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Barriers and adoption of energy efficiency measures in buildings of micro, small and medium-sized Portuguese companies

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Resumo

Indispensável hoje em dia e para as gerações futuras, a eletricidade deve ser utilizada de forma eficiente, uma vez que é um recurso escasso e tem sérias repercussões no meio ambiente devido ao seu processo de geração. A eficiência energética é vital para reduzir as despesas de energia, melhorar a segurança energética e também como uma ferramenta para combater as alterações climáticas, reduzindo a pressão no meio ambiente. Sendo a percentagem de PMEs, em Portugal, 99,9% do total de empresas e representando uma parcela significativa do consumo de energia do país justifica a necessidade da realização deste estudo. Devido à ausência de dados secundários, foi realizada uma Recolha de dados primária. Com base nas teorias da agência e da capacidade de absorção, estuda-se a adoção e barreiras à adoção de quatro medidas transversais de eficiência energética auxiliares (iluminação, isolamento, substituição do sistema aquecimento e operações do sistema de aquecimento). Verifica-se que a capacidade de absorção é um fator chave para a adoção de tecnologias mais eficientes. Pode ser necessário criar políticas de apoio às PMEs que visem informá-las e auxiliá-las, colmatando, assim, a falta de gestores de energia e de sistemas de gestão de energia, pois estes implicam custos que as empresas mais pequenas não conseguem suportar. Além disso, a maioria das decisões e barreiras consideradas pelas PMEs não é apoiada por auditorias ou por profissionais de gestão de energia, já que mais de 65% dos entrevistados nunca realizaram uma auditoria energética e mais de 82% não tem um gestor de energia. Poderá ser necessário criar políticas de consciencialização mais agressivas de modo a mostrar claramente o benefício individual que cada MEE proporciona a cada uma das PMEs.

Palavras-chave

Eficiência energética; Barreiras; Agência; Capacidade de Absorção; PMEs; Adoção, Probit

Resumo Alargado

Indispensável nos dias de hoje, e para as gerações futuras, a eletricidade deve ser utilizada de forma eficiente, uma vez que é um recurso escasso e tem sérias repercussões no meio ambiente devido ao processo de como é gerada. Como afirma o Dr. Fatih Birol, presidente da Agência Internacional de Energia, "A eficiência energética é o único recurso energético que todos os países possuem em abundância" (IEA, 2016a) e isso é vital para reduzir as contas de energia, melhorar a segurança energética e também atuar como ferramenta para combater as alterações climáticas, reduzindo a pressão no ambiente. Assim, este trabalho centra-se nas micro, pequenas e médias empresas, uma vez que representam 99,9% das empresas em Portugal.

Os decisores políticos estão conscientes de que as políticas não devem ser apenas direcionadas para o lado da oferta uma vez que o lado da procura tem, também, muito para oferecer no que à eficiência energética diz respeito. No entanto, a dificuldade na transição para tecnologias mais eficientes deve-se ao fato de que, para avançar na eficiência energética, é necessário um investimento inicial e, mesmo pequeno e propício à poupança de longo prazo, as PMEs optam por medidas que parecem mais atraentes no curto prazo, enfatizando a importância do período de retorno (Jackson, 2010).

Assim, este trabalho pretende avaliar a adoção de quatro medidas de eficiência energética que não estão relacionadas a nenhum núcleo de negócios e não estão especificamente associadas a nenhum tipo de setor, sendo assim possível a observação da heterogeneidade organizacional. Além disso, com a metodologia aplicada, a análise de heterogeneidade tecnológica também é permitida. Esta metodologia foi aplicada na Alemanha por Olsthoorn, Schleich, & Hirzel (2017) em que foram utilizadas variáveis baseadas na teoria da agência e capacidade de absorção. Além da adotação de medidas, um conjunto de barreiras será também escrutinado. A pertinência desta dissertação justifica-se pela percentagem de empresas que são classificadas como PMEs em Portugal, bem como pela necessidade de que o país cumpra os objetivos estabelecidos pela UE. Além disso, como a percentagem dos custos de energia associados a estas medidas é geralmente baixa, a sua eficiência energética tende a ser negligenciada (Schleich, 2009) não sendo percebida como estratégica (Cooremans, 2007).

Devido à ausência de dados secundários, foi realizada uma recolha de dados primários. O inquérito segue de perto a literatura e principalmente o questionário alemão para o consumo de energia do setor de comércio, comércio e serviços do relatório final para o Ministério Federal dos Assuntos Económicos e de Energia (BMWi, 2013). As medidas de eficiência tratadas nesta dissertação são geralmente identificadas como economicamente viáveis em auditorias energéticas e não estão diretamente relacionadas a qualquer tipo de empresa, uma vez que não estão relacionadas a um núcleo de negócios específico (Olsthoorn et al., 2017). Os resultados desta pesquisa dão uma nova visão sobre as barreiras que as PMEs portuguesas enfrentam na adoção de medidas de eficiência energética.

Os fatores de capacidade de absorção são essenciais para a adoção de medidas mais eficientes e lucrativas, independentemente de terem um custo inicial maior. No entanto, considerando o número de empresas que realizaram auditorias energéticas juntamente com aquelas que possuem um gestor de energia ou um sistema de gestão de energia, e considerando o número de empresas que solicitaram fundos de eficiência energética, é reconhecido que poderá haver falta de clareza do benefício individual para cada empresa, mas também uma possível dificuldade em usar fundos direcionados para esses tipos de medidas. Assim sendo, poderá ser necessário criar políticas com o objetivo de informar e assistir as PMEs, preenchendo assim a falta de gestores de energia e sistemas de gestão de energia, já que estes implicam custos que as empresas mais pequenas não conseguem suportar. Anderson & Newell, (2004) afirmam que subsidiar tecnologias mais eficientes pode ser melhor para adotar uma medida do que o uso de políticas para taxar o uso de recursos. Schleich & Fleiter, (2017) chegaram à conclusão de que o programa alemão de auditoria energética acelerou a adoção de medidas pelas PMEs. No cenário português, algumas políticas, como as aplicadas na Alemanha, podem alcançar os mesmos resultados. Não obstante, as auditorias energéticas também podem funcionar como um mecanismo de dissuasão (Frondel & Vance, 2013).

Embora as subsidiárias sofram pressões que podem ser explicadas de acordo com a teoria da agência, elas também podem beneficiar de momentos de aprendizagem. Há, de fato, um impacto positivo das empresas subsidiárias na adoção de aquecimento eficiente, portanto, é pertinente propor a criação de políticas direcionadas às empresas-mãe, uma vez que estas transferem parte do seu conhecimento para as subsidiárias Schlomann & Schleich, (2015).

