Do financial and fiscal incentive policies increase the energy efficiency ratings in residential properties? A piece of empirical evidence from Portugal

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Abstract: The effect of financial and fiscal incentive policies on the energy performance of residential properties in 19 districts of Portugal from 2014 to 2021 was investigated through econometric modelling. The Ordinary Least Squares (OLS) with the random-effects model was used to realise this empirical approach. The results indicated that the income per capita has a negative impact on housing with higher energy efficiency (certificates **A⁺**, **A**, and **B**). This result suggests that the income in Portugal is insufficient and impedes investment in highly energy-efficient housing. Consumers choose the less costly lower-efficiency housing certified in categories (**C**, **D**, **E,** and **F**). The impact of consumer credit is positive for higher-efficiency housing and negative for lower-grade certificates. As for fiscal policies, the effect is also positive for higher-grade certified housing (**A⁺**, **A**, **B**, and **B⁻**).

Keywords: Econometrics; Energy consumption; Energy efficiency; Policies; Portugal.

Acknowledgements: CeBER R&D unit funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., project UIDB/05037/2020.

1. Introduction

Today, energy demand is increasing due to the over-consumption of communities. Consequences of high energy consumption include severe climate change, unexpected storms and floods, rising temperatures, and environmental pollution. The three most crucial energy consumption sectors are industry, building and transportation (European Commission, 2019). Increasing energy efficiency in these sectors can significantly reduce emissions of polluting and destructive gases and thus reduce environmental consequences because increasing energy efficiency is the guaranteed and affordable key to reducing greenhouse gas emissions and increasing energy security.

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The residential sector is an important goal for energy efficiency and resource conservation policies because this sector is responsible for more than a third of the world's final energy consumption and nearly 40% of total pollutant emissions (IEA, 2021). On the other hand, the energy demand of the residential sector is increasing due to the improvement of energy access, the increase in the use of energy-consuming devices and the rapid growth of building construction (IEA, 2021). In addition, the residential sector plays a pivotal role in reducing energy consumption due to its high potential in the use of renewable energy and new technologies (Bonifaci & Copiello, 2017). Therefore, improving energy efficiency in the residential sector is a priority of energy policies in most countries (Nejat et al., 2015). Nevertheless, energy consumption in the residential sector is a complex issue, explained by different factors. In addition, the improvement of energy efficiency in the residential sector over the past decades has not been rapid due to various reasons such as market and behavioural barriers (e.g., Gouveia et al., 2017; and Trotta et al., 2018).

The residential sector in the European Union (EU) also consumes about 25% of total energy (Gouveia et al., 2017). However, the share of energy consumption in the residential sector in different countries of the EU varies due to different climatic conditions, access to energy resources, income levels, economic structures, energy infrastructure, different stages of energy efficiency and the provision of different energy services. The lowest energy consumption is in southern European countries (e.g., Gouveia et al., 2017; and Trotta et al., 2018). The residential sector of Portugal is one of the main factors in this country's final consumption of energy due to severe climate change and severe dependence on fossil fuels (Fonseca, 2014). About 17% of Portugal's total energy consumption comes from its residential sector (Portugal / Energy Profile, 2021). In addition, about 15% of buildings in Portugal were built before 1945 and about 70% before 1990 (INE, 2017). Therefore, the high percentage of old buildings has caused Portugal to rank second in buildings with roofs leaking, wet walls and worn window frames compared to other EU members (Eurostat, 2021a). In addition, Portugal has, on average, lower levels of thermal resistance in the residential sector than other European countries (Gouveia & Palma, 2021). Although most Portuguese buildings are old and inefficient in terms of energy consumption, this country has the second-lowest final energy consumption per capita in the residential sector in the EU, behind only Malta (Eurostat, 2021b). However, Portugal consumes less energy per capita than the EU average. Nonetheless, practical programs to improve energy efficiencies, such as efficient heating, cooling and lighting equipment, efficient buildings and new energy technologies, lag behind other European countries (BPIE, 2017). Therefore, increasing energy efficiency for the residential sector in Portugal can provide significant social and environmental benefits.

Portugal's National Energy and Climate Plan (NECP) sets 2030 targets for a 45-55% reduction in total GHG emissions compared to 2005 levels and final energy demand less than 14.9 million tonnes of oil equivalent compared to 17.1 million tonnes of oil equivalent in 2019. In addition, Portugal is one of the first countries in the world to set 2050 carbon neutrality goals (IEA, 2021). To achieve these goals and reduce environmental consequences, the Portuguese government has supported various measures and programs in the residential sector. One of these programs is the EPC guidelines for analysing the energy performance of the residential properties sector. It helps to clarify information and reduce information asymmetry about the energy performance of small residential and commercial units to improve the energy efficiency of buildings (e.g., Abela et al., 2016; Collins & Curtis, 2018; and Lee et al., 2018). Therefore, EPC measures the energy efficiency of the building and calculates the information of building characteristics such as estimating the need for heating and cooling energy, final energy consumption, evaluation of retrofitting measures, and so forth (e.g., Dell Anna et al., 2019; and Gouveia & Palma, 2019). According to the building energy performance certification system, all residential and commercial buildings must be audited to receive their energy certification during built or renovation, and each time they change ownership or lease (IEA, 2021). The residential sector's energy performance requirements were first introduced in 2008 in all new buildings. In the case of existing buildings, since 2009, these have to possess a valid certificate. Indeed, at the signing of the respective sale, rental or lease contract, the EPC became mandatory with the introduction of Decree-Law no. 118/2013 of August 20 2013. In Portugal, in 2008, was emitted 13,799 certificates in the residential sector. This value more than doubled in 2009, where were emitted 188,716. Nevertheless, this value decreased drastically between 2011-2013 due to the financial and economic crisis in the EU, where Portugal was one of the most impacted countries. The number of new certificates registered returned to growth since 2014 and in 2020 reached a value of 198,090 certificates emitted in the residential sector (see **Figure 1** below).

