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Photovoltaic self-consumption and behaviour changes in electricity consumption

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Resumo

O autoconsumo permite, através da produção descentralizada de energia, satisfazer as necessidades de consumo do produtor, diminuindo a dependência da rede e reduzindo a fatura de eletricidade. O autoconsumo fotovoltaico (PV) no setor residencial permite às famílias consumir a energia produzida através dos seus painéis PV. Esta mudança de paradigma no sistema elétrico, colocando as famílias como produtores, é importante para aumentar a sua consciência energética. A perceção energética e ambiental dos prosumers (isto é, simultaneamente produtores e consumidores) é esperada que mude nesta transição para uma geração de eletricidade mais sustentável. Além disso, os padrões de consumo de eletricidade mudam e vão contribuir para o alisamento do diagrama de carga de eletricidade. Deste modo, é necessário entender quais são os principais fatores que estimulam esta mudança.

Com base na recolha de dados primários através de um inquérito feito aos prosumers portugueses, este trabalho tem como objetivo o estudo do comportamento ambiental e no consumo de eletricidade das habitações, utilizando as abordagens Ordered Logit Regression (OLR) e Generalized Ordered Logit Model (GOLM). Os resultados mostram que a consciencialização energética dos prosumers aumenta após o autoconsumo PV. Este efeito é mais notável quando a instalação é feita devido a preocupações ambientais. Este impacto também é positivo no load shifting, sendo que as motivações ambientais são cruciais para uma gestão eficiente da energia. Embora se verifique um aumento do consumo após a instalação, este é deslocado para acompanhar a produção de eletricidade, sendo que pode ser causado pelo crescente aumento da procura de eletricidade. Com isto, pode-se afirmar que o papel de prosumer torna as famílias consumidores mais informados sobre energia, fazendo uma gestão mais eficiente do consumo de eletricidade.

Palavras-chave

Autoconsumo fotovoltaico; Consumo de energia das habitações; Produção descentralizada; Load shifting; Comportamentos de poupança de energia

Resumo alargado

Nos últimos anos, Portugal apostou em várias políticas que incentivavam à descentralização da produção de energia elétrica através de fontes de energia renováveis. Contudo, apenas em 2015 foi possível produzir eletricidade para benefício próprio. Com esta mudança, as famílias passaram a consumir a eletricidade gerada através dos seus painéis fotovoltaicos, tendo um papel mais ativo no sistema elétrico. Deste modo, é necessário perceber os fatores mais importantes que influenciam os comportamentos dos prosumers no consumo de eletricidade, para perceber que tipos de políticas devem ser aplicadas.

Estudos recentes mostram que fatores políticos, ambientais, económicos e tecnológicos têm influência no consumo de energia no setor residencial. Após o autoconsumo fotovoltaico, várias famílias deslocaram parte do seu consumo para acompanhar a produção de eletricidade através dos painéis fotovoltaicos. Esta mudança inclui algumas tarefas domésticas que não afetam a rotina das famílias, como por exemplo a utilização de alguns eletrodomésticos. Como a geração de energia fotovoltaica é durante o dia, a maioria dos consumidores não se encontra em casa para transferir diretamente o consumo. Deste modo, com recurso à tecnologia é possível fazer esta transferência de procura de energia remotamente. Com um sistema de monitorização de energia é possível analisar em tempo real a geração e, em alguns casos, o consumo de eletricidade. Depois desta análise, é possível fazer a deslocação do consumo com auxílio de controlo remoto e temporizadores, para uma gestão de energia mais eficiente. Outra estratégia para aproveitar a produção fotovoltaica é utilizando baterias que acumulam a eletricidade gerada e esta é usada posteriormente, diminuindo assim os problemas da intermitência destes sistemas.

Não é só no consumo de eletricidade que os estudos verificam alterações. Também a nível comportamental as mudanças são evidentes, principalmente se esta instalação foi feita por motivos ambientais. Após se tornarem prosumers, estes admitem ter mais consciência energética, tendo adquirido comportamentos de poupança de eletricidade. Esta mudança deve-se principalmente à capacidade que estes sistemas têm em aumentar o interesse em energia, assim como os custos associados à eletricidade. A comunicação sobre este assunto também demonstra um impacto importante na transmissão destes valores pelos membros de toda a família.

Com base nestas investigações, foi realizado um inquérito aos prosumers portugueses de modo a que, recorrendo a modelos Logit ordenados, fossem estudados os fatores decisivos nas mudanças do comportamento ambiental e no consumo de energia. De acordo com a Direção-Geral de Energia e Geologia (DGEG), desde a entrada da legislação do autoconsumo até janeiro de 2019, Portugal tinha 733 instalações fotovoltaicas no setor residencial. Apesar de a população ser bastante pequena, ainda foi possível inquirir 145 prosumers, tendo uma representação da população total de 19,78%. Para estudar o comportamento ambiental e

poupança de energia das famílias, foi utilizado o Ordered Logit Regression (OLR) para perceber o efeito das variáveis usadas. Para analisar as alterações no consumo de eletricidade foi utilizado o Generalized Ordered Logit Model (GOLM). Apesar de nestes dois modelos ser possível verificar qual é o efeito que cada variável tem na variável dependente, foram calculadas as pseudo-elasticidades para medir a sensibilidade dos resultados.

Desta forma, ao analisar os resultados é possível verificar que são vários os motivos que levam as famílias a instalar um sistema para autoconsumo, sendo os mais destacados os incentivos financeiros e as preocupações ambientais. Apesar do autoconsumo fotovoltaico ser motivado pelo elevado rendimento do agregado familiar, este tem um impacto negativo nos comportamentos de poupança de energia. Contudo, as preocupações ambientais no momento da instalação são, sem dúvida, as que têm um papel mais significante, quer para aumentar os comportamentos de poupança de energia, como também para a deslocação do consumo para acompanhar a geração fotovoltaica. Ainda foi solicitado aos inquiridos que estes distribuíssem o seu consumo residencial durante um dia, antes e depois do autoconsumo fotovoltaico e foi possível analisar que os padrões de consumo se alteraram. Após a instalação fotovoltaica, existiu uma transferência de consumo de pico para onde existe produção fotovoltaica, contribuindo assim para o alisamento do diagrama de carga de eletricidade. Consequentemente, os prosumers ao deslocarem o consumo de energia para fora de pico vão aliviar a rede elétrica.

Abstract

Self-consumption enables, through the decentralised generation of energy, to meet the consumption needs of the producer, decreasing the dependence of the grid and reducing the electricity bill. The residential photovoltaic (PV) self-consumption allows households to consume all the energy produced through their solar panels. This paradigm has been changed in the electricity generation mix, putting the households as producers, it is important to increase their energy awareness. The environmental and energy perception of prosumers (i.e. simultaneously producers and consumers) is expected to change with the transition to a more sustainable electricity generation. Also, their electricity consumption patterns change and will contribute to smooth the electricity load diagram. Thus, it is necessary to understand which are the main factors that stimulate this shift.

Based on primary data collection through a survey to Portuguese prosumers, this work studies the changes in environmental behaviour and household's electricity consumption, using Ordered Logit Regression (OLR) and Generalized Ordered Logit Model (GOLM) approaches. The results show that energy awareness of prosumers increases after PV self-consumption. These systems have the capacity to boost interest in energy, influence the family for energy-saving and increase knowledge about consumption. This effect is more pronounced when the PV installation is driven by environmental concerns. This impact is also positive for load shifting, as these environmental motivations are crucial for efficient energy management. Despite the consumption increase after self-consumption, this is shifted to follow the electricity generation and can be caused by the growing global electricity demand. Overall, it may be said that the prosumer's role makes households more informed energy consumers, making a more efficient electricity consumption management.

Keywords

Photovoltaic self-consumption; Household's energy consumption; Decentralised generation, Load-shifting, Energy-saving behaviours

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Acronyms list

APREN	Associação Portuguesa de Energias Renováveis
CO2	Carbon Dioxide
DSM	Demand Side Management
DGEG	Direção-Geral de Energia e Geologia
EV	Electric Vehicle
EU	European Union
GOLM	Generalized Ordered Logit Model
GWh	Gigawatt Hour
IEA	International Energy Agency
IoT	Internet of Things
kW	Kilowatt
NUTS	Nomenclatura das Unidades Territoriais para Fins Estatísticos
OLR	Ordered Logit Regression
OCDE	Organization for Economic Co-operation and Development
PV	Photovoltaic
RAM	Região Autónoma da Madeira
RAA	Região Autónoma dos Açores
RES	Renewable Energy Sources

1. Introduction

In an economy more dependent on electricity, the importance of where the energy is obtained is increasingly debated. Since energy production through non-renewable sources is one of the main reasons for climate change, it is required to generate electricity through renewable energy sources (RES). According to Eurostat, Portugal is the third European Union (EU) country that uses more renewable energy[1]. Hydric and wind are the most developed sources and have a great share of energy generated. On the other hand, photovoltaic (PV) is the least explored, even though Portugal has a large solar exposure. Therefore, in the last years, the government has encouraged the investment of this source, promoting decentralised production.

Decentralised production is essential when looking for an efficient grid. Producing the energy as close as possible to the place where it will be consumed, eliminates the losses and infrastructure costs associated with the energy transmission (Araújo & Castanheira, 2015). PV self-consumption allows households to consume the energy produced in their own solar panels. This method relieves the grid in electricity transportation, and with demand increasing, it saves grid reinforcements costs, avoiding human and ecological impacts. Solar PV self-consumption brings advantages not only to the grid but also to the households.

The households with PV systems increase the energy efficiency of their homes and at the same time reduce the electricity bill. In self-consumption, the prosumers[2] have greater control and transparency of energy generated and consumed. With the help of technological tools such as timers, remote control and monitoring systems, households have better control in energy consumption. A monitoring system is essential when a PV system is installed. This technology allows to control the production of PV installation and compare, analyse and visualize data from the PV solar power system (Wittenberg & Matthies, 2018). This real-time information allows prosumers to manage their domestic activities, making better use of what is consumed.

