DOES ENERGY POVERTY INFLUENCE DECARBONISATION THROUGH ELECTRIFICATION OF THE HEATING SECTOR?

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Abstract

Cleaner end-uses of energy, including electrified heating, represent a cornerstone of a decarbonised energy transition. On the other hand, many governments have adopted measures to mitigate energy poverty and facilitate access to modern energy services, including heating. Both objectives may be interrelated, since energy poor people are less likely to use cleaner (and costlier) heating fuels. This paper aims to analyse the impact of energy poverty on the decision to use different heating sources and to identify whether the events of COVID and the Ukraine war have affected this decision. Thus, a multinomial probit model is estimated using information from a large database of Spanish households in 2019, 2021 and 2022. The results show that being energy poor increases the probability to use carbon-intensive energy sources for heating compared to electricity and COVID and the war in Ukraine have negatively affected such relationship. Since energy poverty has increased in those years, it has negatively affected the decarbonisation goal with respect to heating choices. The influence of those events on the probability to use electric heating depends on some household and dwelling features. Therefore, mitigating energy poverty increases the welfare of energy poor people while supporting the choice of cleaner heating.

Key words: Heating, energy poverty, COVID, multinomial probit.

1. Introduction.

The unprecedented challenge of climate change has led to the urgency to implement a decarbonised energy transition. This should be based on the uptake of cleaner energy sources and electrification of end-uses of energy, including heating. Thermal energy use in buildings, mainly for space heating and hot water, accounts for one quarter of final energy use worlwide. Around 85% of heating and cooling in buildings is met by fossil fuels (IEA, 2020).

Several energy sources can be used for heating, including solid fossil fuels (coal), gas, oil, renewables and electricity[1]. Heat can be produced centrally, in specialised energy plants from where it is piped to consumers or, as it is the case in Spain, heat production can be decentralised, such as when citizens use energy to heat buildings (EEA 2023). The focus of this paper is on heating choices in the residential sector and, particularly, on electricity which, following IPCC (2022) and Rosenow et al (2023), is a key "clean heating" option[2]. Encouraging the uptake of those cleaner heating options is a challenge, as path dependencies have often been found in the residential heat supply e.g. in the European Union (EU)(Bertelsen et al 2020).

Access to modern energy services, including heating, is one objective that governments aim for and measures to mitigate energy poverty have been adopted to faciltate such access. For example, the Spanish government stated that, in 2019, between 6.6% to 16.7% of the population was energy poor (Barrella et al 2021). According to Eurostat (2023b) energy poverty (measured as percentages of households which are unable to keep their home adequately warm) has increased substantially between 2019 and 2022 in the EU (from 6.9% in 2019 to 9.3% in 2022). However, this increase was greater in Spain (from 7.5% in 2019 to 17.1% in 2022)[3], suggesting a higher vulnerability of Spanish households to energy poverty.

Both objectives may be interrelated, since a higher energy poverty would make it difficult for households to use the cleaner (but more expensive) heating fuels. These trade-offs are a well-known issue in achieving the goals of the so-called energy trilema (access to energy, clean energy and affordable energy). In addition, the two events of COVID and the war in Ukraine have likely influenced those objectives and, thus, their relationship by either making it more difficult to access energy services or by increasing their costs. This is particularly the case in residential heating, since prices of fuels have surged (Trading Economics 2023).

Thus, the aim of this paper is to analyse the impact of energy poverty on the decision to use different heating sources and to identify whether the aforementioned events have affected this decision. Thus, a multinomial probit model is estimated using information from a large database of Spanish households (the Household Budget Survey) in 2019, 2021 and 2022. The model allows us to disentangle the influence of different factors on the probability of applying one residential heating mode (gas, electricity or oil).

This study builds upon previous literature by identifying key factors influencing heating choices, exploring the effects of household characteristics, dwelling characteristics and location (see section 2). The decision on heating choices is an issue with implications on, both, the decarbonised energy transition and energy poverty, because large shares of household budgets are dedicated to heating. Since space heating is the main source of CO2 emissions in

[1] See Martinopoulos et al (2018) for a classification and a description of different heating sources.

[2] There does not seem to be a consensus on the term "clean heating", with several alternatives belonging to this category, e.g., for Feng et al (2021) clean heating means gas heating, but it may also include renewable energy heating (as in Michelsen and Madlener 2012), hydrogen (as in Sovacool et al 2021) and electric heating (as in IPCC (2022) and Rosenow et al (2023), among others). Rosenow et al (2023) calculate the environmental externalities for five heating fuels (electricity, gas, oil, biomass and coal), and identify electricity as the cleaner fuel (i.e., the one with the lowest environmental externality and also lowest CO2, NOx and PM_{10} emissions). Belaid and Massié (2022) calculate the carbon content of different energy sources and classify them from most to least polluting as follows: coal, heating oil, propane gas, natural gas, electricity, and wood.

[3] For Spain, the respective percentages were: 7.5% (2019), 10.9% (2020), 14.2% (2021) and 17.1% (2022)(Eurostat 2023b). It is the EU country that has experienced the steepest increase in energy poverty in recent years.

the residential buildings sector worldwide, the choice of heating sources towards cheaper, but not necessairly cleaner heating sources would have detrimental effects on those emissions.

Such a micro-level empirical analysis of the factors which influence the choice of a specific heating source (including energy poverty) would reveal relevant policy implications. It may allow identifying a policy mix, i.e. policies in the three realms (support for the decarbnoised energy transition, mitation of energy poverty and mitigation of the effects of COVID and the Ukraine war) which effectively address those challenges. It may also allow the identification of conflicts, synergies and complementarities between those realms, which in turn may lead to win-win policy interventions, i.e., instruments which tackle one objective while also having side-effects on another objective or try to balance trade-offs between them.

While there are several contributions on the determinants of the choice of heating sources (see section 2) and there are also many papers on the determinants of energy poverty (see, e.g. Belaid and Flambard (2023) and Charlier et al 2021), the impact of energy poverty on the decision to choose different heating choices has not been much studied (with the exception of Burguillo et al 2022) and none have investigated the influence of the recent events of COVID and the war in Ukraine on such decision[4]. Indeed, little attention has been paid to the quantitative analysis of the interaction between energy poverty and the choice of heating sources. Both issues may be interrelated if energy poor people are less likely to use cleaner (and costlier) heating fuels such as electricity, locking-in the dirtier alternatives. Our paper tries to close this gap and shows that, indeed, being energy poor leads to a lower probability to select electric heating compared to more carbon-intensive ones. It also shows that the war in Ukraine, and especially COVID, have had an effect on such relationship between energy poverty and heating choices.