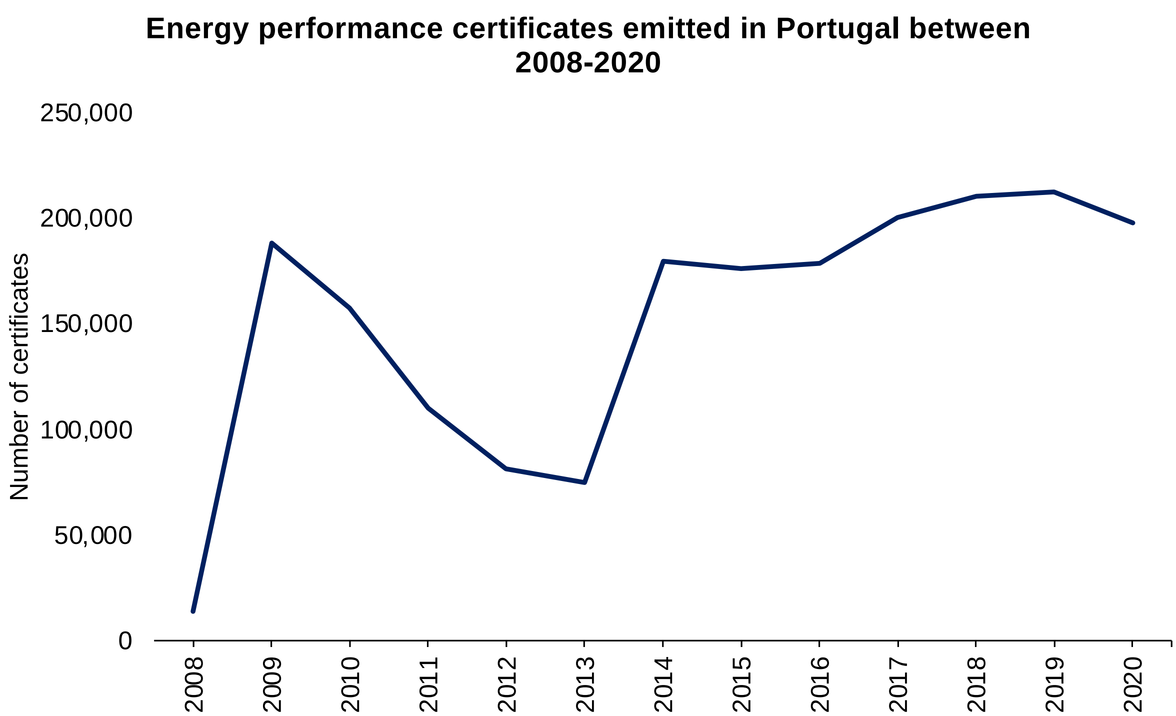


Figure 1. Energy performance certificates were emitted in the residential sector in Portugal between 2008-2020. The authors created this figure with data from Observatório da Energia (2021).

The EPC system in Portugal consists of 8 degrees classified from **A+** (**Very efficient**) to **F** (**Inefficient**) (see **Figure 2** below)

Figure 2. Energy class in Portugal according to Sistema de Certificação Energética dos Edifícios (SCE) (2021).

These certificates include features such as energy consumption for air conditioning, hot water production and necessary measures to reduce energy consumption, and the characteristics of the building, such as year of construction, type of villa or apartment property, area, and so forth, affect it. From 2008 to 2020, about 1,918,147 energy certificates emitted in the residential sector were issued in Portugal. Between 2008 and 2020, about 2.11 per cent of Portuguese residential buildings ranked (**A+)**, 8.11 per cent ranked (**A**), 14.48 per cent ranked (**B**), 12 per cent ranked (**B-**), 25.92 per cent ranked (**C**), 19.17 per cent ranked (**D**), 11.41 per cent ranked (**E**), and 6.01 per cent ranked (**F**) (ADENE, 2021b) (see **Figure 3** below)

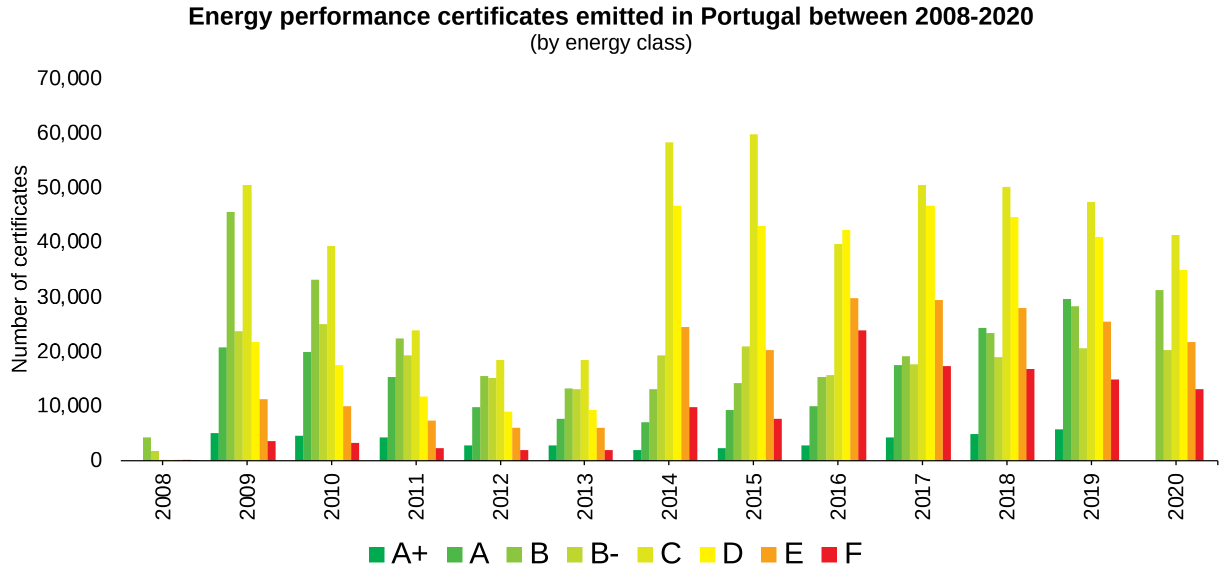


Figure 3. Energy performance certificates by energy class emitted in Portugal between 2008-2020. The authors created this figure with data from Observatório da Energia (2021).

Moreover, between 2008 to 2020 were emitted 40,553 certificates (**A+)**, 170,435 (**A**), 277,798 (**B**), 230,165 (**B-**), 497,174 (**C**), 367,743 **(D**), 219,009 (**E**), and 115,290 (**F**) for residential sector in Portugal.

Although EU countries have a common goal for energy efficiency in the residential sector, different governments use different tools to achieve their goals (Thonipara et al., 2019). Some countries have introduced building performance standards, information tools, building energy codes, and so forth to reduce energy consumption (e.g., Yao et al., 2005; Broin et al., 2015; and Trotta et al., 2018). Some also suggested financial instruments such as subsidies and tax credits (e.g., Neveu & Sherlock, 2016; Bonifaci & Copiello, 2017; and Villca-Pozo & Gonzales- Bustos, 2019). Some studies argue that energy standards may not be fully achieved due to implementation problems. Nevertheless, combining building energy regulations with financial incentives will provide more complete results (e.g., Nadel & Geller, 1996; and Lee & Yik, 2004). Trotta et al. (2018) concluded that although Finland and the United Kingdom implemented various energy efficiency tools in the residential sector but did not achieve the desired goal, Hungary, Spain, and Italy achieved the desired results using financial incentives.