Dadas as taxas de adoção e as barreiras relevantes para a não adoção juntamente com o fato de que mais de 88% das PMEs nunca se candidataram a um apoio financeiro para medidas de eficiência energética, indicam que é necessário criar políticas de conscientização mais agressivas, que mostrem claramente o benefício individual que cada medida oferece a cada PME, bem como melhorar a perceção do benefício que oferecem ao país pelo uso eficiente de energia.

Abstract

Indispensable nowadays and for future generations, electricity must be used efficiently since it is a scarce resource and have serious repercussions in the environment due to the process of how it is generated. Energy efficiency is vital to reduce energy bills, improve energy security and also as a tool to combat climate change reducing the pressure in the environment. Being the percentage of MSMEs in Portugal 99,9% of the total of enterprises and representing a significant share of the country's energy consumption justifies the need to carry out this study. Due to the absence of secondary data, an online survey was carried out. Based on theories of agency and absorption capacity it is studied the adoption and barriers to adoption of four crosscutting, ancillary energy efficiency measures (lighting, insulation, heating replacement and heating operations. Evidence is found that absorptive capacity factors are a key factor for adopting more efficient and profitable measures. It may be necessary to create policies to support MSMEs that aim to inform and assist them thus filling the lack of energy managers and energy management systems since these imply costs that smaller companies cannot afford. Although the subsidiaries suffer pressures explained with agency theory, they can also benefit from learning moments. Most of the decisions and barriers considered by MSMEs are not supported either by audits or by energy management professionals since more than 65% of the respondents have never performed an energy audit and more than 82% do not have an energy manager. It is necessary to create more aggressive awareness-raising policies in order to show clearly the individual benefit that each EEM provides to each MSMEs.

Keywords

Energy efficiency; Barriers; Agency; Absorptive Capacity; MSMEs; Adoption, Probit

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EEMs	Energy efficiency measures
MSMEs	Micro, small and medium sized enterprises
EU	European Union

1. Introduction

Indispensable nowadays, and for future generations, electricity must be used efficiently since it is a scarce resource and has serious repercussions in the environment due to the process of how it is generated. As Dr Fatih Birol, the president of International Energy Agency, states ” Energy efficiency is the one energy resource that every country possesses in abundance” (IEA, 2016a) and this is vital to reduce energy bills, improve energy security as well as a tool to combat climate change by reducing the pressure in the environment. Hence, this work focuses on micro, small and medium sized enterprises, once they represent 99,9% of the enterprises in Portugal.
In order to understand how the transition in Portugal is taking place, since Portugal's energy efficiency policies are aligned with the relevant EU regulations and directives (IEA, 2016b), a collection of primary data will be carried out to provide information of the demand-side for a better understanding of how to move on towards energy efficiency allowing, therefore, a considerable reduction of the energy efficiency gap.

Energy efficiency gap is defined by Brown (2001) as “*the difference between the actual level of investment in energy efficiency and the higher level that would be cost-beneficial from the consumer's (i.e., the individual's or firm's) point of view.*”. This author also argues that this is the reason for public policy intervention since it is based on market failures and barriers.

Policy-makers are aware that policies should not be just directed to the supply-side and that the demand side is not to be neglected since it has a lot to offer in terms of contributing to energy efficiency. However, the difficulty in the transition is due to the fact that, in order to move towards energy efficiency, an initial investment is necessary and, even if it is small and conducive to long-term savings, MSMEs opt for measures that seem more appealing in the short term thus emphasizing the importance of the payback period (Jackson, 2010). These and other barriers will be the factor, for economic theory, which shows that higher priced goods encourage the use of substitute goods. In this case, the difference in the goods will be linked to efficiency since in the long run, and although the initial purchase price is higher, it will be completely justifiable at all levels, i.e. energy saving, more modern features of the new devices, absence of technical problems, duration of the devices, and so on.

This work thus intends to assess the adoption of four crosscutting ancillary energy efficiency measures. Because these measures are not related to any business core and are not specifically associated to any type of sector, the observation of the organizational heterogeneity is made possible. Furthermore, with the methodology applied, technological heterogeneity analysis is enabled as well. This methodology was applied in Germany by Olsthoorn et al. (2017) in which variables based on agency theory and absorptive capacity were used. In addition to adopting measures, a set of barriers will also be dealt with. The pertinence of this dissertation is justified due to the share of enterprises that are classified as MSMEs in Portugal as well as the urge for the country to meet the EU established goals. Additionally, because the share of energy costs is usually low, energy efficiency tends to be neglected (Schleich, 2009) and not be perceived as strategic (Cooremans, 2007).

The work proceeds, in Section 2, to the literature review on energy efficiency measures, heterogenous organizations and barriers to energy efficiency measures. Then, a set of hypotheses, which will be tested, are presented in Section 3. Section 4, under the title Methodology, discriminates primary data collection and data as well as the econometric procedure for the adoption of EEMs and for barriers. The results for organizational heterogeneity, heterogeneity of measures and for barriers are presented in section 5 while section 6 deals with the discussion. Section 7 concludes this work.

2. Literature review

Regardless being cost-effective, energy efficiency measures have a much lower adoption rate than expected. According to the studies of the last decades, this is due to the fact that several barriers still remain. However, in these studies, the energy efficiency measures are treated as homogeneous, recognizing only its profitability (Fleiter, Hirzel, & Worrell, 2012). Notwithstanding, these authors recognize that the EEMs have distinct characteristics while, at the same time, consider them of the utmost importance to enable a correct evaluation on how to proceed towards the design of more effective policies. The reality is that profitability is one of the most relevant features in favor of the adoption of these cleaner technologies but, despite their economic attractiveness, they do not have an instantaneous or automatic implementation once their expensiveness and complexity are bound to slow them down (Kemp & Volpi, 2008).

Olsthoorn et al. (2017) emphasize the need to focus literature review on the heterogeneity of organizations, on the adoption of measures and barriers to those technologies aiming at energy efficiency in non-residential buildings. In fact, several authors demonstrate this sensitivity by separating these organizations by sector and size, by aggregating the industrial sector, distinguishing non-energy-intensive from energy-intensive consumers, or trade and service sectors.

Companies that intensively use energy prove to be more inclined to focus on energy efficiency than those that do not. For the companies under scrutiny here, micro, small and medium-sized enterprises, the most significant barriers to profitable energy efficiency measures (Fleiter, Schleich, & Ravivanpong, 2012) are lack of capital, lack of information, lack of investment and poor quality audits. Yet, it can be considered that low cost energy efficiency measures have small differences in adoption within the field of sectorial heterogeneity (Schlomann & Schleich, 2015).

