



ENERGY MANAGEMENT ALGORITHM FOR END INSTALLATIONS WITH RENEWABLE PRODUCTION AND STORAGE

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ABSTRACT

This paper presents an algorithm to manage different renewable energy sources with storage. The objective of this algorithm is to regulate and control the output currents of the DC-DC converters, which are directly connected to both the DC bus and the inverter. Here, the inverter allows exchanging the energy between the DC bus and the AC grid. The implementation of the proposed algorithm to end facilities in a liberalized market is also presented and tested. In addition, the benefits of such implementation, using eight dispatches, to the operators of the grid is demonstrated. The algorithm considers several situations of the consumption, energy production, various storage capacities, grid manager's demands, forecasts of production and consumption loads. The results, which are obtained by the proposed algorithm, show a good regulation and control of the currents of the DC-DC converters, therefore a better energy management is achieved being this supported by an extensive theoretical analysis.

Key words: Energy management algorithm, liberalized market, DC-DC converters, renewable energy, storage energy, current control

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1. INTRODUCTION

In recent years, the electricity sectors have been changed [1]. This is due to technological advances and changes in the type of loads, high demands to improve the quality of the generated power. The major present market liberalization concerns is about environmental issues, particularly in terms of production, proliferation of distributed generation, as well as customers. The main demands of the customers are energy, products, and services [2-3].

Nowadays, economic agents of the electricity sector usually work with profit a margin. These agents intend to reduce operating costs and maximize profits for their users while providing at the same time ancillary and balancing services [4]. This is a key factor in the competitiveness of a large number of economic activities.[5]

Among possible improvements of the quality of the energy are the distributed generation and the energy storage [6-7]. The advantages of using storages are the improvement of energy which will be a continuous supply during peak times, delay in the investment cost for a new installation of the power generation and uncertainties reduction in electric grids of renewable energies [8].

The algorithm is developed based on the produced energy with storage, taking into account the opportunities that might be considered in market developments. The opportunities are located at the final stage of the consumption level, which could be an energy consumer. Also, this opportunity can be given in the liberalization of the market, to become a producer of energy and contribute to obtain a better operation in the entire electrical system.

By using the energy storage in the final installation, the customer in the energy system will be able to regulate his demands from the grid. In addition, this storage system provides the time when the grid manager asks for a help (both in the sense of providing an energy supply or increasing the consumption) that is also considered as an extra advantage [9-10]. Here, the consumer takes an economical advantage of energy exchanging with the grid, and meanwhile is supporting other services [11-12]. The evolution and development of smart grids, leads to the energy autonomy, and sustainable economic growth [13].

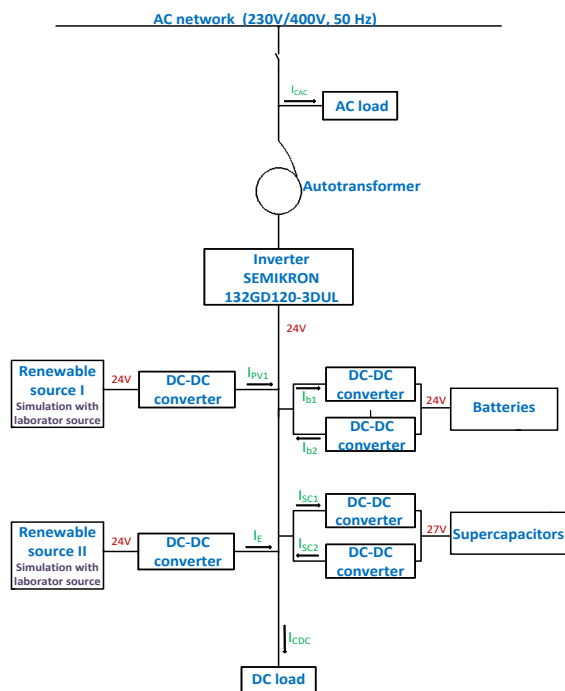


Figure 1 Schematic diagram of the developed multifunctional DC/AC power supply system.

The main goal of the work shown in this paper is to develop a multifunctional DC/AC power supply system for final users with a renewable energy generation in the liberalized energy market. Fig. 1 shows the power system which is built with the multifunctional DC/AC. In this system, different renewable energy sources, as well as the energy storage devices (batteries and supercapacitors) are interconnected through various DC-DC converters. The DC bus supplies a DC load which is interconnected to the grid through an inverter. The autotransformer is also used for adjusting the voltage level. This system allows the bidirectional exchange of energy between the DC bus and the AC network.

The inverter is responsible for a regulation of the voltage at 24 V of the DC bus. The value of this voltage has been selected as it facilitates the association the storage with the production. Moreover, its value is sufficient to supply the load without reaching excessive current values.

A dispatch algorithm has been controlled via the DC-DC converters, which regulate the current from each source to be then provided to the DC bus.

2. COMPARISON BETWEEN AC AND DC SUPPLY SYSTEMS

In AC supply systems, each block is connected to the AC power through an inverter. While in DC supply systems, the DC grid line is connected to the AC supply through a single inverter [14].

When the energy is produced by any one of available renewable sources (such as: solar or wind), the output of these energy sources varies hugely, and thus causes an adverse effect on the system. Therefore, this problem can be solved in two ways. In the first, one inverter voltage stabilizer can be installed on the side of AC distribution line. In a such solution, fluctuations in the AC power supply are needed to be compensated, but it is not an easy task to determine in which end installations these fluctuations occur. In the second solution, many inverters are required to be installed, thus resulting in a higher cost of the equipment's.

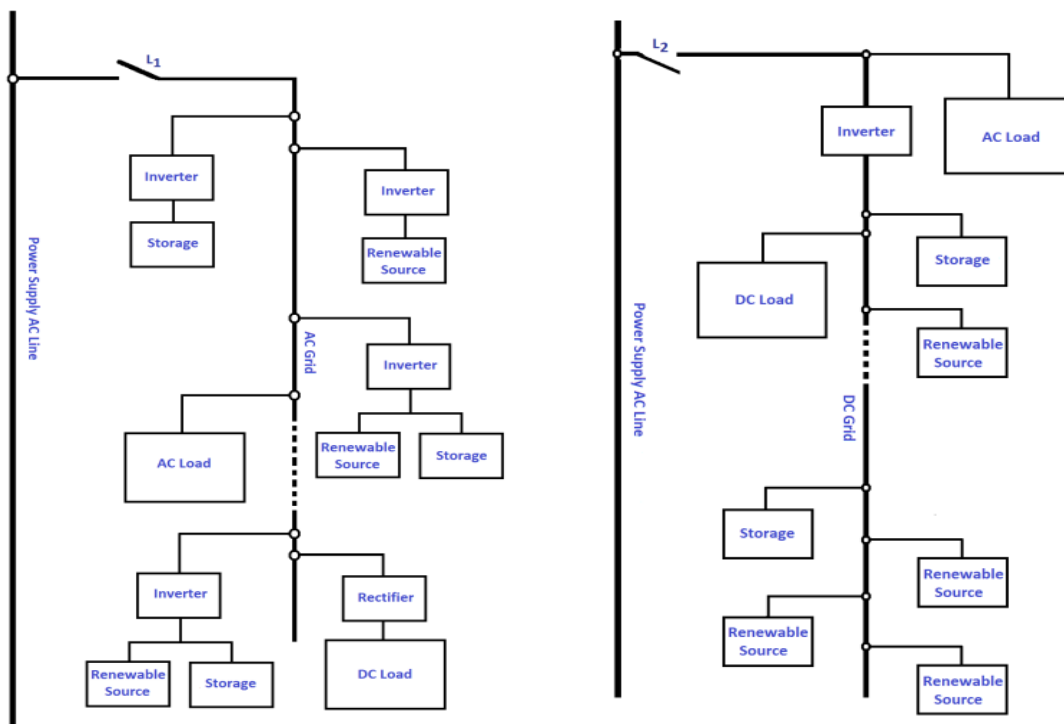


Figure 2 AC and DC supply systems for using in end installations.

On the other hand, the DC supply system is completely separated from the AC grid through an inverter. Therefore, the aforementioned problems do not exist, and an inverter in the DC distribution line is sufficient [15].

In AC supply systems, each inverter operates independently from other inverters which are connected to the same grid. In addition, the connection L_1 must be opened to set the operating voltage and frequency resulting from the interruption of energy supply to the loads. During the stand-alone operation of L_1 , the control of the voltage and phase of the inverters is necessary.

The control of the voltage can be achieved by taking the instantaneous voltage values of different inverters connected to the grid and then conforming if these instantaneous values are coincident with voltage values of the grid. Once this occurs, the inverter circuits will be closed to the grid in parallel. At this stage, the inverter will be synchronized with the grid taking the frequency and phases of this grid as references.

In DC supply systems, when the isolation of the single grid inverter is detected, the connection L_2 will be opened, with no need to the in voltage and frequency adjustment. When the voltage in DC distribution line starts to decrease, the energy will be obtained immediately from the energy storage. Thus, the uninterruptible energy supply can be connected to the loads through the DC distribution line.

The majority of power electronic devices such as converters of air conditioners and switching power supplies can operate using DC power supply. On the other hand, the most of the distributed generators produce a lower DC power supply. Therefore, in these DC power systems, the conversion of power is omitted and hence the efficiency can be improved, because the energy supply to the electronic equipment is provided directly from the DC distribution line [16-17]. With AC supply systems, two conversions of power are needed: the energy is first converted to DC by the grid rectifier, and then is provided to the AC load [18].

As it was locally found that the DC system is preferred from the two points of view: energy efficiency and the power quality due to the absence of the reactive power and power factor, and harmonics.

The main key of the implementation of such systems is that the algorithm regulates the output current of DC-DC converters. As these converters are responsible to allow the interconnection of energy production and storage. The developed algorithm is explained in the following section.

3. ENERGY MANAGEMENT ALGORITHM

3.1. Initial Requirements

The algorithm operates, taking into account the fact that the grid does not fail completely, with the purpose of improving the power quality with respect to voltage drops and transients.

The algorithm is also capable of accepting the requests from the system manager, either towards the supply/ load debalasting or an increase of the consumption.

When the algorithm receives requests from the system manager, it will consider the production forecast, the stored energy, and consumers forecasts to make a good energy management, including an energy exchanges with the grid.

In Figure 3 the algorithm that meets the described requirements is shown.

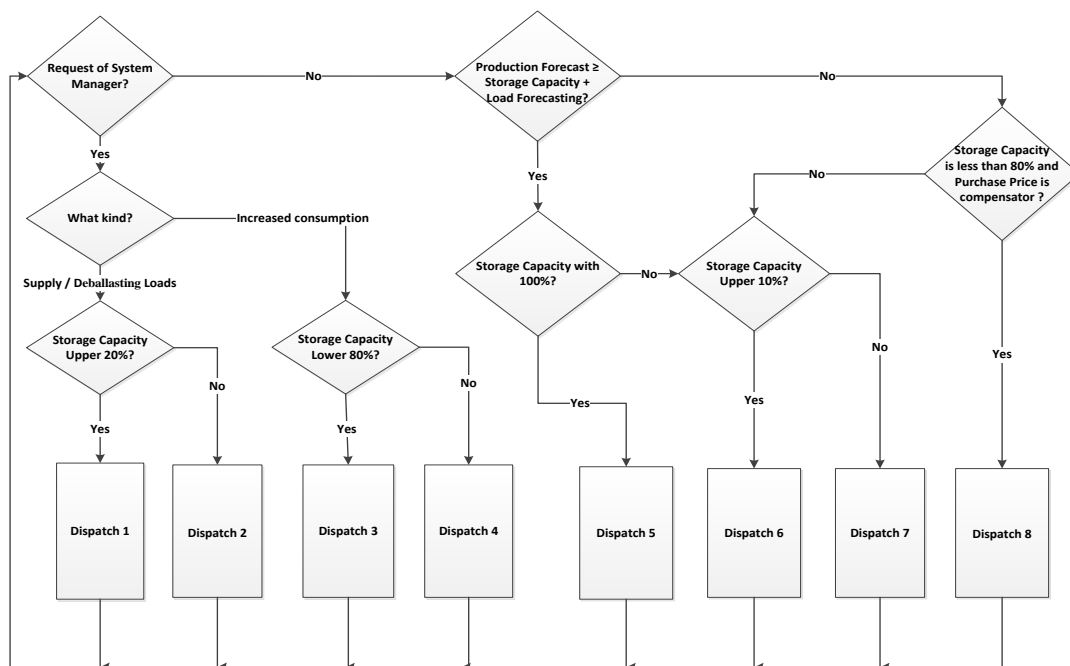


Figure 3 Energy Management Algorithm.