The goal of building energy performance policies in the EU was initially to set minimum requirements for the housing sector, but over time governments have introduced other tools, including financial and fiscal incentives, as building performance policy tools. Financial and fiscal incentive policies aim to rehabilitate the city, increase the rate of building renovation, insulation, purchase efficient equipment, and achieve optimal performance standards in the residential sector (Portugal / Energy Profile, 2021). Given the old age of most buildings in Portugal and the fact that renovation costs include about 34% of the total cost of the building sector in this country (INE, 2017). Therefore, increasing financial and fiscal incentives can be important in improving the energy efficiency of this country's residential properties sector. Numerous studies have shown the effectiveness of energy policy tools on energy efficiency (e.g., Hoicka et al., 2014; Heffron & McCauley, 2017). Some studies also find that tax incentives, subsidies, and tax credits increase energy efficiency (Shen et al. 2016; Chen & Hong, 2015; Villca-Pozo & Gonzales- Bustos, 2019; Haixiong et al., 2020; Liu et al., 2020; He & Chen, 2021; Dehghani et al., 2021; Yang et al., 2021; Nundy et al., 2021; and Mehrpooya et al., 2021). Some studies have also reported the effectiveness of financial and fiscal incentive policies on energy efficiency in the residential sector in various EU countries (Bonifaci et al., 2016; Trotta et al., 2018). Some researchers have also shown that financial incentives significantly increase energy efficiency while informational and educational measures do not have a considerable effect (Filippini et al., 2014). However, some studies also argue that financial and fiscal incentives are obstacles to optimal energy efficiency strategies due to these schemes' growing number and continuous evolution (e.g., Murphy et al., 2012; Berardi, 2013; Wong & Abe, 2014; and Moroni et al., 2016).

As mentioned above, previous studies in EU countries on the effect of financial and fiscal incentive policies on energy efficiency in residential properties have not reached a single conclusion. In addition, most studies analysed various energy policy instruments in the residential sector in a group of EU countries. Considering that the implementation of well-designed policies can lead to significant energy savings, the EU member states must use energy policy tools tailored to their economic and energy structures in the residential sector. This procedure will allow them to achieve the highest energy efficiency (e.g., Geller et al., 2006; and Cucchiella et al., 2013). Hence, in this study, intending to complete previous studies and find appropriate energy policy tools in the residential sector, we sought to answer the question, **Do financial and tax incentive policies effectively increase the energy efficiency of Portuguese residential properties?** Thus, the purpose of this study is to investigate the impact of financial and fiscal incentive policies on the energy efficiency of residential properties in 19 districts in Portugal from 2014 to 2021 using the Ordinary Least Squares (OLS) with random effects. In addition, other independent variables (including codes and standards, information and education policies, GDP per capita, and consumer credit per capita) are used as control variables.

Given that the residential properties sector has (i) high potential to reduce energy consumption, (ii) increase energy efficiency, and (iii) increase the use of renewable technologies, then policy implications of improving energy efficiency in this sector can boost air quality, reduce polluting gases emissions, improve the quality of people's living environment, which increases the health of building occupants (Dongyan, 2009). Furthermore, to our knowledge, this study is the first to examine the impact of financial and fiscal incentive policies on energy efficiency in the Portuguese residential sector.

This topic of investigation is new and not explored by literature and opens new study opportunities regarding this issue. Therefore, this investigation will contribute to the literature, introducing a new analysis related to the impact of financial and fiscal incentive policies on the energy efficiency ratings in Portugal. Furthermore, this investigation will also contribute to the literature by introducing macroeconomic and econometric models that were not explored in this research topic. Moreover, this investigation is innovative because it is the first study that uses a macroeconomic and econometric approach to identify the effect of financial and fiscal incentive policies on the energy efficiency ratings in Portugal.

Finally, this empirical investigation will help governments and policymakers develop more initiatives to promote energy efficiency in residential properties. It also can provide in-depth insights into the effectiveness of financial and fiscal incentive policies in Portuguese residential properties. Moreover, saving energy resources, reducing greenhouse gas emissions, optimising energy efficiency policies in the residential sector in Portugal can discuss the challenges to energy efficiency in the residential sector and suggest possible solutions to achieve safe and sustainable energy for the future.

The rest of this article is set out as follows**.** **Section 2** provides an overview of the literature. **Section 3** describes the data and model used in the study. **Section 4** presents the empirical results. **Section 5** discusses the main findings, and finally, **Section 6** presents the conclusions.

2. Literature review

Governments use policy instruments to advance economic development and achieve the desired goals. The residential sector is one of the sectors in which governments use policy instruments. Policy instruments in the residential sector include specific rules, regulations, economic and financial incentives, labels, and certifications (BEE). This section reviews previous studies on financial incentives (taxes, subsidies, building energy codes, building productivity standards).

Several studies have examined financial incentives and standard energy efficiency policies. Filippini et al. (2014) examined the effect of energy policy instruments on the energy efficiency of the residential sector of 27 EU member states during the period 1996-2009. The results showed that financial incentives and energy performance standards play an essential role in promoting energy efficiency, while informative measures do not have a significant effect. Hoicka et al. (2014) examined energy efficiency resilience in Waterloo, Canada, during 1999-2011. The results showed that performance-based incentives have the most significant potential for energy savings. Shen et al. (2016) investigated key policy instruments to improve building energy efficiency in seven selected countries and regions (United States, European Union, Australia, China, Japan, Singapore, and India). This article uses three policy instruments: mandatory government tools, economic incentives, and voluntary planning tools. This study showed that different countries had made good progress in achieving better energy efficiency in buildings by adopting different policies. Finally, Shah & Phadke (2011) examined the economic incentives for energy efficiency in the building sector in the United States. They summarised the main incentive programs in eight groups. The results showed that financial incentives are the most effective policy measures used to curb energy demand growth in the residential sector.

Using policy instruments, Trotta et al. (2018) examined energy efficiency in the residential sector among selected European countries (Finland, Italy, Hungary, Spain, and the United Kingdom). The analysis showed that the UK government had implemented a wide range of policies to improve energy efficiency. However, the current situation seems to be more problematic than in other countries. On the other hand, Finland's lack of adequate and targeted policies has increased energy consumption. In Hungary, Spain, and Italy, attractive measures have been found, especially financial incentives. Aydin & Brounen (2019) studied the impact of energy efficiency policies on residential energy consumption across Europe during 2015-2016. The results show that both energy labelling requirements for home appliances and strict building standards rules reduce residential energy consumption. Finally, Wang et al. (2019) examined the effect of energy efficiency standards on reducing energy consumption (residential electricity) in China's residential buildings sector. The results showed that the implementation of 65% of the energy efficiency standards of buildings leads to a reduction of 41% compared to inefficient buildings.

Other researchers have studied the effects of another fiscal policy, "tax policy", on energy efficiency in the residential sector. The results of a study by Bonifaci & Copiello (2017) examining tax incentive policies for energy resilience in Italian residential buildings showed that the analysed programs are not entirely capable of stimulating an increase in the minimum energy standards in residential buildings. Neveu & Sherlock (2016) assessed tax credit for residential energy efficiency. The results show that the tax credit for residential energy efficiency is vertically unequal. Taxpayers living in states with colder winters are more likely to claim tax credits for residential energy efficiency, while taxpayers in higher-cost states claim higher tax credits.

