Energy Monitoring and Management for Homes

Ricardo Modesto de Almeida Guerreiro da Silva
Electrical and Computer Engineering
Instituto Superior Técnico
Lisbon, Portugal

Abstract – Due to increasing electricity consumption, which can jeopardise an outdated electrical grid and lead to power failures, along with the environmental problems caused by fossil fuel power plants in recent decades, it has become essential to better manage energy consumption.

From a consumer perspective, the electricity bill is a substantial portion of most people's budget. Hence, given the rise in prices over the last years, finding a way to better manage the power required from the grid while decreasing the costs of electricity is the goal to aim for.

Some concepts like load shifting and peak energy reduction are explored in this paper, along with the usage of solar panels in order to find a way to reduce costs for the end-user while reducing electricity consumption during peak periods, that helps prevents any overload of the electrical grid.

A simulation for a home management energy system (HEMS) using these concepts is considered for the different electricity tariffs available in Portugal, using baseline scenarios with different family types and consumption patterns.

Shifting loads to off-peak periods reduce power peaks at home and allows the final consumer to potentially reduce the contracted power which will result in a lower bill amount.

Depending on the type of devices and usage, we have observed a potential reduction up to 16,9% in a monthly bill.

Keywords: HEMS, Load Shifting, Peak Reduction, Bi-Hourly Tariffs, Electricity Bill, Contracted Power

I. INTRODUCTION

NOWADAYS, we live in a world where electrical energy has become a vital resource for people's daily lives, and its consumption is increasing.

The electrical grid may benefit from more efficient management of energy at homes since some of the load at peak times can get reduced or shifted to another period in which the grid is not overloaded and electricity is cheaper.

In summary, it would be helpful if the user had a tool to see his/her consumption patterns and get some insights and suggestions for improvement.

The main objective is to monitor energy consumption throughout the day according to different user-profiles and seasons and based on that, shift some loads to an off-peak period which can reduce the peak demand at home.

By moving those loads to an off-peak period, the consumers may leverage the bi-hourly tariffs, in which that period is cheaper, to pay less for the electricity bill. That may possibly help reducing the contracted power, which also decreases the monthly electricity bill.

The concept of load shifting should be applied to devices that domestic users are willing to postpone to another time without affecting their well-being (e.g., postponing the washing machine from the afternoon to late evening).

A simulation of a home energy management system will allow us to understand the impact of the concepts above.

Instead of running an automatic logic to move loads, the system should propose new times to run a shiftable device, as the consumers may change their routines.

The aim is to objectively compare electricity consumption and prices before and after implementing specific measures and evaluate which decisions are beneficial for the user in the long run.

The benefits must be analysed from the user's economic point of view and as a way of relieving the load on the grid.

II. RELATED WORK

A. *Electricity in Portugal*

In Portugal, the regulatory authority for the electricity is the ERSE (Entidade Reguladora dos Serviços Energéticos).

To better understand how the electricity sector in the country works [1], a high-level electricity workflow starting from the production point until it reaches the consumer is presented in the figure below:

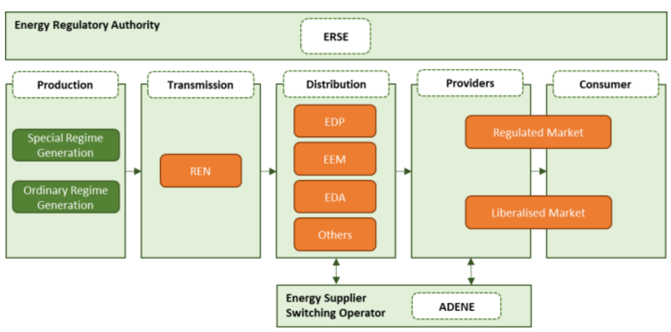

Fig. 1. High-level workflow and principal players of the electric sector in Portugal

The price at which electricity is sold to consumers is called a tariff, which in Portuguese market is defined by ERSE, regardless of the consumer being in the regulated or liberalised market.

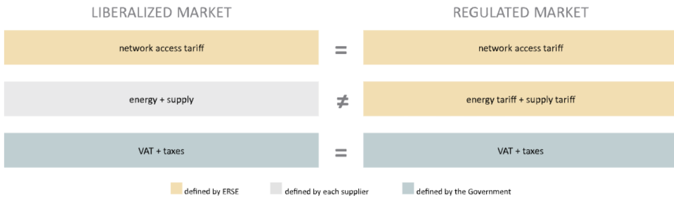

Fig. 2. Tariff Regulation in Portugal in both Liberalised and Regulated Markets, defined by ERSE [2]

As observed in the figure above, both network access tariff and "VAT + taxes" variables are defined by the same entities, ERSE and government, for both markets.

Therefore, the main difference between them falls on the energy and supply tariffs. For these, the consumers will pay the tariff set by ERSE in the regulated market.

In contrast, in the liberalised market, each supplier can define its values, promoting competition. These tariffs reflect the contracted power and the energy consumption.

Finally, the government is responsible for defining VAT (Value Added Tax) and among other set of taxes across both markets.

Although we have both markets now, it is expected that all clients in the regulated market will progressively transit to the liberalised market until the end of 2025 [3], the date from which the regulated market should not be allowed in new contracts anymore.

From a consumer's perspective, there are three main components to be paid in the electricity bill [4]:

1. **Variable Component** – Part of the bill that depends directly on the amount of electricity consumed;
2. **Fixed Component** – Part that is independent of the amount of electricity consumed. It usually depends on the contracted power;
3. **Taxes Component** – VAT and set of Taxes defined by the government and applied on top of the first two components.