3.2. Operation Mode

The algorithm initially verifies if there is an existence of a request from the system manager. If the request exists, the type of dispatches will be checked. If there is a lack of generated power, the algorithm will verify if the storage capacity is above 20%. If so, it will provide the energy to the public grid and/or feeds the internal loads using renewable energy production or the storage. Firstly, the algorithm uses the supercapacitors. However, if their energy capacity is low, the energy from batteries will be instead employed (Dispatch 1).

If the energy storage is less than or equal to 20%, deballasting charges in this condition are not critical. Therefore, the algorithm is going to provide the energy to the internal loads from the renewable generation sources. However, if the energy from these sources is sufficient, the energy from storage will be utilized. In the case, the energy produced by the renewable sources is not sufficient and the storage is without energy, the algorithm will feed the internal load with the energy which comes from the public grid. In order to guarantee a reasonable level of energy at the storage system, and if there is enough renewable production, the supercapacitors will be charged. Once the charge of the supercapacitors reaches its limit, the charge process of the batteries will be then started (Dispatch 2).

If there is a request from the grid to increase the level of the energy, the capacity of the energy storage will be verified if it is less than 80%. If yes, it gives an order to consume the produced energy or save it in the storage system, or it could be transmitted to public grid (Dispatch 3).

If the capacity of the storage is higher than 80%, it supplies the energy to internal loads from renewable production sources and / or public energy grid. However, if this percentage above of 80%, the remaining energy will be employed to charge the supercapacitors and batteries. It is good to mention that this energy can also be used with the purpose of feeding the electric vehicle, or heating the water (Dispatch 4).

If the request from the grid does not exist, the algorithm will check if the production forecast is higher than or equal to the sum of the storage capacity with the load prediction. If yes, the 100 % condition of the storage system will be tested. If this condition satisfied, the algorithm

is going to provide energy from the renewable production sources to internal loads. Nevertheless, if there is yet more produced energy, it could be used to supply the electric vehicle and heating water system, or transmitted to the public grid (Dispatch 5).

When the capacity of the storage system is higher than 20 %, the algorithm provides energy from the renewable production sources to the internal loads. However, if the produced energy by the renewable sources is not sufficient, in this case, the storage system will feed these internal loads. As long as the energy produced by the renewable sources is sufficient, the supercapacitors are firstly going to be charged using the energy produced by these sources. When the charge process of the supercapacitors is achieved and reaches its maximum limit, the batteries charge will be then started with the energy from these sources (Dispatch 6).

If the storage capacity is less than or equal to 20%, the algorithm gives the order that the energy must be bought from the public grid to supply the internal loads. The non-critical internal loads are disconnected (Dispatch 7).

If there is no request from the system manager and the production forecast is higher than or equal to the sum of the storage capacity and the load forecast, the algorithm will verify if the storage capacity is less than 80% and if the purchase price has a value lower than the one that previously defined as a compensator. If these conditions are satisfied, the algorithm will use the energy of both the electric grid and the one generated by the eventual renewable sources to charge the supercapacitors, the batteries, and the storage loads (Dispatch 8). However, if the two mentioned conditions are not satisfied, the algorithm in this case will test if the storage system capacity is above of 20 %. If so, the algorithm operates following Dispatch 6, if no, the Dispatch 7 will take place.

4. VALIDATION OF THE ENERGY MANAGEMENT ALGORITHM

The energy management system algorithm was validated by building a spreadsheet that simulates the behavior of the different dispatches.

A real energy consumption of a house in the Viseu city with an example of the residential consumption load. These measurements were taken during the period of the two weeks (4/1/2021 to 10/1/2021 and 11/01/2021 to 17/01/2021) and the values have been acquired or registered in each 15 minutes.

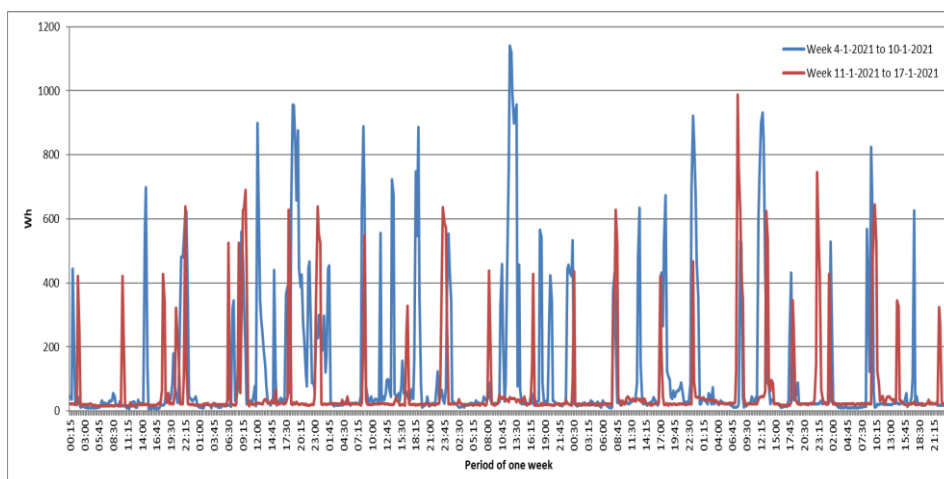


Figure 4 Electrical consumption in the residence during the period of the two weeks.

The charge diagram for the period of one week from 4.01.2021 to 10.01.2021 corresponds to a consumption of 79.3 kWh (DC1), and the week of 11.01.2021 to 17.01.2021 corresponds to 45.5 kWh (DC2).

The energy produced using the renewable sources are predicted and captured in each 15 minutes.

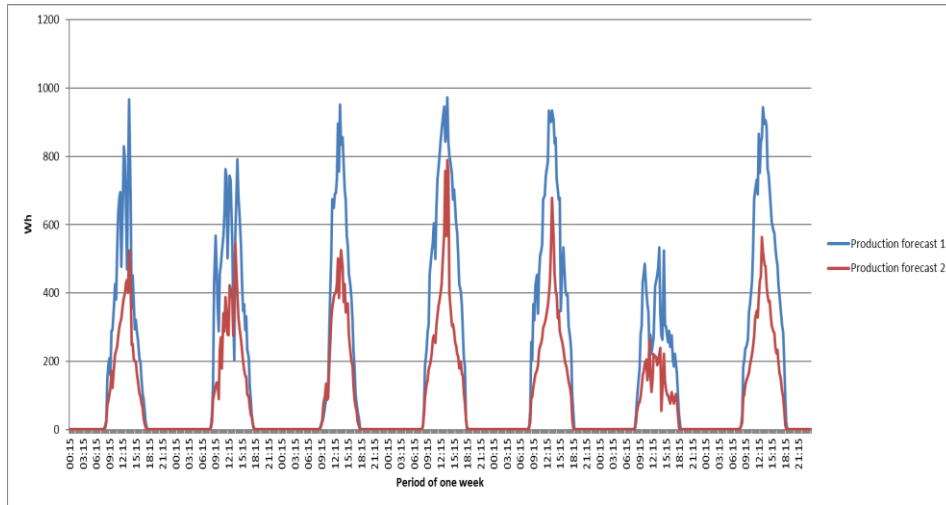


Figure 5 Prediction of the produced energy during the period of one week.

The corresponding energy production to the first period 1 is equal to 122.2 kWh (DP1) and for the second period 2 is equal 63.5 kWh (DP2).

In the worksheet, one can observe the installed storage capacity, the amount of the initial storage as a percentage of the full capacity, losses in storage for loading and unloading, purchase prices and the sold energy, all of these information’s are summarized in Table 1. The storage capacity with the values of 12 kWh (CA1) and 24 kWh (CA2) were used during the simulation process.

With regard to the price of the produced energy, which is transmitted to the public power grid, the normal situation of the self-consumption, i.e 90% of the average practical cost in the energy market, is considered as the starting point (50 euros per MWh). For the simulation, the value of 5 cents per kWh was considered. The algorithm can achieve various tasks, such as: minimization of the energy injections into the public electric grid, maximization the use of energy production for feeding the internal loads, feeding directly the produced energy from the renewable sources and management of the installed storage.

The sale price of the energy in real-time was considered the energy sale price to the end consumers in accordance of the consumer contract in the function of the day time.

For any of the following situations, the values mentioned in Table 1 will be used.

Table 1 Purchase and sale prices of the energy.

Description of the situation:	Euro value:
Energy purchase price from which the consumer considers advantageous.	0.10 (set by the consumer)
Energy selling price to the public grid.	0.05 (contract with the grid)
Energy sales price in aid to the public grid.	0.25 (contract with the grid)
Energy purchase price on aid to public electric grid.	0.01 (contract with the grid)
Energy real-time purchase price.	(Selling price to the consumer)

Regarding the initial value of the storage as a percentage, the value of 50% is used and for the losses in storage system, the 10% of the energy during both the charge and discharge process were considered.

For testing the functionality of the energy management algorithm, five scenarios are studied and characterized as shown in Table 2.

Table 2 Characterization of the studied Scenarios in the test.

	Load diagram:	Production Diagram:	Storage capacity:
Scenario A	DC1	DP1	CA1
Scenario B	DC2	DP1	CA1
Scenario C	DC1	DP2	CA1
Scenario D	DC1	DP1	CA2
Scenario E	DC2	DP1	CA2

In order to make a comparative analysis, 66 grid requests are used in each of the scenarios. 37 of these requests are power reduction, to which the flow management model will respond with the dispatch 1 or the dispatch 2 and 29 requests are power increase being run dispatch 3 or dispatch 4. In terms of the application of dispatches in percentage, the sum of the dispatch 1 with dispatch 2 is 5.5% and the sum of the dispatch 3 with the dispatch 4 is 4.3%. Thus, for requests of grid services (dispatch 1-4) gives a total of 9.8%. The remaining 90.2% is intended to dispatches 5 to 8, running on self-consumption.

4.1. Scenario A

Referring to the first week from 04/01/2021 to 10/01/2021, the total energy consumption is of 79.328 kWh. The total energy production by the renewable sources is 122.194 kWh. With a total storage capacity is of 12.000 kWh. The obtained results are shown in Figure 6:

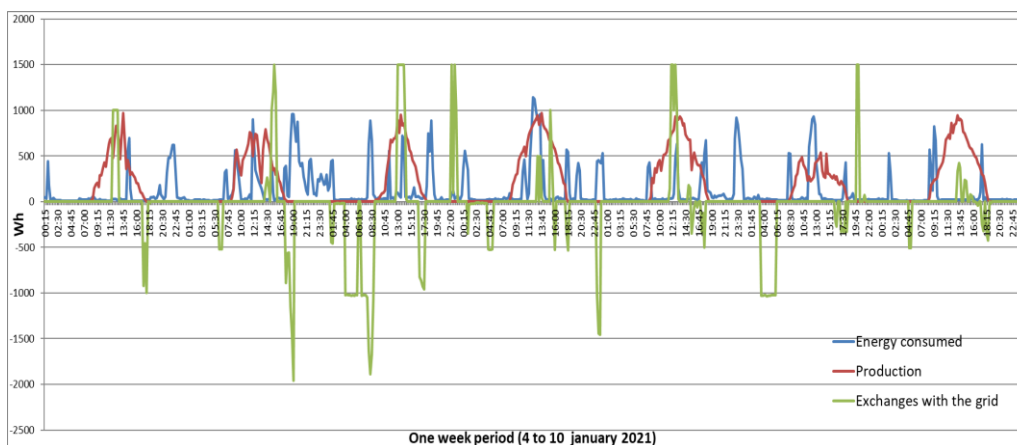


Figure 6 Scenario A shows the consumed energy, production and energy exchanges with the grid.