On the other hand, several researchers have studied the effects of subsidy-based policy instruments on the energy efficiency of the residential sector. He & Chen (2021) examined the incentive effects of various government subsidy policies on green buildings. Four different subsidy policies were considered: (i) subsidies paid to developers alone, (ii) subsidies paid to consumers alone, (iii) subsidies paid to both, and (iv) non-payment of subsidies. The results of the analysis showed that subsidies are a positive incentive for the development of green buildings. Simultaneous subsidies to developers and consumers yielded the most significant benefits for developers and the highest social welfare. Chen & Hong (2015) examined the design of effective subsidy policies to develop green buildings. The results showed that construction costs, end-user transfers, and developer priority over green buildings from policy benefits affect subsidy policy. Fan et al. (2013) studied economic incentive policies to promote green buildings in China. The Chinese green building is still in its infancy. Based on the analysis of the current situation and the lack of economic incentive policies in China's green building, this article presents some suggestions on economic incentive policies such as special funds, tax incentives, and financial subsidies, and so forth to promote green building development.

Other studies have examined the effects of the Energy Conservation Building Codes. Yu et al. (2017) studied building energy efficiency improvement in India, resulting from building code energy efficiency policies. The results showed that without creating energy policies, building energy use in Gujarat will increase 15 times in commercial buildings and four times in urban residential buildings between 2010 and 2050. Energy codes for buildings will improve energy efficiency in commercial facilities and could reduce building electricity consumption in Gujarat by 20% by 2050. Ameer & Krarti (2016) investigated the impact of subsidies on the energy efficiency of Kuwaiti residential buildings using energy codes. The analysis shows that households and the government benefit from a strict energy efficiency code even below the highly subsidised energy price. The result was that energy bills would be reduced by 21 per cent for households, while Kuwaiti government energy subsidies would be reduced by 28 per cent from current policy. In addition, financing the Energy Efficiency Program costs can be recovered within two years due to revenue from rising electricity prices.

3. Data and Method

This section will be divided into two parts. The first will approach the group of countries and data/variables used in this investigation, while the second will show the method.

3.1 Data

In this subsection, we will present the data/variables utilised in this empirical analysis. Therefore, nineteen portuguese districts were selected (e.g., **Aveiro**, **Beja**, **Braga**, **Bragança**, **Castelo Branco**, **Coimbra**, **Évora**, **Faro**, **Guarda**, **Leiria**, **Lisboa**, **Madeira**, **Portalegre**, **Porto**, **Santarém**, **Setúbal**, **Viana do Castelo**, **Vila Real**, and **Viseu**) for the period between 2014 to 2021. **Figure 4** below show the districts that were selected in Portugal.

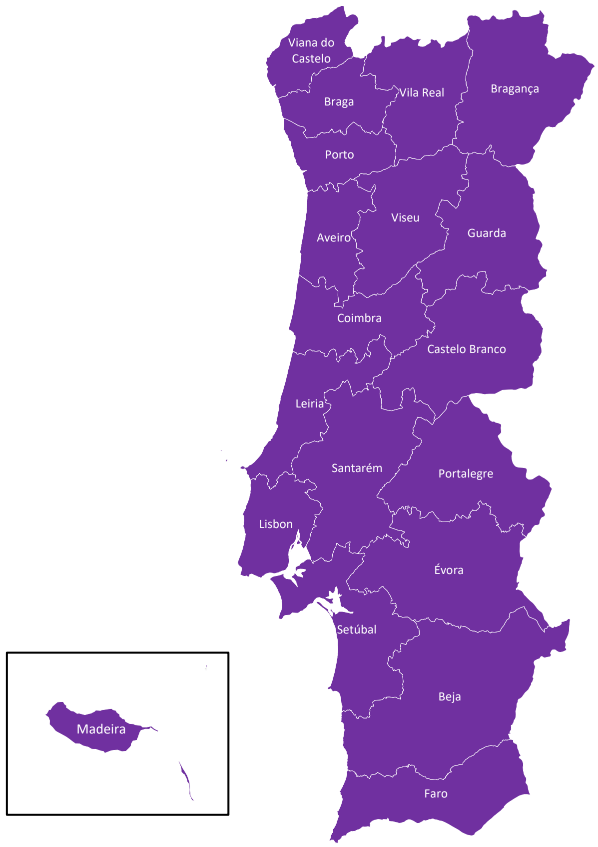


Figure 4. Portuguese districts. The authors created this figure.

Indeed, these districts were selected due to data availability in *Sistema de Certificação Energética dos Edifícios* (SCE) (2021). This investigation used data from 2014-2021 due to data disponibility for all Portuguese districts in the SCE. Therefore, the variables that will be used to find if the energy policies encourage a higher energy efficiency of residential properties in Portugal, through the number of energy efficiency performance certificates (EPCs) emitted, are shown in **Table 1** below.

Table 1. Variables' description

Dependent variables		
Variable	**Description**	**Source**
EPC_A+	Number of emitted EPCs rating A+	Sistema de Certificação Energética dos Edifícios (SCE) (2021)
EPC_A	Number of emitted EPCs rating A	Idem
EPC_B	Number of emitted EPCs rating B	Idem
EPC_B-	Number of emitted EPCs rating B–	Idem
EPC_C	Number of emitted EPCs rating C	Idem
EPC_D	Number of emitted EPCs rating D	Idem
EPC_E	Number of emitted EPCs rating E	Idem
EPC_F	Number of emitted EPCs rating F	Idem
Independent variables		
FFIP	Fiscal and financial incentive policies (FFIP) for energy efficiency for the residential sector. This variable includes grants and subsidies and tax relief policies	IEA (2021)
GDP	GDP per capita constant (Euros)	PORDATA (2021)
CCPC	Consumer credit per capita (CCPC) is granted to customers by banks, savings banks and mutual agricultural credit banks (Euros)	Idem

All energy performance certificates (**EPCs**), i.e. emission certificates for new and existing residences, that are the number of certificates emitted was constructed in accumulated form for each district until May 2021, and **FFIP** (national policies in force) accumulated form until May 2021.

For the variables **CCPC** and **GDP**[2], we use data until 2020. As we already know, the EPCs are energy performance certificates. In Portugal, the EPCs are used to summarise the energy efficiency of residential properties. Moreover, in Portugal, the residential properties are rated between A+ (**Very efficient**) and **F** (**Inefficient**). These certificates include energy consumption characteristics for air conditioning and hot water and measures to reduce energy consumption. Some of these measures can be, for example, installing double glazing or reinforcing insulation. This certificate is valid for ten years for residential buildings. Indeed, these certificates are determined by the property's location, the year it was built, whether it is a building or a house, the floor and the area, and the composition of its surroundings (walls, roofs, floors, and glazing). The equipment associated with air conditioning (ventilation, heating, and cooling) and domestic hot water production also influence.

Indeed, Portugal's energy efficiency performance scale, resulting from the ratio between the primary energy demand Ntc of a building/residence and the respective limit value Nt. **Table 2** below show the reference consumption by EPC.

[2] We used an estimated GDP per capita for 2020.

Table 2. Reference consumption by energy class.

EPC	R=Ntc/Nt	Consumption of energy reference in (%)
	High energy efficiency	
A+	R ≤ 0,25	25% or less
A	0,25< R ≤ 0,50	Between 25% to 50%
B	0,50< R ≤ 0,75	Between 50% to 75%
B-	0,75< R ≤ 1,00	Between 75% to 100%
	Low energy efficiency	
C	1,00< R ≤ 1,50	Between 100% to 150%
D	1,50< R ≤ 2,00	Between 150% to 200%
E	2,00< R ≤ 2,50	Between 200% to 250%
F	R>2,50	More than 251%

Notes: This table was based on data from the *Sistema de Certificação Energética dos Edifícios* (SCE) (2021).