The adoption of more complex EEM is affected by the quality of the energy audits (Fleiter, Schleich, et al., 2012), nonetheless, for the measures under analysis, simple ancillary measures, the necessity for more detailed audits was not to be found (Schleich & Fleiter, 2017), even though these audits are not equally effective in what these measures are concerned.

Energy efficiency measures, often neglected, have different diffusion speeds due to their characteristics and attributes (Fleiter, Hirzel, et al., 2012), such as the internal rate of return, the return period, the initial costs, non-energy benefits, the distance to the core of production or the durability of the measure in question. To corroborate these statement Cagno & Trianni (2014) found that compressed air and HVAC systems suffer from higher barriers than energy efficiency measures of lighting or motors.

It is important to acknowledge that energy efficiency comes from the use of equipment with the ability to consume less energy to perform a certain task, but also from the use of renewable sources. Both energy-efficient technologies and renewable energy production equipment have high implementation costs (Abulfotuh, 2007) that the company will have to bear initially and that, consequently, will make it lose competitiveness. The choice of measures to be taken should depend on the need, profitability and flexibility.

Germany has implemented grants for energy audits in SMEs and such step seems to have proved to be a good tool in order to increase not only their energy efficiency and allowing the enterprises to save more, but it also led to an increase of private investment (Fleiter, Gruber, Eichhammer, & Worrell, 2012; Fleiter, Schleich, et al., 2012). These authors further argue that this kind of audit programs do help overcoming barriers derived from lack of information and capacity related. Another signaled aspect was that SMEs apply a more restrictive investment criterion than the audit programs which indicate that auditors should try to supply further information or arrange it differently.

Energetic performance contracting structures are beginning to appear in the literature as a benchmarking to increase energy efficiency in southern Europe, (Viesi, Pozzar, Federici, Crema, & Mahbub, 2017).

3. Hypothesis

Several of the variables tested in this work are present in various studies such as Fleiter, Hirzel, et al. (2012), Fleiter, Schleich, et al. (2012), Cagno & Trianni (2014), Schlomann & Schleich (2015). However, the complete set of hypothesis used is based on Olsthoorn et al. (2017), but for the exception of applying for an energy efficiency fund. It was decided to include this hypothesis because it is expected that the most reported barriers be the ones related to monetary problems, and this kind of funds can be a way of response to diminish the monetary gap to make the MSME efficient.

The methodology utilized is based on proxies from two different streams of literature: Agency factors and Absorptive capacity factors. The signs that the proxies will have upon the models are liable to be predicted. Since the Agency Theory concerns the relationships characterized by information asymmetry, conflicting goals and different risk preferences between principals and agents a negative impact can be expected. For Absorptive Capacity proxies, positive signs are expected once it reflects the ability of the MSME to absorb and use information in its own benefit.

H1. Hypothesis based on Agency Theory

H1.1- MSMEs that do not own their work spaces are less likely to adopt EEMs.

H1.2- MSMEs that do not own their own energy supply equipment are less likely to adopt EEMs.

H1.3- MSMEs that are subsidiaries are less likely to adopt EEMs.

H2. Hypothesis based on Absorptive Capacity

H2.1- MSMEs that have an energy management system are more likely to adopt EEMs.

H2.2- MSMEs that have an energy manager are more likely to adopt EEMs.

H2.3- MSMEs that have already performed an energy audit are more likely to adopt EEMs.

H2.4- MSMEs that have their own source of renewable energy are more likely to adopt EEMs.

H2.5- MSMEs that have already applied for an energy efficiency fund are more likely to adopt EEMs.

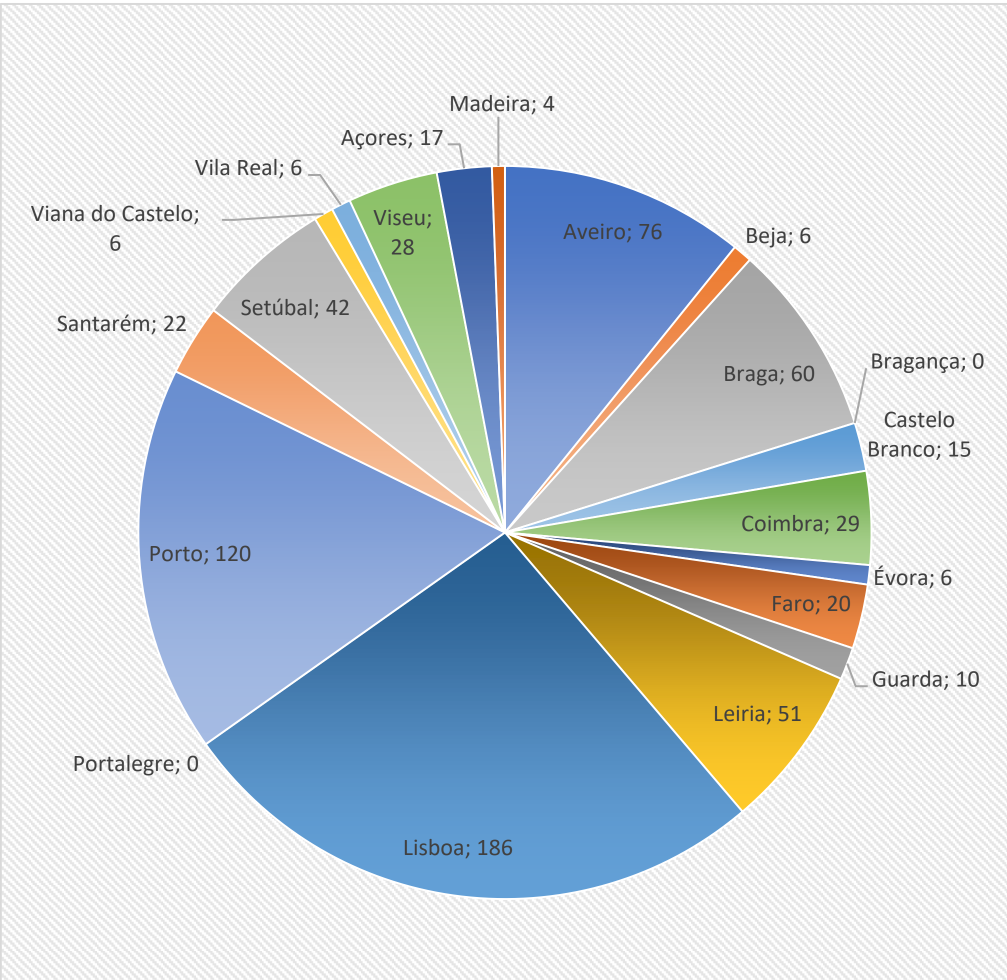
4. Methodology

4.1- Primary data collection

Being the percentage of MSMEs in Portugal 99,9% of the total of enterprises and representing a significant share of the country's energy consumption justifies the need to carry out this study. Due to the absence of secondary data, an online survey was carried out. The survey closely follows the literature and mostly the German questionnaire for energy consumption of the sector trade, commerce and services for the Final report to the Federal Ministry for Economic Affairs and Energy (BMWi, 2013). The EEMs dealt with in this survey are usually identified as cost-effective in energy audits and are not directly related to any type of enterprise as they are unrelated to a specific business core (Olsthoorn et al., 2017).