We can observe that although the amount of electricity consumed each month plays a significant role in the final amount of the electricity bill, the contracted power is also an essential factor to consider.

For domestic users, the most common contracted power falls on the interval between 3.45 kVA and 6.90 kVA [5]. The user will pay a daily fixed rate based on the selected power, regardless of the consumed amount of energy.

Typically, a power of 3.45 kVA is enough for a single person, while for a family of four, it is usually short, and 6.90 kVA is a safer choice. However, the necessary power relies on the routines and appliances the consumers have.

Regarding the consumption of energy during the month, usually expressed in €/kWh, there are two main types of tariffs related to the time of the day:

1. **Single rate** - The user pays the same rate regardless of the time of the day the energy gets consumed;
2. **Time of use (ToU) –** The price of electricity changes at different times of the day. Usually, there are two rates attached to two periods:
   - **Peak** – This is the period when electricity costs the most. It usually applies in the evenings;
   - **Off-Peak** – This is when electricity is cheapest. Off-peak rates usually apply overnight.

In the graphic below, we have the distribution of clients per type of tariff in the liberalised market in Portugal, for which the contracted power is equal to or lower than 20,7 kVA:

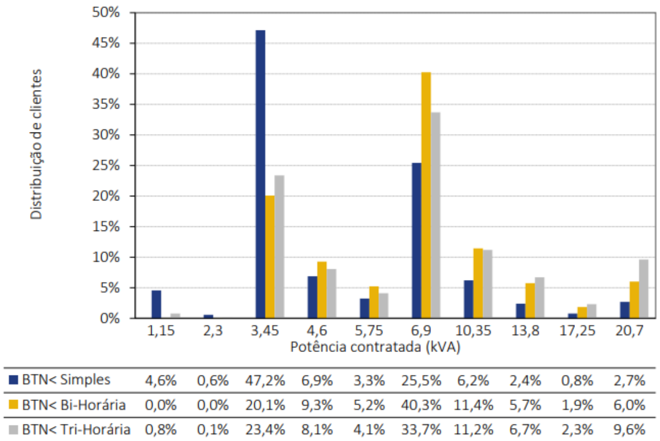

Fig. 3. Clients distribution in the liberalised market, per tariff and contracted power (ERSE) [6]

The total number of clients per tariff is summarised in the next table.

Table 1. Number of clients per tariff in the liberalised market.

Type of Tariff	Number of clients
Single	4.685.230
Bi-Hourly	486.511
Tri-Hourly	48.523

The single rate is lower than the peak rates of a time-of-use tariff. Therefore, this rate is a good choice for people who usually stay the afternoon at home during weekdays and need to use high-consumption appliances (like a heater or air conditioning) during that period.

For the ToU tariffs, the consumer needs to indicate what type of cycle [7] should the tariff follow:

- **Daily** – With this option, the two daily periods are always the same during the year, meaning the winter/summer time or weekdays/weekends will not play any role;
- **Weekly** – The peak and off-peak periods are not the same in the Summer and Winter, and there are also differences between the periods at the weekends and weekdays.

The daily and weekly cycle periods are defined by ERSE [8], as per the images below:

- **Daily Cycle**

Fig. 4. Daily periods defined by ERSE for daily cycle tariffs

- **Weekly Cycle**

Fig. 5. Weekday periods defined by ERSE for weekly cycle tariffs

Fig. 6. Saturday periods defined by ERSE for weekly cycle tariffs during summer time

Fig. 7. Saturday periods defined by ERSE for weekly cycle tariffs during winter time

Fig. 8. Sunday periods defined by ERSE for weekly cycle tariffs

Additionally, some countries have happy hour tariffs, where electricity is free for a certain period, or dynamic tariffs, in which price varies according to energy demand. However, due to their uncertainty, these are mainly experimental tariffs.

B. *Smart Grids and Meters*

The power grid is a network of power lines and substations that transport electricity from power plants to homes/companies and has remained almost unchanged over the past decades.
Nowadays, the power grid is struggling, it needs to be updated, and it is running at its maximum capacity [9].
When power lines break or power plants cannot produce enough electricity, blackouts can occur, which is a problem that can lead to fatalities.

We built new power plants in the past to overcome this, but now we can work towards sustainability and reduce our dependence on fossil fuels by using a smarter grid.

The smart grid adds sensors and software to the electric grid, providing utilities and individuals with new information that helps them understand and respond quickly to changes. It is a network that allows a two-way flow of power and data.
It can be used to detect and automatically respond to problems on the power grid. For example, a tree falls on a power line, and 1000 homes are without power. With the current power grid, utility workers often must physically reroute power, which takes time.
With the smart grid, sensors and software would detect the problem and reroute power immediately, limiting the problem to fewer households [23].

Although they may be independent of each other, managing a home's energy consumption can be integrated into a smart grid. It may even allow the user to sell energy to the grid (micro-production) if it is not used or inform the user of a peak in the network.

Smart meters are the next generation of gas and electricity meters that provide more information about energy supply and control over energy consumption [10].

They are gradually being installed in several countries at no upfront cost, and the goal is to bring them to as many households as possible.

Originally, the full roll-out in Portugal was supposed to be completed in 2020, but it has been postponed until 2024 [11].

They are called smart meters since they have two-way communication instead of the old-style electricity meters they are replacing:

- **Automatic meter reads** – Smart meters send up-to-date information to the supplier automatically, so no more dark cupboards and spiderwebs;
- **Pay only for power consumption** – As consumption data is automatically transmitted, the provider will never charge the user for an estimate. The user pays for exactly what was consumed;
- **Smart data display** – The user gets an in-home display, a gadget that monitors the usage and costs, giving accurate readings in euros and kilowatt-hours.