The prosumer's role is rising partly due to the diversification and cost reduction of decentralised production technologies. These systems transform indifferent consumers into sustainable consumers, who consume what they produce (Gomes & Franco, 2018). This transition from a conventional power system to decentralised production changes the energy perception of prosumers (Hondo & Baba, 2010; J. Palm, Eidenskog, & Luthander, 2018; Wittenberg & Matthies, 2016). Although several authors have focused their studies on the

[1] Share of electricity from renewable sources in 2016 (% based on gross electricity consumption)

[2] Prosumer: It is a combination of the word's "producer" and "consumer". This refers to the users who produces and consume their own electricity (Lettner et al., 2018)

environmental behaviour of the households after the installation of PV, few have analysed how these factors influence this change.

Energy policies of EU countries are focused on self-consumption models, as electricity generated by RES has reached grid parity. This means that the marginal cost of a unit of electricity produced from these sources is equivalent to the marginal cost of an energy unit from the grid (Gomes & Franco, 2018). Portugal followed the same model, implementing the self-consumption by Decree-Law 153/2014, which entered into force in January 2015. (Ministério do Ambiente Ordenamento do Território e Energia, 2014).

This energy transition from conventional energy production to RES energy production brings important changes in human behaviour (Wittenberg & Matthies, 2016). The characteristics of PV systems can influence the energy consumption and environmental behaviour of households. Based on these conclusions, this work investigates the relation of solar PV self-consumption, behaviour changes in electricity consumption and which factors influence this change in households.

Hence, by collecting primary data, and resorting ordered logit models, this paper contributes with energy policies in residential solar PV self-consumption through the analysis of the prosumers profiles, the main PV installation drivers, the analysis of the energy and environmental behaviour. Regarding the household's electricity consumption, it is analysed the distribution of daily consumption before and after installation and the relationship between load shift, active monitoring and home automation. The decentralisation of the electricity generation brings some challenges and this dissertation could be a relevant contribution to the literature by adding empirical evidence, supported on econometric techniques, about the decision of investing on the PV self-produced electricity, allowing to design proper energy policies in order to enhance the energy efficiency.

This study is organized as follows. Section 2 presents the literature review which analyses the main existing investigations on this subject. Section 3 describes the development of decentralised PV solar energy in the Portuguese electricity market. Section 4 presents the data and methodology used in this work. The results of this investigation are presented in Section 5 and discussed in Section 6. Section 7 presents the main conclusions of the study and proposals for future research.

2. Literature Review

The concern to reduce the use of fossil fuels in electricity generation is increasing, which leads to higher use of RES. The residential PV self-consumption helps to produce a significant quantity of the electricity that is used by the households, making families more conscious about the energy they spend. Keirstead (2007) found evidence of a ‘double-dividend’ from solar PV, that is, the importance of this system comes not only from the electricity generated by RES but also from the ability to influence the household’s behaviours.

2.1. Energy-savings behaviours

According to the literature, there are several factors influencing the energy use of prosumers such as technological, economic, policy and environmental. Wittenberg and Matthies (2016) proved that energy-saving behaviours were correlated with sufficiency attitudes and environmental motivation in households with PV systems. The transmission of these values among households about energy and environmental concerns is crucial. Hondo and Baba (2010) stated that family communication about PV self-consumption increases the propensity to have more energy awareness. Such motivations seemed to be decisive for efficient electricity consumption (Wittenberg & Matthies, 2018).

In Hondo and Baba (2010) the survey respondents stated that they changed some energy behaviours after becoming prosumers. According to this investigation, 30% said that they turn off the lights more often and do not leave the devices in standby. Regarding the heating system, approximately 10-20% of the prosumers used it more consciously. The main reason for this behaviour change was increased energy interest and electricity costs. Therefore, after the installation of residential PV systems, the households who are aware of their systems tend to increase environmental behaviour in their daily lives.

2.2. Load Shifting

What prosumers do in their daily lives is an important starting point for understanding energy consumption. An obstacle found in domestic self-consumption is that solar peak production does not match with the peak consumption (Gomes & Franco, 2018). For self-consumption to be successful, it is necessary to change some consumption patterns and that do not interfere in the household routine. One method is to use higher consumption appliances during the day when there is more energy production, and this shift does not interfere in the family’s routine.

This household flexibility is designated by load shifting which consists of changing the electricity consumption to the moment when electricity is produced (Wittenberg & Matthies, 2016). This term is related to the concept of Demand Side Management (DSM), which according to the International Energy Agency (IEA), consist of initiatives and technologies that promote optimization of energy consumption. As can be seen in Figure 1, with the load shifting method it is possible to displace the demand out of peak. In PV self-consumption, the most favourable hypothesis is to change consumption when there is solar production. When the investment of PV system is driven by environmental concerns, the tendency to change consumption to where there are more PV generation increases (Gautier, Hoet, Jacqmin, & Driessche, 2019).

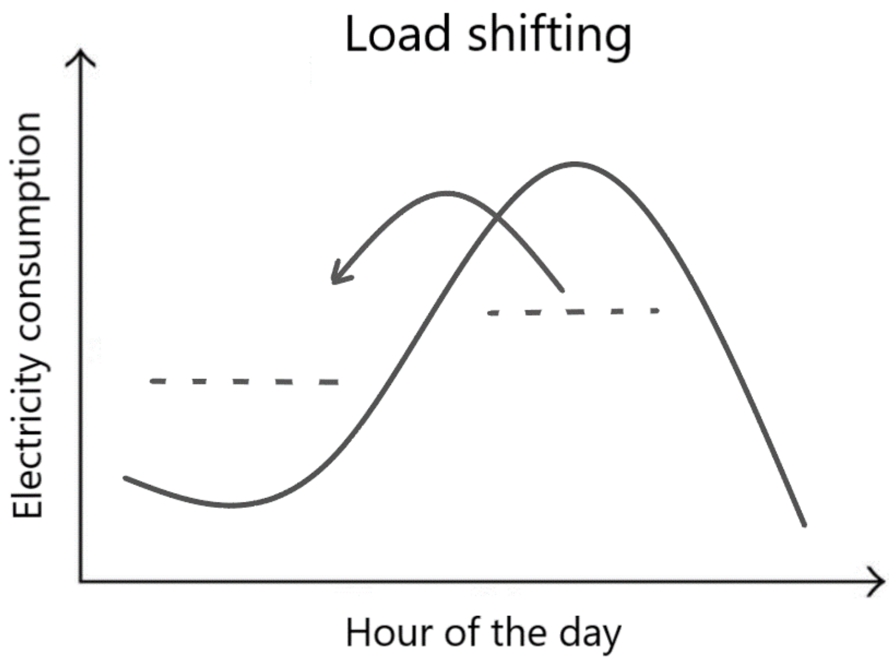

Figure 1. DSM: Load Shifting   Source: Adapted from Kailas, Cecchi and Mukherjee (2012)

Some domestic activities can be rescheduled to take advantage of this energy production, such as the use of the washing machine. Most of the prosumers shifted the utilization of their washing machine from hours with peak demand to hours when the PV production is high (Kobus, Klaassen, Mugge & Schoormans, 2015). In the other hand, cooking activities are not flexible, not even using the computer or the television. The social organization of activities was an obstacle to more flexible electricity consumption (J. Palm et al., 2018).

2.3. IoT

Technology is a great support for prosumers to take advantage of their PV production. The Internet of Things (IoT)[3] in houses can be used essentially to manage the energy consumption of electronic appliances (Park, Kim & Jeong, 2018). Even if prosumers cannot be at home in hours of higher electricity production, the technology allows to schedule the appliances to harness the energy produced. Remote control is a great strategy since it can control remotely the lighting, air conditioner, shutters and household appliances. Also, to maximize the energy produced from their PV system during the day, the prosumers started to use timers on appliances (Wolsink et al., 2017).

To find out when to program these devices, monitoring systems are good supporters in energy management. Even, it is important analyse not only the production but also the consumption. Studies have shown that should be paid attention to monitoring and the design of devices to encourage energy-saving behaviours, support energy efficiency and awareness of households (Keirstead, 2007; J. Palm et al., 2018; Wittenberg & Matthies, 2018). These control applications are essential for families who cannot be at home in a period of higher electricity production.

2.4. Electricity consumption

However, the prosumers are little motivated to change their activities to another time, mainly because the incentives were too small. This switch is complicated and they do not save enough money to compensate for this change in daily routine (J. Palm et al., 2018). The only changes that the prosumers did are small adaptations in their daily lives, as described above. A study carried out in Germany showed that prosumers do not have low electricity consumption but higher environmental motivations than other households.

In fact, households with PV systems tend to have medium to high electricity consumption mostly because they usually have electric mobility (e.g., electric bike, electric car) (Wittenberg & Matthies, 2016). However, this consumption could increase after the installation of PV panels. J. Palm et al. (2018) revealed that prosumers who had an increase in electricity consumption bought electric vehicles. In this manner, the behaviour and energy consumption pattern changed, starting to use more electricity than before the PV self-consumption, a phenomenon called 'rebound effect'[4] (Veen, 2014).

[3] Internet of Things (IoT) is a concept that refers to the digital interconnection of everyday objects with the internet. The IoT creates large opportunities in the energy sector: reduce energy demand, manage patterns in demand and supply, and drive innovation (Government Office for Science, 2014; Park et al., 2018)

[4] Rebound Effect: in certain contexts, people tend to increase energy consumption when electricity prices fall (Greening, Greene, & Difiglio, 2000)

2.5. Peak shaving and energy storage

Usually, in the residential sector peak loads are the same in the overall grid, so in that period the electricity price is generally higher. In these cases, peak shaving[5] can provide a reduction in energy cost (Karmiris & Tengnér, 2013). This is another method that, as load shifting, integrates DSM. This reduction in power grid consumption can be achieved with energy storage, which consists in charging the battery when there is PV production excess and discharging when the opposite occurs, as can be observed in Figure 2. With the development of this technology, new solutions are being developed allowing batteries to have higher loading/unloading cycles and more accessible prices. This method may be advantageous since it stores PV energy and uses it when the grid price is expensive (Luthander, Widén, Munkhammar & Lingfors, 2016).

