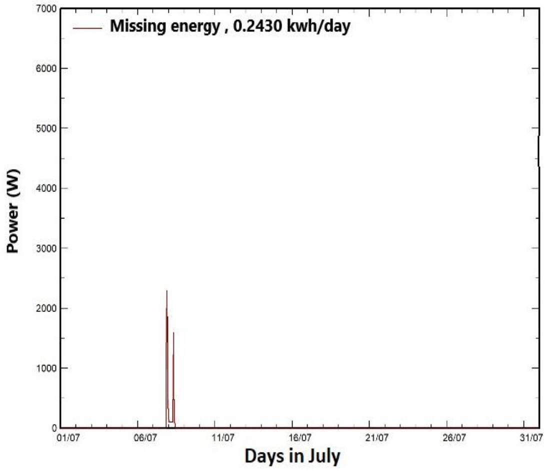

Figure 16. Average provided energy from the network in July scenario 2 (kWh/day)

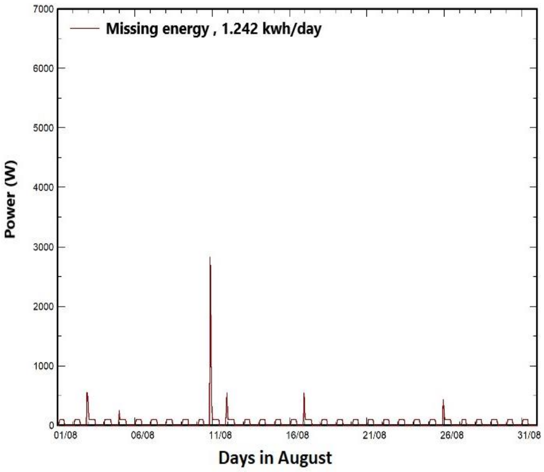

Figure 17. Average provided energy from the network in August scenario 1 (kWh/day)

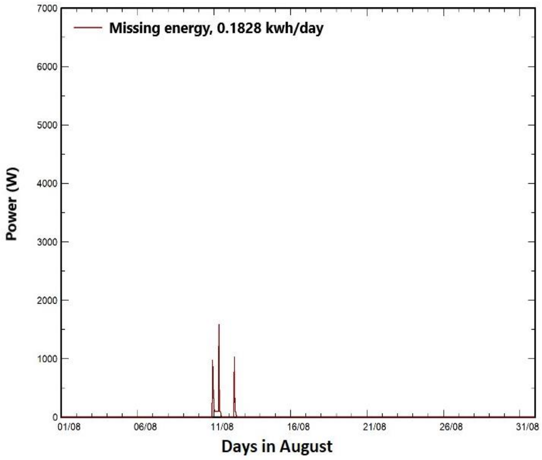

Figure 18. Average provided energy from the network in August scenario 2 (kWh/day)

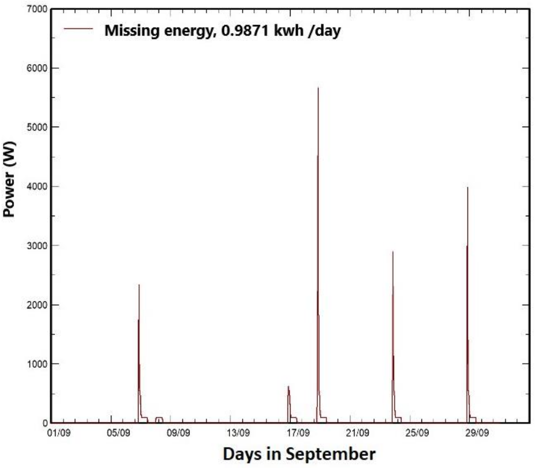

Figure 19. Average provided energy from the network in September scenario 1 (kWh/day)

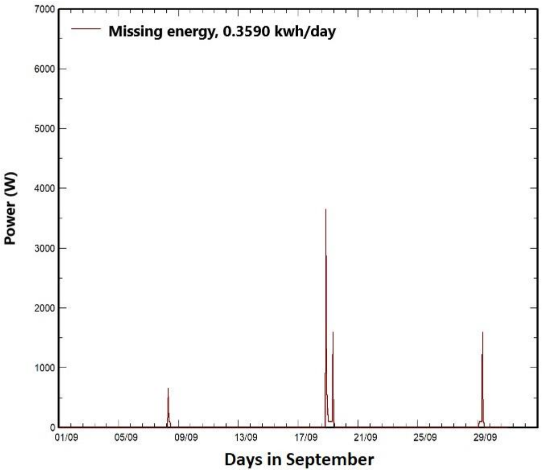

Figure 20. Average provided energy from the network in September scenario 2 (kWh/day)