C. *Home Energy Management System*

It is estimated that buildings in Europe are responsible for 40% of our energy consumption [12].
Unsurprisingly, home energy management systems are rapidly gaining popularity worldwide as their technology improves and small solar panels become more viable [13].

However, when defining and using these systems, there are conflicting descriptions and confusion among people.
Essentially, a home energy management system consists of hardware and software that allows the user to monitor energy consumption and generation and manually/automatically control energy use in a home.

The hardware consists of a "hub" device, which is responsible for mediating communications between the users and, in some cases, local utilities or power retailers. This communication will include usage patterns and consumption of home users.
The software moderates the incoming and outgoing data and communications.
From the user's perspective, the software is the interface that provides access to the system's monitoring data and control functions. The interface is usually accessed through an app or a web portal.

The main goal of HEMS' software is to increase energy efficiency while other systems are usually designed to control devices remotely or automatically for convenience or security reasons.
From the user's point of view, we can divide the HEMS software into two primary purposes, monitoring and control:

- Monitoring:
  - Device data – What devices are on/off and how much energy each is consuming. The user can see the current information in real-time or check the history;
  - Insights – The system can warn the user of specific problems or send tips to increase energy efficiency.

- Control:
  - Turn devices on/off remotely:
  - Set devices to operate on specific schedules;
  - Set up conditional rules for devices operation;
  - Manage the flow of energy coming from solar panels or other generators;

We can say that HEMS is responsible for managing four main aspects of home energy [14]:

1. **Electricity** – The core functionality of a versatile home energy management system begins with electricity in the home.
   A HEMS should allow the user to monitor what devices are doing and access them remotely to turn them on or off or change their operation (e.g., lower the thermostat temperature of an air conditioner).
   Since one of the main goals of HEMS is to save the user some money, the management of electricity consumption takes into account, among other things, the grid's electricity rates, whether the customer bills based on consumption, and whether solar energy or batteries are available on site.
   Critical considerations in power consumption management include electricity rates and whether solar power or batteries are available on site.
   A HEMS can also operate in an off-grid scenario. In this case, it is even more critical that the energy is used effectively and consistently available when needed.

2. **Solar Photovoltaic** – Solar PV (Photovoltaic System) systems are now widespread in many countries and allow households to generate some of their electricity locally.
   Depending on the situation and incentive structure, it may be a priority for the owner of a PV system to directly "self-consume" their solar electricity or export it to the grid as much as possible.
   A HEMS can show the user how much solar power they generate, consume, and feed to the grid [14]. With this information, the user can change its energy usage patterns at home to get the most out of its solar panel system.
   The presence of solar battery storage adds complexity to the equation, making a home energy management system an even more attractive option than a home without its micro-production system.

3. **Battery Storage** – Battery storage is the next step in residential energy. They are a step towards greater energy self-sufficiency and lower electricity bills' prices – not to mention the future of our electricity infrastructure itself. However, to maximise the value of battery storage, it is helpful to have an intelligent management system that can account for multiple variables, such as whether we have a time-limited flat-rate tariff or whether we have an incentive to sell the stored energy to the grid.

4. **Solar Thermal Panels** – It is a popular technology that uses the sun's power to heat water in a home. Solar hot water systems often operate largely independently of the rest of a home's electrical appliances. However, a good HEMS with the proper connectivity and monitoring capabilities can further enhance their value.

Users typically use only one or two of the above aspects, and this paper will focus on electricity and solar PV, the most common in HEMS.

III. Proposal

A. *Home Energy Management System*

The main goal of this paper is to propose an easy system that manages electricity through a home energy management system.

Most people have their routines, but there are always periods when they want to do something different and temporarily change their priorities and routines. For this reason, people will not necessarily welcome a fully automated system that decides everything for them when it comes to turning off devices or moving loads, even if they have set their preferences.

Therefore, some assumptions were made for the proposed solution:

1. Each load is connected to a smart plug so that HEMS can detect which device is connected;
2. Instead of a fully automated solution, the system should make suggestions to the user. The main objective is to understand what the impact is if the user follows the recommendations.

For example, suppose that a user tries to start an intensive washing machine programme. In this case, the system could pause the operation for 5 minutes, notify the user via mobile app, and recommend starting the programme later, depending on the number of appliances turned on.

The HEMS will focus on three main factors to achieve better energy management:

1. **Reduction of energy peaks** – Any peaks that residents have during the day should be reduced to avoid home outages and reduce the load on the grid.
2. **Load shifting**
   a. Off-peak – This time is usually cheaper, so the user can use it to reduce both the electricity bill and electricity consumption at peak times;
3. **Solar panel –** This can significantly reduce the energy drawn from the grid and potentially shift some loads from other peak times.

These three factors will be explored to understand their actual impact on energy peaks and electricity bills.

Since each house has a different number of consumers and routines, different scenarios will be explored in this paper to understand better who can benefit from any of the already mentioned strategies.

Table 2. Summary of the scenarios to be used in the simulation

Scenario ID	Family Type	Work Location	Season	Solar Panel
1	Single	Onsite	Summer	No
2	Couple	Onsite	Autumn	No
3	Couple with Children	Offsite	Spring	Yes

It is not explicitly stated in the table, but both weekdays and weekends are examined in the scenarios, as both are needed to obtain the estimated amount of the bill for a given month.

These scenarios are based on the three most common family types in Portugal [15] and for each of them a sample of a usage pattern will be considered.

Although all the logic is applicable in any country, the consumption patterns that are analysed may differ in other countries.

B. *Power Demand*

We can reduce peak hours in two main ways:

1. Shift loads that can be moved to another time (e.g., washing machine or dishwasher).
2. Switch off an appliance to immediately reduce the total electricity consumption.