To guarantee the representativeness of the Portuguese territory, it was decided to widespread the survey by e-mailing questionnaires to various enterprises across the country, including the insular areas. In Figure 1 one can see the geographical area where the observations originate.

Figure 1 - Number of observations per district



Due to the difficulty to find a database with the e-mail addresses of the companies, a database with the companies' websites was used and then the respective addresses gathered. The data were collected in the period between 8th of November of 2017 and 6th of August of 2018. In a total of 2052 surveys that were opened, 776(37.82%) were submitted and of those 704(34.31%) were validated and considered in this work.

Table 1 – Survey rate of valid answers

Questionnaires opened	Valid obs.	% Valid obs.
2052	704	34.31

The survey is composed of five steps. Step one, two, three and four assess the EEMs lighting, insulation, heating and heating operations, respectively. The procedure is identical for all of them. If the EEM is adopted, it is asked how much was invested and how many years are expected to recover the investment. If the EEM was considered but not adopted, a set of twelve barriers is shown and it is asked to classify them as important or not important for not being adopted. If the EEM was not considered, nothing is asked about it and the survey continues to the next step. In the fifth step, the remaining and more general information about the MSME is asked.

The response of the adopters is observable in table 2 which discriminates the amount of money spent and the return period by EEM.

Table 2 - Investment and payback of adopters

	Lighting		**Insulation**		**H. Replacement**		**H. Operations**	
	Investment	Years	Investment	Years	Investment	Years	Investment	Years
	3383	4.06	11850	9.33	7833	5.94	5492	4.80
Obs.	403	390	140	132	125	116	67	59

It should be noted that the more the EEM is related to the building structure the greater the return period and the amount spent. However, these values may have some bias since they may not be supported by studies or audits. Nevertheless, it shows the perception that entrepreneurs have.

4.2- Data

In this section the descriptive statistics of the dependent and independent variables are displayed, as well as an intuitive explanation of the meanings of the variables used in the model. The dependent variables are in the first four lines followed by the independent ones. In these statistics the mean of each variable, dependent or independent, tells us the percentage that the same variable was registered, (e.g. lighting with a mean of 0.631 tells one that ≈ 63% adopted this EEM, or audit with a mean of 0.349 that ≈ 35% audited their MSME).

Table 3 - Descriptive statistics of variables

	Obs.	Mean	Std. Dev.	Min	Max
EEM adoption (1= yes; 0=no)					
Lighting	704	0.631	0.483	0	1
Insulation	704	0.240	0.427	0	1
Heating replacement	704	0.193	0.395	0	1
Heating operations	704	0.162	0.369	0	1
EEM dummies EEM dummies (1= yes; 0=no) (stacked data)					
Lighting	2816	0.250	0.433	0	1
Insulation	2816	0.250	0.433	0	1
Heating replacement	2816	0.250	0.433	0	1
Heating operations	2816	0.250	0.433	0	1
MSMEs attributes EEM dummies (1= yes; 0=no)					
Subsidiary	704	0.200	0.400	0	1
Energy management system	704	0.210	0.408	0	1
Energy manager	704	0.173	0.379	0	1
Energy audit	704	0.349	0.477	0	1
Energy efficiency fund	704	0.116	0.321	0	1
Energy efficiency fund acceptance	82	0.695	0.463	0	1
Decentralized clean energy	704	0.196	0.397	0	1
Heating system external	704	0.044	0.205	0	1
Tenant	704	0.376	0.485	0	1
Control variables					
Manufacturing	704	0.310	0.463	0	1
Ln(employees)	704	2.881	1.079	0	6.9077
Electricity rate (€/kWh)	704	0.165	0.103	.06	.68

Only for the responders who considered adoption but did not adopt the EEMs, a set of barriers were presented, and they were asked to report them as important or not in their decision for not adopting the measure. By not seeking answers from the responders that adopted and from those who never thought about EEMs hypothetical bias were automatically excluded (Olsthoorn et al., 2017).

Table 4 - Descriptive statistics of barriers

	Obs.	Mean	Std. Dev.	Min	Max
Already efficient	721	0.473	0.500	0	1
Investment costs	721	0.793	0.405	0	1
Uneconomical	721	0.617	0.486	0	1
Time consumption	721	0.362	0.481	0	1
Lack of Know-how	721	0.205	0.404	0	1
Techn. risk to production	721	0.191	0.394	0	1
Risk to product quality	721	0.193	0.395	0	1
Investment priorities	721	0.732	0.443	0	1
Technology and energy price uncertainty	721	0.337	0.473	0	1
Internal disagreement	721	0.161	0.368	0	1
Lack of capital	721	0.498	0.500	0	1
Rented spaces	721	0.329	0.470	0	1

By carrying out a quick analysis of the descriptive statistics, one can see that the most reported barriers are, as expected, monetary related. However, in this sample, only about 12% applied for an Energy Efficiency Fund, and of those who have applied, 70% were accepted. Low percentage of applications together with this kind of barriers suggest that maybe a lack of knowledge about the funds or difficulty in applying for them account for these results.

In fact, applying for an Energy Efficiency Fund is moderately correlated with having an energy manager (≈31%). One can also see that having an energy manager or an energy management system is a fairly correlated with energy audits, energy efficiency funds and decentralized clean energy used.

These facts may indicate that, because many of the MSMEs do not have the possibility to count on an energy manager or energy management system need some other sort of mechanisms to stimulate and help them to realize what is better for their MSME.

To complement the descriptive statistics, table A1 displays the number of enterprises that have adopted exactly one, two, three, four or none of the EEMs under study.

4.3- Econometric procedure for adoption

The methodology applied is based on Olsthoorn et al. (2017), hence, a random-effects probit model was applied where the coefficients do not vary across EEM i.e. the data is stacked to eliminate the technological heterogeneity. By stacking the data, the dependent variable becomes the adoption of any of the four EEMs. Since Yij are dummies that indicate whether an organization i=1,…,704 adopted an EMM j=1,…,4 one can formulate that:

$$y_{ij^*} = \beta_{j'} x_{ij} + \varepsilon_{ij} \quad (1)$$

For the second part of this analysis, probit models were applied for each EEM allowing the analysis and comparison of the relative advantage of each EEM vis-à-vis the previous model (random-effects probit model) and suggesting further discussion of the two currents of the literature used. Probit models are applied assuming that the Error terms are normally distributed. A multivariate probit model is presented in appendix where the error terms capture possible correlations between the dependent variables. The Individual Variance Inflation Factors for independent variables vary between 1.02 and 1.67 so multicollinearity does not seem to be a problem.