Regarding the variable **GDP**, as we do not have data for income per capita for each district just by Nomenclature of Territorial Units for Statistics (NUTS), we used the national income for each cross. Moreover, it was impossible to construct this variable using the income per capita for each district municipality because we do not have data. The same occurs with the variable the **CCPC**, where we do not have data for consumer credit granted in per capita values to customers by banks, savings banks, and mutual agricultural credit banks in each district just by NUTS. Therefore, we used the consumer credit granted in per capita values at the national level for each cross in this case.

Moreover, the variable **FFIP** was used at the national level were used. These are policies that encourage the energy efficiency and quality standards of residential proprieties in Portugal. Indeed, the use of national-level policies is because the districts and municipalities do not have the autonomy to legislate or create their policy of energy efficiency and quality standards in houses or proprieties in Portugal. Therefore, these variables were built in accumulated form, where each policy that was created is represented by (1) accumulated over other policies throughout its useful life or end (e.g., 1, 1, 2, 2, 2, 3,3). In literature, this method of constructing this variable was used for the first time by Fuinhas et al. (2017).

3.2 Method

This subsection presents the main method used in this empirical investigation and the preliminary and post-estimation tests necessary.

3.2.1. Ordinary Least Squares (OLS) with random effects

This subsection will present the estimation method. Therefore, Ordinary Least Squares (OLS) with random effects will be used. The OLS with random effects estimates the slope and intercepts for a set of observations and other estimates of mean response for the predictors using the conditional mean function in this study. Therefore, this model approach will assess the impact of the financial incentive policies on energy efficiency performance in residential properties in Portugal. In this investigation, we estimate the following panel regression for each energy class,

$$LogEPC\_k_{i,t} = \alpha^k + \beta^k X_t + c_i^k + u_{i,t}^k, \qquad \textbf{(1)}$$

where $LogEPC\_k_{i,t}$ represents the natural logarithm of the cumulative number of emitted EPC's of class k (k = **A+, A, B, C, D, E,** and **F**), for district i, in the year t, $X_t = [LogGDP_t, LogFFIP_t, LogCCPC_t]$ is the vector of the natural logarithm of the covariates in the year t, α^k, and β^k are the constant term and the covariates' coefficients for regression k, c_i^k, and $u_{i,t}^k$ are the unobserved effect of district i and the idiosyncratic error term for equation k, respectively.

Indeed, this method was selected to carry out this investigation through the results from the Hausman test mentioned in **subsection 3.2.2,** and their results will be evidenced in **section 4**. Moreover, this method which is widely used by economists and areas of science has some advantages. One of them is the integrity of data use because that the fundamental elements of diverse scales in a sample are considered (Huang & Chen, 2015). In addition, this method can create robust estimations in the presence of panel data and shocks (that is the case of this investigation).

3.2.2. Preliminary and Post-estimation tests

This subsection will present the pre-estimation and post-estimation tests performed to evaluate the adequacy of the model approach. Therefore, before estimating the model regression, these tests are necessary to detect the proprieties of variables used in this empirical study and verify the existence of singularities, which is not considered and could lead to inconsistent and incorrect interpretations (Koengkan & Fuinhas, 2021). Thus, we conduct the tests present in **Table 3** below.

Table 3. Preliminary tests

Test	Finality
Skewness/Kurtosis test for normality (D'Agostino, 1990)	This test checks the normality based on skewness and another based on kurtosis and then combines the two tests into an overall test statistic. The null hypothesis states that data is normally distributed. This test achieves a higher power than the simple skewness and kurtosis tests for normality by combining them.
Shapiro-Wilk test for normality (Shapiro & Wilk, 1965)	This test verifies the normality of the model. Based on the first two moments of the order statistics, this test shares the same null hypothesis as the previous one.
Levin-Lin-Chu panel unit root test (Levin et al., 2002)	This test verifies the presence of unit roots in the variables. The null hypothesis is that variables are non-stationary. Stationarity is crucial to avoid the well-known problem of spurious regressions.
Hausman test (Hausman, 1978)	This test identifies heterogeneity, i.e., whether the panel has random-effects (RE) or fixed-effects (FE). This test is based on random and fixed effects estimates. The null hypothesis states that the random estimator is consistent. However, this hypothesis fails when the unobserved effect is correlated with the covariates, and the fixed effects estimator should be used.

After the estimation of model regression, the statistical properties of the residuals were tested. Thus, the absence of heteroscedasticity, autocorrelation, and cross-sectional dependence was assessed (see **Table 4** below). If any of these features are present, the estimated standard errors are biased, and we must compute robust standard errors.

Table 4. Post-estimation tests

Test	Finality
Wooldridge test for autocorrelation (Wooldridge, 2002)	This test analyses if the idiosyncratic residuals are correlated. The null hypothesis is the absence of autocorrelation.
Breusch-Pagan test for heteroscedasticity (Breusch & Pagan, 1980)	This test identifies the presence of heteroscedasticity. The null hypothesis of this test states that the idiosyncratic errors are homoscedastic.
Cross-sectional dependence test (Pesaran, 2004	According to the null hypothesis, the idiosyncratic errors are uncorrelated across units, while, under the alternative hypothesis, they may be cross-sectionally correlated.

Then, this investigation will follow the following conceptual framework (see **Figure 5** below) that highlights the methodological approach. Indeed, this conceptual framework was developed by Koengkan & Fuinhas (2021).

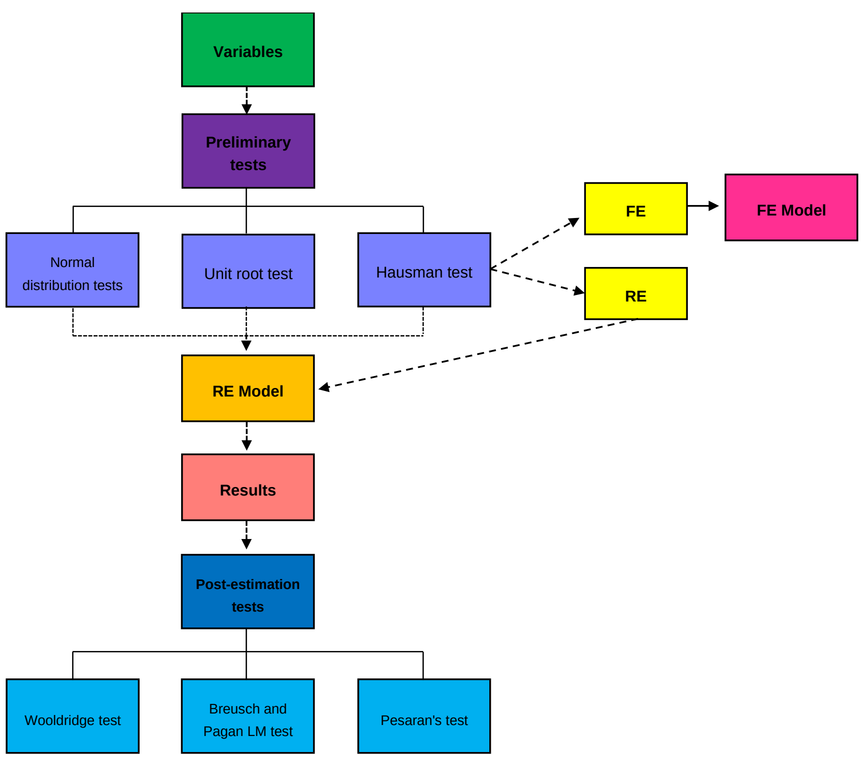


Figure 5. Conceptual framework. The authors created this figure; **Notes**: (RE) denotes the random-effects model, while (FE) is the fixed-effects model.