Given the different socioeconomic, institutional, cultural and climatic conditions across countries, focusing on a single country is a common way to proceed in the literature. Spain is an appropriate choice for several reasons which make it quite unique compared to other (European) countries. First, the country is the fourth largest energy consumer and greenhouse gas (GHG) emitter in the EU. Second, the potential to reduce fossil fuel consumption for heating is large in Spain because, despite 33% of heating coming from renewables and 7.9% from electricity, fossil fuels account for almost 60% of heating, a higher share than in the EU (54%). Third, Spain has three clearly differentiated climatic zones, one is common to central European countries (continental climate in the center), another is more common to other Southern European countries (the Mediterranean coast) and the Atlantic coast bears some resemblance with zones in the West of Europe[5]. Four, in contrast to the rest of EU member states, and especially those in North and Eastern European countries (Martinopoulos et al

[4] This paper has considerable differences with Burguillo et al (2022), who also carry out an analysis of energy poverty on heating. Whereas Burguillo et al (2022) analyse cooking and heating, this paper focuses on heating and, most importantly, this one analyses the choice of different heating sources as well as the impact of COVID and the war in Ukraine. Other relevant differences include the country of application (Spain vs. Argentina in Burguillo et al (2022)), method (multinomial probit versus bivariate binary logit), distinct explanatory variables, a different indicator of energy poverty and different results and conclusions.

[5] Continental climate: characterized by very extreme temperatures, long and very cold winters, hot summers and low rainfall. Mediterranean climate: characterized by short and mild winters and long and hot summers. Atlantic climate: characterized by abundant rainfall (distributed regularly throughout the year) and soft temperatures in winter and summer (Ortega-Izquierdo et al 2019). The average number of heating hours per year are: Continental (1459 hours), Mediterranean (853 hours) and Atlantic (843 hours)(ADL 2023).

2018), with considerable shares of centralized heat production, Spain uses only decentralised heating sources[6]. Finally, as mentioned above, it has a relatively high energy poverty rate.

To the best of our knowledge, despite some research on the heating sector, the drivers of heating choices in Spain has not been analysed with quantitativey techniques. Ortega-Izquierdo et al (2019) conduct a survey to identify end-users' decision-making factors when choosing between heating/cooling systems. Their descriptive analysis shows that half of those respondents who know any renewable energy technologies would pay more for them. López-Bernabé et al (2022) use Fuzzy Cognitive Mapping to test policy mixes based on expert perceptions and find that environmental education and information significantly reduce heating bills and taxes are more effective than subsidies. Barrella et al (2021) propose a bottom-up methodology to characterise Spanish households' expenditures for heating and hot water.

Accordingly, the paper is structured as follows. Section 2 provides the background and a literature review on the topic. Section 3 describes the data and method. The main results of the estimations are provided and discussed in section 4. Section 5 concludes with some policy implications.

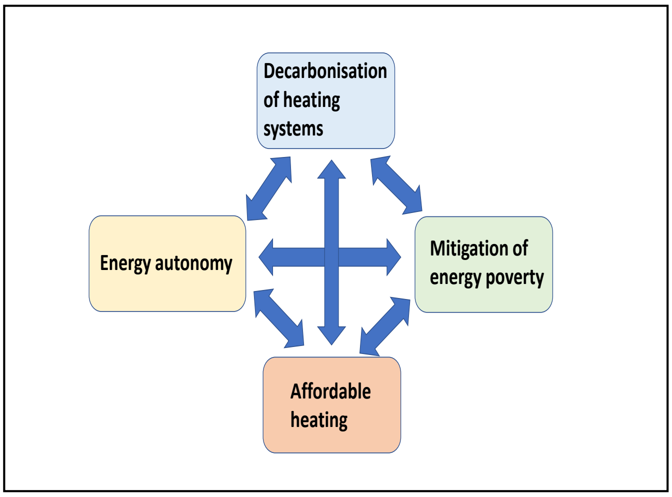
2. Background and literature review.

The energy trilemma, which refers to three often conflicting goals (energy security, energy equity (access to affordable, clean energy) and environmental sustainability (Miyanaga 2021)) is an appropriate starting point to frame the issues addressed in this paper. In the context of the choice of heating systems, this entails four key goals: households should have access to (clean) heating, using local energy sources at affordable prices[7]. Therefore, energy poverty mitigation is ingrained in the attainment of other goals (Figure 1). After the war in Ukraine, energy autonomy is regarded as a key goal for many countries around the world. Electric heating is a modern energy service and, if based on renewable electricity, contributes to decarbonization and energy independence (autonomy). However, it is often an expensive heating mode (see below).

[6] The four other countries which do not have centralized heating production in the EU are Ireland, Cyprus, Luxembourg and Malta (Eurostat 2023a). The share of centralized heat in final energy consumption is negliglible in Belgium (0.2%) and Portugal (0.1%).

[7] This is in line with the IPCC (2022) Sixth Assessment report which defines modern energy services as clean, reliable and affordable energy services for cooking and heating, lighting, communications, and productive uses.

Figure 1. Goals in the heating context.



Source: Own elaboration.

Heating has high importance in the energy consumption and GHG emissions of countries. In the EU, space heating represents 64.4% of the energy consumption of households and 17% of overall final energy consumption (Eurostat 2023a), being the largest energy-using activity in households and, thus, the most prominent item of household energy-related expenditure. The residential sector accounts for 35% of energy-related GHG emissions in the EU (EEA 2023).

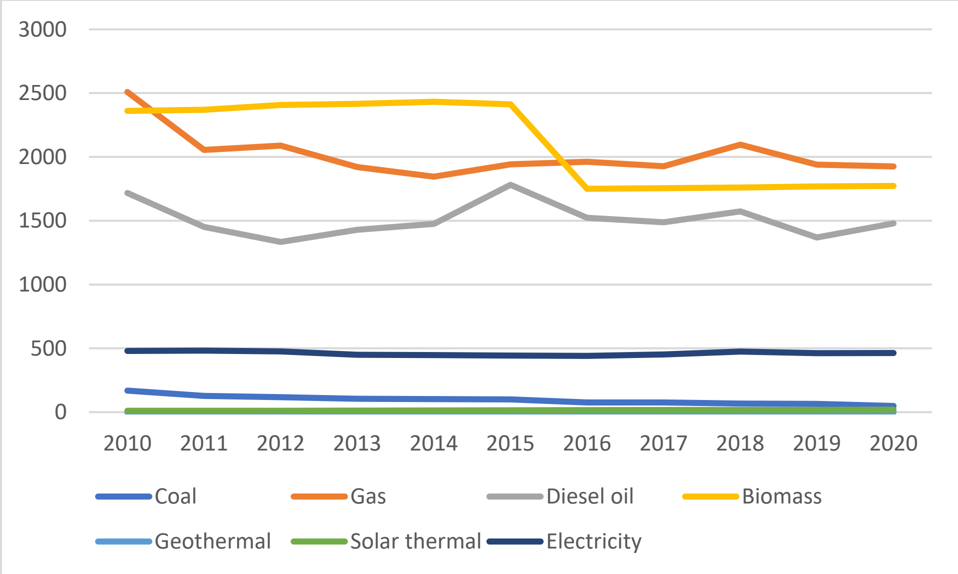
Due to the important role of oil and gas in residential heating[8], it is strongly linked to policy considerations on global warming, security of energy supply, and increasing energy prices (Michelsen and Madlener 2013). Low-carbon energy systems are expected to rely heavily on end-use electrification, with electricity produced with low GHG emissions being used for building and industrial heating (IPCC 2022)[9]. Widespread electrification of end uses, including space heating, should be accompanied by increasing renewables in electricity systems to produce no net CO2.