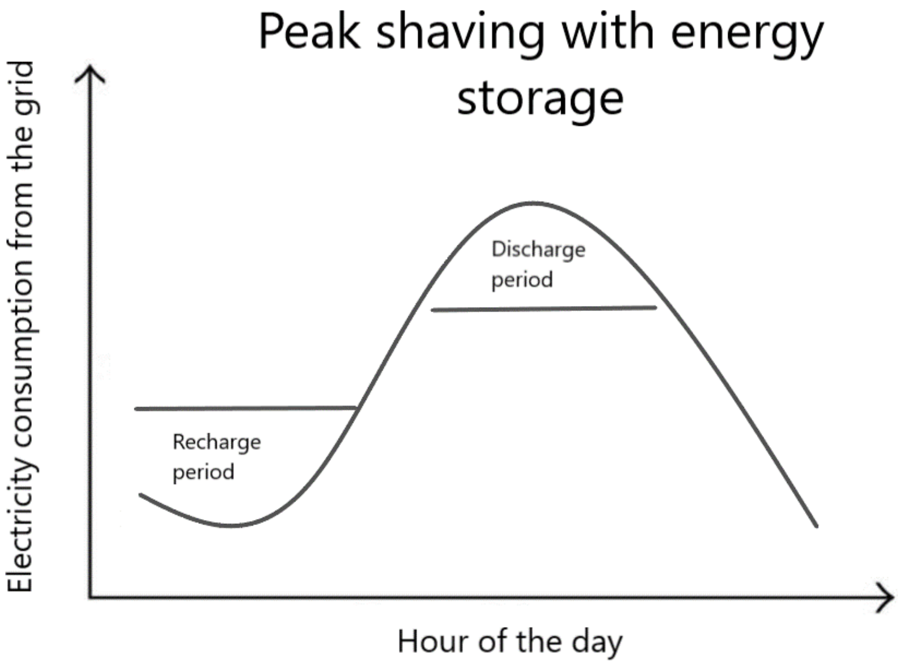

Figure 2. DSM: Peak shaving with energy storage Source: Adapted from Karmiris and Tengnér (2013)

These systems make a more efficient consumption of energy produced, reducing the need for electricity from the grid, decreasing congestion problems. In addition, Gomes and Franco (2018) give some examples of other mechanisms, such as hot water heaters that convert excess electricity into heat to be used later, or even the electric vehicle (EV) batteries. Klingler (2018) found that prosumers with an EV usually benefit more with a battery in their systems considering that charging occurs mostly at evening hours, where there is no sun. The use of batteries is the greatest solution to fix the intermittency problem of RES.

[5] Peak shaving: method to reduce feed-in power to the grid (Luthander et al., 2016)

2.6. Renewable Energy Communities

Currently, batteries are still expensive and durability is short (Camilo, Castro, Almeida & Pires, 2017), so one way to lower these fixed costs is to join in a Renewable Energy Community. This consists in the implementation of RES projects by a group of people residing in a same geographic area, who share PV panels and/or batteries, decreasing costs and staying with the same benefits (Cachinho, Seixas, & Lopes, 2017). These projects allow residents to invest in the generation of energy through RES to provide electricity to the entire community.

Since the middle of the nineteenth-century community energy initiatives have been developed (REN21, 2016). In that period, these projects were using non-renewable sources and were used for industrial activities. The community's initiatives more related to modern renewable energies appear in Denmark with the Danish Wind Turbine Owners Association in 1978 (REN21, 2016). Currently, the generated electricity is used mostly to provide energy to households.

There are successful cases in Belgium, more precisely in Flanders, which since 1991 the electricity supplied for households is from wind energy. According to Bauwens and Devine-Wright (2018), the members of two of those communities have more positive attitudes towards energy than non-members.

2.7. Peer Effects

There is evidence that local factors play an important role in PV diffusion, not only in the creation of these Energy Communities but also in the installation of individual solar PV systems. A. Palm (2017) found that prosumers have been influenced by noticing PV systems in their neighbourhood as well as by direct communication with local peers. Sharing their solar PV experience with friends, neighbours and family members has become the most effective way to promote the installation of these systems. When there is a positive experience, people are interested in PV self-consumption and they also want in their home. Peer effects[6] have been observed in some recent studies, which means people are becoming more predisposed to adopt a PV system as a result of adoptions in their proximity (A. Palm, 2016).

[6] Peer effect: Peer effects are the influence of a person's peers – such as neighbours, co-workers or friends – on their behaviour (A. Palm, 2017)

3. Development of decentralised solar PV energy in the Portuguese electricity market

Climate change is one of the biggest problems that humanity faces in the twenty-first century. These changes are caused mostly because of the Carbon Dioxide (CO2) emitted in energy generation through fossil fuels. In this regard, governments have struggled to decarbonize the economies. The Kyoto protocol was the first international legal treaty that proposes to limit the greenhouse gas emissions of developed countries. In order to meet these terms, the countries have begun to invest in RES to produce electricity.

Portugal was one of the most active countries in this energy transition. According to APREN, since 2005 the installed RES has grown at an average annual rate of 7%. In the first quarter of 2019, about 58.5% (6 954 GWh) of the electricity produced comes from RES (APREN, 2019). Although most of the electricity is produced through RES, it is necessary to increase the installed capacity, mainly in the solar sector. In a country with large hours of sun exposure, there is only about 5% of solar PV installed capacity (Direção-Geral de Energia e Geologia, 2019).

However, in the last years, the Portuguese government has been implementing policies that encourage investment in solar energy. With the Decree-Law 363/2007 (revised by the Decree-Law 118-A/2010 and Decree-Law 25/2013), the legal regime applicable to the production of electricity by microgeneration units has been established. This system consisted of generating electricity (with solar PV panels or micro-wind turbines) and sell it to the grid, through low voltage and small power installations. The connection power was limited to 50% of the contracted power with a maximum of 5,75 kW. Later the mini-generation was introduced by the Decree-Law 34/2011 which allowed the generation of electricity in installed power between 5,75 kW and 250 kW.

With the implementation of the Decree-Law 153/2014, the self-consumption was implemented in 2015, encouraging companies and individuals to consume the energy generated in their renewable systems. These production systems with low carbon technologies are more efficient, as they are located close to consumption. With these technologies, the traditional power system needs to adapt, with greater participation on the demand side, forcing the development of the power grid, especially in the distribution (Esteves et al., 2016). This requires that the traditional twenty-first-century power grid, in which existed the classic paradigm “production follows the demand” evolves into a grid of the future, denominated

Smart Grid[7]. In this new paradigm, demand contributes to the production of electricity for a more well-adjusted system.

Over the years were detected barriers to the residential systems PV systems installation in Portugal. According to PV Financing[8], a severe barrier is in PV systems construction, especially in technical guidelines. Technical guidelines are not appropriate for PV installations since these are very expensive and the labour costs increase significantly. For example, this law allows selling the excess energy to the grid and this requires the same license as a regular producer of electricity (Lettner et al., 2018). The connection to the grid is also pointed as one of the main barriers, being difficult to contact a technician in charge. Portuguese policymakers should pay attention to these obstacles because they are potential reasons for the producer giving up on the PV project.

More decentralised production, and therefore closer, promote greater energy independence and efficiency, as well less susceptibility to external fluctuations of electricity prices. In the last decades, there has been an increase in electricity consumption and with the development of IoT, artificial intelligence and smart cities the demand for energy will rise even more. This peak demand puts stress on the grid that will impact citizens, cities and utility infrastructures. A solution for this problem in the residential sector is a decentralised system capable of satisfying the new household's consumption patterns and so relieve the grid. In this energy transition, production, efficiency and monitoring technologies play a key role in transforming habits and behaviours for better energy management.

[7] According to IEA a smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users.

[8] PV Financing was an EU project supported under Horizon 2020. The project assessed what political framework for the application of new financing models was required and which barriers slow the PV expansion.

4. Data and Methodology

This section is divided into six subsections. The first one explains the survey groups and questions, as the collection process and is determined the sample representativeness. The second subsection describes the methods used and the third describes the test used to investigate the parallel regression assumption. The model's description is made in point four while in the fifth subsection explains how elasticities are calculated. In the last subsection, the research hypotheses are defined.

4.1. Survey design and sample description

This study is based on primary data collection through a survey, that has been distributed to Portuguese households with solar PV systems for self-consumption. The survey was designed based on the literature review mentioned, it was divided into four groups and can be seen in the appendix. The first group was focused on the socio-economic data of the households (e.g. age, gender, education level, profession, monthly income). These variables are also selected as the control variables. Michelsen and Madlener (2012) concluded that socio-economic were the main determinants of the household decision process. Ameli and Brandt (2015) also demonstrated the significance of income and household's energy use in decision making for energy technology investments.

The second group intends to know if they are in a Renewable Energy Community, that is, use shared PV panels and/or batteries. In the same group is still asked how long they have been inserted in that community and what were the reasons to join it. In the third group was asked information regarding the investment of PV panels (e.g. total investment, individual panel power, monitoring system). In the last group, the questions were based on the behavioural and consumption changes of families (e.g. what were the most flexible activities, changes in consciousness in relation to energy, allocation of daily electricity consumption throughout the day, the hours when most of the households were at home).

The survey was made mostly online through social networks and email, what could be an obstacle in this study. Still, according to the World Bank in 2017, 73.79% of the Portuguese population has internet access, a trend that is increasing over the years. In the data collection process, the technique used was non-probability sampling, which means that the process does not give all the persons in the population equal chances of being selected. More precisely, the technique used was convenience sampling, where the subjects are selected because of their availability and proximity. This method is used in situations like this, where it is intended to get results in a shorter time interval and without investing too much money. A pre-test was conducted to 22 prosumers to assess the clarity of the survey, helping to identify problems that could lead to biased responses and suitability to the participants.