Before a device is powered on, the system will analyse if that device compromises the house's power consumption, possibly causing an outage.

A system of this kind monitors the total power of all devices (n) using electricity in real-time:

$$Total\ Power\ (W) = \sum_{1}^{n} Device\ Power\ (W) \qquad (1)$$

Whenever a new device is switched on, HEMS will sum the new device's power with the current total power and further analyse if it will surpass the contracted power.

However, the system will consider 95% of the contracted power as the threshold amount to avoid further risks.

These devices are marked as shiftable in the device properties. Thus, if the user decides to turn on these devices, the system can advise the user to defer them later and rely on the user to decide whether to run them immediately.

This advice would be given in a HEMS app accessed via the web or mobile app in real-time.

The focus of the solution is to find a period for which that device should run, based on the tariff, and let the user confirm it.

Table 3. List of devices of pre-defined devices that will be used in the simulation

Device Type	Average Power (W)	Peak Power (W)	Special Pattern	Runtime
Air Conditioner (Living Room)	1050	1500	Yes	-
Air Conditioner (Bedroom)	620	900	Yes	-
Blender	350	500	No	-
Coffee Machine	1050	1050	No	-
Cooker Hood	170	300	No	-
Desktop (Computer)	220	550	No	-
Dishwasher	1400	2200	Yes	55 min
Hair Dryer	1600	2000	No	-
Hair Straightening Brush	100	100	No	-
Iron	1800	3000	No	-
Kitchen Robot	1000	1500	No	-
Laptop	80	120	No	-
Light Bulb	12	15	No	-
Microwave	1200	1500	No	-
Monitor	105	160	No	-
Oven	1600	3500	No	-
Phone (Fast Charging)	50	60	No	-
Phone (Regular Charging)	15	15	No	-
PlayStation 5	180	220	No	-
Refrigerator	100	200	No	-
Stove Burner	1000	1500	No	-
Toaster	950	950	No	-
Tumble dryer	800	800	No	45 min
TV	100	120	No	-
TV Box	11,3	11,5	No	-
Vacuum Cleaner	1300	1500	No	-
Washing Machine	450	2300	Yes	1 h 20 min
Water Heater	1020	4000	No	-
Wi-Fi Router	15	15	No	-

The table above includes the list of devices characteristics that have been considered in the simulation.

Some devices do not have a regular power consumption (e.g., washing machine), meaning they do not always consume the same power and are therefore marked with a special pattern. These devices have a specific runtime.

For the devices with no special pattern, it was assumed that the power consumption is always the same during the use of that device. The average power was assumed for such cases.

The devices with a special pattern have been characterised in the below figures.

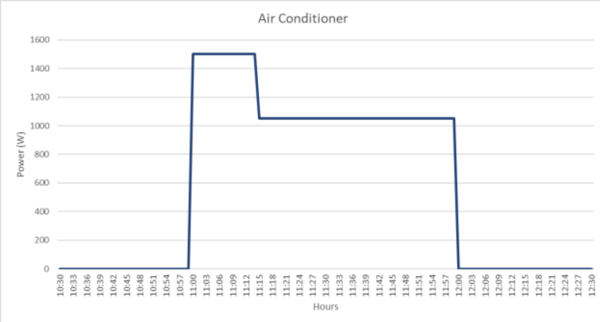

Fig. 9 Air Conditioner typical usage (with inverter technology)

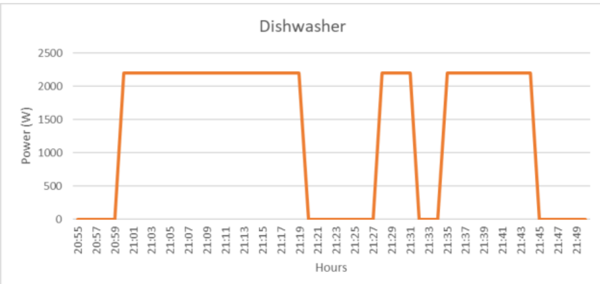

Fig. 10. Dishwasher typical usage pattern for a standard 65º C

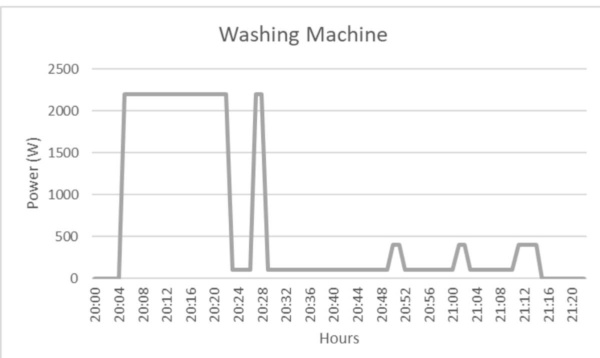

Fig. 11. Washing machine pattern for a standard mixed program at 40º C

C. Overall Solution Design

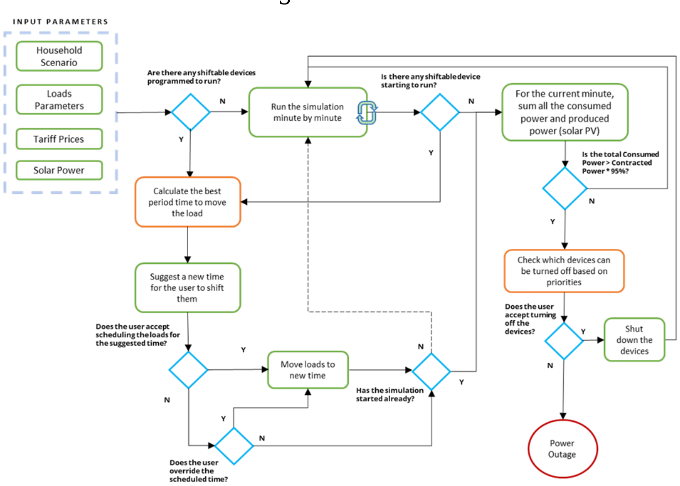

Fig. 12. Flowchart of the overall solution

The system verifies two main points:

- Whether a shiftable device is about to run in a peak period, and for such case it proposes a new period to reschedule the device;
- In case the contracted power may be not enough to handle all the devices, the system alerts the user that should turn off some devices.