In Spain, energy consumption for heating in the residential sector has decreased in the last 10 years by 27% as a result of energy efficiency improvements and better equipment performance (ADL 2023). Energy for all heating sources has dropped, except for solar thermal (Figure 2) and electrification of heating has not experienced significant changes in the last decade. The shares of natural gas, oil and biomass are between 33% and 25%, whereas electricity accounts for only 8% of heating consumption (Figure 3).

Figure 2. Evolution of the consumption of different energy sources for residential heating in Spain (ktoe).

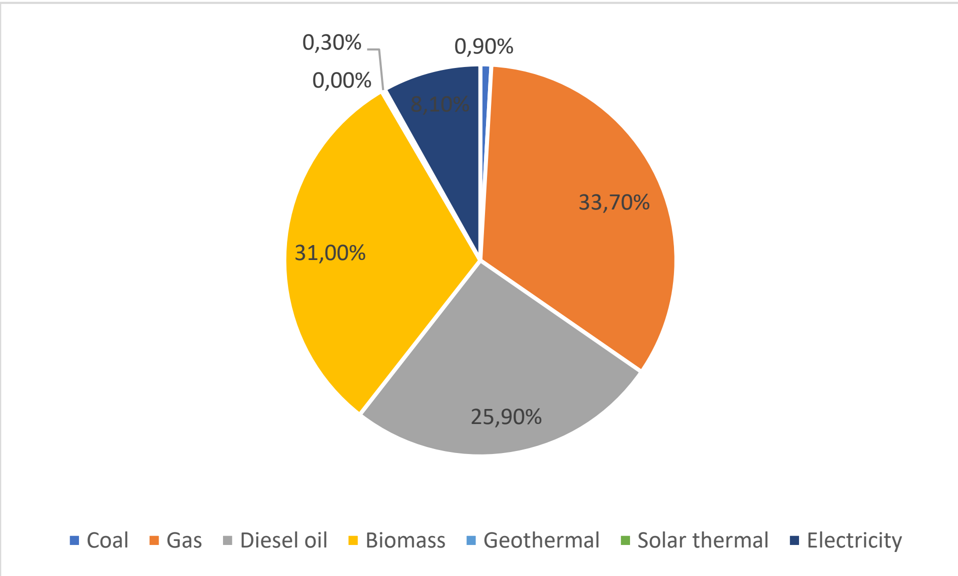
[8] In 2021, 54% of energy consumption in the EU came from fossil fuels: solid fossil fuels (3.6%), natural gas (39.4%) and oil and petroleum products (11.3%), whereas the shares of renewables (29.2%) and electricity (6.1%) were lower (Eurostat 2023a).

[9] For example, scenarios for Japan project continued electrification of residential buildings to 65% by 2050 to reach 70–90% CO2 reduction from 2013 levels (Kato and Kurosawa 2019). Similarly, a mitigation pathway for China compatible with 1.5°C would require 58% to 70% electrification of buildings (IPCC 2022). For the EU-28 to reach net carbon neutrality, complete substitution of fossil fuels with electricity (up to 65% share), district heating, and direct use of solar and ambient heat are projected to be needed for buildings, along with increased use of solar thermal and heat pumps for heating (Duscha et al. 2019)(IPCC 2022).



Source: Own elaboration based on IDAE (2023).

Figure 3. Share of energy consumption sources in total heating consumption in the residential sector in Spain.



Source: Own elaboration based on IDAE (2023).

These data suggest that there is a considerable potential to increase electric heating in Spain. However, heating systems have special characteristics which make them difficult to be adopted by householders: they are a durable product (used for about 20 years), expensive to buy (with investment costs between €9000 and €17,000) and with unknown future variable costs (Braun 2010, Decker and Menrad 2015). Different types of heating have distinct characteristics, with electric heating being the most expensive alternative (Martinopoulos et al 2018, Rosenow et al 2023, Wang et al 2019, Sunderland and Gibb 2022).

The use of heating choices over time has traditionally been explained with the so-called energy-ladder model, which suggests that households abandon inefficient, cheap, and polluting technologies and choose more sophisticated energies as income increases (Belaid and Massié 2022). They move from more primitive fuels (dung coke, agricultural waste and firewood) to transition fuels (coal, charcoal and kerosene) to modern fuels (LPG, natural gas and electricity). With increasing income, households may bear the higher heating costs for cleaner heating to obtain a better indoor environment (Wang et al 2019)[10]. This important role of income is also assumed in this paper, which focuses on the influence of energy poverty on heating choices. But additional factors influencing the adoption of cleaner sources are considered, such as path dependencies caused by habit and previous investments in infrastructure (dwellings) and several dwelling and household characteristics (e.g. rural location, age and education).

Indeed, this paper adopts a pragmatic theoretical framework which draws on the variables included in the abundant literature on the determinants of different heating sources in the residential sector. We are particularly interested in the literature which specifically analyses the factors which lead households to choose one specific heating type versus others. The appropriate methodological tool is the multinomial model (logit or probit). Therefore, we have focused on the contributions in the literature which use this methodology (Table 1)[11].

The dependent variables in those papers usually include electricity, gas, coal or oil, as in this article, using one of them as the reference category. The explanatory variables refer either to household characteristics (e.g., household size, age, income, educational level, nationality and gender of the breadwinner), the dwelling (e.g., size and age) or the dwelling location (e.g. in rural or urban areas, in regions with a colder or warmer climate)[12]. Some explanatory variables (income, age of household head, household size, education and building age) are most often included in the models, whereas others are seldom used (Table 2).

[10] Although the energy ladder model has been criticized and a partial amendment has been proposed (the energy stack model), both models assume that, with an improvement in their socio-economic status, households will move up along the aforementioned energy ladder, although possibly with some combinations of energy carriers in each of those three phases (Chen 2021). For an in-depth comparison of both models, see Waleed and Mirza (2023).

[11] Three other papers also use a multinomial model to assess the determinants of different heating choices. However, they have not been included in the review because they either analyse the choice of heating systems in the commercial sector (Pizer and Newell 2008) or focus on combinations of heating sources (as in Nesbakken (1999) and Vaage (2000)). Michelsen and Madlener (2013) also use a multinomial logit in the context of heating, but they do not assess the drivers of different heating sources. Rather, they carry out a cluster analysis which reveals three adopter types. Then, they analyse the determinants of cluster membership.

[12] The choice of the same goal and methodology for the selection of papers leads to a rather homogenous group of papers and, thus, facilitates the comparability among them. However, care should be taken in this respect, since there are still relevant differences regarding the institutional and climatic conditions across countries or different methodological details (e.g., the heating source used as the reference category for the comparisons).