According to DGEG[9] until January 2019, about 733 households have a PV system for self-consumption in Portugal. As can be seen, this population is small demonstrating that this technology is not being adopted by Portuguese families. This is a barrier found during the investigation, which lead to a low number of participants in the survey. When the sample size is small, the intention of the study is to report the existence of an effect (Anderson & Vingrys, 2001). In the data collection process, there were 43 dropouts, 55 non-responses[10] and 145 prosumers who answered to the whole survey. This study obtained a response rate of 59,67%. With a population of 733 individuals and 145 respondents, the margin of error is 7,29%, with a confidence level of 95%.

The following table shows the number of respondents of the survey compared with the total number of PV installations by NUTS II[11]. Comparing with the total population, this study has a sample of 145 prosumers, with the representativeness of 19,78%. It can be analysed that the regions with the least representative sample are Algarve and Alentejo.

Table 1. Representativeness of sample

NUTS II	Installations	Respondents	%
Alentejo	83	9	10,84
Algarve	172	6	3,49
Centro	128	56	43,75
Lisboa	109	29	26,61
Norte	232	42	18,10
RAA	6	1	16,67
RAM	3	2	66,67
Total	733	145	19,78

4.2. Methodology

For the purpose of the present analysis, this work uses the Ordered Logit Regression (OLR) and the Generalized Ordered Logit Model (GOLM) methods to investigate the main changes in energy consumption and behaviour when there is self-consumption. These approaches were chosen because it has been shown to fit well in studies in which dependent

[9] DGEG (General Direction of Energy and Geology) is the Portuguese public administration agency which has the mission to contribute to the design, promotion and evaluation of policies relating to energy and geological resources.

[10] OECD defines a non-response has a form of non-observation. Non-response means failure to obtain a measurement on one or more study variables or the respondent refuses to answer.

[11] According to PORDATA, NUTS is a hierarchical system for dividing the territory into regions.

variable has more than two categories and the values of each category have a meaningful sequential order.

According to Borooah (2002) and Menard (2002), in both models, the dependent variable is an observed ordinal variable, Y, which is a function of Y*, an unmeasured latent variable whose values determine what the observed ordinal variable Y equals. Y* has various threshold points, k. The latent dependent variable Y* is equal to:

$$Y_i^* = \sum_{k=1}^{K} \beta_k X_{ki} + \varepsilon_i \quad (1)$$

where ß is the parameter to be estimated and ε_i denotes the residual error which is logistically distributed. In the above equation, *X* is a vector of *k* values for the *i* observation (Williams, 2010). In terms of probability, the OLR can be written as:

$$P(Y_i > j) = g_j(.) = \frac{\exp(\alpha_j + X_i\beta)}{1 + [\exp(\alpha_j + X_i\beta)]}, j = 1, 2, \ldots, M - 1 \quad (2)$$

where M is the number of categories of the ordinal dependent variable and X_i is the vector of the independent variables associated with the individual *i* (Polimeni & Mihnea, 2018; Williams, 2006). The probability that *Y* takes on a particular value is equal to:

$$P(Y_i = 1) = 1 - g_1(.) \quad (2.1)$$

$$P(Y_i = 2) = g_1(.) - g_2(.) \quad (2.2)$$

$$P(Y_i = 3) = g_2(.) \quad (2.3)$$

4.3. The parallel lines assumption

In these models it is required to test the parallel regression assumption, using the *oparallel* test. It performs five tests: a likelihood ratio test, a score test, a Wald test, a Wolfe-Gould test and a Brant test. These tests compare an OLR with the GOLM, which relaxes the parallel regression assumption on all explanatory variables. If this assumption is violated, which is quite usual, estimating an OLR will lead to inconsistent results (Andor, Schmidt, & Sommer, 2018; Long & Freese, 2014). When this occurs, it is recommended to employ the GOLM. This method can fit models that are less restrictive than the parallel-lines models fitted by OLR (Williams, 2006).

The parallel lines assumption was investigated in both models. In Model 1, all tests presented non-significant values indicating that the assumption was not violated. In this way, the OLR approach can be performed. Conversely, in Model 2 this assumption was violated, having to be necessary to apply the GOLM method. The description of both regressions is presented in the following subsection.

4.4. Models description

In order to study if the consciousness in relation to energy increases after the installation, an OLR was estimated (Model 1). To study this topic, the following question was asked: “After installation of the PV system, what were the changes in energy consumption behaviour[12]?”, with response options ranging from (1) “Less often” to (10) “More often” for each behaviour. As there were few observations in some levels, they were grouped into 3 categories (1 to 4 it is the category 1, 5 and 6 belong to the category 2 and category 3 is from 7 to 10). The OLR will examine the effect of each factor in the dependent variable and if its impact is positive or negative. It allows understanding which variables influence the energy consumption behaviour of the households.

In order to study the flexibility of domestic activities of the households when there is more PV production, a GOLM regression was estimated (Model 2). For the variable dependent, in the survey, the following question was asked: “What is the possibility of changing the following activities[13] to a time where there is more PV production?”, with response options ranging from (1) “Unlikely” to (10) “Likely”. The method to group the levels into in 3 categories was also applied (1 to 4 it is the category 1, 5 and 6 belong to the category 2 and category 3 is from 7 to 10). The GOLM approach allows a variable to gain or lose statistical significance or change signs as it moves through the different levels of the dependent variable, unlike the OLR, which assumes the influence is constant across these levels.

4.5. Average Direct Pseudo-elasticity of variables

Although regressions coefficients indicate the effect that the independent variables have on the dependent variable, it is necessary to measure the sensitivity of the results, using direct pseudo-elasticities. However, the standard elasticity calculation is not considered as a valid measure for dummy variables (Çelik, 2015). For this type of variables, a pseudo-elasticity measure is given by

[12] Energy behaviours: 1= “Turn off the lights even when it comes out for a short period”; 2= “Unplug or switch off the appliances”; 3= “Buy household appliances and see their energy efficiency”; 4= “Decrease the number of times it opens the refrigerator door”; 5= “Use of air conditioning/heating systems more consciously”

[13] Flexible activities: 1= “Washing machine”; 2= “Dishwasher”; 3= “Dryer machine”; 4= “Ironing”; 5= “Vacuum”; 6= “Charging the phone and/or the computer”; 7= “Heating system”

$$E_{x_{ki}}^{P(i)} = \frac{\exp[\Delta(\beta_i x_i)] \sum_{\forall I} \exp(\beta_{kI} x_{kI})}{\exp[\Delta(\beta_i x_i)] \sum_{\forall I} \exp(\beta_{kI} x_{kI}) + \sum_{\forall I \neq I_n} \exp(\beta_{kI} x_{kI})} - 1 \quad (3)$$

Where I_n denotes the set of alternate outcomes with x_k in the function determining the outcome, and I denotes the set of all possible outcomes. These elasticities are called direct elasticities, which capture the effect that a change in a variable determining the likelihood of alternative outcome *i* has on the probability of that outcome will be selected (Çelik, 2015).

4.6. Hypothesis

H1: Domestic activities become more flexible in self-consumption and with technology support

In the domestic sector, the electricity peak consumption concentrates in the evening, which is when most people return home after work. It is in this period that most domestic activities are done. In self-consumption, as the PV production does not coincide with the consumption pattern, some domestic activities can be displaced for periods where there is solar production. This change is supported by technological devices that allow rescheduling domestic activities, for example, timers and remote control.

H2: Households are becoming more skilled energy consumers through their prosumer's role

Recent studies show that households who have installed RES for self-consumption make them more conscious about energy spend. The introduction of energy technologies increases the interest of prosumers about the electricity produced and consumed, making more efficient energy management.

H3: A monitoring system allows a more efficient energy consumption

With a monitoring system, the energy management is more efficient considering the prosumer knows in real time the electricity produced and consumed. It is expected that with this information the electricity is not wasted. Monitoring helps to know which appliances could start using when there is more PV production instead of grid power, increasing self-consumption ratio.

H4: Prosumers didn't report lower electricity consumption but high energy awareness

Wittenberg and Matthies (2016) show that prosumers have a higher energy consumption than the average, mainly due to smart appliances. The energy transition based on global energy usage especially in the automobile sector is another reason for this high consumption. This decarbonization of the economy leads to the use of RES to compensate this energy consumption.

5. Results

This section is divided into three subsections. The first shows the descriptive statistics of the variables obtained from the survey. In the second subsection, the econometric results are presented, as well as the multicollinearity test and the elasticities. The last shows the impact of PV generation on peak load shifting.

5.1. Descriptive statistics

5.1.1. Socio-economic characteristics of households

Table 2 shows the descriptive statistics of the socio-economic variables used in this study. As can be seen, most of the surveys were answered by males, with an average age of 45 years old and the household's average monthly income was between 2000€ and 2500€. Numerous studies have shown that households who made investments to improve the energy efficiency of their homes also have higher incomes than the average population (J. Palm et al., 2018; Trotta, 2018; Wittenberg & Matthies, 2016). It is also indicated that this high income is associated with a high education level of households.

Table 2. Summary statistics of socio-economic characteristics of households

Variables	Type	Description	Obs	Mean	Std. Dev.	Min	Max
Age	Continuous	Age of respondent	145	45.32	11.66	25	85
Gender	Dummy	Gender of respondent (1=female, 0=male)	145	0.08	0.27	0	1
Income	Categorical	The average monthly income of household: (1=500-1000€; 2=1000-1500€; 3=1500-2000€; 4=2000-2500€; 5= >2500€)	145	3.55	1.31	0	1
Children	Dummy	The household have at least one child until 12 years (1= yes, 0= no)	145	0.49	0.5	0	1
H_number	Continuous	Household size	145	3.16	1.4	1	9
H_owner	Dummy	The respondent is the homeowner (1= yes, 0= no)	145	0.87	0.34	0	1
Edu	Dummy	The respondent has a college degree (1=college degree; 0=otherwise)	145	0.62	0.49	0	1

Profession	Dummy	The respondent works has specialists in intellectual and scientific activities (1= yes, 0= no)	145	0.42	0.5	0	1

The education level is the most commonly examined socio-economic determinant, and according to the results presented above, 62% of the respondents have a college degree. Instead, according to the last Census in 2011, the average academic degree of the Portuguese population was middle school (Instituto Nacional de Estatística, 2012), a lower degree compared with this sample. The existing literature on energy efficiency and renewable energy technology diffusion suggested that education influences this adoption.