4.4 Econometric procedure for barriers

To analyze barriers, and still following the method applied by Olsthoorn et al. (2017), data were stacked by barrier, where y_{ij^*} are dummies that indicate whether the MSME i=1,…,721 reported a barrier j=1,…,12 as having been important or not for their decision not to adopt. Due to the sample size, probits for each barrier are applied but not separated by EEM. And because of possible correlation between barriers, and the impossibility to perform a multivariate probit model due to lack of convergence, a Seemingly Unrelated Regression (SUR) model is applied. The Individual Variance Inflation for barriers vary between 1.03 and 2.29.

5. Results

The results of this research shed light onto new insights about the barriers that the Portuguese MSMEs are facing in the adoption of energy efficiency measures. The Pearson's correlation between dependent variables are all positive and statistically significant. The Pearson's correlation between the independent variables are displayed in Appendix.

5.1- Random effects probit model- Organizational heterogeneity

By analyzing the results of the random-effects probit model, which eliminate the heterogeneity of measures, an analogy with the hypothesis previously explained can be established.

Although the Agency proxies were expected to have a negative impact upon the adoption, that is not completely the case. The coefficients for subsidiary and non-ownership of energy supply equipment are statistically significant at the 0.01% level while being a tenant is not significant in this model. Not possessing ownership of energy supply equipment makes it less likely to adopt an EEM by 16.2%. Unlike the Olsthoorn et al. (2017) and other literature on the matter, evidence that subsidiaries are 4.1% more likely to adopt an EEM can be found.

For absorptive capacity proxies, a positive impact on adoption is expected. The proxies for energy efficiency fund and energy management system are not statistically significant and the causes for that may be the rate of adoption of 11.6% for the first one and the correlation that energy management system has with energy manager (r= 0.5374, p=0.000) and with audits (r=0.40 p=0). For the remaining, energy manager, energy audit and clean energy used they are significant and present marginal effects of 6.1%, 7.2% and 6.2%, respectively.

The control variables show that as the number of employees increases the MSME is less likely to adopt EEMs. The marginal effect for employees on adoption is -0.017.

To avoid collinearity, heating operations is set as base and so the marginal effects of lighting, insulation and heating replacement show the percentage that each one is more or less likely to be adopted in relation to heating operations. Thus, lighting is 40.1% more likely to be adopted than heating operations, and insulation and heating replacement 8.7%, and 3.9%, respectively. These figures show a clear distance between lighting and the other measures.

5.2- Probit models- Heterogeneity of measures

Setting aside the organizational heterogeneity, probit models for each of the four EEMs were applied. This allows one to see which variables directly affect each EEM. While the level of significance varies, all significant variables common to RE model and univariate probit models show the same signals. In these models, a higher number of significant variables are found in more complex EEMs, i.e. heating replacement, heating operations and insulation. The results of the multivariate probit model performed for the four EEMs, in appendix, are in agreement with the results in the univariate probit models showing only small variations in the coefficients.

Starting with absorptive capacity proxies MSMEs that have energy management systems are 11.8% more likely to adopt the EEM heating operations at a level of significance of 1%, however, energy manager is not significant. On the contrary, for heating replacement the variable energy manager is significant (p-val. 0.063) with a marginal effect of 9.1%. The fact that the order of significance is the one shown, highlights a sharing of knowledge and security that an energy manager can transmit to make the replacement, something that the energy management system cannot so easily offer. Still because an energy management system may be cheaper, it is preferable for heating operations. Also, the correlation between the two variables may explain why only one is significant for each of the EEMs (r=0.5374, r=0.000).

Those who have performed an energy audit are liable to register a marginal effect of 9.4% statistically significant at the level of 10% for heating replacement, and 9.3% at the level of 1% for heating operations. For lighting and insulation energy audit is only significant at the level of 14% and 15.7%, respectively.

For decentralized clean energy used, the models have found a synergy between it and insulation. MSMEs that have a decentralized clean energy system (e.g. solar panels) are 10.7% more likely to adopt a more efficient insulation technology. The fact that both are usually technologies placed outside the building may play a role here.

For the last absorptive capacity proxy energy efficiency fund is not significant for any EMM, nevertheless, it possibly shows a lack of knowledge or difficulty in accessing these funds since for those who have applied the rate of acceptance was about 70%.

Regarding agency proxies, no evidence for subsidiaries is found since there is not a reasonable level of significance for any of the EEMs. Having a heating system external shows, as expected, a negative impact for heating replacement and heating operations with marginal effects of -17.1% and -10.5%, respectively. For most of the significant variables, the signs are consistent with literature review. Tenants are 11.7% less likely to adopt the EEM lighting and 10% less likely to adopt the EEM insulation.

The only control variable statistically significant in univariate probit models is the MSME capacity of being manufacturer, therefore having a negative impact on the heating measures both significant at the 5% level. The marginal effect for heating replacement is -6.8% and for heating operations is -7.5%. The fact that manufacturing firms usually have bigger spaces for their activity and use energy more intensively can possibly be the main reason for this to happen.

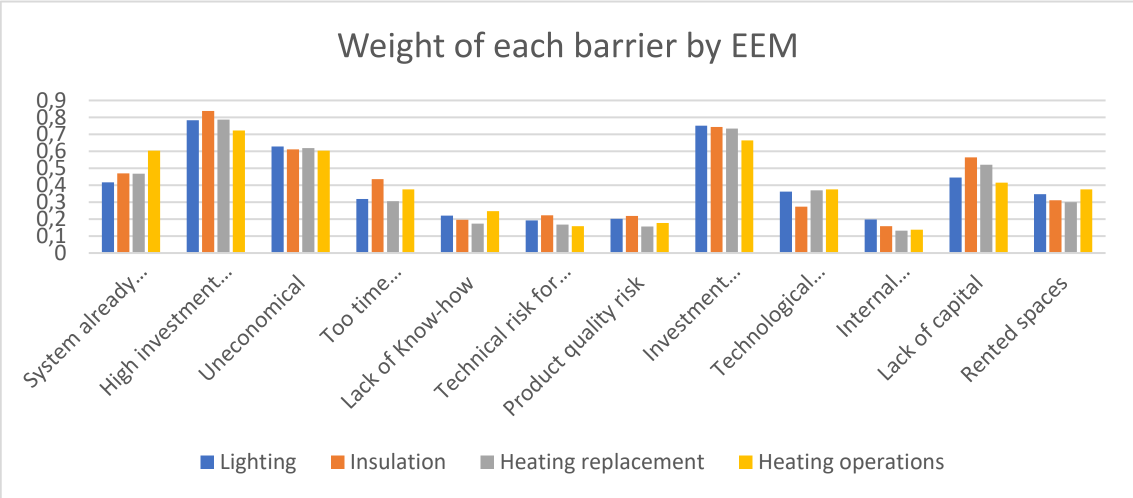
Table 5 - Random effects probit model and univariate probit models for the EEMs: Coefficients, p-values and marginal effects