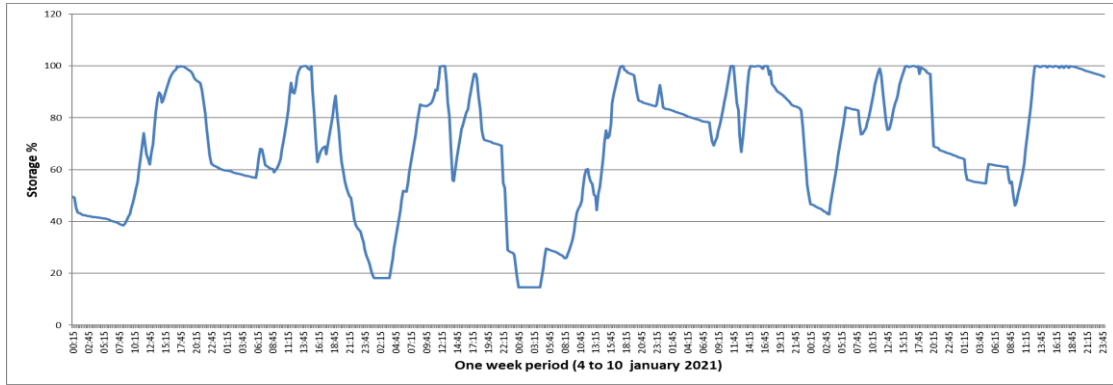


Figure 7 Scenario A over time of the storage process.

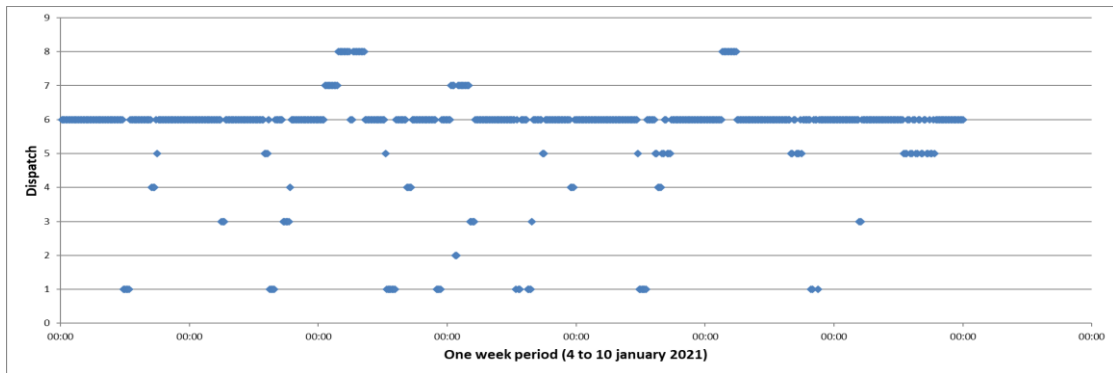


Figure 8 Dispatches used over the time in scenario A.



Figure 9 Comparison between the production forecast, storage capacity and consumption forecast in scenario A

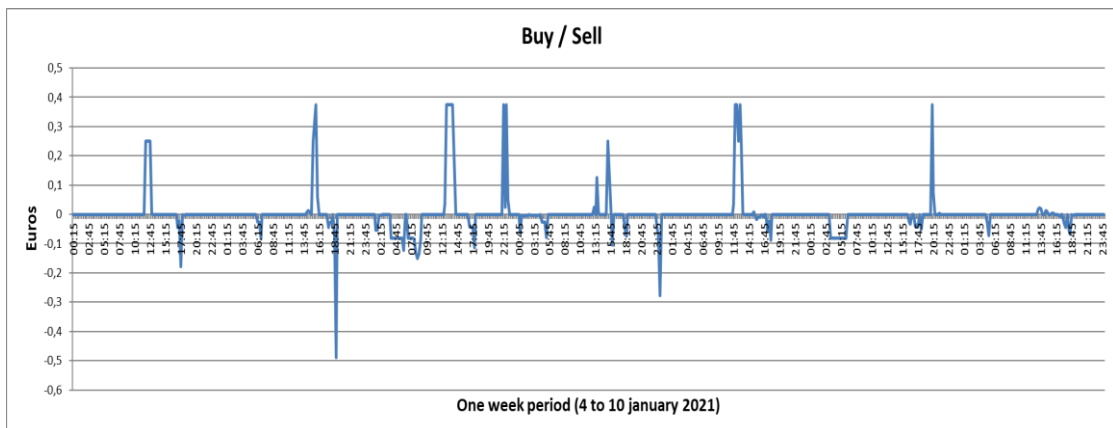


Figure 10 Economic performance with the algorithm over the time in scenario A.

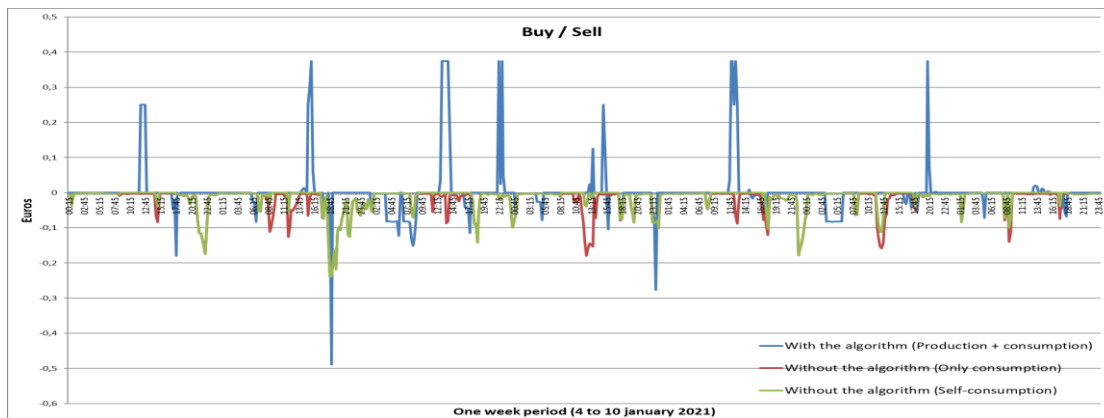


Figure 11 An economic performance comparison with and without the algorithm, only with consumption and self-consumption over the time in scenario A.

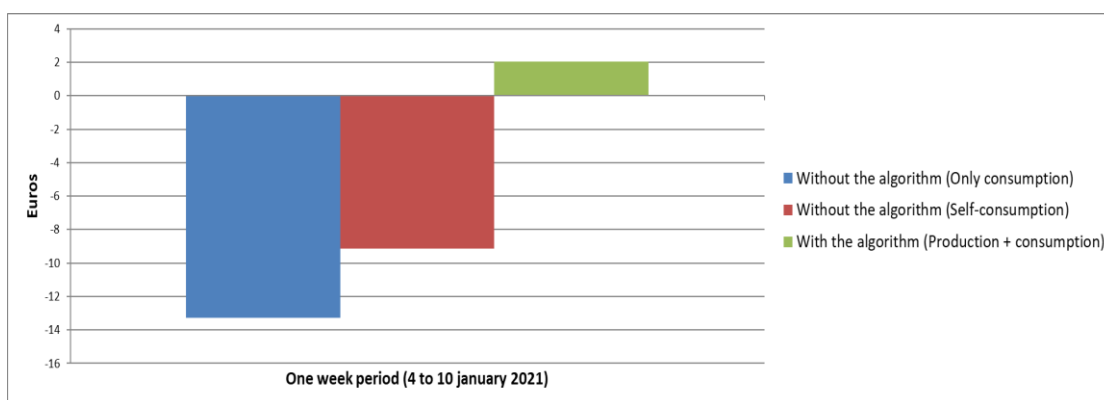


Figure 12 Results of the costs from week 4 to 10 of January without the use of the algorithm with only consumption and self-consumption and application of the algorithm with the production plus consumption in scenario A.

During the week, the average value of the used storage of 12 kWh was 69.72%.

In Table 3, the number of occurrences and the corresponding time to each of the available dispatches is shown. In this table, it is obvious that the occurrence percentage of the dispatch 6 is high comparing the other dispatches, reaching to 77.4%.

Table 3 Occurrence percentage and the corresponding time to each of the dispatches.

	Number of occurrences	Time in hours	Percentage
Dispatch 1	35	8.75	5.2%
Dispatch 2	2	0.50	0.3%
Dispatch 3	15	3.75	2.2%
Dispatch 4	14	3.50	2.1%
Dispatch 5	35	8.75	5.2%
Dispatch 6	520	130.00	77.4%
Dispatch 7	22	5.50	3.3%
Dispatch 8	29	7.25	4.3%

It is noticed that for this scenario A, the algorithm in the power reduction situation (37 occurrences), responds to the 35 of the dispatch 1 because the storage capacity is above 20%, while only 2 for the dispatch 2, as the storage capacity is equal to or less than 20%. The dispatch 1 provides a energy to the grid of production and / or storage system. In the dispatch 2 will disconnect the non-critical loads. For increasing the level of the energy, the dispatch 3 is occurring with 15 time, this due to the storage capacity is being less than 80%. The dispatch 4

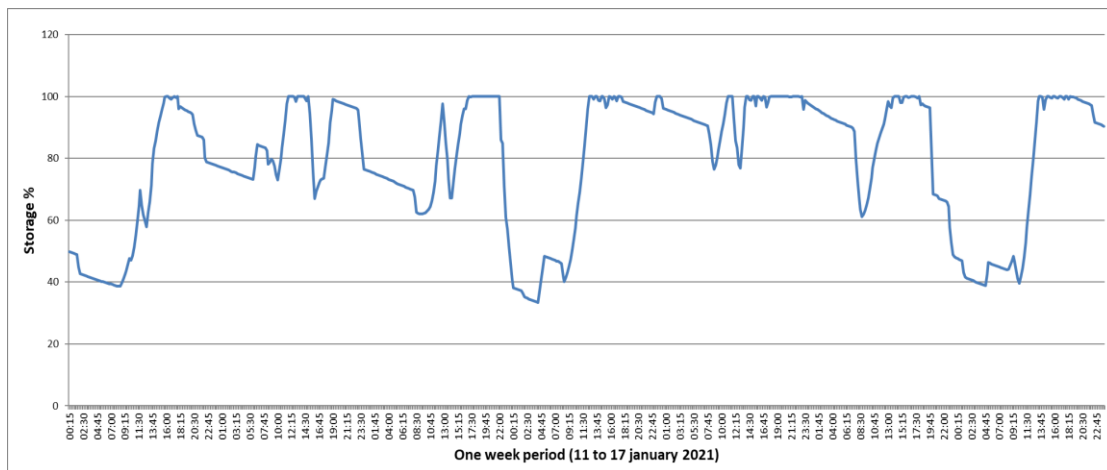


Figure 14 Scenario B over time of the storage process.