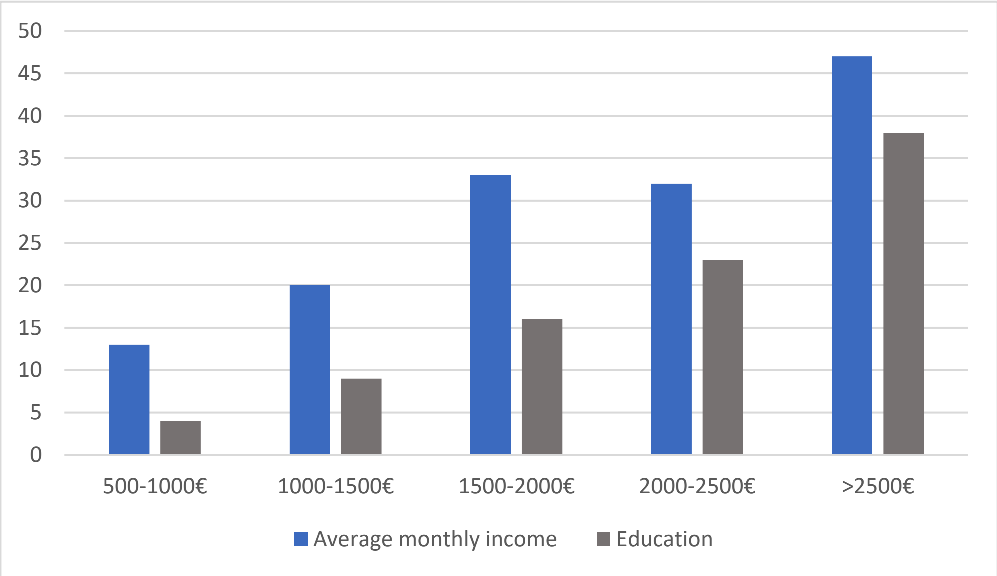

Figure 3. Household's income vs education level

In Figure 3, can be analysed the distribution of the household's average monthly income compared with the respective number of respondents who have a college degree. These two variables were compared since the literature shows a correlation between them. Interpreting this distribution, it can be affirmed that most of the prosumers have a high monthly income. Thus, it can be verified that the education level follows income. It can be affirmed that higher incomes are associated with higher education levels.

5.1.2. PV installation

When asked about how they discovered self-consumption, can be seen in Table 3 that 52% said it was on the Internet, 18% through television and only 12% by peer groups. With these results can be analysed that in this sample, the media have a more dominant factor in the diffusion of this technology than the peer effects. As show in Figure 4, at the moment when they determined to make this installation, the most important decisive determinant that respondents pointed out was the monetary savings. This is confirmed by Kurdgelashvili et al. (2019), which proved that the presence of electricity price fluctuations is related to PV adoption rates. Succeeding, 66% indicated that environmental concerns were also one of the reasons that made them install this technology.

Table 3. Summary statistics of PV installation variables

Variables	Type	Description	Obs	Mean	Std. Dev.	Min	Max
Internet	Dummy	The respondent discovered self-consumption through the Internet (1= yes, 0= no)	145	0.52	0.5	0	1
TV	Dummy	The respondent discovered self-consumption through the television (1= yes, 0= no)	145	0.18	0.38	0	1
Peers	Dummy	The respondent discovered self-consumption through peer groups (1= yes, 0= no)	145	0.12	0.32	0	1
R_environconcerns	Dummy	The respondent has installed PV self-consumption due to environmental concerns (1= yes, 0= no)	145	0.66	0.47	0	1
R_savings	Dummy	The respondent has installed PV self-consumption due to monetary savings (1= yes, 0= no)	145	0.88	0.32	0	1
R_easiness	Dummy	The respondent has installed PV self-consumption due to facility of use and installation (1= yes, 0= no)	145	0.32	0.47	0	1
R_peers	Dummy	The respondent has installed PV self-consumption due to influence of peer's groups (1= yes, 0= no)	145	0.07	0.25	0	1
R_self-sufficiency	Dummy	The respondent has installed PV self-consumption due to energy self-sufficiency (1= yes, 0= no)	145	0.48	0.5	0	1
Panels	Categorical	Number of solar panels (1 = 1-2, 2= 3-4, 3= 5-6, 4= >6)	145	1.41	0.53	1	4
Battery	Dummy	Have a battery (1= yes, 0= no)	145	0.17	0.38	0	1
Sell	Dummy	Sell the electricity produced (1= yes, 0= no)	145	0.14	0.35	0	1
Remote	Dummy	Has remote control (1= yes, 0= no)	145	0.44	0.5	0	1
Monit	Dummy	Has a monitoring system (1= yes, 0= no)	145	0.79	0.41	0	1
Timers	Dummy	Uses timers in the appliances (1= yes, 0= no)	145	0.57	0.5	0	1
Meteo	Dummy	The respondent often consults the weather to reschedule their activities (1= yes, 0= no)	145	0.46	0.5	0	1
Analysis	Dummy	The respondent did an analysis of their consumption to choose the proper power system (1= yes, 0= no)	145	0.9	0.31	0	1

On average, prosumers have 1 to 2 PV panels and only 14% sells the excess electricity generated for the grid. In Figure 5, it can be stated that most households have between 1 and 4 PV panels. This means that most prosumers have adjusted the PV panels number to their daily house consumption. This is evidenced by the variable *analysis*, since 90% examined their

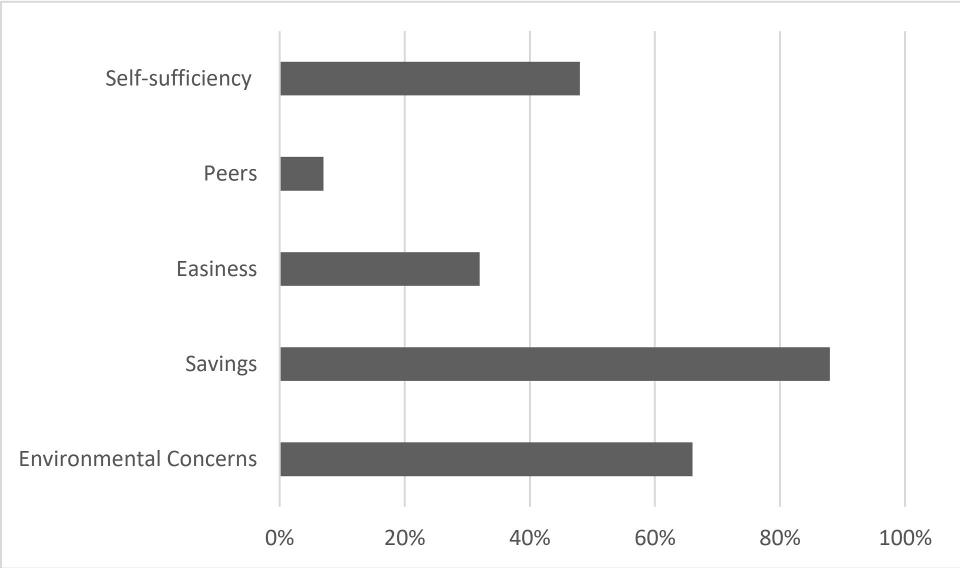

Figure 5. Reasons to become prosumers

consumption to choose the proper power system, only generating the necessary electricity without waste. Accompanying this trend, having a system for energy storage won't be a big advantage. Only 17% have a battery in their systems, while there is a higher percentage of prosumers with other technologies that help to consume more efficiently as timers, monitoring systems and remote control.

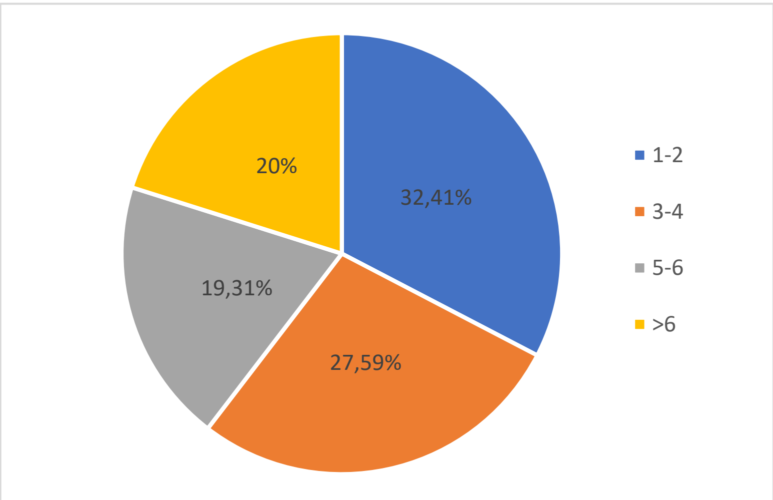

Figure 4. PV panels number

5.1.3. Behavioural and consumption changes

The main reasons for changing energy-saving behaviours pointed out by prosumers was presented in Figure 6. It was analysed that the increased knowledge in electricity consumption, the generation of their own electricity and, the most important, the family members encouragement are the main reasons to increase energy-saving behaviours. This change through the influence of family members is proven by the *perception* variable since in 72% of households