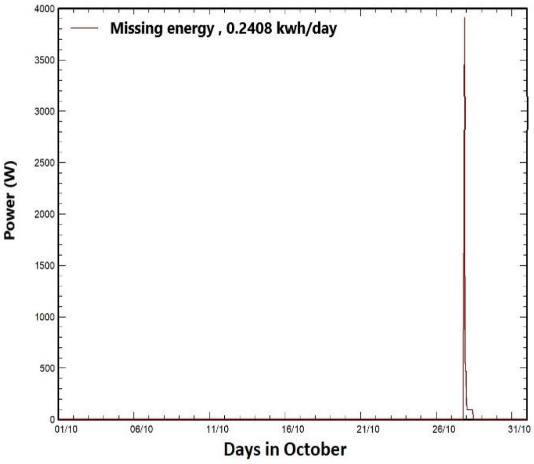

Figure 21. Average provided energy from the network in October scenario 1 (kWh/day)

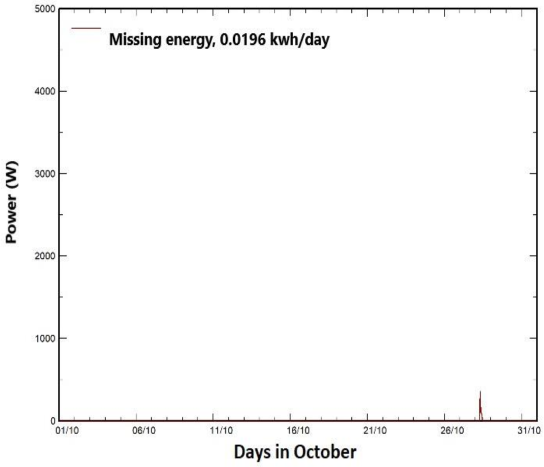

Figure 22. Average provided energy from the network in October scenario 2 (kWh/day)

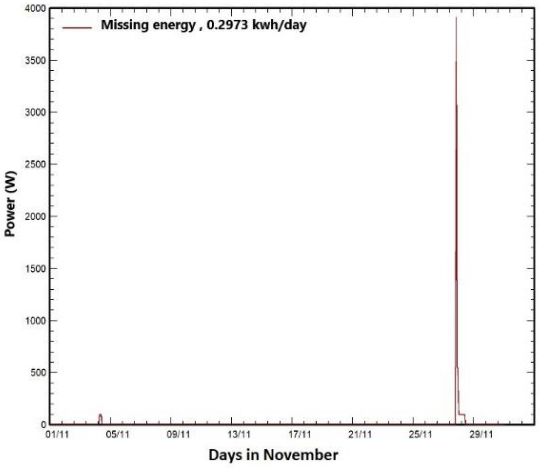

Figure 23. Average provided energy from the network in November scenario 1 (kWh/day)

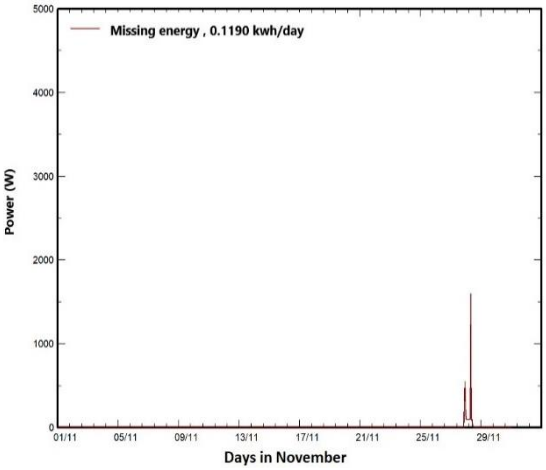

Figure 24. Average provided energy from the network in November scenario 2 (kWh/day)

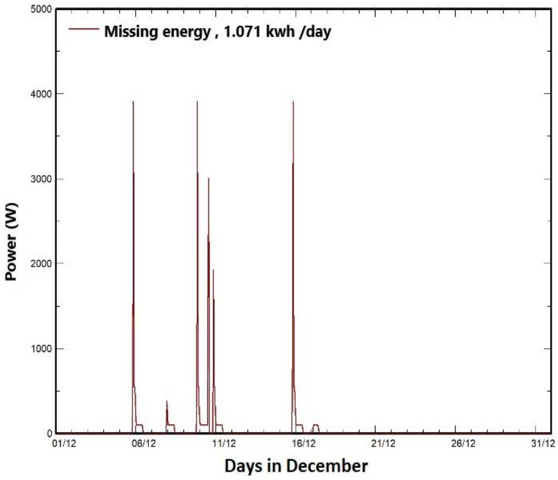

Figure 25. Average provided energy from the network in December scenario 1 (kWh/day)