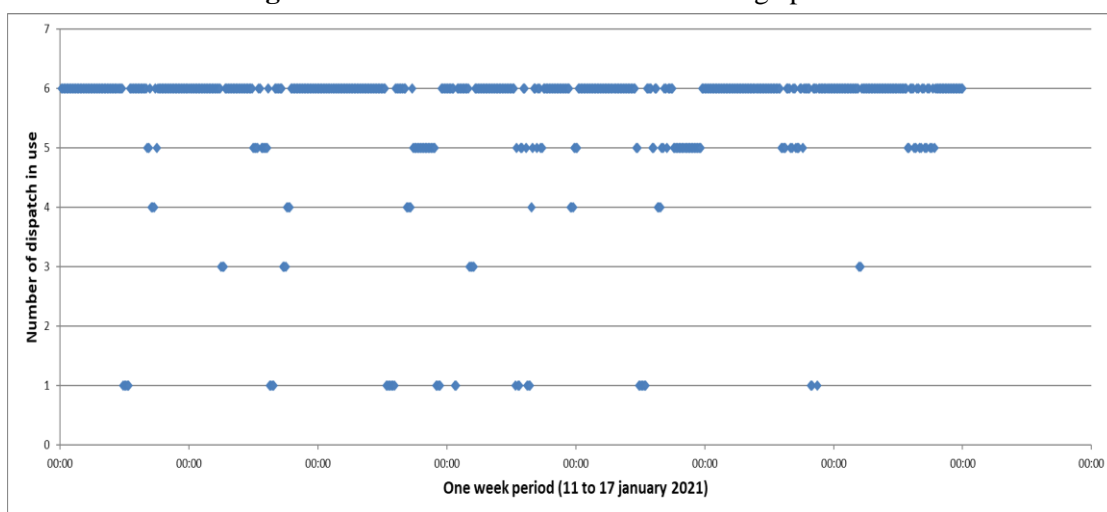


Figure 15 Dispatches used over the time in scenario B.

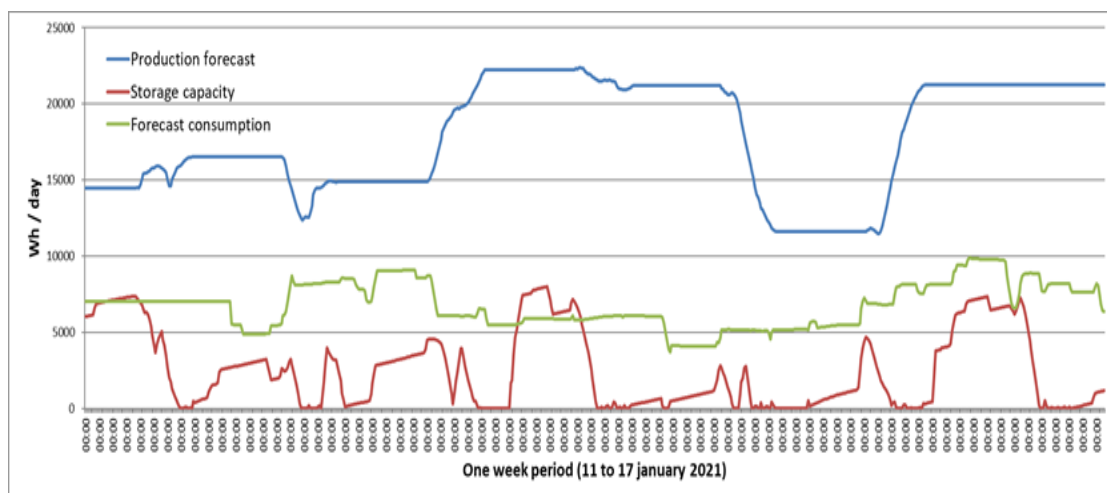


Figure 16 Comparison between the production forecast, storage capacity and consumption forecast in scenario B

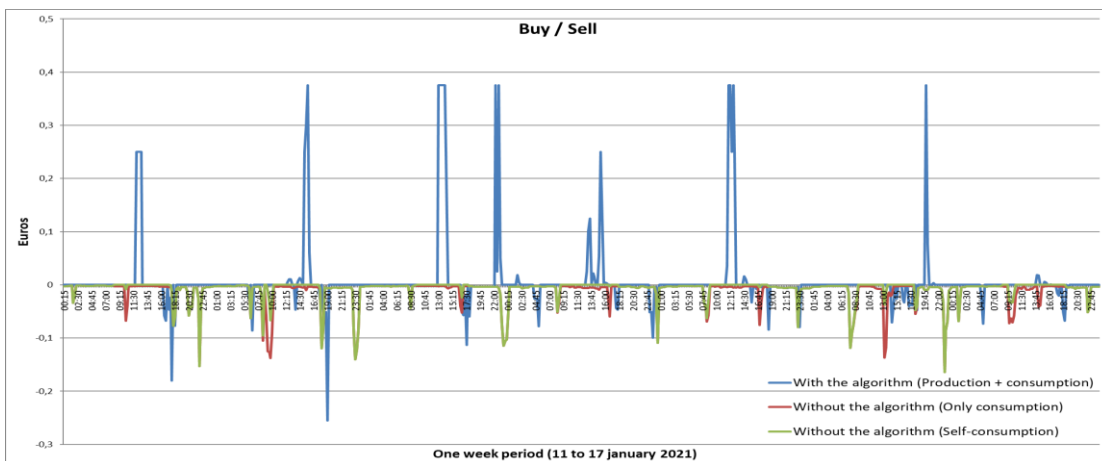


Figure 17 Economic performance with the algorithm over the time in scenario B.

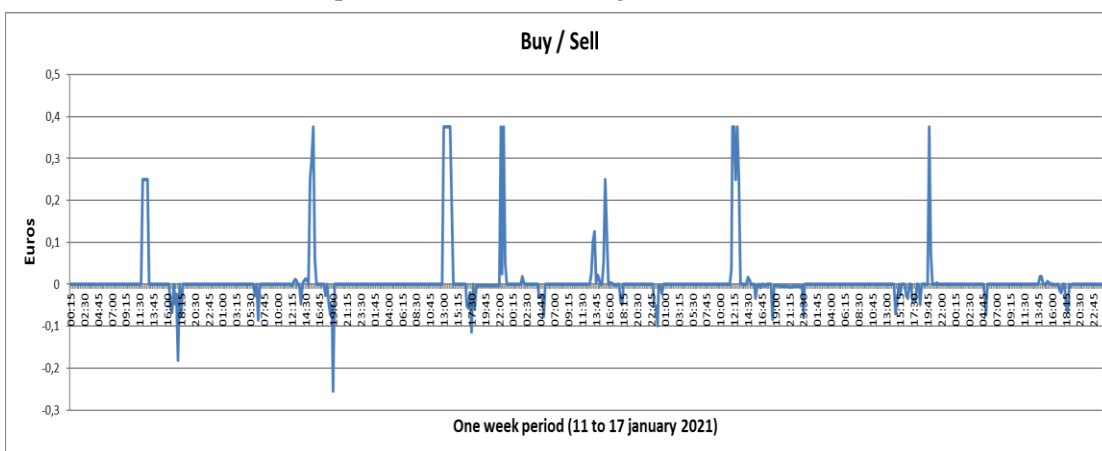


Figure 18 An economic performance comparison with and without the algorithm, only with consumption and self-consumption over the time in scenario B.

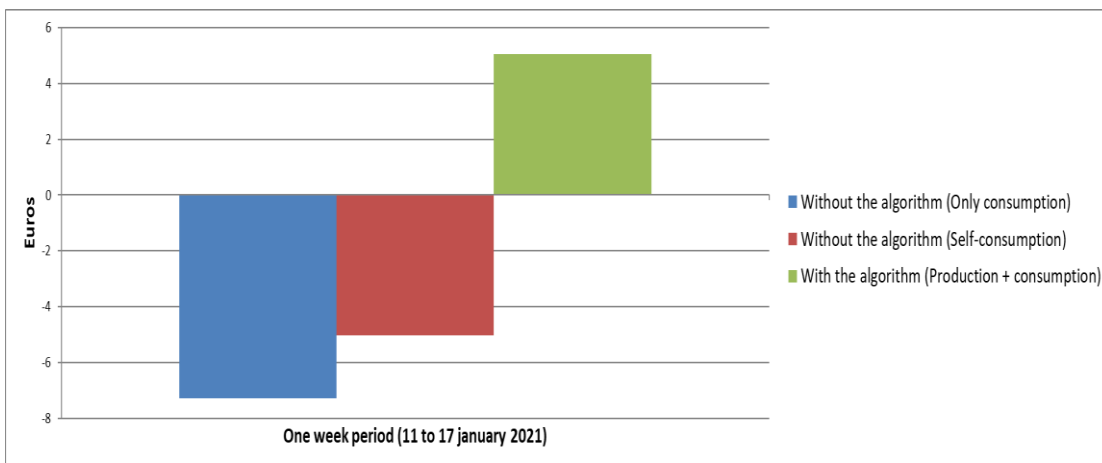


Figure 19 Results of the costs from week 11 to 17 of January without the use of the algorithm with only consumption and self-consumption and application of the algorithm with the production plus consumption in scenario B.

During the period of the week, the average value of the use of the installed storage (12 kWh) was 79%.

The occurrence percentage and the time of each of the available dispatches in scenario B are presented in Table 5.

Table 5 Occurrence percentage and the corresponding time to each of the dispatches.

	Number of occurrences	Time in hours	Percentage
Dispatch 1	37	9.25	5.5%
Dispatch 2	0	0.00	0.0%
Dispatch 3	12	3.00	1.8%
Dispatch 4	17	4.25	2.5%
Dispatch 5	89	22.25	13.2%
Dispatch 6	517	129.25	76.9%
Dispatch 7	0	0.00	0.0%
Dispatch 8	0	0.00	0.0%

In the scenario B, the algorithm in the power reduction situation (37 occurrences), responding to 37 of the dispatch 1 since the storage capacity is more than 20% and there is no time for the dispatch 2, as the storage capacity is never equal to or less than 20%. During the dispatch 1, the energy is supplying to the grid of production and / or storage. For increasing the level of the energy, the dispatch 3 is occurring with 12 time, this due to the storage capacity is being less than 80%. The dispatch 4 is taking place for the 17 times when the capacity is equal to or greater than 80%. In the dispatch 3, if it is possible, it will allow the energy of the grid to be consumed and saved in the storage system. In the dispatch 4, the batteries and supercapacitors are going to be charged, in addition, to the other systems like electric vehicle and heating water.

When there are no requests (90.2% of the time period), the system operates with the dispatches 5 until the dispatch 8, taking the advantage of the energy produced in the renewable energy resources for self-consumption, thus avoiding the exchanges with the grid. With this condition, a considerable reduction of energy will be achieved .

The dispatch 6 is active for more hours (76.9%) because the capacity storage is higher than 20%, but it is not at its maximum level.

During half an hour (dispatch 8), there are opportunities to take the advantage of buying an energy with less price to be then saved in the storage system. Thus, the algorithm gets the economic benefits from this operating condition, therefore, the consumer is able to use this saved energy in his installation, or even can be utilized in any of the grid services.

Table 6 Functionality description of the algorithm in scenario B.

Consumption (kWh)	45.5
Production (kWh)	122.2
Capacity installed (kWh)	12.0
Average capacity of storage used (%)	79%
Energy bill with the algorithm (euros)	-5.04
Energy bill without production and without the algorithm (euros)	7.28
Energy bill with production and without the algorithm (euros)	5.03

From the Table 6, it can be seen in terms of the production situation, the bill is reduced to 2.25 euros (31%). With the storage system and the algorithm, for the same production capacity, the consumer still receives 5.04 euros which translates into an economic advantage of 12.32 euros.