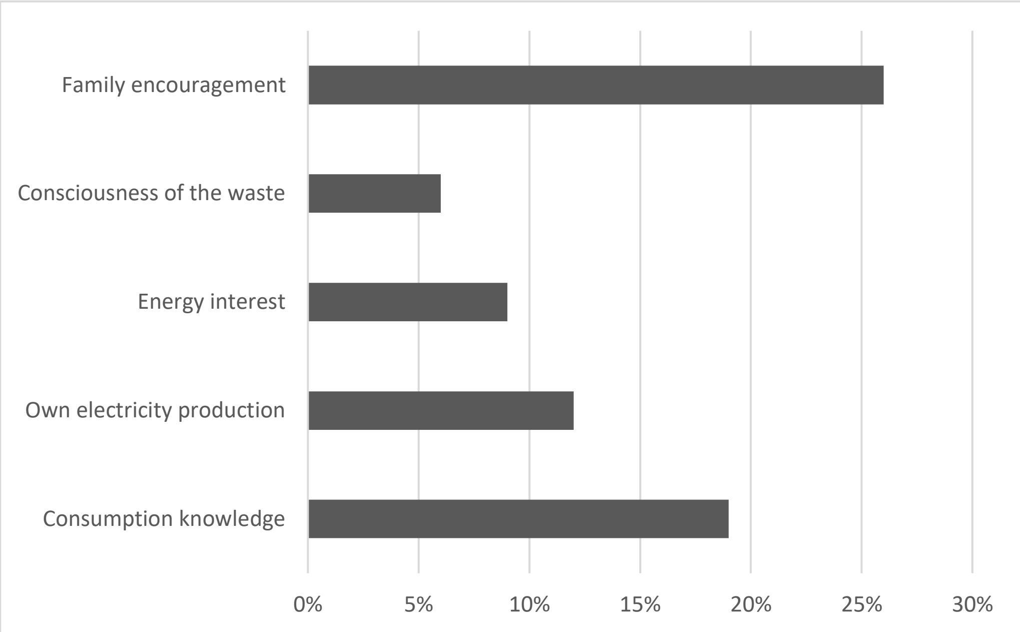

Figure 6. Reasons for changing energy-saving behaviours

the energy awareness spread to all members. This change made that 92% of prosumers decreased their electricity bill.

In Table 4 can be analysed that about 30% of the prosumers have revealed consuming more energy after the installation of the PV system, resulting in a *rebound effect*. With a decrease in the electricity price through PV panels, this may result in an increase in demand. Wittenberg and Matthies (2016) showed that prosumers have a higher energy consumption than the average, mainly due to smart appliances. The energy transition based on global energy usage, especially with the automobile sector, is another reason for this high consumption. This decarbonization of the economy leads to the use of RES to compensate this energy consumption.

Table 4. Summary statistics of behavioural and consumption changes variables

Variables	Type	Description	Obs	Mean	Std. Dev.	Min	Max
Beh_m	Categorical	Changes in energy behaviours after PV installation: an average of all behaviours (1= Less often, 3= More often)	145	2.07	0.75	1	3

C_consumptionknowledge	Dummy	The respondent changes their energy behaviour because it knows better the consumption (1= yes, 0= no)	145	0.19	0.39	0	1
C_energyproduction	Dummy	The respondent changes their energy behaviour because of the production of their own energy (1= yes, 0= no)	145	0.12	0.32	0	1
C_energyinterest	Dummy	The respondent changes their energy behaviour because the interest in energy and electricity costs have increased (1= yes, 0= no)	145	0.09	0.29	0	1
C_waste	Dummy	The respondent changes their energy behaviour because the feeling of waste increased (1= yes, 0= no)	145	0.06	0.24	0	1
C_family	Dummy	The respondent changes their energy behaviour because the family members encouraged each other to save energy (1= yes, 0= no)	145	0.26	0.44	0	1
Actm	Categorical	Predisposition to change domestic activities: an average of all activities (1= Unlikely, 3= Likely)	145	2.1	0.88	0	1
Cons_more	Dummy	The households consume more energy after the installation of the PV system (1= yes, 0= no)	145	0.3	0.46	0	1
Perception	Dummy	The household energy perception has changed (1= yes, 0= no)	145	0.72	0.45	0	1
Family_8h12h	Dummy	1 if most of the households are at home between 8 a.m. and 12 a.m.	145	0.17	0.38	0	1
Family_12h17h	Dummy	Most of the households are at home between 12 a.m. and 17 p.m. (1= yes, 0= no)	145	0.12	0.32	0	1
Bill_reduction	Dummy	The respondent has reduced the electricity bill (1= yes, 0= no)	145	0.92	0.28	0	1
Elect_mobi	Dummy	The respondent has electric mobility (1= yes, 0= no)	145	0.26	0.44	0	1
Ener_efficiency	Dummy	The respondent has another energy efficiency measures (1= yes, 0= no)	145	0.81	0.39	0	1

5.2. Empirical results

Before regressions estimation, a multicollinearity test was calculated. The variables which have the Variance Inflation Factor (VIF) values more than 10 lead to multicollinearity problems and biased results. As shown in Table 5, the VIF values are less than this value, confirming the absence of collinearity in the data.

Table 5. Multicollinearity test

Model 1			Model 2		
Variable	VIF	1/VIF	Variable	VIF	1/VIF
Age	1.47	0.68	Age	1.27	0.79
Income	1.68	0.59	Income	1.36	0.73
Profession	1.73	0.58	Edu	1.21	0.83
Children	1.62	0.62	Children	1.32	0.76
Edu	1.56	0.64	R_ environconcerns	1.35	0.74
H_number	1.48	0.68	R_savings	1.03	0.97
R_savings	1.11	0.90	Remote	1.29	0.77
R_ environconcerns	1.41	0.71	Timers	1.26	0.79
C_consumptionknowledge	1.55	0.65	Perception	1.13	0.89
C_energyproduction	1.41	0.71	Cons_more	1.09	0.92
C_energyinterest	1.38	0.73	Mean VIF	1.23	
C_waste	1.46	0.69			
C_family	1.60	0.62			
Ener_efficiency	1.26	0.79			
Perception	1.28	0.78			
Cons_more	1.17	0.85			
Mean VIF	1.45				

Table 6 presents the econometric results for the estimated models. As can be seen, the income has a negative coefficient with a statistical significance at 1%. This result indicates that households with larger incomes have less predisposition to change environmental behaviours. By analysing the elasticities in Table 7, the same conclusion is also achieved, since prosumers with a higher monthly income are less likely to increase the environmental behaviour.

Evaluating the results of the ORL, when the PV system installation is led by environmental concerns, this has a significant and positive effect on the model of the energy-saving behaviours. Under these conditions, households have more susceptibility to having greater energy awareness. Looking at the pseudo-elasticities, these prosumers are 42% more likely to increase their energy consciousness. This is also proven in the load-shifting model. As in the first model, the environmental reasons variable has a significant positive coefficient.

Table 6. Models estimation results

Variables	Model 1_OLR Energy-saving behaviours	Model 2_GOLM Load-shifting	
	Coefficient	1 vs 2,3	1,2 vs 3
Age	0.0127 (0.0166)	0.0102 (0.0200)	0.0250 (0.0171)
Income	-0.4192*** (0.1595)	-0.1356 (0.1825)	-0.1539 (0.1690)
Edu	-0.3271 (0.4128)	-0.8253* (0.4493)	-0.4698 (0.4160)
Prof	0.1112 (0.4334)	-	-
Childreen	0.2925 (0.4082)	-0.3888 (0.4435)	-0.5314 (0.4344)
H_number	-0.0864 (0.1379)	-	-
R_ environconcerns	0.8856** (0.4158)	0.7405 (0.4894)	1.3340*** (0.4971)
R_savings	-0.7260 (0.5441)	-0.2730 (0.6598)	-0.1558 (0.6056)
Remote	-	0.0294 (0.4537)	0.4213 (0.4309)
C_energyinterest	0.8943* (0.5108)	-	-
C_waste	0.8279 (0.6484)	-	-
C_family	1.3131** (0.6433)	-	-
C_consumptionknowledge	1.1064** (0.5291)	-	-
C_energyproduction (base)	-	-	-
Cons_more	0.2702 (0.3753)	1.3226** (0.4946)	1.0805** (0.4431)
Perception	0.9197** (0.4121)	1.4214*** (0.4479)	1.2923** (0.5042)
Ener_efficiency	0.7545* (0.4564)	-	-
No. of observations	145	145	
LR test	29.47	43.82	
Pseudo-R^2	0.0948	0.1418	

Note: *, * * and * * * denote statistical significance at 10%, 5% and 1% level, respectively.

Based on the reasons that explain the higher environmental behaviour, the increase in energy interest, family influence for energy-saving and consumption knowledge are the factors that have a positive impact on the energy consciousness of prosumers. Meanwhile, by the interpretation of the pseudo-elasticities, can be reached the same conclusions. 11.93% of households are more likely to improve energy behaviour when there is a greater understanding of electricity consumption. Extending this energy consciousness to all households has an impact on electricity consumption behaviour since the *perception* variable is positive and significant in all models. Analysing the elasticities, it can be affirmed that a greater energy awareness of all household increases the propensity to change their behaviour by 47.25%.

Table 7. Average Direct Pseudo-Elasticity of variables

Variables	Model 1			Model 2		
	1	2	3	1	2	3
Age	-0.4487	-0.3781	0.4109	-0.5933	-0.091	0.5026
Edu	0.1588	0.0134	-0.1454	0.2717*	0.0416	-0.2301*
Prof	-0.0366	-0.0031	0.0335	-	-	-
Income	1.1648**	0.0982	-1.0667**	0.3560	0.0544	-0.3015
Childreen	-0.1120	-0.0094	0.1026	0.1529	0.0234	-0.1295
H_number	0.2134	0.0180	-0.1954	-	-	-
R_savings	0.5013	0.0422	-0.4591	0.1197	0.0183	-0.1014
R_ environconcerns	-0.4587**	-0.0387	0.4200**	-0.4700**	-0.0719	0.3981**
C_energyinterest	0.0047	0.0004	-0.0043	-	-	-
C_waste	0.0399	0.0034	-0.0366	-	-	-
C_family	-0.0434	-0.0037	0.0398	-	-	-
C_consumptionknowledge	0.1303*	0.0110	0.1193*	-	-	-
C_energyproduction	-0.0384	-0.0032	0.0352	-	-	-
Perception	-0.5260***	-0.0435	0.4725**	-0.6745***	-0.1032	0.5714***
Cons_more	-0.0614**	-0.0054	0.0587	-0.2397***	-0.0367	0.2030***
Ener_efficiency	-0.4803	-0.0404	0.4398	-	-	-
Timers	-	-	-	0.1196	0.0183	-0.1013
Remote	-	-	-	-0.0721	0.579	0.0610

Note: *, * * and * * * denote statistical significance ate the 10%, 5% and 1% level, respectively.