Table 1. Summary of results of the reviewed papers.

Paper	Geographical and temporal scope	Aim	Method of data collection and data treatment	Results				
				General findings	Dependent variable	Explanatory variables†††		COEF, OR, EM††
						Significant (sign)	Non-significant	
1.Decker and Menrad (2015)	Germany 2014	To analyze the buying behavior of house owners in Germany with respect to heating systems and the main factors influencing choice when purchasing a specific heating system (e.g., oil heating or wood pellet heating).	MNL. A Germany-wide written survey n=775	The membership of different ecological clusters primarily segregates the owners of a specific heating system, but the assessment of the different combustibles also plays a major role in this context.	Gas heating Wood pellet heating Heat pump Oil heating.	12 significant variables **<u>Numeric variables:</u>** -OIL VS. GAS and OIL vs. HEAT PUMPS General economy aspects (+) Evaluation of fossil oil (+) -GAS vs. HEAT PUMPS Evaluation of natural gas (+) Convenience (+) -HEAT PUMP vs.GAS Comfort (+) Sq meters/kW (+) Evaluation of electricity -HEAT PUMP vs. OIL Sq meters/kW (+) Evaluation of natural gas (+) Evaluation of electricity (+) **<u>Categorical variables:</u>** -GAS VS. WOOD PELLET Heating system neighbour (+) Ecological attitude (+) -GAS VS. HEAT PUMP Heating system neighbour (+) -GAS VS. OIL Heating system neighbour (+) -WOOD PELLET VS. HEAT PUMP Heating system neighbour (+) Ecological attitude (+) -WOOD PELLET VS. OIL Ecological attitude (+) Interpretation of coefficients (not OR).	17 non-significant variables: -Experience of the product (Importance of ecology aspects before purchasing the heating system, the supply of the fuel before purchasing the heating system, informational aspects before purchasing the heating system, individual contact with the heating installer when running the heating system and the kind of fuel when running the heating system). -Number of information contacts. -Household size. -Age of household head. -Education. -Income. -Evaluation of fire wood. -Price trend of natural gas, fossil oil, electricity, firewood and wood pellet. -Whether family members have been involved in decision making.	COEF, OR

2.Belaïd and Massié (2022)	France 2016	To examine factors influencing heating energy consumption	MNL Using the 2016 French Housing Survey, provided by the French National Institute of Statistics and Economic Studies (n=37000 dwelings)	Dwelling type, year of construction, and location (urban density and climate) are the most potent explanatory variables of heating energy consumption.	Four categories Gas (reference) Electricity Oil Other energies	• Electricity. Income (<1) Foreigner (vs. French)(>1) Age (<1) Household size (<1) Dwelling size (<1) Individual house (vs. twin houses) (>1) No double glazing (vs. yes)(<1) Signs of moisture (vs. no)(>1) Recent renovation (<1) Climate of the region (<1)** Rural (vs. to edge of a big city)(>1) • Gas Tenant (vs. owner)(<1) Dwelling size (>1)* Individual house (vs. twin houses (>1) No double glazing (vs. yes)(>1) Signs of moisture (vs. no)(>1) Recent renovation (<1) Climate of the region (<1)** Rural (vs. location on the edge of a big city)(>1) * >1 for greater than 106 m2 (compared to <61 m2) but <1 for 61-80 m2 (vs. <61 m2). ** (hot, cold and very cold vs. very hot).	• Electricity. Tenant (vs. owner) • Gas Income Foreigner (vs. French) Age Household size	OR
3.Bai et al (2023)	China 2022	To identify the causal relationships of rural households' energy choices considering subjective factors that may influence the energy choices and willingness to pay.	MNL with selection bias correction. Survey on households carried out by the authors (n=394).	Results contradict the energy ladder hypothesis and conclude that it might be caused by energy consumption habits and fuel stacking strategy. Both demographic characteristics and education level have a significant effect on heating energy choices. As for residents' willingness to pay for clean heating, it	Biomass (ref category) Coal Electricity	• Coal (vs. biomass) Education (-) Fraction of adult women (+) • Electricity (vs. biomass) Family size (-) Education (+) Labor force (+)* * Number of household members working Interpretation of coefficient sign.	• Coal (vs. biomass) Income Age of household head Family size Living area Heating area Labor force* • Electricity (vs. biomass) Income	COEF, rrr, ME

				shows that households' environmental perceptions, socioeconomic status, and demand for policy subsidies play an important role.			Age of household head Fraction of adult women Living area Heating area	
4.Michelsen and Madlener (2012)	Germany 2010	To analyze the influence of preferences about renewable heating systems (RHS) specific attributes on the homeowners' adoption decision	MNL Data based on a representative and self-administered national survey (carried out by the authors) among randomly selected owners of existing or newly built 1- and 2-family homes in Germany	There are different drivers of the adoption of innovative RHS in newly built and existing 1- and 2-family homes. The importance of key drivers also differs across groups of homeowners and RHS, respectively.	Four categories of RHS: GAS-ST = gas-fired condensing boiler with solar thermal support. OIL-ST = oil-fired condensing boiler with solar thermal support. HEAT-P = heat pump. PELLET = wood pellet-fired boiler. The reference category is "any other previously installed RHS not based on the fossil fuels oil or gas" (e.g. electric heating, biomass- or coal-fired RHS).	• Gas Income (+) Education (+) Female (+) Dwelling size (-) Dwelling age (0) Regional Infrastructure (+) Total cost** (-) Confort**** (+) • Oil Income (-) Age of homeowner (+) Dwelling size (+) Dwelling age (+) Rural (+) Regional Infrastructure (+) EnConsult* (-) Confort**** (-) • Heat Pump Income (-) Age of homeowner (-) Education (+) Dwelling size (+) Dwelling age (-) One family home (+) Rural (-) Regional Total cost** (+) Environment*** (-) Confort**** (+) • Pellet	• Gas Age of homeowner One family home Rural EnConsult* Environment*** • Oil Education Female One family home Total cost** Environment*** • Heat Pump Female Infrastructure EnConsult* • Pellet Female Dwelling size Rural EnConsult* Total cost** (-)	ME