4.3. Scenario C

This situation is set in the week from 4/1/2021 to 10/01/2021. The total energy consumption is 79.328 kWh, which is equal the consumed energy in the case of the scenario A. The total energy production from the renewable sources is 63.464 kWh, which is half of the energy produced in the scenario A. The total capacity storage is a 12.000 kWh. Here, the same plots are presented as in the previous scenarios:

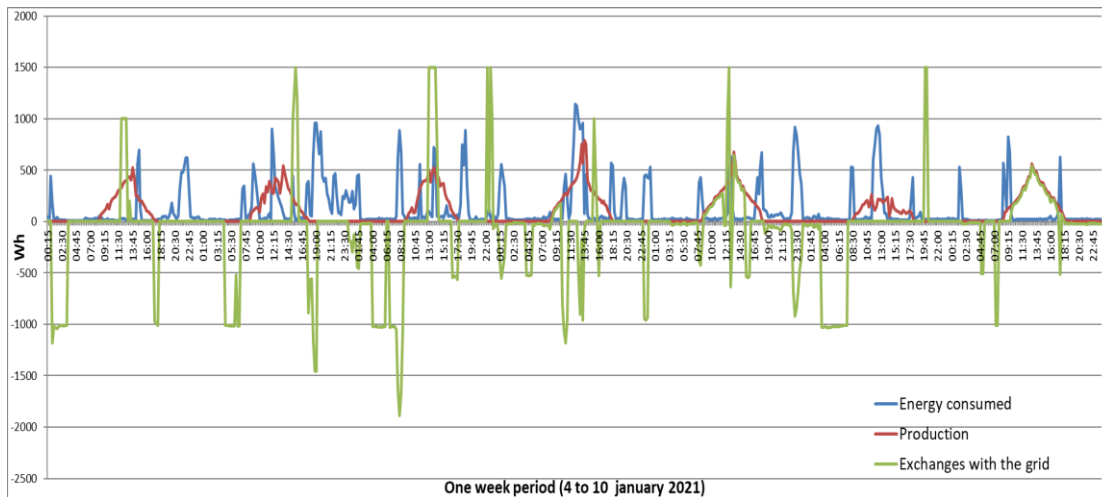


Figure 20 Scenario C shows the consumed energy, production and energy exchanges with the grid.

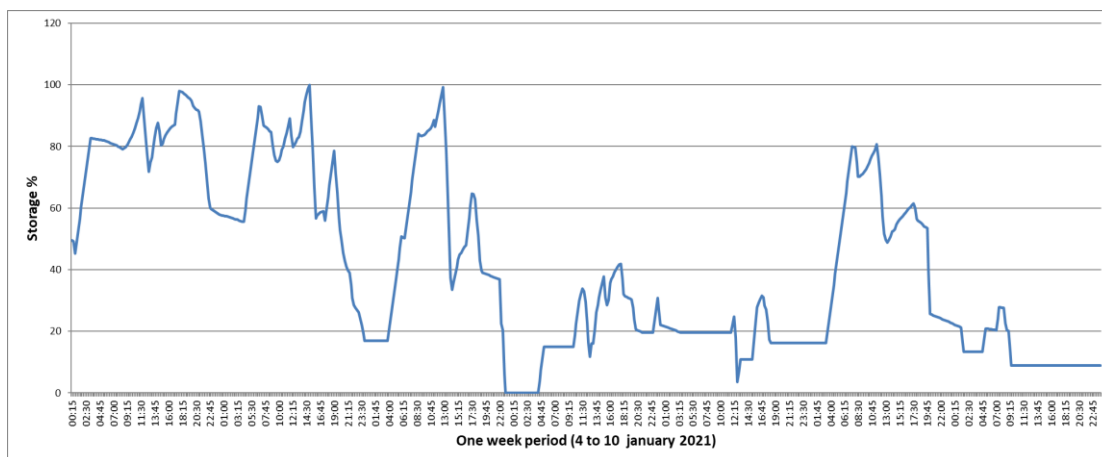


Figure 21 Scenario C over time of the storage process.

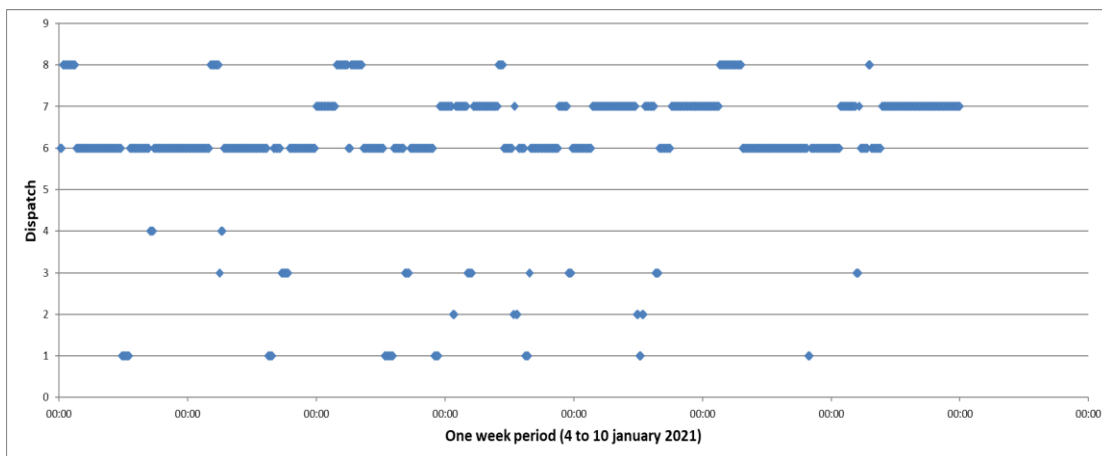


Figure 22 Dispatches used over the time in scenario C.



Figure 23 Comparison between the production forecast, storage capacity and consumption forecast in scenario C.

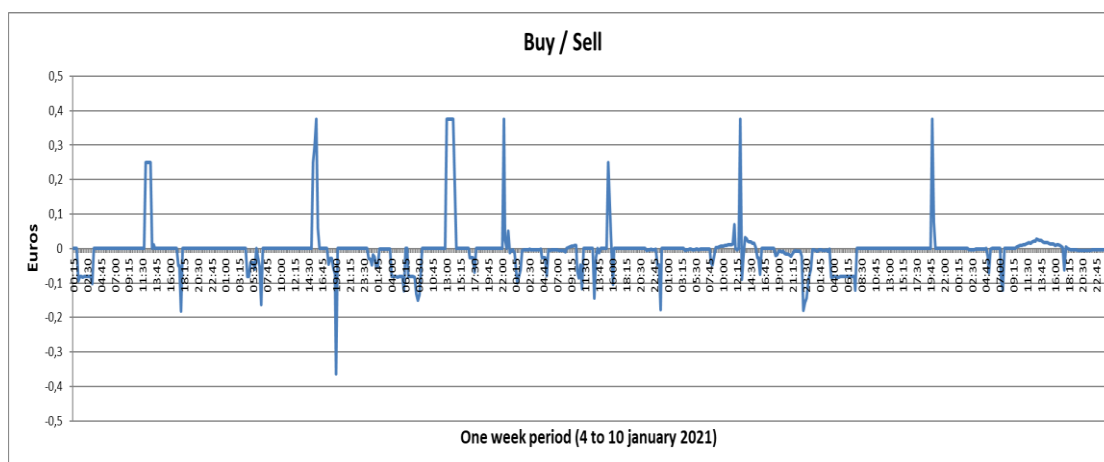


Figure 24 Economic performance with the algorithm over the time in scenario C.

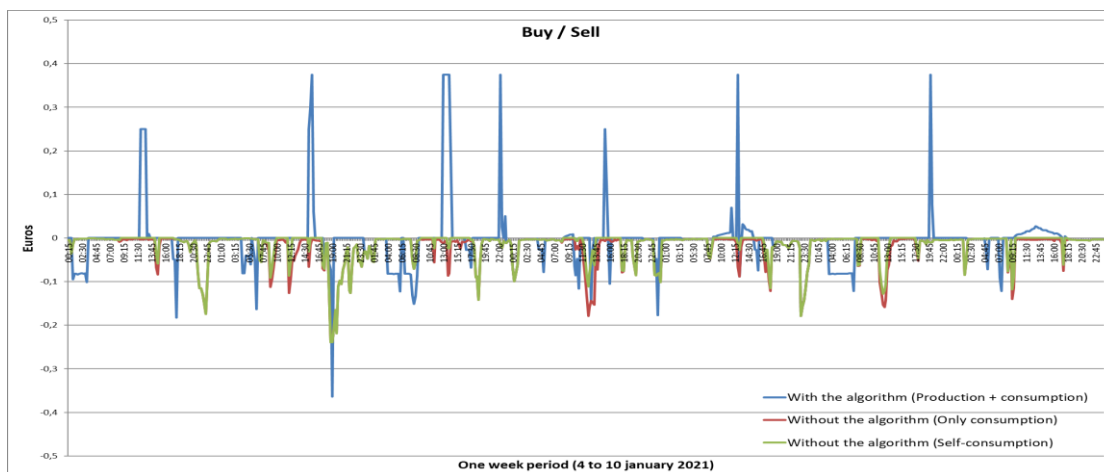


Figure 25 An economic performance comparison with and without the algorithm, only with consumption and self-consumption over the time in scenario C.

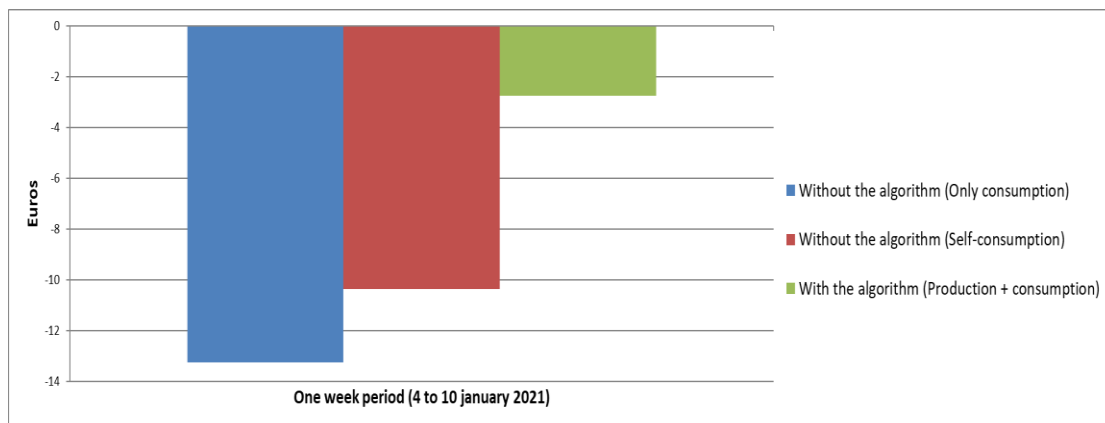


Figure 26 Results of the costs from week 4 to 10 of January without the use of the algorithm with only consumption and self-consumption and application of the algorithm with the production plus consumption in scenario C.

During the period of the week, the average value of the use of the installed storage (12 kWh) was 42%.

The occurrence percentage and the time of each of the available dispatches in scenario C are presented in Table 7.

Table 7 Occurrence percentage and the corresponding time to each of the dispatches.

	Number of occurrences	Time in hours	Percentage
Dispatch 1	28	7.00	4.2%
Dispatch 2	9	2.25	1.3%
Dispatch 3	24	6.00	3.6%
Dispatch 4	5	1.25	0.7%
Dispatch 5	0	0.00	0.0%
Dispatch 6	339	84.75	50.5%
Dispatch 7	209	52.25	31.1%
Dispatch 8	58	14.50	8.6%

In the scenario C, the algorithm in the power reduction situation (37 occurrences), responding to 28 of the dispatch 1 since the storage capacity is more than 20% and 9 for the dispatch 2, as the storage capacity is equal to or less than 20%. During the dispatch 1, the energy is supplied to the grid of production and / or storage. In the dispatch 2 will disconnect the non-critical loads. For increasing the level of the energy, the dispatch 3 is occurring with 24 time, this due to the storage capacity is being less than 80%. While the dispatch 4 is taking place for the 5 times when the capacity is equal to or greater than 80%. In the dispatch 3, if it is possible, it will allow the energy of the grid to be consumed and saved in the storage system. In the dispatch 4, the batteries and supercapacitors are going to be charged, in addition, to the other systems like electric vehicle and heating water.