	Random effects model			Lighting			Insulation			Heating replacement			Heating operations		
	Coeff.	p-val.	dydx	Coeff.	p-val.	dydx	Coeff.	p-val.	dydx	Coeff.	p-val.	dydx	Coeff.	p-val.	dydx
Lighting	1.378***	0.000	0.401												
Insulation	0.299***	0.000	0.087												
Heating replacement	0.136***	0.000	0.039												
Heating operations (base)															
Energy management system	0.131	0.213	0.038	0.124	0.444	0.046	-0.008	0.960	-0.002	-0.026	0.876	-0.007	0.458***	0.007	0.118
Energy manager	0.205***	0.000	0.060	0.204	0.225	0.074	0.115	0.483	0.036	0.317*	0.063	0.091	0.251	0.145	0.061
Energy audit	0.255***	0.000	0.074	0.177	0.140	0.066	0.176	0.157	0.055	0.340***	0.010	0.094	0.388***	0.005	0.093
Decentralized clean energy	0.214***	0.000	0.062	0.228	0.114	0.083	0.329**	0.018	0.107	0.106	0.488	0.029	0.188	0.219	0.045
Energy efficiency fund	-0.024	0.773	-0.007	0.220	0.238	0.080	-0.116	0.517	-0.034	-0.039	0.840	-0.010	-0.166	0.393	-0.035
Subsidiary	0.141***	0.000	0.041	0.065	0.599	0.024	0.113	0.396	0.035	0.199	0.143	0.055	0.215	0.138	0.052
Heating system external	-0.557***	0.000	-0.162	-0.372	0.117	-0.145	-0.387	0.211	-0.102	-1.120**	0.013	-0.171	-0.658*	0.084	-0.105
Tenant	-0.157	0.211	-0.046	-0.310***	0.004	-0.117	-0.340***	0.004	-0.100	0.201	0.100	0.054	-0.095	0.482	-0.021
Manufacturing	-0.097	0.343	-0.028	0.072	0.528	0.027	0.043	0.721	0.013	-0.271**	0.039	-0.068	-0.355**	0.012	-0.075
Ln(employees)	-0.058***	0.000	-0.017	-0.066	0.228	-0.025	-0.054	0.347	-0.017	-0.069	0.253	-0.018	-0.047	0.458	-0.011
Electricity rate (€/kWh)	-0.238	0.148	-0.069	-0.198	0.681	-0.074	0.113	0.823	0.035	-0.185	0.739	-0.049	-0.829	0.179	-0.187
Constant	-0.930***	0.000		0.482***	0.006		-0.618***	0.001		-0.849***	0.000		-0.958***	0.000	
lnsig2u	-44.057														
Rho	0.000														
Obs.	2816														
Number of enterprises	704			704			704			704			704		
Pseudo r^2				0.045			0.035			0.042			0.085		
df	14			11			11			11			11		
Log likelihood				-442.619			-374.306			-330.986			-285.261		
Log pseudolikelihood	-1455.767														
Chi^2	506.036			42.059			27.400			29.080			53.023		
Prob>Chi^2	0.000														
Correctly predicted				63.35%			76.28%			80.68%			83.52%		

5.3-Barriers

As for barriers, the number of respondents that considered the EEM but not adopted it was 213 for lighting, 234 for insulation, 173 for heating replacement and 101 for heating operations thus composing a sample of 721 observations for each barrier. In fig 2, it is possible to see the relevance of each barrier by EEM and, with a quick analysis, one can see that each barrier has a similar impact across the EEMs.

Figure 2 - Weight of each barrier by EEM



The percentage of MSMEs that stated that barriers were relevant to non-adoption in this research are relatively higher than the results reached in other studies such as Olsthoorn et al. in 2017. In line with the described by Cagno & Trianni in 2014, who explain that small companies tend to have higher barriers, and in this work the sample used is composed not only of small and medium sized companies but also of micro enterprises. Even though, the most reported barriers are still financial related i.e. high investment costs, investment priorities, uneconomical and lack of capital. Fleiter, Schleich, et al. (2012) found that because the EEMs under study are related to ancillary processes technical risks may be considered as unimportant. However, and although the descriptive statistics show a low percentage of them reported as important, significance for manufacturing enterprises and for electricity rate can be found.

Analyzing the seemingly unrelated regressions of the probit barriers shown in table 6, one can immediately see the most recurrent barriers that appear significant in the models. Those are system already efficient, high investment costs, lack of know-how, lack of capital and rented spaces.