The empirical analysis was carried out using the econometric software **Stata 17.0.** Moreover, this investigation will use the following Stata commands (e.g., *sum*, *sktest*, *swilk*, *xtunitroot llc*, *hausman,* and *xtreg with option re*). The following section will present the empirical results of this investigation.

4. Empirical results

This part of the study aims to describe and explain the empirical results, starting with the preliminary tests, post estimation test and presenting the main model regression results. First, all variables are transformed to natural logarithms to harmonise the interpretation of results and linearise the relationships between variables. Then, the variable's descriptive statistics are presented (**Table 5** below).

Table 5. Descriptive statistics

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std.-Dev.**	**Min.**	**Max.**
LogEPC_A +	133	4.6870	1.3530	1.0986	7.0859
LogEPC_A	133	5.9091	1.4422	2.7725	8.8037
LogEPC_B	133	6.2837	1.0377	4.1588	8.8190
LogEPC_B_-	133	5.8975	1.0855	4.1271	8.3997
LogEPC_C	133	6.7108	1.3239	4.6151	9.7247
LogEPC_D	133	6.9506	1.1728	5.1059	9.5685
LogEPC_E	133	6.7253	0.9328	4.8598	9.0605
LogEPC_F	133	6.3346	0.8258	2.8903	8.4980
LogFFIP	133	1.5566	0.2269	1.0986	1.7917
LogGDP	133	9.8213	0.0449	9.7564	9.8924
LogCCPC	133	8.7079	0.1348	8.5101	8.9349

Notes: (Log) denotes variables in the natural logarithms; Obs. denotes the number of observations in the model; Std.-Dev. denotes the standard deviation; Min. and Max. denote minimum and maximum, respectively; the command *sum* of Stata was used.

Descriptive statistics in **Table 5** above show that more certificates are emitted for less energy-efficient residences (**C**, **D**, **E**, and **F**) than for more efficient ones. There are also more information and education policies than any other kind, but the number of fiscal and financial incentive policies is the most variable during the time studied. Normality was tested with skewness and kurtosis test and with Shapiro-Wilk test to learn about the distribution of the variables (**Table 6** below).

Table 6. Normal distribution tests

Variables	Obs.	Skewness	Kurtosis	Skewness/Kurtosis test	Shapiro-Wilk test
				Prob>Chi2	Prob>z
LogEPC_A_+	133	0.0002	0.7615	0.0031***	0.0000***
LogEPC_A	133	0.7129	0.0131	0.0493**	0.1728
LogEPC_B	133	0.3415	0.0380	0.0755*	0.1176
LogEPC_B_-	133	0.0158	0.2321	0.0338**	0.0004***
LogEPC_C	133	0.0360	0.0073	0.0065***	0.0002***
LogEPC_D	133	0.0299	0.0406	0.0179**	0.0002***
LogEPC_E	133	0.0513	0.1263	0.0523**	0.0026**
LogEPC_F	133	0.0005	0.0004	0.0001***	0.0003***
LogFFIP	133	0.0001	0.7686	0.0013***	0.0000***
LogGDP	133	0.1606	NA	NA	0.1775
LogCCPC	133	0.5774	0.0000	0.0007 ***	0.0189**

Notes: ***, **, * denote statistically significant at 1%, 5%, and 10%, levels respectively; (Log) denotes variables in the natural logarithms; the command *sktes*t and *swilk* of Stata were used; NA denotes not available.

The results in **Table 6** show that variables are positively skewed and with lighter tails meaning fewer extreme values. Regarding energy certificates, variables **LogEPC_A+** and **LogEPC_A** stand out, where the first has few extreme values, but the second is highly positively skewed. As for policies, **LogFFIP** also has a few extreme values. For **LogGDP**, the kurtosis test results are not available. The D'Agostino et al. (1990) omnibus skewness/kurtosis test results allow to reject normal distribution of data. Using the Shapiro-Wilk test, the normal distribution can also be rejected for all variables, except **LogEPC_A**, **LogEPC_B**, and **LogGDP**, which are normally distributed. Hence, data is not normally distributed. Furthermore, cross-sectional dependence was tested with first-generation panel Levin-Lin-Chu (2002) unit-root test (**Table 7** below).

Table 7. Unit Root test

Variables		Levin-Lin-Chu unit-root test (LLC-test)			
		Without trend		With trend	
	Lags	Adjusted t		Adjusted t	
LogEPC_A_+	1	-10.3574	***	-35.9503	***
LogEPC_A	1	-5.9879	***	-9.4100	***
LogEPC_B	1	-5.7227	***	-25.6855	***
LogEPC_B_-	1	-21.1892	***	-18.6313	***
LogEPC_C	1	-71.5136	***	-55.9105	***
LogEPC_D	1	-16.1621	***	-17.0379	***
LogEPC_E	1	-13.2848	***	-61.0671	***
LogEPC_F	1	-38.5522	***	-1.1e+02	***
LogFFIP	1	-6.8679	**	2.5922	
LogGDP	1	-12.5721	***	43.0495	
LogCCPC	1	10.8918		-1.3e+02	***

Notes: ***, ** denote statistically significant at 1%, and 5% levels respectively; (Log) denotes variables in the natural logarithms; The command *xtunitroot llc* of Stata was used.

In **Table 7** above, unit root test results show that most panels are stationary. However, some panels (**LogGDP** and **LogCCPC**) are quasi-stationary, on the boundary between I(0) and I(1). Nevertheless, the test results reject the null hypothesis and conclude that the series is stationary. Next, Hausman's (1978) specification test is done with results presented in **Table 8**.

Table 8. Hausman test

Model	Prob>chi2(5)
Model EPC A+	-0.00
Model EPC A	-0.00
Model EPC B	0.00
Model EPC B-	0.00
Model EPC C	-0.00
Model EPC D	0.00
Model EPC E	0.00
Model EPC F	0.00

Notes: The command *hausman* of Stata was used.

As the data fails to meet asymptotic assumptions of the Hausman test contrasting the applicability of random or fixed-effects models (see **Table 8**), it can be concluded that random effects are present. That is, there is a non-systematic difference in coefficients. **Table 9** below reveals the results from the random-effects model regressions.