When there are no requests (90.2% of the time period), the system operates with the dispatch 5 until the dispatch 8, taking the advantage of the energy produced in the renewable energy resources for self-consumption, thus avoiding the exchanges with the grid. With this condition, a considerable reduction of energy will be achieved.

The dispatch 6 is active for more hours (50.5%) because the capacity storage is higher than 20%, but it is not at its maximum level.

Also the dispatch 7 is occurred with the parentage 31.1% of the total time, because the storage capacity is equal to or less than 20%.

During 14.5 hour (dispatch 8), there are opportunities to take the advantage of buying an energy with less price to be then saved in the storage system. Thus, the algorithm gets the economic benefits from this operating condition, therefore, the consumer is able to use this saved energy in his installation, or even can be utilized in any of the grid services.

Table 8 Functionality description of the algorithm in scenario C.

Consumption (kWh)	79.3
Production (kWh)	63.5
Capacity installed (kWh)	12.0
Average capacity of storage used (%)	42%
Energy bill with the algorithm (euros)	2.74
Energy bill without production and without the algorithm (euros)	13.26
Energy bill with production and without the algorithm (euros)	10.38

From the Table 8, it can be seen in terms of the production situation, the bill is reduced to 2.88 euros (21.7%). With the storage system and the algorithm, for the same production capacity, the consumer only pays 2.74 euros which translates into an economic advantage of 10.52 euros.

4.4. Scenario D

This situation is set in the week from 4/1/2021 to 10/01/2021. The total energy consumption is 79.328 kWh, which is equal the consumed energy in the case of the scenario A. The total energy production from the renewable sources is 122.194 kWh, which is equal to the energy produced in the scenario A. The total capacity storage is a 24.000 kWh, which is a double of the scenario A. Here, the same plots are presented as in the previous scenarios:

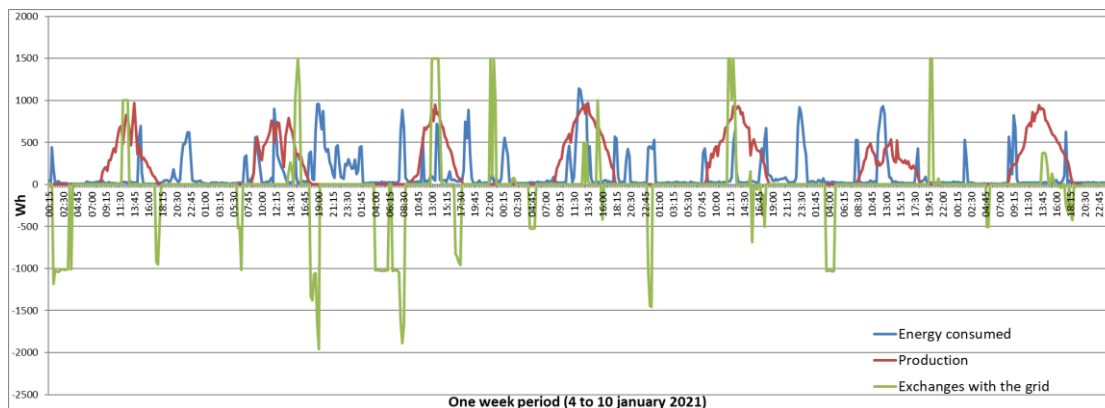


Figure 27 Scenario D shows the consumed energy, production and energy exchanges with the grid.

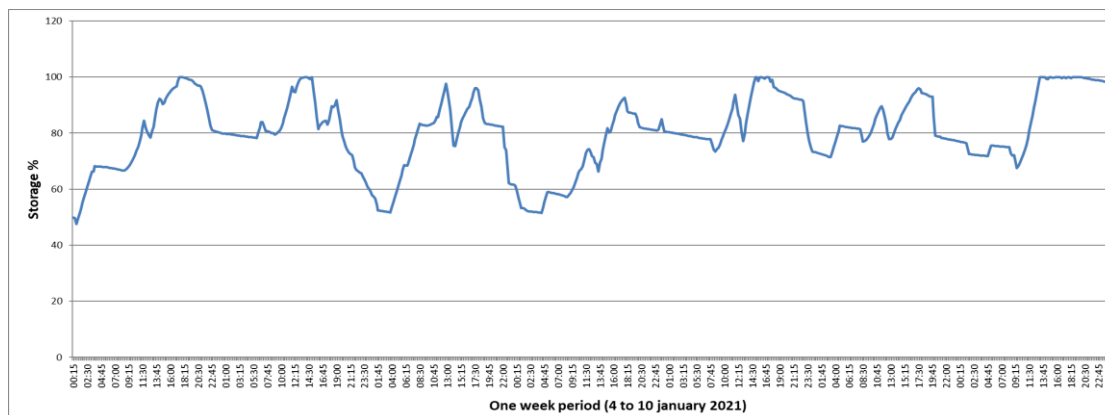


Figure 28 Scenario D over time of the storage process

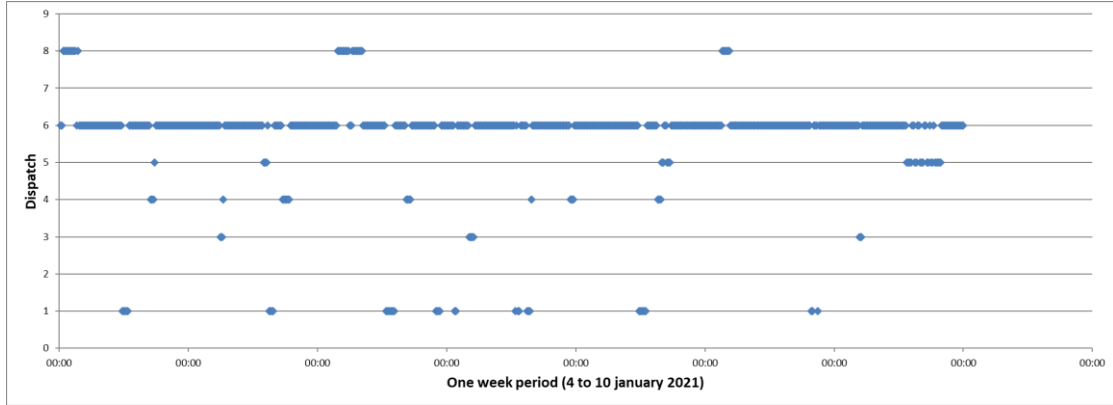


Figure 29 Dispatches used over the time in scenario D.

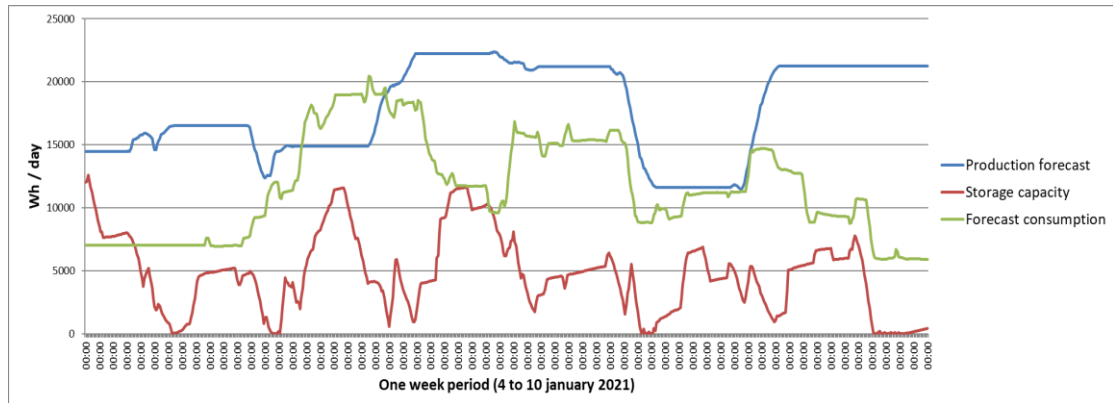


Figure 30 Comparison between the production forecast, storage capacity and consumption forecast in scenario D.

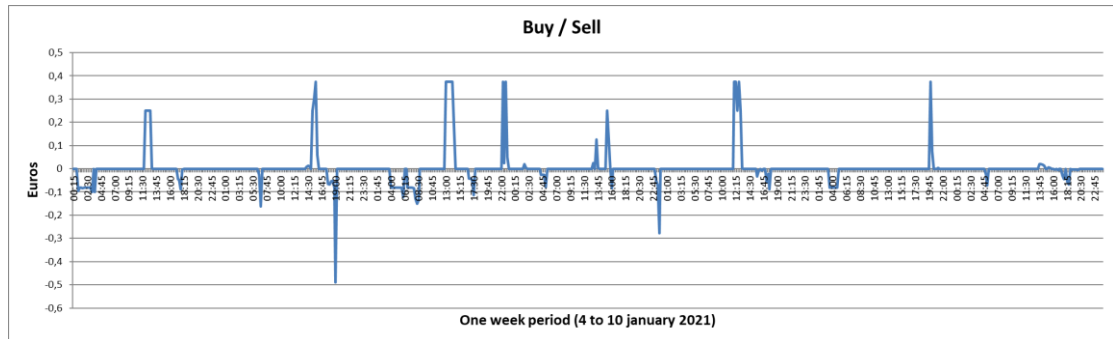


Figure 31 Economic performance with the algorithm over the time in scenario D.

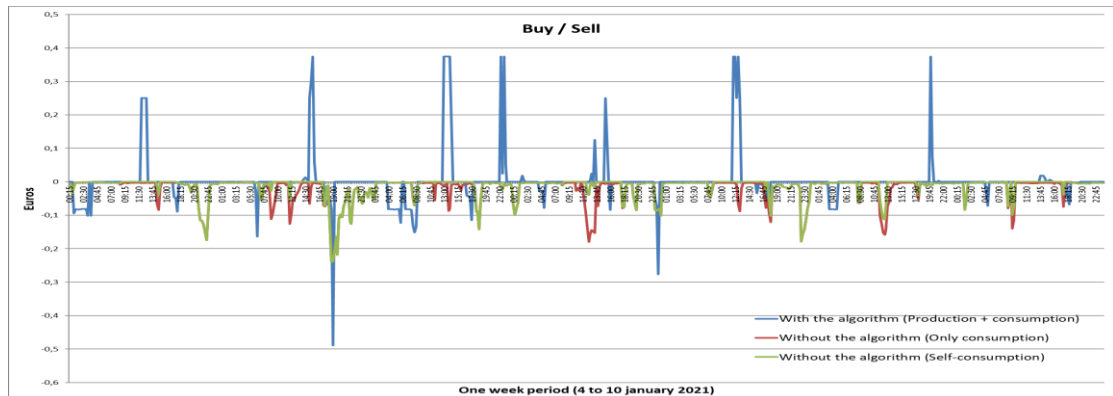


Figure 32 An economic performance comparison with and without the algorithm, only with consumption and self-consumption over the time in scenario D

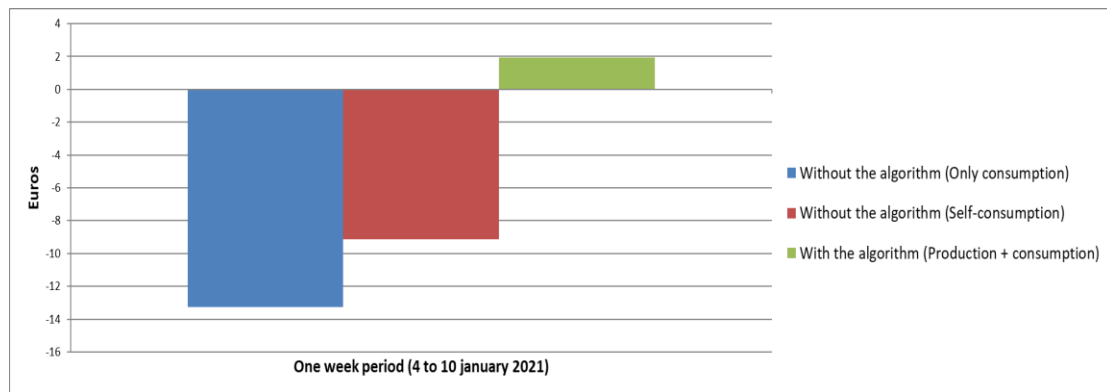


Figure 33 Results of the costs from week 4 to 10 of January without the use of the algorithm with only consumption and self-consumption and application of the algorithm with the production plus consumption in scenario D.