						Income (-) Age of homeowner (-) Education (-) Dwelling age (+) One family home (-) Regional Infrastructure (-) Environment*** (+) Confort**** (-) * Energy consultant or architect gave advice (yes=1, no=0) ** Consideration of total costs over lifetime (yes = 1/no = 0) *** Preference for environmental protection (5-point Likert scale ranging from "1" = "strongly disagree" to "5" = "strongly agree"). **** Preference for ease of use (5-point Likert scale ranging from "1" = "strongly disagree" to "5" = "strongly agree"). Not reported here: Ensavings, Independent and Image		
5.Wang et al (2019)	China (rural áreas) 2018	To identify the key factors that affect cleaner heating choices under the national pilot program of the dual substitution policy, which targets the replacement of coal heating with gas and electric heating.	MNL Household survey covering 1,030 rural households conducted in Hebi City (Henan province of China)	Electric heating is the most popular heating method, and the adoption of cleaner heating rises with income, and energy and device costs may be the major barriers to adopting cleaner heating. MNL findings: income, heating area, energy cost, and education had significant impacts on heating choices. In addition, the gas substitution policy was more effective in promoting the cleaner heating transition than was the electric substitution policy.	Coal (reference category) Electricity Gas No heating	• Electricity Household size (+) Heating energy cost (-) Income (+) Education (+) Gas substitution policy (+) • Gas Household size (+) Heating area (+) Heating energy cost (+) Gas substitution policy (+) • No heating Heating area (+) Heating energy cost (-)	• Electricity Heating area Electricity substitution policy • Gas Income Education Electricity substitution policy • No heating Household size Income Education Electricity substitution policy Gas substitution policy (+)	COEF

6. Laureti and Secondi (2012)	Italy 2009	To identify the factors with a strong effect on the choice of a specific fuel by using a MNL model taking into account the heterogeneity of households in the Italian regions. The paper also examines the implications of a simulated scenario concerning tax incentives for energy efficiency improvement.	MNL Disaggregated data from the 2009 Italian Household Budget Survey.	Many of the variables concerning the socio-economic characteristics of households (i.e. family income and type of family) and the characteristics of the dwellings (i.e. year of construction) are important determinants of the choice of space heating technologies and energy consumption. There are geographic differences in the determinants of fuel choice. Many variables on the socio-economic characteristics of households and the characteristics of the dwellings proved to be important determinants of the choice of space heating technologies and of energy consumption.	5 categories: Oil Gas LPG gas cylinders Coal-wood Electricity & solar panels	• Oil Children (-) Dwelling size (+) Dwelling age (+ and -)** Isolated (+)*** Detached (+)**** Green space (-) HDD (+) Retrofit (+) Gas price (+) Coal price (-) Electricity price (-) • Gas Income (+) Education (+) Owner (+)* Dwelling age (+) Isolated (-)*** Detached (-)**** Regional variables (-) Green space (+) HDD (-) Retrofit (-) Gas price (-) Coal price (+) Electricity price (+) • Coal-wood Income (-) Children (+) Education (-) Dwelling size (+) Dwelling age (-)** Isolated (+)*** Detached (+)**** Regional variables (+) Green space (+) HDD (+) Retrofit (+) Gas price (+) Coal price (-) Electricity price (-) • Electricity & solar panels Children (-)	• Oil Income Education Owner* Regional variables • Gas Children Dwelling size • Coal-wood Owner* • Electricity & solar panels Income Education (slightly – and non-signicant) HDD Retrofit Electricity price	ME

						Education (slightly – and non-signicant) Owner (-)* Dwelling size (-) Dwelling age (+ and -)** Isolated (-)*** Detached (+)**** Regional variables (+) Green space (-) Gas price (+) Coal price (+) *Owner (household owns the property=1; it does not own the property=0). ** Depending on the year of construction. *** households live in isolated áreas **** Detached house=1, flat=0			
7.Braun (2010)	Germany 2003	To provide empirical evidence on the determinants of the space heating technology applied by a household. Three sets of variables are examined as potential influences: building, socio-economic, and regional characteristics.	MNL The data are obtained from a sample of house owners, and from a sample including all households. Data are taken from a larger representative household survey: the German Socio-Economic Panel.	The influence of socio-economic factors is similar across house owners and all households. Income is found to exert only a minor impact on the system choice. Dwelling features are significant in determining the heating type, particularly in the sample including all households.	7 categories: Owner of oil heating only Owner of gas heating only Owner of electric heating only District Owner of district heating only Solid Owner of solid fuel heating only Owner of oil and solid fuel heating Owner of gas and solid fuel heating 0.045	• Oil ME: Income (-) Owner (+) Age of house* (-) Dwelling type** (-) Detached*** (-) Retrofit**** (-) East/West Germany (-) Rural***** (+) • Gas ME: Income (+) Children (+) Education (+) Age of house* (+) Retrofit**** (+) • Electric ME: Owner (-) Education (-) Age of house* (-) Dwelling type** (-) Detached*** (-) East/West Germany (-) • Solid fuels: Income (-) Owner (-) Education (-) Age of house* (-)	• Oil ME: Children Education • Gas ME: Owner Children Dwelling type** Detached*** East/West Germany Rural • Electric ME: Income Retrofit**** Rural • Solid fuels: Children Rural	ME

						Dwelling type** (-) Detached*** (-) Retrofit**** (-) East/West Germany (+) * If built after 1991=1 ** Row house=1 *** Dwellings are part of a multi-unit facility (=1), a detached house (=0) **** If heating retrofitted in the last 5 years. ***** Household located in rural area (=1).		
8.Couture (2012)	France 2006	To analyse household fuelwood demand in France. The choice concerning the energy used for heating is modeled, stressing the combination between one type of energy used as a main source and another one used as a back-up. They studied the profile of households according to the way they see wood as a potential source of energy.	MNL Telephone survey on household fuelwood consumption in the Midi-Pyrénées region, carried out by the BVA polling institute at the request of the Midi-Pyrénées Regional Energy Observatory (OREMIP).	The choice of energy mix is determined by the income and the socio-economic characteristics of households. Fuelwood consumption is price-sensitive in the case where wood is the main source of energy.	Five categories: Non-consumption of Wood (ref). Wood Electricity Gas Oil	• Electricity Income (+) Executive * (-) Equip *** (+) Existence of main gas connection (-) Building age **** (+) Nº of rooms ****** (+) • Gas Income (+) Executive * (-) Equip *** (+) Existence of main gas connection (+) Building age **** (+) Dwelling type (flat=1)***** (-) Nº of rooms ****** (-) • Oil Executive * (-) Owner ** (+) Equip *** (+) Existence of main gas connection (-) Dwelling type (flat=1)***** (-) Dwelling size (+) * Executive=1 if household head socio-professional category belongs to manager, higher intellectual profesión, 0 otherwise. ** Owner=1 if household owns its main residence, 0 otherwise	• Electricity Price of wood Household size Age of household head Owner ** Dwelling type (flat=1)***** Dwelling size Nº of rooms ****** • Gas Price of wood Household size Age of household head Owner ** Dwelling size • Oil Price of wood Income Household size Age of household head Building age **** Nº of rooms ******	COEF, ME