Table 9. Random-effects model regression

Independent variables	Dependent variables							
	High energy efficiency							
	EPC A+		EPC A		EPC B		EPC B-	
LogGDP	-4.5729	**	-5.3426	***	-5.8831	***	0.1913	
LogFFIP	0.5294	**	0.5248	***	0.3880	**	-0.5022	***
LogCCPC	3.375	**	4.5341	***	3.6436	***	0.6552	*
Constant	19.3869	*	18.0806	*	31.7315	***	-0.9057	
Obs	133		133		133		133	
Independent variables	Low energy efficiency							
	EPC C		EPC D		EPC E		EPC F	
LogGDP	4.7159	***	4.6634	***	3.5447	***	-0.9312	
LogFFIP	-1.0803	***	-0.3556	***	0.1422		1.7870	**
LogCCPC	-0.3082		-1.1528	***	-0.9261	***	-0.9354	*
Constant	-35.2394	***	-28.2578	***	-20.2461	**	20.8439	**
Obs	133		133		133		133	

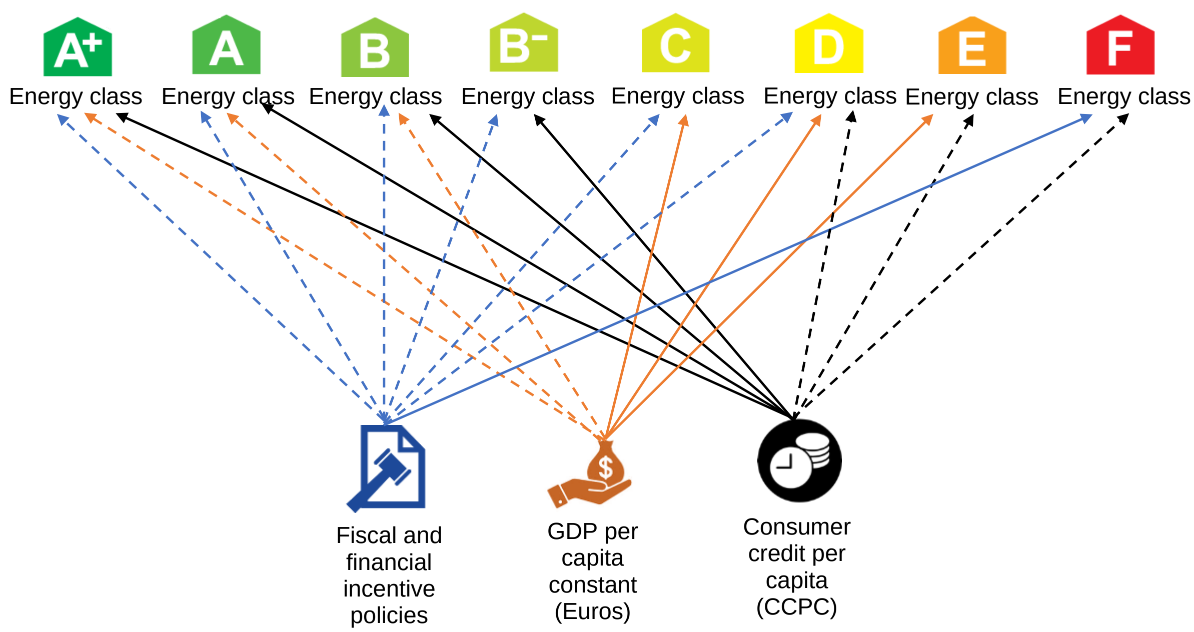
Notes: ***, **, *denote statistically significant at 1%, 5%, and 10% levels respectively; (Log) denotes variables in the natural logarithms; the command *xtreg with option re* of Stata was used.

The model regression results in **Table 9** above show that income is the most critical determinant of obtaining an energy certificate. Financial incentive policies, income and credit availability matter the most for the grade **(A)** and **(B)** housing, and to a lesser extent, for **(A+)**

housing. Financial incentive policies, income, and credit availability matter the least for the lowest-efficiency grade housing, suggesting they primarily incentivise higher efficiency certificates.

The negative effect of income and positive impact of credit availability for the highest efficiency housing suggest the inability to meet the high cost of such housing from incomes is compensated by credit. The fiscal and financial incentive policies do so only moderately. Compared to fiscal and financial incentive policy, negative effects on medium-efficiency housing (**B**–, **C**, and **D**) and positive effects on least efficient (**F**) housing suggest that these policies incentivise differentiation in the market by energy efficiency. For (**B**–) level housing, income and credit availability do not matter, suggesting that this energy efficiency grade may characterise the standard choice of EPC for buildings. For the other medium- to lower-grade efficiency housing (**C**, **D**, and **E**), income positively determines such efficiency-grade housing adoption, as there is less credit obtained for such housing. For (**E)** grade, fiscal and financial policy incentives are not strong enough.

For the least efficient housing (**F**), fiscal and financial incentive policies work towards least efficient housing adoption. Income has no significant effect, suggesting such residences are not newly built. Overall, income determines the choice of energy efficiency in housing, except for the least efficient (**F**) and the average (**B**–) housing. Credit availability compensates for limited income, and the fiscal and financial incentives are less important. Moreover, **Figure 6** below summarises the impact of independent variables on dependent ones. This figure was based on results from **Table 9.**



Positive impact ———————— **Negative impact** - - - - - - - - - - - -

Figure 6. Summary of the variable's effect.This figure was created by authors.

After realising linear random-effects model regression, it is necessary to carry out the post-estimation tests for the linear random-effects model (e.g., Wooldridge, Breusch and Pagan LM, and Pesaran's tests). **Table 10** below shows the results from the post-estimation tests.

Table 10. Post-estimation tests for the random-effects model

Model	Wooldridge test	Breusch and Pagan LM test	Pesaran's test
Model EPC A+	F(1,18) =4.733**	chibar2(01) =342.45***	6.234***
Model EPC A	F(1,18) =16.899**	chibar2(01) =373.90***	14.965***
Model EPC B	F(1,18) =22.522***	chibar2(01) =372.06***	15.307***
Model EPC B–	F(1,18) =12.373**	chibar2(01) =372.14***	2.963**
Model EPC C	F(1, 18) = 0.257	chibar2(01) =385.30***	18.051**
Model EPC D	F(1,18) =1.765	chibar2(01) =387.93***	1.188
Model EPC E	F(1,18) =3.167*	chibar2(01) =372.05***	7.009***
Model EPC F	F(1, 18) =0.629	chibar2(01) =285.76***	26.192***

Notes: ***, **, *denote statistically significant at 1%, 5%, and 10% levels respectively; the Stata commands *xtserial*, *xttest0,* and *xtcsd, pesaran abs* were used.

In **Table 8,** testing the applicability of OLS or random-effects models with Breusch and Pagan LM test (Breusch & Pagan, 1980), the null hypothesis of homoscedasticity was rejected. Thus, a random-effects model was found to be more suitable. Woolridge (2002) test of autocorrelation in panel data results returned mixed results. The null of the absence of autocorrelation in the model was rejected for energy efficiency certificates of grades (**A+**), (**A**), (**B**), (**B–**)**,** and (**E**). In contrast, there is no autocorrelation for grades (**C**), (**D**), and (**F**). Finally, as it can lead to bias in the estimated results, Pesaran's (2004) test of cross-sectional dependency in residual, i.e., the correlation between entities, was tested. The null hypothesis of no cross-sectional correlation can be rejected for energy EPC of grades (**A+**), (**A**), (**B**), (**B–**), (**C**), (**E**), and (**F**), but there is no cross-sectional correlation in the (**D**) model.