During the period of the week, the average value of the use of the installed storage (24 kWh) was 80%.

The occurrence percentage and the time of each of the available dispatches in scenario D are presented in Table 9.

Table 9 Occurrence percentage and the corresponding time to each of the dispatches.

	Number of occurrences	Time in hours	Percentage
Dispatch 1	37	9.25	5.5%
Dispatch 2	0	0.00	0.0%
Dispatch 3	8	2.00	1.2%
Dispatch 4	21	5.25	3.1%
Dispatch 5	27	6.75	4.0%
Dispatch 6	545	136.25	81.1%
Dispatch 7	0	0.00	0.0%
Dispatch 8	34	8.5	5.1%

In the scenario D, the algorithm in the power reduction situation (37 occurrences), responding to 37 of the dispatch 1 since the storage capacity is more than 20% and zero for the dispatch 2, as the storage capacity is equal to or less than 20%. During the dispatch 1, the energy is supplied to the grid of production and / or storage. In the dispatch 2 will disconnect the non-critical loads. For increasing the level of the energy, the dispatch 3 is occurring with 8 time, this due to the storage capacity is being less than 80%. While the dispatch 4 is taking place for the 21 times when the capacity is equal to or greater than 80%. In the dispatch 3, if it is possible, it will allow the energy of the grid to be consumed and saved in the storage system. In the dispatch 4, the batteries and supercapacitors are going to be charged, in addition, to the other systems like electric vehicle and heating water.

When there are no requests (90.2% of the time period), the system operates with the dispatch 5 until the dispatch 8, taking the advantage of the energy produced in the renewable energy resources for self-consumption, thus avoiding the exchanges with the grid. With this condition, a considerable reduction of energy will be achieved.

The dispatch 6 is active for more hours (81.1%) because the capacity storage is higher than 20%, but it is not at its maximum level.

During 8.5 hour (dispatch 8), there are opportunities to take the advantage of buying an energy with less price to be then saved in the storage system. Thus, the algorithm gets the

economic benefits from this operating condition, therefore, the consumer is able to use this saved energy in his installation, or even can be utilized in any of the grid services.

Table 10 Functionality description of the algorithm in scenario D.

Consumption (kWh)	79.3
Production (kWh)	122.2
Capacity installed (kWh)	24.0
Average capacity of storage used (%)	80%
Energy bill with the algorithm (euros)	-1.94
Energy bill without production and without the algorithm (euros)	13.26
Energy bill with production and without the algorithm (euros)	9.15

From the Table 10, it can be seen in terms of the production situation, the bill is reduced to 4.11 euros (31%). With the storage system and the algorithm, for the same production capacity, the consumer only receives 1.94 euros which translates into an economic advantage of 15.2 euros.

4.5. Scenario E

This situation is set in the week from 11/01/2021 to 17/01/2021. The total energy consumption is 45.533 kWh. The total energy production from the renewable sources is 122.194 kWh, which is equal to the energy produced in the scenario A. The total capacity storage is a 24.000 kWh, which is a double of the scenario A. Here, the same plots are presented as in the previous scenarios:

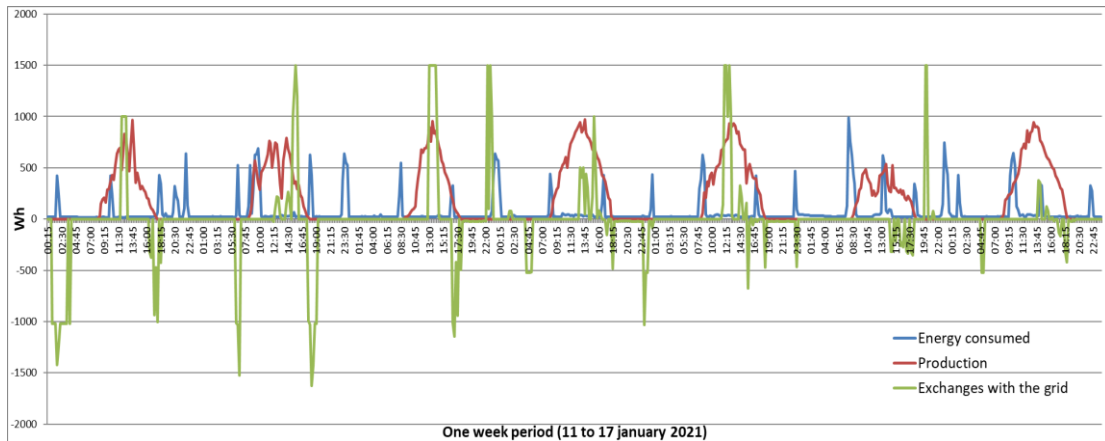


Figure 34 Scenario E shows the consumed energy, production and energy exchanges with the grid

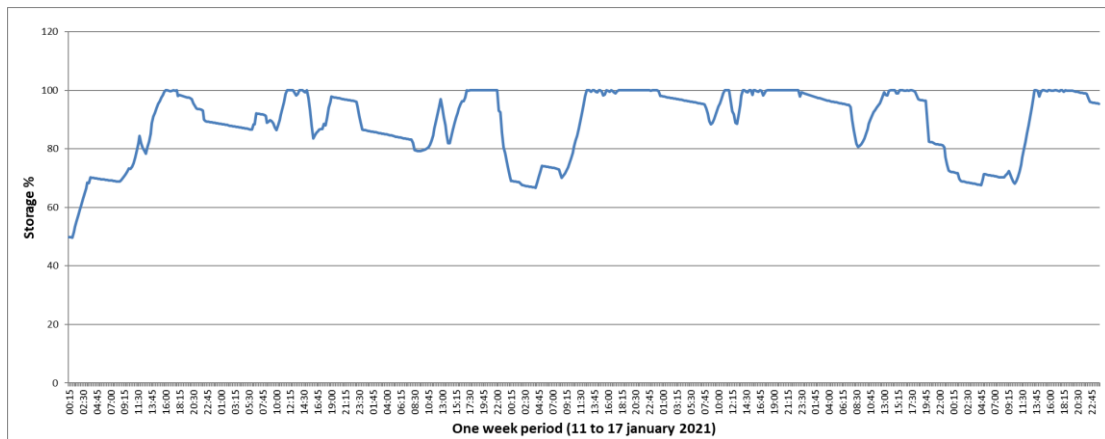


Figure 35 Scenario E over time of the storage process.

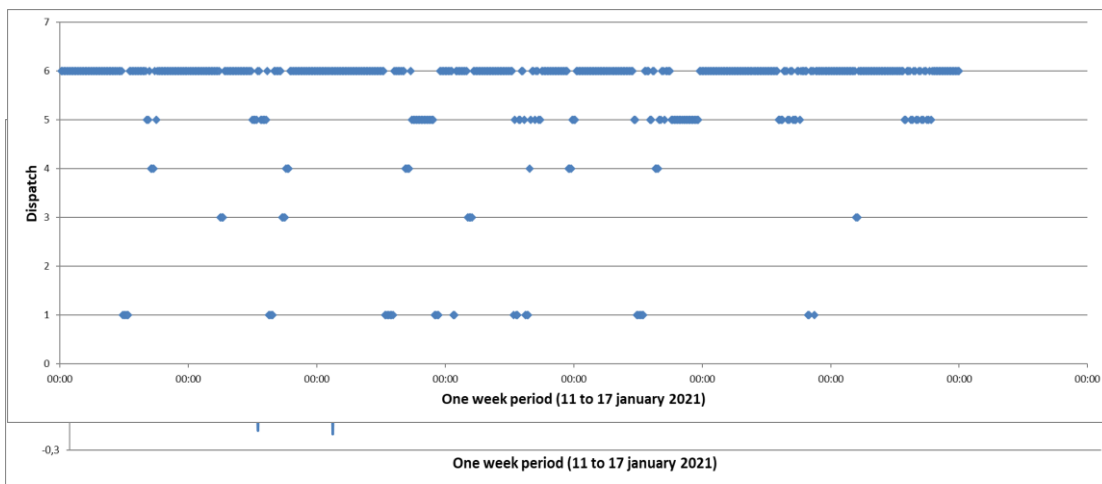


Figure 36 Dispatches used over the time in scenario E.

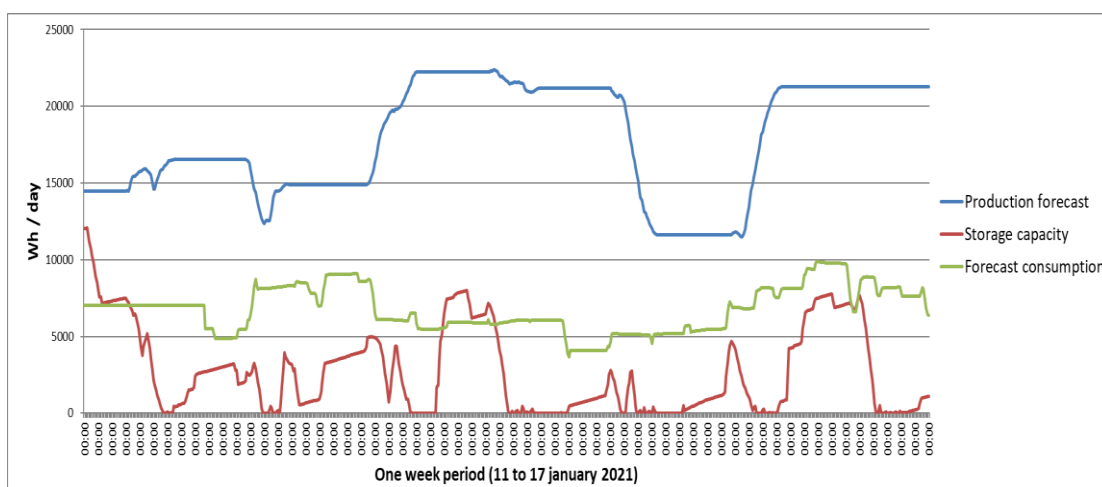


Figure 37 Comparison between the production forecast, storage capacity and consumption forecast in scenario E.

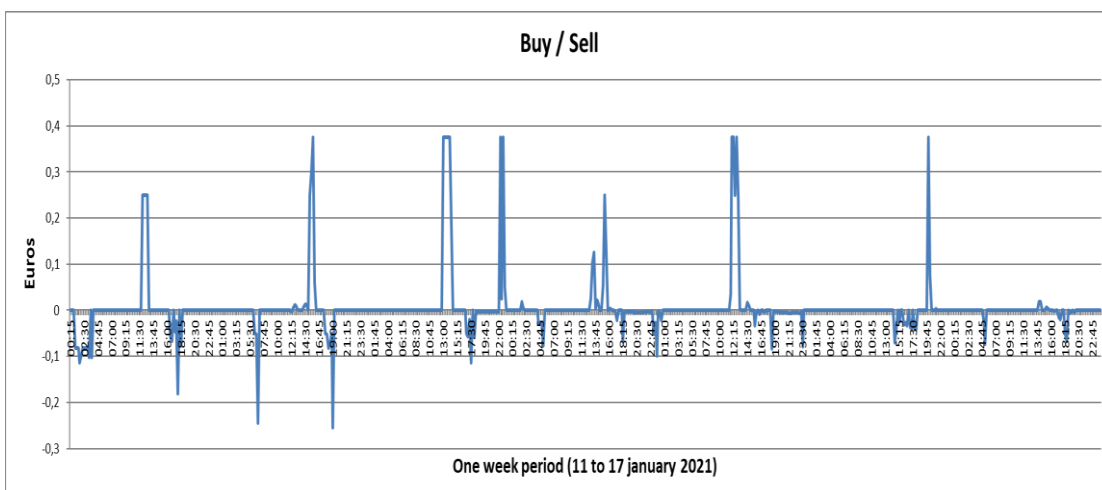


Figure 38 Economic performance with the algorithm over the time in scenario E.