Table 6 - SUR: probit models for barriers

	Already efficient	Investment costs	Uneconomical	Time consumption	Lack of Know-how	Techn. risk to production	Risk to product quality	Investment priorities	Technology and energy price uncertainty	Internal disagreement	Lack of capital	Rented spaces
Lighting	-0.174***	0.042	0.016	-0.070	-0.047	0.032	0.017	0.086	-0.030	0.064	0.021	-0.046
	(0.003)	(0.391)	(0.790)	(0.228)	(0.336)	(0.506)	(0.726)	(0.107)	(0.603)	(0.154)	(0.724)	(0.234)
Insulation	-0.150**	0.107**	-0.008	0.059	-0.062	0.057	0.029	0.081	-0.122**	0.020	0.151***	0.024
	(0.011)	(0.025)	(0.890)	(0.303)	(0.195)	(0.227)	(0.536)	(0.124)	(0.029)	(0.644)	(0.010)	(0.539)
Heating replacement	-0.149**	0.059	0.003	-0.071	-0.084*	0.007	-0.032	0.075	-0.020	-0.003	0.109*	-0.015
	(0.015)	(0.240)	(0.965)	(0.233)	(0.094)	(0.891)	(0.519)	(0.177)	(0.729)	(0.955)	(0.074)	(0.701)
Subsidiary	-0.051	-0.005	-0.065	-0.034	-0.096**	-0.024	-0.023	0.039	-0.088*	0.004	0.075	-0.027
	(0.284)	(0.896)	(0.167)	(0.460)	(0.013)	(0.530)	(0.550)	(0.360)	(0.051)	(0.918)	(0.111)	(0.373)
Energy management system	0.096*	-0.062	-0.035	-0.124**	-0.078*	0.013	0.009	-0.068	-0.023	0.026	0.030	-0.010
	(0.097)	(0.187)	(0.547)	(0.027)	(0.099)	(0.780)	(0.850)	(0.189)	(0.674)	(0.546)	(0.606)	(0.801)
Energy manager	0.026	-0.058	0.059	0.005	0.001	-0.026	0.068	-0.068	0.026	-0.011	-0.130**	0.016
	(0.652)	(0.213)	(0.294)	(0.935)	(0.978)	(0.567)	(0.139)	(0.185)	(0.627)	(0.788)	(0.021)	(0.670)
Energy audit	0.039	0.033	0.002	0.051	-0.043	-0.007	-0.041	0.028	-0.044	-0.023	-0.029	-0.002
	(0.366)	(0.350)	(0.960)	(0.220)	(0.215)	(0.837)	(0.231)	(0.464)	(0.279)	(0.467)	(0.494)	(0.941)
Energy efficiency fund	-0.062	0.026	0.037	-0.093	-0.025	0.003	-0.033	0.035	-0.038	0.036	0.064	-0.056
	(0.334)	(0.623)	(0.558)	(0.139)	(0.634)	(0.959)	(0.518)	(0.547)	(0.535)	(0.459)	(0.321)	(0.182)
Decentralized clean energy	0.145***	-0.071*	0.010	0.014	0.032	0.018	0.028	-0.008	-0.032	0.014	-0.041	0.009
	(0.004)	(0.085)	(0.839)	(0.775)	(0.435)	(0.647)	(0.488)	(0.851)	(0.502)	(0.720)	(0.413)	(0.774)
Heating system external	0.152*	-0.047	0.075	0.079	0.076	0.031	0.007	-0.026	0.073	-0.007	0.006	0.232***
	(0.063)	(0.482)	(0.356)	(0.322)	(0.253)	(0.633)	(0.919)	(0.724)	(0.347)	(0.907)	(0.940)	(0.000)
Tenant	-0.005	-0.012	-0.036	-0.007	-0.073**	0.018	-0.004	-0.056	-0.103***	0.022	-0.081**	0.684***
	(0.895)	(0.723)	(0.354)	(0.850)	(0.024)	(0.569)	(0.912)	(0.116)	(0.007)	(0.471)	(0.041)	(0.000)
Manufacturing	0.065	0.058*	0.070*	0.050	-0.002	0.105***	0.046	0.064*	0.065	0.051	0.063	-0.008
	(0.123)	(0.094)	(0.095)	(0.223)	(0.964)	(0.002)	(0.175)	(0.093)	(0.109)	(0.110)	(0.139)	(0.760)
Ln(employees)	-0.033	-0.030*	-0.058***	-0.007	-0.021	-0.012	-0.025	-0.014	-0.020	-0.000	-0.050**	-0.005
	(0.109)	(0.076)	(0.005)	(0.716)	(0.210)	(0.477)	(0.136)	(0.438)	(0.316)	(0.993)	(0.015)	(0.701)
Electricity rate (€/kWh)	0.126	-0.011	0.212	0.055	0.095	0.090	0.092	0.239	0.167	0.097	0.599***	0.164
	(0.444)	(0.937)	(0.193)	(0.730)	(0.480)	(0.493)	(0.487)	(0.106)	(0.290)	(0.435)	(0.000)	(0.126)
Constant	0.603***	0.836***	0.738***	0.398***	0.380***	0.143**	0.233***	0.675***	0.480***	0.092	0.491***	0.064
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.034)	(0.001)	(0.000)	(0.000)	(0.144)	(0.000)	(0.241)
Obs.	721											
Pseudo r^2	0.051	0.037	0.020	0.032	0.038	0.018	0.16	0.026	0.033	0.012	0.061	0.545
df	14	14	14	14	14	14	14	14	14	14	14	14
Log pseudolikelihood	-3935.535											
Chi^2	38.599	27.881	14.364	23.699	28.171	13.251	11.706	19.442	24.481	9.036	46.858	862.290
Prob>Chi^2	0.000	0.015	0.423	0.050	0.014	0.507	0.630	0.149	0.040	0.829	0.000	0.000

6. Discussion

6.1- Agency

Unlike what some of the literature review shows for agency theory, being a subsidiary (in the organizational heterogeneity model) does not have a negative impact on adoption. Because of principal-agent relationships between the holding company and its subsidiary or branch, which can be connected to information asymmetry, conflict of interest or moral hazard, a negative impact is bound to be expected. However, subsidiaries have a low correlation with lack of capital or internal disagreement that may justify these findings, which are in accordance with Delmas & Pekovic (2015). This allows one to argue that the transfer of knowledge may surpass the remaining principal agent difficulties. Indeed, it has already been found that the transfer of knowledge of the holding company to its subsidiary contributes at least to a better energy management practice as well as when they buy a new equipment more efficient ones will be considered (Schlomann & Schleich, 2015). Unfortunately, it is not possible to see this impact in any of our univariate probit models even though the p-values for subsidiary in heating replacement and heating operations are under 0.15.

Not possessing the ownership of the heating system hinders the adoption of heating replacement, nonetheless, this model cannot tell how many MSMEs would change it were the system not external to them. The same tendency is found for heating operations but in a lower level of significance and a lower marginal effect. This variable jointly with tenancy (r=0.1048 p=0.000) reinforces the idea that tenancy is not the best proxy for having control over a technology, since many of non-tenants may use, but not own, the same technology as in the case of the heating system (Olsthoorn et al., 2017) which shows a tendency of share between this kind of enterprises.

6.2- Absorptive capacity

Evidence is found that an energy manager influences the adoption of heating replacement but not of heating operations. However, evidence is also found that an energy management system influences the adoption of heating operations but not of heating replacement. These results reveal that a difference between these two variables effectively exists. Firstly, because owning an energy management system may come out cheaper for an enterprise, e.g. the correlation between the energy manager and the number of employees is higher as the number of the latter increases. Secondly, because to take the decision of carrying out a physical change to the heating system an energy manager is preferable since he has the power to explain and the capacity to help in the transition, a dower that an energy management system does not possess. Nevertheless, these two variables are moderately correlated (r=0.5374 p=0.000).

Evidence that energy audits contribute positively to the adoption of heating replacement or heating operations is also found. The fact that energy audits are not significant for lighting and insulation (both p-val. below 0.16) may indicate that energy audits are better suited for more technological EEMs where it is harder for the MSME to implement it by its own. This goes in line with Fleiter, Schleich, et al. (2012) and Schleich & Fleiter (2017) that argue that the quality of the energy audit is an important factor for the adoption of more complex EEMs. Lighting is usually a measure with a lower cost and most of the times do not suffer a radical chance (e.g. lamps can be changed as they get faulty). Also, audits are arguably said to be effective in overcoming agency asymmetry as well as indicative of a more rational use of energy (Olsthoorn et al., 2017).