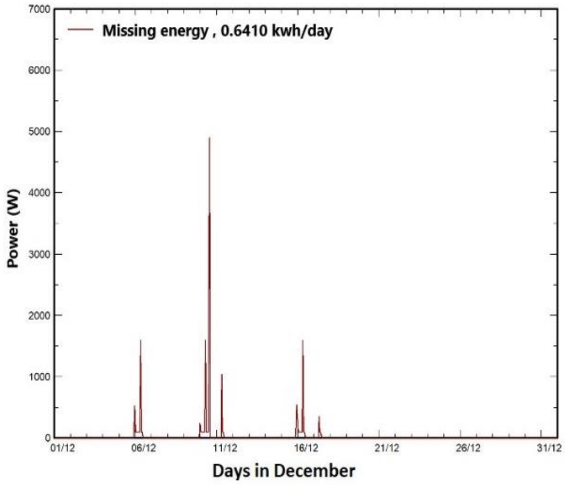

Figure 26. Average provided energy from the network in Decembre scenario 2 (kWh/day)

4.4. Results and discussion

From the above comparison, we can see that our solar system with the battery cannot ensure the entire demand in both cases. We have avoided the over-sizing of the battery by opting for only one day of autonomy since our installation is already connected to the grid. Nevertheless, and following the comparison between the ordinary scenario called normal-random and the proposed optimal scenario which also considers the comfort of the consumer. We notice that there is a considerable difference as shown in Figure 27.

In total, the energy supplied by the grid is reduced by 62% compared to the first scenario. April and May were not considered because the grid energy demand is very low. Consumer behavior has been moderately adjusted by only changing the time of use, trying not to affect the user's comfort. However, it should be noted that the difference could always be greater if the consumer were prepared to adapt his daily consumption a little more, for example by limiting the air conditioning during certain periods corresponding to peak hours. It should be noted that the behavior of the consumer has a remarkable influence on the behavior of the photovoltaic system, especially in the presence of a battery. In the case of a connected installation, but without the presence of a battery, the consumer has to adapt his daily use more if he wants to gain in terms of energy savings compared to in our case with the presence of a battery.

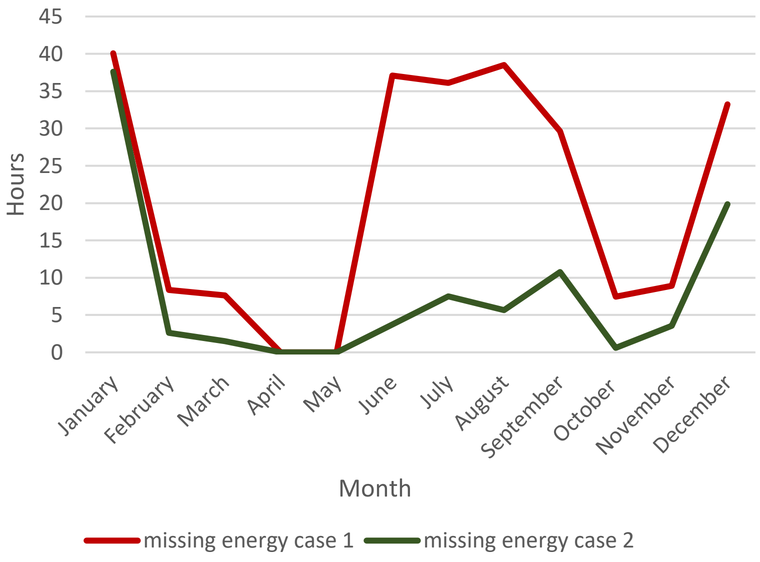

Figure 5. Energy supplied by the network in two cases (kWh)

5. CONCLUSION

In this paper, we have considered a photovoltaic system connected to the grid, it has been optimally dimensioned in order to have access to the grid when needed and to ensure a certain autonomy. We have analyzed the reaction of our installation to two scenarios of consumer behavior: the first is random corresponding to a spontaneous use of energy without taking into account the presence of the battery or the PV system, the second scenario corresponds to consumer who is aware of the times of availability of solar energy and ensuring an optimal interaction with its system. The comfort of the user has been well taken into account and a moderate and logical adaptation of his behavior has been ensured. The results show a reduction of the grid dependency of about 62% in total during the year in comparison with the first scenario. This percentage can increase further if the consumer can adapt and improve more his daily behavior. Several initiatives are being developed in order to encourage the consumer to invest in adapting his behavior towards electricity demand. We already have the price component, in our case for Morocco, a reduction in terms of energy in kWh directly generates an economic gain and this depends on the corresponding hours (off-peak hours, full hours and peak hours).

It is also recommended that the government and industry develop energy literacy measures related to solar with storage in order to help consumers more clearly understand the costs, risks and benefits of their systems. Some initiatives can encourage the consumer to get involved in addressing the energy crisis, especially since it is not yet possible to take advantage of the energy surplus in the case of PV systems at the country level. It is also necessary to emphasize on the importance of correct actions which make the difference at the level of electricity consumption like the optimal use of the air-conditioners, the choice of the lamps, the location of the washing machines, the importance of cleaning and other parameters. Our research has certainly demonstrated concrete benefits in terms of energy and, consequently, economic gains from adapting consumer behavior which is not sufficiently considered in another research. However, in our future research, it is essential to carry out surveys with a representative sample of the consumers involved in order to demonstrate the degree of compliance with these types of consumption scenarios and to analyze the challenges that may exist.

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