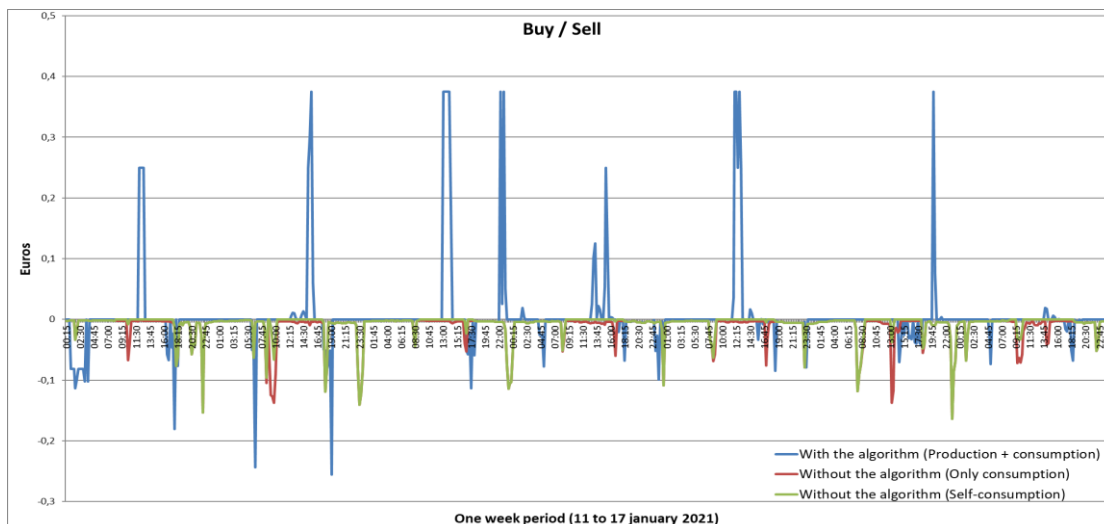


Figure 39 An economic performance comparison with and without the algorithm, only with consumption and self-consumption over the time in scenario E.

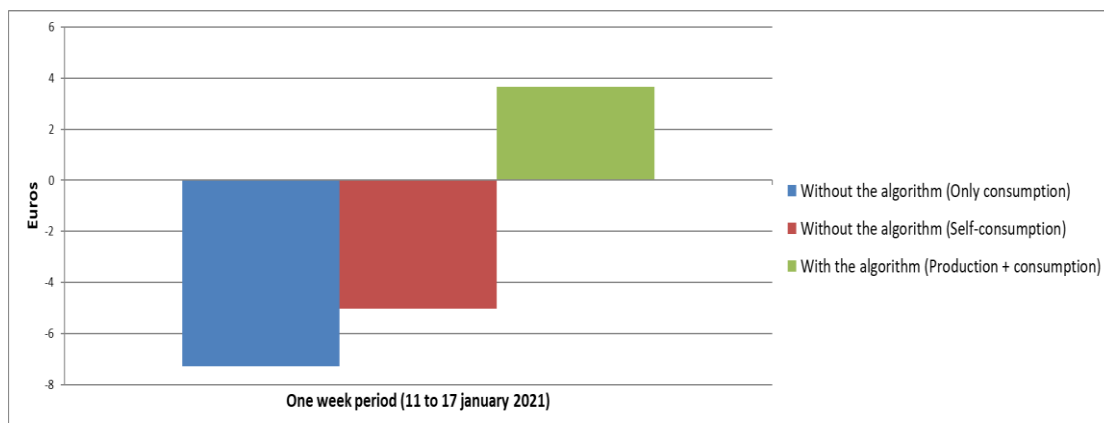


Figure 40 Results of the costs from week 11 to 17 of January without the use of the algorithm with only consumption and self-consumption and application of the algorithm with the production plus consumption in scenario E.

During the period of the week, the average value of the use of the installed storage (24 kWh) was 89%.

The occurrence percentage and the time of each of the available dispatches in scenario E are presented in Table 11.

Table 11 Occurrence percentage and the corresponding time to each of the dispatches.

	Number of occurrences	Time in hours	Percentage
Dispatch 1	37	9.25	5.5%
Dispatch 2	0	0.00	0.0%
Dispatch 3	6	1.50	0.9%
Dispatch 4	23	5.75	3.4%
Dispatch 5	110	27.50	16.4%
Dispatch 6	485	121.25	72.2%
Dispatch 7	0	0.00	0.0%
Dispatch 8	11	2.75	1.6%

In the scenario E, the algorithm in the power reduction situation (37 occurrences), responding to 37 of the dispatch 1 since the storage capacity is more than 20% and zero for the dispatch 2, as the storage capacity is equal to or less than 20%. During the dispatch 1, the energy is supplied to the grid of production and / or storage. For increasing the level of the energy, the dispatch 3 is occurring with 6 time, this due to the storage capacity is being less than 80%. While the dispatch 4 is taking place for the 23 times when the capacity is equal to or greater than 80%. In the dispatch 3, if it is possible, it will allow the energy of the grid to be consumed and saved in the storage system. In the dispatch 4, the batteries and supercapacitors are going to be charged, in addition, to the other systems like electric vehicle and heating water.

When there are no requests (90.2% of the time period), the system operates with the dispatch 5 until the dispatch 8, taking the advantage of the energy produced in the renewable energy resources for self-consumption, thus avoiding the exchanges with the grid. With this condition, a considerable reduction of energy will be achieved

The dispatch 6 is active for more hours (72.2%) because the capacity storage is higher than 20%, but it is not at its maximum level.

During 2.75 hour (dispatch 8), there are opportunities to take the advantage of buying an energy with less price to be then saved in the storage system. Thus, the algorithm gets the economic benefits from this operating condition, therefore, the consumer is able to use this saved energy in his installation, or even can be utilized in any of the grid services.

Table 12 Functionality description of the algorithm in scenario E.

Consumption (kWh)	45.5
Production (kWh)	122.2
Capacity installed (kWh)	24.0
Average capacity of storage used (%)	89%
Energy bill with the algorithm (euros)	-3.67
Energy bill without production and without the algorithm (euros)	7.28
Energy bill with production and without the algorithm (euros)	5.03

From the Table 12, it can be seen in terms of the production situation, the bill is reduced to 2.25 euros (31%). With the storage system and the algorithm, for the same production capacity, the consumer only receives 3.67 euros which translates into an economic advantage of 10.95 euros.

In Table 13 shows a comparative analysis of the various scenarios using this algorithm.

Table 13 Performance comparison of different scenarios using the algorithm.

	Scenario A:	Scenario B:	Scenario C:	Scenario D:	Scenario E:
Energy consumed (kWh):	79.328	45.533	79.328	79.328	45.533
Renewable production (kWh):	122.194	122.194	63.464	122.194	122.194
Storage capacity (kWh):	12.000	12.000	12.000	24.000	24.000
Average amount of storage usage (%):	69.72	79.17	41.64	80.31	88.86
Application of dispatches					
Dispatch 1:	5.21%	5.51%	4.17%	5.51%	5.51%
Dispatch 2:	0.30%	0.00%	1.34%	0.00%	0.00%
Dispatch 3:	2.23%	1.79%	3.57%	1.19%	0.89%
Dispatch 4:	2.08%	2.53%	0.74%	3.13%	3.42%
Dispatch 5:	5.21%	13.24%	0.00%	4.02%	16.37%

Dispatch 6:	77.38%	76.93%	50.45%	81.10%	72.17%
Dispatch 7:	3.27%	0.00%	31.10%	0.00%	0.00%
Dispatch 8:	4.32%	0.00%	8.63%	5.06%	1.64%
Energy bill (with the algorithm) (euros):	-2.02	-5.04	2.74	-1.94	-3.67
Gain provided by the management system compared to a situation without production (euros):	15.28	12.32	10.52	15.20	10.95
Gain provided by management system compared to a situation only production (euros):	11.17	10.07	7.63	11.09	8.70

In any of the five scenarios, the use of the algorithm leads to substantial reductions in energy bills with an average of 12.85 euros per week comparing to the situation without production and 9.73 euros per week comparing to the situation only production (without management storage). The obtained results show the good performance of the algorithm in different operating situations.

Comparing the scenario, A with the scenario, B, when the consumption of the power in the residence decreases, the average value of the storage capacity increases from 70% to 79%. This an increase, which facilitates the reduction of the power with the dispatch 1 (detriment of the dispatch 2) but on the other hands, it makes it difficult to respond the requests of the power increase, or it reduces the operating time of the dispatch 3 and increases the time of the dispatch 4.

When the level of the storage capacity increases (scenario D and scenario E), in comparison with the other scenarios, the average value of the used storage capacity also will increase due to the higher amount of power that comes from the public grid.

The analysed data show that the demands on the power is decreasing, this is because the storage capacity is higher than 20% as it is always used the dispatch 1. If there is a request to increase the power, especially in the scenario E, the percentage of dispatch 3 tends to decrease while the dispatch 4 tends to increase since the storage capacity is equal to or higher than 80% for most of the time.

Comparing the scenario, A with the scenario C, the energy produced by the renewable sources is high, thus one can concluded that the average value of the used storage is also high. In this case, the scenario A with a renewable production of 122.194 kWh has an average of the used storage capacity equals to 70%. The scenario C with renewable production of 63.464 kWh has an average value of the used storage capacity of equals to 42%.

The dispatch which has been occurred in most of the scenarios was the dispatch 6, this is because during the simulation period none of the grid requests have been ordered and in most of the time the storage has a higher storage capacity utilization which equals to 20%, but less than 100 %.

5. CONCLUSION

The algorithm was developed to take advantage of renewable energy with storage that can be utilized in the liberalized market, based on a set of dispatches with different functions. Dispatches from 1 to 4, act in the direction to "assist" the grid manager. This assistance is made in the line of the grid services, and the economic benefits are presented. Dispatches from 5 to 8, can operate without receiving any request from the grid manager, as the grid manager will

never make such a request, or because the transformation of the energy market has not yet been made in this direction.

The function of these dispatches and their validation was implemented and presented through a spreadsheet in Excel, where it is possible to see the behaviour of different dispatches of a house, with real consumption data for two weeks. To facilitate the interpretation and analysis of algorithm performance various dispatches are drawn and depicted in multiple graphics.

With the dispatches, it is possible to observe that the consumed energy over the time, energy production and energy exchanges with the grid. It is also possible to observe the evolution of the storage situation over time, the dispatches in use, the forecast of energy production and energy consumption, the available storage capacity, and the economic performance of the algorithm over time (Buy/Sell).

Another important aspect is to compare the economic benefit with and without using the developed algorithm in the simple consumption situation or the self-consumption. It was clearly shown that in different scenarios (with greater or lesser consumption of the house loads production, using more or less storage) the algorithm is always economically more advantageous to be installed in the system.

The economic benefits earned by using this algorithm can be shared between the final installation and the operator(s) of the public grids. Thus, the owner of the final installation can be compensated economically by the fact that it can provide the energy to grid services, in addition it contributes to increase the availability of energy. Moreover, another benefit of using this algorithm for the public electricity grid is that it prevents or postpones the investments at the level of centralized production or transmission and distribution of energy. In addition, the energy that circulates in the transmission and distribution is low, this results in a reduction of the energy losses in the lines.

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