						*** Binary variable=1 if the household has specific equipment (wood burner, room heater, fireplace). **** Binary variable=1 if recent dwelling (built after 1975), 0 otherwise ***** Binary variable=1 if the household lives in an apartment ****** Binary variable=1 if dwelling has more than five rooms (0 otherwise) (results for wood not reported here) (results for explanatory variables not reported: altitude of municipality, if changes in main heating system in the last 15 years, forest cover, if household thinks that wood is a declining energy and if household thinks that wood is positive from an environmental point of view) Interpretation based on ME.		
9.Chen (2021)	China 2013-2014	To investigate household heating choices with a particular focus on the rural residential sector.	MNL with sample selection correction (and an alternative-specific conditional logit (ASCL)) Survey data from Sichuan Province (n=556 households)	Energy-specific attributes such as safety level and smoky level have statistically significant effects on household stated preferences for heating systems. Households prefer to adopt lower-cost heating system with high quality energy sources. Among household-specific characteristics, income level, educational level of the decision-maker, household demographic structure, and household location are important determinants of heating fuel choices.	Firewood (reference category) Coal Electricity	• Coal Income (+) Distance from the nearest forest (-) • Electricity Income (+) Age of household head (+) Education (+) Distance from the nearest forest (-) Children (+) COEF reported here (not rrr)	• Coal Gender Age of household head Education Household size Children • Electricity Gender Household size COEF reported here (not rrr)	COEF, rrr
10. Liao and Chang (2002)	U.S. 1993	To investigate the space heating and water heating energy demands	MNL Data from the 1993 Residential	The aged required more natural gas and fuel oil but less electricity for space	Gas (reference categoory) Fuel oil	• Fuel oil Building age** (+) • Electricity	• Fuel oil Rent Gender	COEF, EM

		of the aged in the United States	Energy Consumption Survey (RECS) from the department of Energy (DOE)	heating. The space-heating energy requirement increased as the aged became older. People > 80 years old used not only more natural gas and fuel oil but also more electricity for space heating.	Electricity	Building age** (-) Heating area (-) Dwelling type ***(-) * Rent=1, if dwelling is owned; others 0 ** Year of home built, 1993 is the basic year *** = 1, if dwelling is 1, family detached; others = 0	Age of household head Household size Income Heating area Dwelling size Dwelling type *** • Electricity Rent Gender Age of household head Household size Income Dwelling size	

Source: Own elaboration. † These two columns indicate which variables are statistically significant and non-statistically significant. For those which are significant, the sign of the relationship between the variable and the heating mode ((+) or (-)) is reported. †† Results provided in terms of coefficients (COEF), odds ratio (OR), risk relative ratios (rrr) or marginal effects (ME).

Table 2. Most common variables in the reviewed papers.

	Ownership	Age of household head	Gender	Size. Household living area (m2)	Heating area	Income	Household Size	Children	Education	Building age	Location (in one region)	Rural
1.Decker and Menrad (2015)		*				* (not included in MNL)	*		*			
2.Belaïd and Massié (2022)	*	*		*		*	*					
3.Bai et al (2023)		*	*	*	*	*	*		*			
4.Michelsen and Madlener (2012)	*	*	*	*		*			*	*	*	*
5.Wang et al (2019)					*	*	*		*			
6. Laureti and Secondi (2012)				*		*	*	*	*	*	*	
7.Braun (2010)						*	*	*	*	*	*	*
8.Couture (2012)	*	*		*		*	*			*		
9.Chen (2021)		*	*			*	*	*	*			
10. Liao and Chang (2002)	*	*	*	*	*	*	*			*	* (if dwelling is in city, town or suburbs)	

Source: Own elaboration.

Given the focus of this paper, household energy poverty is included as the main explanatory variable, since we are interested in how it influences heating choices. The rest of variables are included as controls, considering the aforementioned review of the literature and data availability.

Energy poverty

Energy poverty is indeed related to income, and our measure of energy poverty has an income dimension (see section 3). The literature shows that income drives the choice for heating sources and that the higher the income of the household, the less likely that it will adopt coal or oil and the more likely that it will adopt gas (Braun 2010; Laureti and Secondi 2012; Wang et al 2019), electricity (Vaage 2000) or either gas or electricity (Michelsen and Madlener 2012) for heating. However, two studies contradict the energy ladder model, showing that higher-income households were less likely to use electricity instead of gas (Belaid and Massié 2022) or that the share of electric heating did not increase with higher income (Bai et al 2023). Since the cleanest heating alternative (electricity) is also the most expensive one, energy poor people are less likely to use it.

Temperature

Some studies show that gas is preferred over electricity and oil in colder regions (Belaid and Massié 2022 and Selectra (2013). This is explained by Belaid and Messié (2022) on the basis of the efficiency of gas and the costs of electricity[13]. In contrast, Secondi and Laureti (2012) showed that living in cold regions positively (and significantly) influenced the probability to choose oil and coal, negatively and significantly influenced the probability to choose gas, and was not related to the choice of electric heating. A non-significant relation between climate conditions and appliance choice for heating was found in Vaage (2000).

Rurality of the dwelling location

Most contributions in the literature indicate a lower probability to use gas for heating in rural areas because the gas grid is generally less developed (which limits access to it) and more space is available for external storage of fuels in rural areas (Braun 2010, Liao and Chang 2002, Michelsen and Madlener 2012, Laureti and Secondi 2012, Belaid and Massié 2022)[14].

Household size

The impact of household size on heating system is ambiguous in the literature. Some authors find that larger households use less electricity (Belaid and Massié 2022, Bai et al 2023), whereas the probability of choosing electric heating was positively correlated with household size in Wang et al (2019)[15]. Flexibility in the use of fuel types and costs may be behind heating choice by households of different sizes. Electric heating is favorable for small households whose homes are occupied for fewer hours during the days. It is also a relatively flexible mode of heating, but its high operating costs may impede its use in large families in order to keep up with a given budget constraint (Braun 2010, Bai et al 2023).

Educational level

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[13] "For households in need of strong heating power, gas is more efficient. Besides, as heating represents a large share of expenditures in colder regions, households tend to favor energy sources cheaper than electricity, notably gas" (Belaid and Messié 2022, p.12).

[14] However, the higher preference for electricity over gas in rural regions is in contrast to Bai et al (2023) for China, who found that only a few rural households in Qinghai Province used electricity for heating.

[15] Braun (2010) showed that an additional member raised the probability for solid heating whereas family size, on the contrary, negatively affected the gas mode.

The influence of education is also ambiguous in the literature. A higher educational level is related to the choice of gas in Laureti and Secondi (2012), Braun (2010), Belaid and Massié (2022) and Michelsen and Madlener (2012). However, the probability of choosing electric heating was positively correlated with education in Wang et al (2019), Bai et al (2023) and Chen (2021). Decker and Menrad (2015) didn't find a significant relationship between education and the choice of heating systems. Several explanations have been proposed to justify the effect of education on different heating types, including a higher environmental awareness of the more educated households (which would lead them to use cleaner heating alternatives) and the greater opportunity costs of time for the most educated which would lead them to adopt the easy-to-use gas technology (Braun 2010)[16].

Building age

More recent buildings are found more likely to have electric heating (Vaage 2000, Liao and Chang 2002) and gas for heating than oil or solid fuels (Braun (2010), Laureti and Secondi (2012), Vaage (2000), Belaid and Massié (2022), Michelsen and Madlener (2012) and Liao and Chang (2002)). Families living in old houses are more likely to use oil or coal for heating, given that technologies relying on these fuels were mostly applied in the past (Laureti and Secondi 2012).