The next flowchart describes the HEMS suggestion for which the user should move a shiftable device.

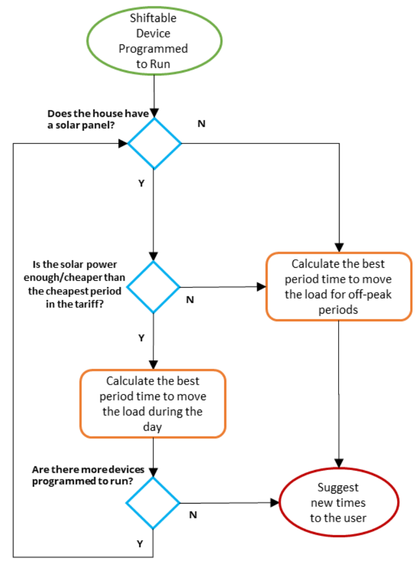

Fig. 13. *– Flowchart for new load shifting times ending with a time suggestion for users.*

In the below diagram, we the overall flow for the system to propose a new time for an off-peak period, based on some user preferences.

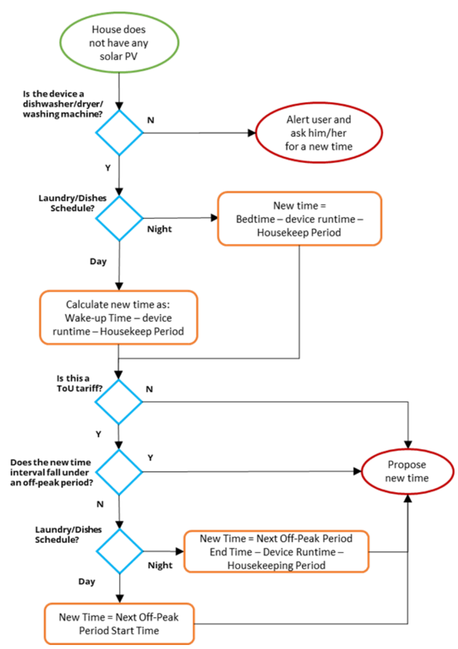

Fig. 14. Flowchart for calculating the time period for shifting a load to an off-peak period

IV. Results and Discussion

Each tested scenario includes the following daily consumption patterns:

- Saturday;
- Sunday;
- Two different weekdays patterns.

This gives a total number of four different samples to extrapolate the monthly electricity costs.

At the end, a table is presented with the monthly/annual amounts with the following values:

- Contracted Power;
- Tariff;
- Total amount of the bill.

A. *Scenario 1*

The first scenario is the characterisation of a single person working in an office with a single rate tariff and a contracted power of 6,9 kVA. That person wants to understand whether it is feasible to lower the contracted capacity at home or to use a ToU tariff.

It was assumed that the consumer washes the dishes in the dishwasher on Wednesday, Saturday and Sunday, while the washing machine is used twice a week (Wednesday and Sunday).

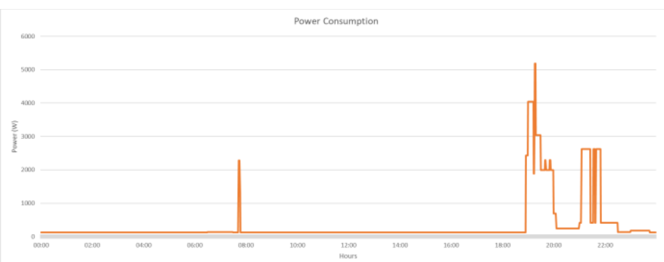

Fig. 15. Consumption power of scenario 1 for a weekday before HEMS

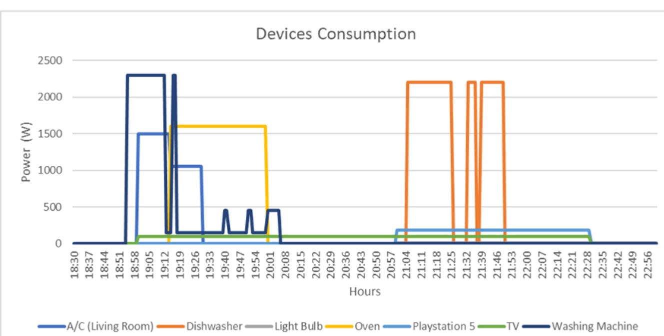

Fig. 16. Closer look to the evening period at scenario 1

If we take a closer look, we observe both washing machine and dishwasher can be moved to a later stage, leading to a peak reduction as seen below:

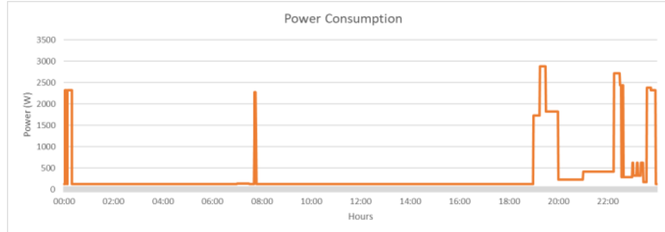

Fig. 17 – Scenario 1 – Power consumption for Wednesday after HEMS

This can lead to a decrease in the contracted power, since HEMS could automatically manage and shift high consumption appliances that can put at risk surpassing that contracted capacity.