6.3 – General

According to this information, one can argue that the absorptive capacity factors are a key factor for adopting more efficient and profitable measures, regardless of the fact that these have a higher initial cost. However, considering the number of companies that carried out energy audits together with those that have an energy manager or an energy management system, and considering the number of companies that applied for energy efficiency funds, it is recognized that there may be a lack of clarity of the benefit to each individual but also difficulty in using targeted funds for these types of measures. Therefore, it may be necessary to create policies aiming to inform and assist the MSMEs, thus filling the lack of energy managers and energy management systems since these imply costs that smaller companies cannot afford. Anderson & Newell (2004) state that subsidizing more efficient technologies may be better for adopting an EEM than the use of policies to tax the resource usage. Schleich & Fleiter (2017) reached the conclusion that the German energy audit program accelerated the adoption of EEMs by the MSMEs. In the Portuguese scenario, some policies, like those applied in Germany, may attain the same achievements given the results of this work.

Notwithstanding, energy audits can work as a deterrent mechanism too (Frondel & Vance, 2013). In fact, of the sample group which carried out an energetic audit, 72% adopted an EEM lighting, but the adoption rates for insulation, for heating replacement and for heating operations is only 30%, 24% and 25%, respectively. Nevertheless, it is not possible to precise which technologies were audited.

Although the subsidiaries suffer pressures which can be explained according to the agency theory, they can also benefit from enriching learning moments. As shown, there is a positive impact of the subsidiary companies on the adoption of heating replacement, thus it is a matter of pertinence to propose the creation of policies targeting the holding companies since they can transfer their knowledge to their subsidiaries, as already argued by Schlomann & Schleich, (2015).

7. Conclusion

For this study a specific survey was created and applied to micro, small and medium sized enterprises in Portugal. The objective of such a survey was to create a sample of the contingent of Portuguese enterprises focusing on energy efficiency measures particular to other studies, thus allowing not only to study the precise situation of the country, but also to compare with the studies carried out in other countries. The measures dealt with in this study were four crosscutting, ancillary energy efficiency measures: lighting, insulation, heating replacement and heating operations. The primary data collected enables the understanding of how MSMEs take their decisions concerning matters of energy efficiency.

The hypothesis, based on Olsthoorn et al. (2017), were formulated upon literature on agency theory and absorptive capacity which reflect the principal-agent problematic and the ability to absorb knowledge derived from various sources.

It is noticeable that most of the decisions and barriers considered by MSMEs are not supported either by audits or by energy management professionals since more than 65% of the respondents have never performed an energy audit, and more than 82% do not have an energy manager.

The way our survey was conceptualized does not, unfortunately, make it possible to categorize the usefulness that these buildings have for MSMEs. Therefore, there is a material impossibility to precise the specific number of EEMs that each MSME should have, since the usefulness concerning the building itself is not known.

Given the adoption rates and barriers relevant to non-adoption, together with the fact that more than 88% of the MSMEs have never applied for financial support for energy efficiency measures, indicate that it is necessary to create more aggressive awareness-raising policies, in order to clearly show the individual benefit that each EEM provides to each MSME , as well as to improve the perception of the benefit that is bound to occur in the country by the efficient use of energy.

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9. Appendix

Tabela A1 – Number of EEMs adopted by each MSME		
	Nr. of adopters	%
One EEM	286	40.63
Two EEM	142	20.17
Three EEM	63	8.95
Four EEM	26	3.69
Zero EEM	187	26.56
Total	704	100

Table A2 - Multivariate probit models

	Lighting	Insulation	Heating replacement	Heating operations
Subsidiary	0.072	0.107	0.211	0.194
	(0.563)	(0.406)	(0.118)	(0.178)
Energy managment system	0.114	-0.003	-0.049	0.466***
	(0.481)	(0.987)	(0.789)	(0.004)
Energy manager	0.205	0.116	0.364**	0.272
	(0.215)	(0.488)	(0.042)	(0.111)
Energy audit	0.173	0.167	0.342**	0.399***
	(0.153)	(0.198)	(0.011)	(0.004)
Energy efficiency fund	0.216	-0.132	-0.053	-0.193
	(0.253)	(0.473)	(0.782)	(0.328)
Decentralized clean energy	0.230	0.330**	0.096	0.184
	(0.107)	(0.021)	(0.529)	(0.230)
Heating system external	-0.368	-0.383	-1.052**	-0.626*
	(0.124)	(0.162)	(0.024)	(0.088)
Tenant	-0.308***	-0.343***	0.185	-0.109
	(0.005)	(0.005)	(0.129)	(0.412)
Manufacturing	0.066	0.049	-0.284**	-0.362***
	(0.567)	(0.690)	(0.029)	(0.009)
Ln(employees)	-0.066	-0.055	-0.066	-0.040
	(0.222)	(0.345)	(0.258)	(0.536)
Electricity rate (€/kWh)	-0.191	0.097	-0.111	-0.607
	(0.683)	(0.846)	(0.828)	(0.289)
Constant	0.481***	-0.611***	-0.860***	-1.016***
	(0.006)	(0.001)	(0.000)	(0.000)
Obs.	704			
Log pseudolikelihood	-1365.572			
Pseudo r^2				
Chi^2	148.354			
df	44			
$Prob>Chi^2$	0.000			

Table A3 - Pearson's correlation of independent variables

	1	2	3	4	5	6	7	8	9	10	11
1- Subsidiary	1										
2- Energy m. system	-0.00559	1									
3- Energy manager	0.0334	0.537***	1								
4- Energy audit	-0.0392	0.404***	0.333***	1							
5- E. efficiency fund	-0.0268	0.302***	0.313***	0.328***	1						
6- Decentralized clean energy	-0.0325	0.360***	0.228***	0.238***	0.300***	1					
7- Heating system external	0.0829**	0.00821	0.0115	-0.0411	-0.0563	-0.0362	1				
8- Tenant	0.0654*	-0.214***	-0.185***	-0.225***	-0.209***	-0.243***	0.105***	1			
9- Manufacturing	-0.00508	0.197***	0.172***	0.179***	0.130***	0.0872**	-0.0838**	-0.165***	1		
10- Ln(employees)	0.0214	0.354***	0.343***	0.355***	0.343***	0.251***	0.0151	-0.222***	0.315***	1	
11-Electricity rate (€/kWh)	0.0338	-0.0159	-0.039	0.0287	-0.0397	-0.0331	-0.0211	0.0205	-0.0677*	0.00703	1