Dwelling type

Not much evidence on the influence of the dwelling type (flat, row houses or detached houses) on the choice of heating systems is available. Whereas Braun (2010) found that gas is a more attractive option for row houses compared to detached houses and the opposite is found for the oil-fired category, Vaage (2000) identified a high preference for electric heating in apartment blocks. Belaid and Massié (2022) showed that the probability of using electricity rather than gas increases in individual houses (compared to twin houses) due the difficulty for individual houses to connect to existing gas networks.

Age of household breadwinner

The impact of age on the heating choice is ambiguous in the literature. Belaid and Massié (2022) didn't find evidence that age significantly impacted the choice of oil with respect to gas but found that aging was associated with a lower probability of choosing electricity. In contrast, aging led to a higher probability of choosing electricity in Chen (2021). In Michelsen and Madlener (2012), older homeowners favored oil, while younger homeowners were more open towards heat pumps or wood, reflecting different risk aversions. Liao and Chang (2002) found that older families used more fuel oil heating appliances.

It is unclear whether the elderly may prefer electricity heating to other heating sources. Liao and Chang (2002) argue that convenience is the main requirement of oldest households and the reason that they spend more on electricity than other age groups. However, if older households have a higher energy consumption (Nesbakken 2001)[17], they may reduce their bills by not consuming the most expensive heating choice (electricity).

Nationality

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[16] Braun (2010, p.5499) argued that "one can also explain the fairly high propensity for gas among the well-educated households with the relative ease of these technologies. Fewer inspections and long-term contracts with suppliers make gas less time-intensive than other modes of residential space heat generation".

[17] This may be due to the fact that the elderly spends more time at home than the young and they often need higher indoor temperatures.

Only Belaid and Massié (2022) have included this variable in their model, finding that people of foreign nationality at birth (non-French) were 10% more likely to use electricity and 16% more likely to use other energies instead of gas.

Ownership (owners vs. tenants)

The influence of ownership status on heating choices is ambiguous in the literature. Braun (2010) reported that homeowners preferred the oil option, whereas Laureti and Secondi (2012) found that they were more likely to choose gas but were less prone to choose electricity than tenants. Belaid and Massié (2022) found that, compared to owners, tenants were more likely to use oil rather than gas but occupancy status did not impact the choice of heating modes.

Gender

A priori, an influence of gender on the choice of heating types in one given direction cannot be expected. Michelsen and Madlener (2012) found that the variable "female" was only significant for gas heating and Chen (2021) showed that households with more women had a higher preference for electricity over firewood.

3. Methods and data.

3.1 Database

The data used in this paper come from several waves of the Spanish Households Budget Survey (HBS), which is conducted with a representative sample of approximately 24,000 households, representng 18.5 million households each year. It includes detailed information on 256 expenditure groups and socioeconomic characteristics of households. Data for 2019 (20817 households), 2021 (24631 households) and 2022 (20585 households) have been used to analyse the effects of COVID and the Ukraine war on energy poverty as mediated by its determinants. The information is used to calculate an indicator of energy poverty and to estimate the determinants of heating choice by Spanish households.

3.2. Indicator of Fuel Poverty

There are at least 71 indexes to measure fuel poverty (Siksnelyte-Butkiene et al. 2021), based on expenditure data or individual perceptions. They have their pros and cons (see, e.g., Romero et al. 2018) and none can be considered the best. Their choice depends on different criteria, e.g. the particular focus of analysis and data availability.

This paper uses one of the most widespread fuel poverty indicator based on expenditure data, the Low Income–High Cost (LIHC) indicator proposed by Hills (2012) and modified by Romero et al. (2018) for its application to the Spanish case. The LIHC is calculated so that fuel-poor households are those that verify Equations (1) and (2):

$$[Household\ expenditure\ on\ energy] > [Median\ expenditure\ on\ energy] \quad (1)$$

$$[Household\ income] - [Household\ expenditure\ on\ energy] < 60\%\ [Median\ households'\ income - Mean\ expenditure\ on\ energy] \quad (2)$$

Following Romero et al. (2018), the mean expenditure on energy has been subtracted from the mean household income in Spain in order to be consistent with the first term of the equation, in which the household income is considered after the energy cost. Our results show that the fuel poverty indicator increased from 7.93% in 2019 to 9.15% in 2021 and remained constant in 2022 (9.12%), i.e., the percentage of energy-poor households has increased after the shocks.

These results are in the range of other studies on Spain which use the LIHC indicator. For instance, 8.1% of households were energy poor in 2015 in Romero et al. (2018), and 8.3% of households were energy poor in the 2011–2017 period in Costa-Campi et al. (2019).

3.3 Descriptive statistics

The definition of the variables is provided in Table 3.

Table 3. Definition of the variables used in the estimation

Variable	Definition
Dependent variable	
Households without heating	1 if the household does not have heating
Households using electricity	2 if the household uses electricity for heating
Households using gas	3 if the household uses gas for heating
Households using oil or solid fuels	4 if the household uses oil or solid fuels (coal) for heating*
Explanatory variables	
Energy poverty index	1 if the household is energy poor; 0 otherwise
Nationality of the breadwinner	1 if the breadwinner is Spanish; 0 otherwise
Education of the breadwinner	1 if he/she has higher education; 0 otherwise
Gender of the breadwinner	1 if he is a man; 0 if she is a woman
Age of the breadwiner	1 if he or she is 67 years old or more; 0 if he or she is younger than 67 years
Household size	1 if it has one member; 2 if it has two members, etc.
Ownership	1 if the house is rented; 0 if it is owned
Type of dwelling	1 if it an individual house; 0 if it is a building with apartments
Building age	1 if the dwelling is less than 25 years old; 0 if it is more than 25 years old
Location	1 if the household is rural; 0 if it is not
Average temperature in the household's region during the winter	1 if it is less than 10 ºC; 0 if it is more than 10 ºC

* Heating oil and solid fuels are included under the same category in the database and, thus, the impact on the probability to choose each of those two heating sources can not be analysed. However, since solid fuels (coal) represent only 0.9% of energy consumption for heating in Spain (IDAE 2023), the category can be called "oil".

One third of Spanish households don't use heating (Table 4). The main energy source for heating is gas. As for electricity and oil (and other solid fuels), the percentage of households using them is quite similar.

Table 5 shows the percentage of non-energy-poor and energy-poor households which use heating and different heating sources. Energy poor households use less heating and more oil (or solid fuels) and less gas and electricity for heating than non-energy-poor households, i.e. they use dirty fuels for heating much more intensively.

Table 4: Percentage of Spanish households using heating and different energy sources for heating.