Although the *cons_more* variable is not significant in Model 1, it is in pseudo-elasticities. With an increase in electricity consumption after self-consumption, 6.14% of prosumers are less likely to be in a lower category. This means that even though there is an increase in consumption, the energy behaviour grows. In Table 7 it can be noticed that 39.81% of prosumers are more likely to change electricity consumption when there is more solar production. In model 2, the only significant socio-economic variable is the education level. By the result obtained, it is possible to state that a higher education level decreases the probability of load-shifting when there is more PV generation. This conclusion is supported by the pseudo-elasticity since in a higher education level, 23.01% of prosumers are less likely to displace the energy consumption.

5.3. Impact of PV generation on peak load shifting

The average peak consumption of the residential sector is different from the peak PV generation. This asymmetry is one of the biggest challenges of self-consumption since that time of the day most of the prosumers are not at home. To solve this problem, it is necessary that some consumption is shifted and does not interfere in the daily life of households. This displacement of the load out of peak is one of the solutions to improve PV self-consumption.

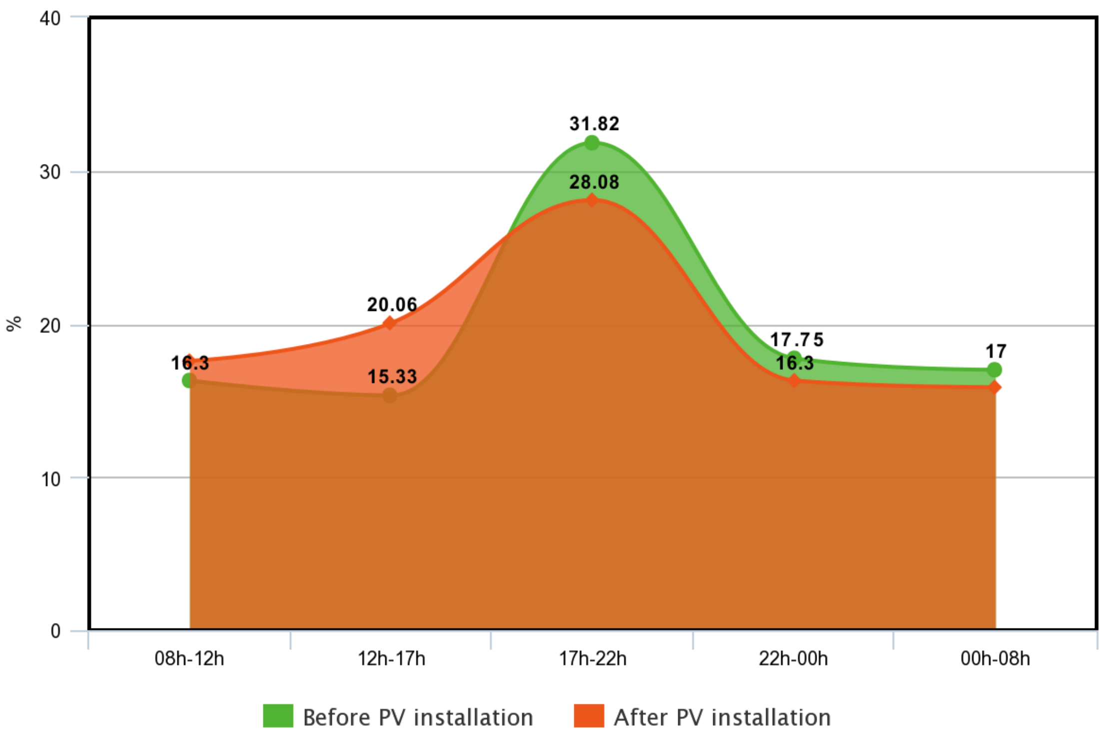

Figure 7. Impact of PV generation on peak load shifting

The previous results show that households with PV systems are committed to synchronizing their electricity production and consumption. In the survey, it was asked how the energy household's consumption was distributed through the day, before and after the PV installation (value in % knowing that the sum is equal to 100%). Figure 7 is obtained from this self-reported perception about electricity consumption during the day and it is noticeable that self-consumption smooths the load diagram, reducing the peak load, what is demonstrated by Gautier et al. (2019), Gomes and Franco (2018), Kobus et al. (2015), J. Palm et al. (2018) and Wittenberg and Matthies (2016).

6. Discussion

People's lives are increasingly dependent on electricity and it is necessary to look for new ways to meet this demand. In the last years, decentralised production with RES has been developed to accommodate the consumer's needs without being dependent on the grid. The self-consumption through PV panels brings challenges, mainly in the consumer perspective. Thus, this study has analysed the factors that have the most impact on energy consumption through a survey. Primary data collection was a limitation on this study since in Portugal, this technology is not yet being widely adopted in the residential sector and the collection period was short. These systems are still an expensive investment and the households who make this installation have higher incomes than the average.

However, the results showed that households with larger incomes have less predisposition to change environmental behaviours. This goes according to the conclusions of Trotta (2018), which proved that investments in energy efficient measures are driven by income levels but these households are less likely to save energy through daily life. Policymakers should take these results into account since the income is a driver of PV installation but high incomes are not related to higher energy-saving behaviours. In this manner, there should be financial incentives for households who do not have monetary availability to make this investment but have environmental and energy-saving attitudes. These incentives must be complemented with energy awareness-raising measures to prevent unbridled adherence. Also, recent studies concluded that income is related to education level and for that reason, both have a negative impact in energy-saving behaviours and in load shifting, respectively. Policymakers should be aware of these results, since the energy literacy of Portuguese prosumers should be increased, to make a more efficient self-consumption.

When the PV system installation is led by environmental concerns, households have more susceptibility to acquiring higher energy awareness and flexibility in electricity consumption. This result is proven by Gautier et al. (2019), coming to the conclusion that when prosumers are driven by environmental concerns for the PV installation, they have more willingness to displace the load. The most pointed reasons that explain the higher environmental behaviour are the increase in energy interest, family influence for energy-saving and consumption knowledge. These are the factors that have a positive impact on the energy consciousness of prosumers. Then can be stated that prosumer's role has an important capacity in increasing the electricity consumption knowledge, becoming more skilled consumers, supporting the H2. As Hondo and Baba (2010) have verified, the self-consumption increments interest in energy and electricity costs and the prosumers have a greater knowledge about what they consume, being more rational in energy utilization.

Extending this energy consciousness to all households has a positive impact on electricity consumption behaviour. As can be seen, increasing the energy perception is very important to have a more conscious electricity spending. The study of Hondo and Baba (2010) came to the same conclusion since the increase in energy-related discussion between households tends to be associated to higher environmental behaviour. This perception is also significant for the displacement of electricity consumption since prosumers are more likely to move the load. The load shifting to follow PV production is challenging for households (J. Palm et al., 2018). Thereby, should be imposed policies that compensate prosumers for displacement consumption out of peak, considering they are relieving the grid when there is more electricity demand.

This change can be promoted by technologies as monitoring systems, timers or remote controls since most prosumers are not at home to make this consumption shift. Contrary to expectations, the variables related to the technology were not significant in the estimated models, not being possible to have conclusions about the effect on PV self-consumption, especially in load-shifting. These results do not confirm hypothesis 3. Also, hypothesis 1 cannot be fully confirmed, despite the domestic activities are actually more flexible, it is not possible to state if this change is supported by technological devices.

Even with an increase in electricity consumption after self-consumption, energy behaviour grows, which supports hypothesis 4. This can be explained by the increase in global energy demand. Despite the greater energy consumption, there is a high probability of this being moved when there is solar production. These technologies have the ability to influence the household's electricity consumption behaviour, already proven by Hondo and Baba (2010), Keirstead (2007) and Wittenberg and Matthies (2016, 2018).

However, there are circumstances that are impossible to displace energy consumption. EVs are an excellent representation of this situation, considering that most of them are charged in the evening when there is no PV generation. The only way to store that energy production is using batteries, however, at this moment they are an expensive investment. Thereby, a policy that should be implemented is that batteries would be cheaper for prosumers who have an EV, thus encouraging decentralised production and electric mobility.

Renewable energy communities were omitted from the results because there were few prosumers who are inserted in these associations. Thus, it is possible to assume that these communities are not yet been adopted in Portugal but should be encouraged. The self-consumption brought relevant technological and economic challenges, which to achieve success, it is essential that grid operators and governments play a key role in this energy transition. Consumers have active participation in the electric market, implying that the traditional power grid has to follow this evolution, allowing them to play a more interactive role.

With this investigation, it was possible to analyse that the introduction of self-consumption technology has a positive impact on environmental behaviour and electricity consumption in daily life. Still, there are several challenges that must be faced, for example, it is essential to increase the energy literacy of Portuguese households. PV self-Consumption adoption is not enough since it is important that prosumers make efficient energy management.

Households should be encouraged for self-consumption with a combination of monetary incentives and energy information to consumers. Also, it is needed to do a more detailed analysis of production and consumption, to know if there is energy waste. When there is more production, prosumers should be compensated to displace the demand out of peak, since they are relieving the grid when there is more electrical demand. Policymakers should pay special attention to this topic considering that it is difficult to make changes in the daily lives of prosumers.

7. Conclusion and further research

The PV self-consumption in Portugal was investigated based on primary data collection. An OLR and a GOLM were carried out in order to find which factors have the most effect on the electricity consumption behaviour of Portuguese prosumers. With this investigation, it was possible to obtain interesting conclusions of the residential PV self-consumption. The income may be an important reason to install PV panels but they are not a determinant element in energy-saving behaviours. The same happens with education level, that the higher academic level of the prosumer, the lower will be the predisposition to have an environmental behaviour in daily life. Before PV installation, it is essential that people already have environmental concerns, since this is one of the drivers for self-consumption. By becoming prosumers, environmental behaviour increases, considering that this has a positive effect on energy consciousness. This factor is also critical in load shifting since the prosumers who already had environmental concerns are more willing to move the consumption to coincide with solar production, making a more conscious energy consumption. After the self-consumption, some households admitted consuming more electricity. Despite this increase in energy consumption, this is used when there is solar production.