Table 4. List of the electricity bill amounts after a simulation for scenario 1

Capacity (kVA)	Tariff	Variable	Fixed	Taxes	Total
6,90	Single	30,76 €	13,37 €	12,07 €	56,20 €
6,90	Bi-Hourly (Daily)	32,42 €	13,79 €	12,53 €	58,73 €
6,90	Bi-Hourly (Weekly)	30,37 €	13,79 €	12,05 €	56,21 €
3,45	Single	29,57 €	7,67 €	8,81 €	46,05 €
3,45	Bi-Hourly (Daily)	32,26 €	8,19 €	9,36 €	49,81 €
3,45	Bi-Hourly (Weekly)	30,23 €	8,19 €	8,89 €	47,30 €

After HEMS logic and considering the remaining patterns of the week, we can observe decreasing the contracted power can lead to a potential saving of 10,15€ in that specific month.

We can see that because the user does not regularly use the shiftable devices, so there would be no improvement in changing to a bi-hourly rate for a 3,45 kVA contract power.

B. *Scenario 2*

The second scenario is the characterisation of a married couple who work in an office and usually do their domestic activities at the weekend.
They currently have a single tariff but want to explore other possibilities.

This couple uses the dishwasher two times a week while having all the remaining housekeeping activities during the weekend, mainly on Sunday.
They also eat dinner away from home on Wednesdays and Fridays, so they do not spend much time at home during the week.

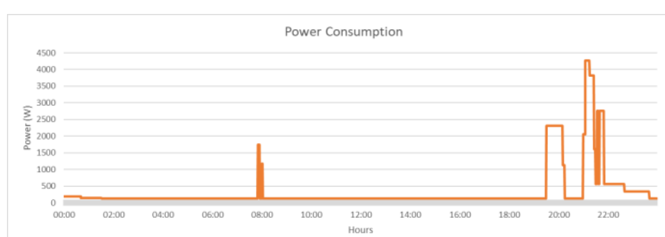

Fig. 18. Daily power consumption for weekdays at home before HEMS

On weekdays, HEMS suggests to only move the dishwasher, since no other shiftable device runs during the week.

Taking into consideration the runtime of the dishwasher programme, it is rescheduled from 06:00 a.m. until 06:54 a.m.

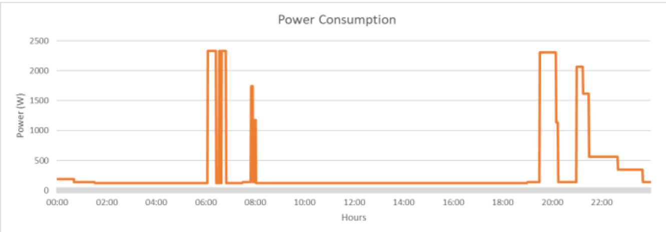

Fig. 19. Daily power consumption for weekdays at home after HEMS

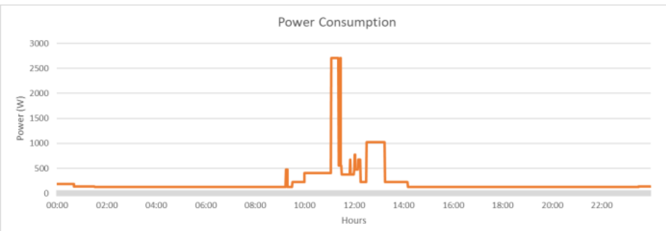

Fig. 20. Scenario 2 – Daily power consumption on Saturday before HEMS

For Saturday the couple is expected to have two devices that can be moved:

1. Washing machine between 11:00 a.m. and 12:19 p.m.
2. Tumble dryer between 12:30 a.m. and 01:14 p.m.

Before HEMS proposes any time to move these devices, we can see a challenge already due to necessity of taking out the clothes from the washing machine and put them on the dryer.

Once the couple will be absent of home almost whole day after lunch, once proposed a new time by HEMS, the consumers prefer to override the suggestion to better suit their needs.

The user is aware of the off-peak periods, so he/she is aware of a suitable period for which the appliance may be moved.

Considering the couple arrives around 11p.m., the washing machine was rescheduled for 10 p.m., time for which the off-peak starts in both daily and weekly cycles.

The tumble dryer is scheduled for midnight, to give time for the consumers to pick up the clothes and dry them.

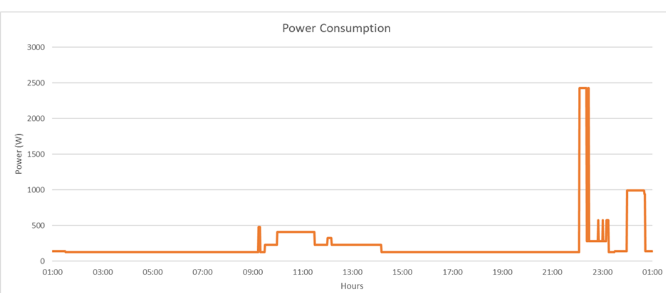

Fig. 21. Scenario 2 – Daily power consumption on Saturday after HEMS

The weekly cycle was favorable in this case, so a comparison between that bi-hourly rate and the standard one is found below.