5. Discussions

This section will present the discussion of the results from **Table 7**. The results indicate that income on highest efficiency housing is negative and significant (**A+**, **A**, and **B**). In contrast, the effect of income on lowest efficiency housing is positive and significant (**C**, **D**, and **E**). In the meantime, income has the most significant impact on (**B**) level housing.

Based on results, the fiscal and financial incentive policy has negative and significant effects on medium-efficiency housing (**B**– and **C**) and positive and significant effects on highest efficiency housing (**A+**, **A**, and **B**). Also, the impact of the fiscal and financial incentive policy on (**F**) is positive and significant. In other words, in nineteen districts of Portugal, in the highest efficiency housing and least efficient housing, fiscal and financial incentive policies increase the energy efficiency. Furthermore, Gamtessa (2013), Filippini et al. (2014), Morton et al. (2018), and He & Chen (2021) confirm a positive relationship between fiscal and financial incentive policies and energy efficiency in residential properties.

As shown in **Table 7**, credit granted to customers by banks has positive and significant effects on the highest efficiency housing (**A+**, **A**, and **B**). This result is because it promotes energy efficiency in residential properties in Portugal. Nevertheless, the impact of this variable on lowest-efficiency housing (**C**, **D**, and **E**) is negative and significant, so credit granted to customers by banks reduces energy efficiency.

Indeed, as seen from our models' results, there is still a significant constraint to investing in highly energy-efficient housing in Portugal. According to OECD (2020), the country's relatively low household income. Despite the efforts made in the policy field, the budget constraint that many Portuguese families face turns the development of fiscal and financial incentive policies to support energy efficiency projects into necessary action.

Following the "The Energy Efficiency Watch Survey Report 2020" (Egger and Gignac, 2020, p.142), we can see that it is in this field where Portugal's policies seem to be more ineffective. 46% of the experts consider that the financial incentives for energy efficiency investments are not effective. Due to this fact, it is not strange that, in our models, the magnitude of the effects from the consumer credit variable is substantially higher than those from the fiscal and financial incentive policies variable. This fact could mean that, without adequate fiscal and financial incentives, the owners turn themselves to credit to support their energy efficiency projects.

However, it seems that there is already an acknowledgement of this failure by the Portuguese government. Indeed, to cope with the "Plano Nacional Energia e Clima 2030" (National Energy and Climate Plan 2030) goals, the Portuguese government launched the "*Programa de Apoio Edifícios Mais Sustentáveis*" (More Sustainable Buildings Support Program). The first phase allocated 4.5 million euros in 2020/2021 to support measures and interventions to promote rehabilitation, decarbonisation, energy efficiency, water efficiency, and circular economy in buildings. These initial 4.5 million euros were quickly depleted, leading to a boost of 5 million euros. In the summer of 2021, the Portuguese government announced the second phase of this program, falling within the scope of the "*Plano de Recuperação e Resiliência*" (Recovery and Resilience Plan), opening the applications to the attribution of incentives to projects that make housing more energy sustainable. As a result, the government has now another 30 million euros to support this type of investment.

6. Conclusions

This analysis explored the effect of financial and fiscal incentive policies on the energy efficiency ratings in residential properties in nineteen districts of Portugal between 2014-2021. Thus, this study is kick-off regarding the effect of financial and fiscal incentive policies on the energy efficiency ratings. Indeed, this investigation is in the early stages of maturation and will supply a solid foundation for second-generation research regarding this topic.

The results showed that per capita income negatively impacts housing with higher energy efficiency (certificates **A+**, **A** and **B**). Therefore, the income in Portugal is insufficient and prevents investment in housing with high energy efficiency. On the other hand, the categories (**C**, **D** and **E**) have lower efficiency and cost. Regarding consumer credit policies, their impact is positive for more efficient housing and negative for less efficient housing. In addition, fiscal policies positively affect certified tertiary housing (**A+, A, B** and **B–**).

Economic instruments, especially fiscal and financial incentives, aim to encourage investments in energy-efficient products and processes by reducing costs for consumers. Financial incentives are used to support energy efficiency measures in residences. Some examples of financial incentives are (i) provision of credit to the real estate sector, (ii) incentives for the residential sector, (iii) incentives for more efficient construction, and (iv) investment in inefficient appliances. Tax incentives include measures to reduce taxes/fees paid by consumers who invest in energy efficiency. Some examples of tax incentives are (i) tax reduction for the purchase of efficient equipment, (ii) tax reduction for renewable sources, (iii) tax reduction for efficient equipment, and (iv) fees for polluting activities (reversed to energy efficiency).

The implementation of energy efficiency programs as an instrument of energy and environmental policy requires, on the one hand, the public authorities' action through economic incentives and/or disincentives and regulation and, on the other hand, social participation. With this, the results achieved will be the deduction of greenhouse gas emissions and reducing energy consumption. These benefits are essential public policy tools to drive sustainable economic growth and development.

Portugal is committed to achieving carbon neutrality by 2050 to contribute to the global and European goals assumed in the Paris Agreement. Thus, the "National Energy and Climate Plan 2030" (NECP 2030) was implemented to fulfil the goals of decarbonisation and energy, social and economic transition. This plan establishes measures to reduce greenhouse gas emissions, promote energy efficiency by reducing primary energy consumption, expand renewable energies in the final gross consumption of energy, guarantee the security of supply, and develop the internal energy market. Furthermore, for buildings and residential properties, NECP 2030 establishes specific lines of action intending to reduce their carbon intensity and promote the energy renovation of the real estate portfolio, with particular attention to the objective of implementing the "*Nearly Zero Energy Buildings*" concept (NZEB) in the construction of buildings and new residences and the transformation of existing buildings and residences.

The construction sector also plays a vital role in the environmental performance of buildings, residences and infrastructures throughout their life cycle. It is essential to encourage design improvements that reduce their environmental impacts and increase the durability and recyclability of its components. Therefore, it is crucial to reinforce fiscal, financial and credit incentive policies. Furthermore, creating or reorientating credit lines for the energy renovation of buildings and residences is essential, in line with the respective energy performance and sustainability criteria. It is always necessary to balance with climate goals and efficient management of resources. Indeed, to meet its energy efficiency goals, Portugal has already started to grant direct incentives to taxpayers who adopt more efficient electrical equipment and techniques that contribute to the thermal comfort of buildings. This measure reinforces the direct stimulus to taxpayers in carrying out expenses that, in addition to having long-term financial returns for themselves, also reduce national energy consumption. Finally, this investigation is new and not explored by literature and opens new study opportunities regarding this issue. Therefore, this investigation can open new lines of investigations related to the energy efficiency certificates and the macroeconomic aspects, such as the impact of these certificates on energy consumption and environmental degradation.

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