This study contributes to the literature by identifying the drivers of the electricity generation using an econometric approach. For future research is advised to increase the sample size to intensify the explanatory power of the models and apply the survey in different regions or countries to compare the disparity. It is also advised to investigate the effect of the timers, remote controls and monitoring systems in self-consumption of Portuguese prosumers.

Appendix: Survey

Autoconsumo fotovoltaico e mudanças de comportamento no consumo de eletricidade

No âmbito da realização de uma Dissertação de Mestrado em Economia na Universidade da Beira Interior, este inquérito visa responder a questões relativas ao perfil do consumidor e comportamentos das famílias que produzem e consomem a sua própria eletricidade, gerada através de painéis fotovoltaicos.
De modo a que o inquérito reflita o máximo de realidade possível, é de extrema importância que o tente responder com precisão.
Toda a informação que for prestada será anónima e confidencial, sendo que os dados serão usados unicamente para este trabalho académico.
Desde já agradeço a sua colaboração!

Tendo tomado conhecimento que as suas respostas serão usadas exclusivamente para os objetivos desta Dissertação e que esta informação será anónima, autoriza que as suas respostas sejam usadas exclusivamente para os fins da mesma?

☐ Sim ☐ Não

Dados gerais

Sexo	☐ Feminino ☐ Masculino
Idade	_____
Código-Postal	____________________
Habilitações literárias	☐ Não completou qualquer nível de escolaridade ☐ 1º ciclo do ensino básico ☐ 2º ciclo do ensino básico ☐ 3º ciclo do ensino básico ☐ Ensino Secundário ☐ Bacharelato ☐ Licenciatura ☐ Pós-graduação ☐ Mestrado ☐ Doutoramento
Profissão	____________________
Constituição do agregado familiar	Crianças (até 12 anos): _____ Adolescentes (12-18 anos): _______ Adultos: _______
Rendimento médio mensal do agregado	☐ 500-1000€ ☐ 1000-1500€ ☐ 1500-2000€ ☐ 2000-2500€ ☐ >2500€
Tipo de habitação	☐ Apartamento ☐ Moradia isolada ☐ Moradia geminada
Ano de construção da habitação	____________________
Já fez alguma reabilitação na habitação?	☐ Sim ☐ Não
Se sim, em que ano?	____________________

Comunidade de energia

Encontra-se inserido numa comunidade de energia (utiliza painéis fotovoltaicos ou baterias partilhadas)?	☐ Sim ☐ Não
Se sim, há quanto tempo está nessa comunidade?	____________________
Quais foram os motivos para aderir?	☐ Repartição de custos ☐ Partilha da capacidade de baterias ☐ Partilha da geração de painéis solares ☐ Outro: __________________

Instalação dos Sistemas Fotovoltaicos

Ano de instalação	____________________
A instalação fotovoltaica foi feita pelo atual proprietário?	☐ Sim ☐ Não
Como teve conhecimento da possibilidade de produzir eletricidade em casa com painéis solares?	☐ Televisão ☐ Jornais ☐ Amigos, vizinhos ☐ Internet ☐ Distribuidora de eletricidade ☐ Outro: ____________
Quais foram as razões para fazer este investimento?	☐ Poupança monetária ☐ Fácil de usar e instalar ☐ Preocupações ambientais ☐ Recomendações de amigos/família ☐ Aumentar o valor da casa ☐ Autosuficiência
Nº de painéis solares	___________
Potência individual de cada painel solar	____________
Total do investimento	_____________
Esse investimento foi financiado por:	☐ Receitas próprias ☐ Empréstimo bancário ☐ Outro financiamento: ________________
Qual o valor, em média, que já reembolsou?	_____________
Antes de fazer este investimento, teve o cuidado de analisar qual era o seu consumo para escolher a potência adequada?	☐ Sim ☐ Não
Tem um sistema de monitorização de energia?	☐ Sim ☐ Não

Se sim, o que monitoriza?	☐ Consumo ☐ Produção
Qual a marca desse sistema?	☐ Owl ☐ Solar Log ☐ Efergy ☐ Circutor ☐ EDP re:dy ☐ Smappee ☐ Mirubee ☐ Cloogy ☐ IPDOMO ☐ Outra: ___________
Com que regularidade consulta a **produção** realizada pelos painéis fotovoltaicos?	☐ Nunca ☐ 1 vez por mês ☐ 1 vez por semana ☐ 2 a 3 vezes por semana ☐ 1 vez ao dia ☐ Várias vezes ao dia
Com que regularidade consulta o seu **consumo**?	☐ Nunca ☐ 1 vez por mês ☐ 1 vez por semana ☐ 2 a 3 vezes por semana ☐ 1 vez ao dia ☐ Várias vezes ao dia
A eletricidade não consumida é vendida para a rede? Se sim, a que preço/ kWh?	☐ Sim ☐ Não Preço/kWh: ___________
Tem uma bateria no seu sistema?	☐ Sim ☐ Não
Se sim, qual a potência?	________________
E quando é que esta é utilizada?	☐ Durante o dia ☐ Noite ☐ Dias nublados ou com pouco sol ☐ Falhas elétricas

Geração e comportamento no consumo de eletricidade

Consumo médio de eletricidade mensal (kWh)	Verão: ____________ Inverno:____________
Valor médio mensal da fatura de eletricidade (€)	Verão: ____________ Inverno: ____________
Depois de instalar os painéis, reduziu a fatura de eletricidade?	☐ Sim ☐ Não
Em quanto?	☐ <10% ☐ 10-20% ☐ >20%
Como reparte o consumo diário da habitação, pelos vários períodos do dia, **antes da instalação**? (Valor em % sabendo que o somatório é igual a 100%)	☐ 8h-12h ☐ 12h-17h ☐ 17h-22h ☐ 22h-00h ☐ 00h-8h
Como reparte o consumo diário da habitação, pelos vários períodos do dia, **depois da instalação**? (Valor em % sabendo que o	☐ 8h-12h ☐ 12h-17h ☐ 17h-22h ☐ 22h-00h ☐ 00h-8h

<table>
<tr><td>somatório é igual a 100%)</td><td></td></tr>
<tr><td>Quais os períodos do dia em que o agregado está maioritariamente em casa?</td><td>☐ 8h-12h ☐ 12h-17h ☐ 17h-22h ☐ 22h-00h ☐ 00h-8h</td></tr>
<tr><td>Qual a possibilidade de mudar as seguintes atividades para uma altura onde existe mais produção solar?</td><td>
<table>
<tr><th></th><th>1 (Improvável)</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10 (Muito Provável)</th></tr>
<tr><td>Máquina de lavar roupa</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Máquina de lavar loiça</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Máquina de secar roupa</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Passar a ferro</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Aspirar</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Carregar telemóvel e/ou pc</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sistema de aquecimento</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Utiliza temporizadores nos seus aparelhos elétricos?</td><td>☐ Sim ☐ Não</td></tr>
<tr><td>Costuma consultar a meteorologia para reprogramar as suas atividades?</td><td>☐ Sim ☐ Não</td></tr>
<tr><td>Utiliza controlo remoto para controlar o consumo de energia elétrica (p.ex. usando tomadas inteligentes; termostatos digitais)?</td><td>☐ Sim ☐ Não</td></tr>
<tr><td>Se sim, o que costuma controlar?</td><td>☐ Iluminação ☐ Ar condicionado ☐ Caldeiras ou bombas de calor
☐ Estores elétricos ☐ Eletrodomésticos ☐ Outros equipamentos: _______________</td></tr>
<tr><td>Depois da instalação, quais foram as alterações de comportamento no consumo de energia?</td><td>
<table>
<tr><th></th><th>1 (Menos frequentemente)</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10 (Mais frequentemente)</th></tr>
<tr><td>Desliga as luzes mesmo quando sai por um curto período</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Desliga o standby dos aparelhos elétricos</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quando compra produtos vê a sua eficiência energética</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Diminui o nº de vezes que abre a porta do frigorífico</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Deixa o ar condicionado/ sistema de aquecimento ligado mesmo quando ninguém está em casa</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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Qual a principal razão para haver essas alterações de comportamento no consumo?	☐ O interesse em energia e custos de eletricidade aumentaram ☐ A sensação de desperdício aumentou ☐ Os membros da família incentivam-se uns aos outros para a poupança ☐ Existe mais conhecimento no consumo de eletricidade ☐ A produção da própria eletricidade ☐ Outra: ____________________
Quais são as razões pelas quais é impossível alterar determinadas atividades?	☐ Não existem incentivos financeiros suficientes ☐ Os horários das atividades ☐ Existem incentivos financeiros, mas são demasiados baixos ☐ O horário de trabalho ☐ Outra: ________________
Possui algum meio de mobilidade elétrica?	☐ Sim ☐ Não
Se sim, qual?	☐ Carro elétrico ☐ Bicicleta elétrica ☐ Mota elétrica
Qual a marca e o modelo?	Marca: _______________ Modelo: ______________
Esta aquisição foi feita depois da instalação dos painéis fotovoltaicos?	☐ Sim ☐ Não
A perceção face à energia, do restante agregado familiar, mudou após a instalação?	☐ Sim ☐ Não
Vê o autoconsumo como uma oportunidade de consumir mais energia?	☐ Sim ☐ Não
Tem outras medidas de eficiência energética em sua casa?	☐ Sim ☐ Não
Se sim, quais?	☐ Isolamento térmico na cobertura e/ou paredes exteriores ☐ Lâmpadas LED ☐ Painéis solares térmicos para aquecimento de águas sanitárias ☐ Janelas eficientes ☐ Outras:______________
Em que medida ficou satisfeito com este investimento?	☐ Nada satisfeito ☐ Pouco satisfeito ☐ Satisfeito ☐ Muito satisfeito

Obrigada pela colaboração!

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