Table 5. List of the electricity bill amounts after a simulation for scenario 2

Capacity (kVA)	Tariff	Variable	Fixed	Taxes	Total
6,90	Single	29,66 €	12,94 €	11,71 €	54,31 €
6,90	Bi-Hourly (Weekly)	28,27 €	13,34 €	11,46 €	53,08 €
4,60	Single	29,58 €	9,43 €	10,89 €	49,91€
4,60	Bi-Hourly (Weekly)	28,23 €	9,75 €	10,63 €	48,61 €
3,45	Single	28,51 €	7,42 €	8,56 €	44,50 €
3,45	Bi-Hourly (Weekly)	28,14 €	7,93 €	8,40 €	44,47 €

We can conclude that if the consumers want to decrease the contracted power as much as possible, there is not a significant difference between the two tariffs.
However, for an increased capacity, the bi-hourly (weekly) is a better option to choose from.

C. *Scenario 3*

The third scenario will be the characterisation of a couple with two children that have a single rate tariff, but want to understand if it is worth to change to the bi-hourly.
For this family, the following characteristics have been assumed:

- Lives in a detached house;
- Both parents work remotely from home;
- Scenario happens in May (Spring) for which the air conditioner starts to be more used;
- Six solar panels of 340 Wp each;

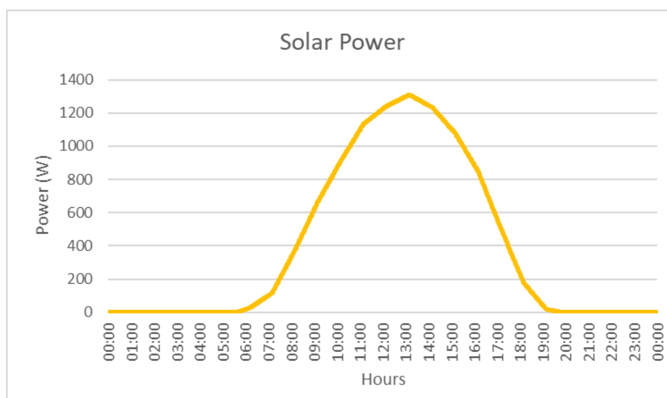

Fig. 22. Solar power that has been considered for a set of six solar panels, 340 Wp each. This output was defined according to the 2016 data in Lisbon, shared by the European Commission [16].

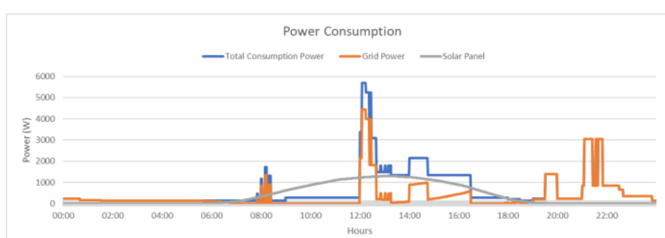

Fig. 23 – Scenario 3 – Daily power consumption on Tuesday/Thursday before any logic applied.

With a washing machine and tumble dryer running at lunch time, there is an increase of the grid demand which the solar panel cannot cover alone.

However, since the dishwasher has an irregular pattern of consumption, there are still some peaks that the solar panel simply cannot cover.

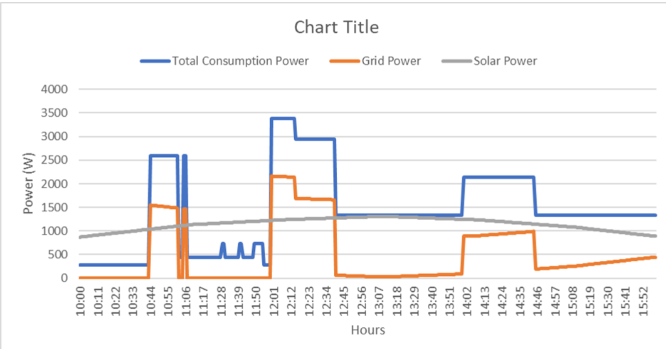

Fig. 24. Scenario 3 – Daily power consumption on Tuesday/Thursday after possibly shifting the washing machine.

In a bi-hourly rate tariff, before proposing a time to the user, the system compares running the washing machine at a peak time and using energy from the solar PV, with shifting it completely to an off-peak period:

1. Moving the load to 10:39 a.m.:
    a. 0,5037 kWh x 0,1836 €/kWh = 0,0925 €
2. Moving to an off-peak time (e.g., 05:00 a.m.):
    a. 0,9440 kWh x 0,0924 €/kWh = 0,0872 €

Considering the possibility of selling the energy surplus from the solar PV to a supplier, the second approach becomes even better. Therefore, the washing machine was moved to an off-peak time.

Leveraging the solar panels for load shifting depend on their total capacity installed and whether the peak consumption of a given device is higher than what the solar panel can produce.

D. *Comparison Results*

To conclude the results, a summary of the results before and after HEMS was applied to each scenario is presented below.

Table 6. Possible electricity bill savings in each scenario

Scenario ID	Initial Tariff & Contracted Power	Initial Costs	Final Tariff & Contracted Power	Final Costs	Monthly Savings (%)
Scenario 1	Single & 5,75 kVA	54,27 €	Single & 3,45 kVA	46,05 €	15,1 %
Scenario 2	Single & 4,60 kVA	49,91 €	Bi-Hourly (Weekly) & 3,45 kVA	44,47 €	10,9 %
Scenario 3	Single & 6,90 kVA	59,19 €	Single & 3,45 kVA	49,18 €	16,9%

To make a fair comparison, it has been assumed the contracted power immediately above the peak power of each scenario before HEMS was implemented as the initial contracted power.

More than leveraging the time of use tariff, HEMS allows the user saving costs by potentially reducing the contracted power.

The algorithm that verifies the risk of a power outage will be important to avoid people using two or three high consumption appliances at the same time. The user needs to decide if he/she is willing to lose the ability to switch on some devices of this kind at the same time.

The focused weekend pattern on scenario 2 provided an advantage to the weekly cycle over the other tariffs since the consumers in the house heavily focused their energy consumption on weekends.

V. Conclusions and Future Work

The results of all simulations show that HEMS has a potentially positive impact on reducing the monthly bill.

To take full advantage of HEMS, instead of changing the electricity contract to a bi-hourly tariff, the consumer should focus more on reducing contracted power.

The results show that, for a 3,45 kVA contracted power, the time of use tariffs lose their main advantage since the single rate tariff components become cheaper at this power capacity.

Given the tariffs offered by EDP in Portugal, their customers should generally not consider switching from a single rate tariff if they have a reduced contracted power.

When the available capacity power is 4,60 kVA or greater, the family needs to have a particular routine focused on the off-peak periods, for the bi-hourly tariff to be the right choice.

A daily cycle for a bi-hourly tariff was the least efficient for the tested scenarios since it should be focused on very specific users. It is probably the right choice for anyone who barely has any relevant energy consumption at home during the day.

The weekly cycle in a bi-hourly tariff should be more suited for secondary residences, only used on weekends, or for people who usually only spend the day at home on Sundays or during the specific off-peak periods on Saturdays.

As the power through day never reached a value near the standard contracted value (3,45), there was no need to ask the user to switch off some devices eventually. For example, with the washing machine, dishwasher, and tumble dryer running at off-peak times and not simultaneously with other devices, avoids having a possible power failure at home.

As observed in the second tested scenario, a system of this kind should not be fully automated. For some cases needs to ask the user's approval because there may be no ideal periods to shift a set of devices. Therefore, some compromises may be made.

Additionally, and even bringing the devices consumption history of the house owners into account, people do not stick to a unique routine every day, every year, leading to a more user-intervention focused system than an automated application.

As future work, since the consumption pattern of some devices was simplified, a more realistic pattern should be considered in future simulations.

When it comes to the algorithm that was used, HEMS should also account for dependencies between devices before proposing any time to move a shiftable load. Since only the dishwasher, washing machine and tumble dryer are classified as shiftable devices on this paper, other types of possible shiftable devices should be explored to try to leverage the bi-hourly tariffs, but always without compromising the wellbeing of the consumers.

The logic to avoid a power outage can also be more explored for residences with lower contracted power since in this paper, the peak instant power after using HEMS was usually lower than 3 kW.

Other countries' electricity tariffs should also be explored to understand the applicability of this algorithm in other markets.

VI. References

[1] Portugal Energia, "Setor Energético," [Online]. Available: https://www.portugalenergia.pt/setor-energetico/.

[2] ERSE - Entidade Reguladora dos Serviços Energéticoss, "Tariffs and prices - electricity," 2021. [Online]. Available: https://www.erse.pt/en/activities/market-regulation/tariffs-and-prices-electricity/.

[3] Endesa, "Qual é a diferença entre o mercado livre e o mercado regulado de energia?," 14 04 2021. [Online]. Available: https://www.endesa.pt/particulares/news-endesa/efici%C3%AAncia-energ%C3%A9tica/mercado-livre-vs-mercado-regulado.

[4] Entidade Reguladora dos Serviços Energéticos, "Compreender a Fatura," [Online]. Available: https://www.erse.pt/consumidores-de-energia/eletricidade/compreender-a-fatura/.

[5] EDP, "O que é a potência contratada e qual devo escolher?," [Online]. Available: https://www.edp.pt/particulares/apoio-cliente/perguntas-frequentes/pt/contratos/novo-contrato/o-que-e-a-potencia-contratada-e-qual-devo-escolher/faq-4676/.

[6] ERSE, "Caracterização da Procura de Energia Elétrica em 2021," 2020.

[7] ERSE, "Tarifas e preços - eletricidade," 2021. [Online]. Available: https://www.erse.pt/atividade/regulacao/tarifas-e-precos-eletricidade/.

[8] ERSE, "Períodos Horários na energia elétrica em Portugal," 2020.

[9] SmartGrid.gov, "The Smart Grid," [Online]. Available: https://www.smartgrid.gov/the_smart_grid/smart_grid.html.

[10] "Smart meters: a guide for households," 04 01 2018. [Online]. Available: https://www.gov.uk/guidance/smart-meters-how-they-work.

[11] ERSE, "Balanço da implementação das redes inteligentes de distribuição de energia elétrica em 31 de dezembro de 2020," 2021.

[12] European Commission, "In focus: Energy efficiency in buildings," 02 2020. [Online]. Available: https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_en.

[13] carbonTrack, "What is a home energy management system?," [Online]. Available: https://carbontrack.com.au/blog/what-is-a-home-energy-management-system/.

[14] carbonTrack, "Home Energy Management System," [Online]. Available: https://carbontrack.com.au/guides/energy-efficiency-guide/home-energy-management-systems/.

[15] Instituto Nacional de Estatística, "Agregados domésticos privados (Série 2011 - Nº) na população residente por Tipo de agregado," 10 02 2021. [Online]. Available: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0007861&contexto=bd&selTab=tab2&xlang=pt.

[16] European Commission, "JRC Photovoltaic Geographical Information System (PVGIS) - European Commission," [Online]. Available: https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP.

[17] Z. Guo and R. W. Hall, "Parallel thinning with two-subiteration algorithms,”," *Comm. ACM*, vol. 32, pp. 339-373, 1989.

[18] Portugal Energia, "Agentes," [Online]. Available: https://www.portugalenergia.pt/agentes/#.

[19] IotaComm, "What Is A Smart Building? (The Ultimate Guide)," 06 10 2020. [Online]. Available: https://www.iotacommunications.com/blog/smart-building/.