Year/Energy Source	No heating	Electricity	Gas	Heating oil or Solid Fuels

2019	33.2	13.8	37.2	15.9
2021	30.3	13.9	39.9	15.9
2022	31.9	13.6	39.0	15.4
AVERAGE	31,8	13,8	38,7	15,7

Source: Spanish Households Budget Survey (HBS).

Table 5. Percentage of non energy-poor (non-EP) and energy-poor (EP) Spanish households which use heating and different energy sources for heating.

Type of household/Energy Source	No heating	Electricity	Gas	Heating oil or Solid Fuels
2019				
Non-EP	33.65	13.95	37.57	14.83
EP	27.94	11.82	32.48	27.76
2021				
Non-EP	30.44	14.19	40.21	15.16
EP	28.35	11.27	37.36	23.03
2022				
Non-EP	31.80	13.81	39.78	14.61
EP	32.59	11.98	31.68	23.75
Average for the period				
Non EP	31.96	13.98	39.18	14.86
EP	29.62	11.68	33.84	24.84

Source: Own elaboration based on data from Spanish Households Budget Survey (HBS).

3.4. Multinomial probit model.

In order to isolate the effect of the different determinants on the probability to choose one of the three heating alternatives (electricity, gas and oil/coal), an econometric model is specified. The unconditional probability p_{jt} that a Spanish household *i* uses a specific energy source *j* for heating instead of another one, subject to a set of characteristics X_{it} in period t, is estimated through a non-ordered multinomial discrete choice model, in which the depedent variable takes three values (1, 2 and 3 if the household chooses electricity, gas or oil/coal for heating, respectively).

As shown in Table 1, non-ordered multinomial models have usually been estimated using the multinomial logit (MNL) alternative. However, the MNL makes the strong assumption of the independence of irrelevant alternatives (IIA). However, when the IIA is violated, the MNL is incorrectly specified, and the estimated coefficients are biased and inconsistent (Jumbe and Angelsen 2011, Kropko 2008). Thus, to overcome this problem, we estimate a non-ordered multinomial probit model (MNP), since the MNP model does not assume IIA and yields robust estimates relative to MNL estimates (Alvarez and Nagler 1998, Jumbe and Angelsen 2011 Mensah and Adu 2015). However, the MNP is not without problems. It avoids imposing IIA through the disturbance term rather than the systemic component, which may not be an entirely satisfactory approach to solving the IIA problem (Álvarez and Nagler 1998). The estimations have been made for 2019, 2021 and 2022 using the maximum likelihood method. The model is especified with a categorical dependent variable and several explanatory variables, including energy poverty (ENPOV). Table 3 provides the definition of the variables used in the estimation[18].

An important issue in the assessment of heating choices in households is that the analysis is often carried out with those households which report using a given heating alternative, disregarding the fact that some households do not use any heating system at all. This is

[18] For a formal representation of the multinomial probit model, see Cameron and Trivedi (2005) and Greene (2000).

problematic from an econometric point of view, since it leads to the well-known sample selection bias. However, in our case, this problem is mitigated, since the whole sample (including households with and without heating) is analysed.

4. Results.

Table 6 and 7 summarise the results of the model (see Annex 1 for full details). All coefficients have the expected sign and most of them are statistically significant. The model is also jointly statistically significant according to the likelihood ratio chi-square test (p-values of 0.000 in the three years, i.e., at least one of the coefficients in the model is not zero). The classification tables show that the model correctly classifies 62%, 63% and 64% of cases in 2019, 2021 and 2022, respectively.

In the multinomial probit model, the estimated parameters provide the impact of the explanatory variable on the probability of choosing the category of use compared to the reference category (electricity)(Table 6). Since the values of the coefficients cannot be directly interpreted, but only their sign, the marginal effects (MEs) are also provided (at sample means) to help better understand the substitution relationships among different types of heating (Table 7)[19]. Given that all the explanatory variables are dummies, MEs are interpreted in terms of probability differences (1 versus 0), considering the predicted probability that each heating type is chosen by a household (Chen 2021).

Energy poverty (ENPOV).

The coefficients for ENPOV are all positive and significant (exception: gas in 2022). Therefore, being more energy poor increases the probability to use gas and oil for heating with respect to electricity. MEs are negative for gas and electricity and positive for oil, i.e., being energy poor increases the probability to use oil and reduces the probability to use gas and electricity.

MEs are lower in 2022 than in 2019 and 2021, suggesting that such probability to choose oil has decreased after COVID and the Ukraine war. However, COVID had a greater impact (MEs strongly decrease between 2019 and 2021, and slightly increase between 2021 and 2022). In contrast to oil, however, MEs are greater in 2021 than in 2019, suggesting that COVID increased the probability that the energy poor chose gas. The lack of statistical significance in 2022 indicates that, similarly to oil, the war in Ukraine has not affected the choice of heating modes as much as COVID has. In contrast to oil/gas, being energy poor reduces the probability to choose electricity (the negative sign of the ME, although only significant for 2021).

Temperature

The coefficients are all positive and significant, whereas MEs are all significant: negative for electricity and positive for oil and gas. Therefore, the colder the region where the dwelling is located, the higher the probability that gas and oil would be chosen (versus electricity). Belaid and Massié (2022) also found that dwellings located in colder regions were more likely to use gas than electricity and oil. But our results are in contrast to Vaage (2000), who found that climate conditions and heating choice were unrelated and, especially, Secondi and Laureti (2012), who showed that dwelling location in colder regions positively influenced the probability to choose oil, negatively influenced the probability to choose gas, and was unrelated to the choice of electricity. MEs are not substantially different over time, i.e. neither COVID nor the Ukraine war have had a strong effect in such a choice.

Rurality

[19] MEs are computed by averaging the individual MEs across all observations (Greene 2000).

The coefficients and MEs are all significant. The coefficients for gas are negative, and positive for oil. MEs are positive for electricity and oil and negative for gas. Thus, if the dwelling is located in a rural area, electricity and oil will more likely be used compared to locations in non-rural areas. In rural dwellings, electricity is more likely to be used than gas (compared to non-rural areas). The lower probability to use gas in rural areas is in line with the literature (Braun 2010, Liao and Chang 2002, Michelsen and Madlener 2012, Laureti and Secondi 2012, Belaid and Massié 2022) and explained by an underdeveloped gas grid and the greater space available for fuel storage in rural areas.

Large differences between MEs for gas and oil over time cannot be observed. In contrast, MEs for electricity substantially decreased between 2019 and 2021 and between 2021 and 2022. Thus, both COVID and the Ukraine war influenced rural households to use less electricity.

Household size

The positive (and significant) sign of the coefficients for gas and oil in all years suggests that, the larger the household, the higher the probability to use oil or gas (vs. electricity). MEs are all significant, with a positive sign for gas and oil and a negative one for electricity. Therefore, a greater size increases the probability to choose gas and oil and reduces the probability to use electricty. These findings are broadly in line with Belaid and Massié (2022) and Bai et al (2023), who showed that larger households use less electricity (for the aforementioned reasons of flexibility in the use of fuel and costs), but in contrast to Wang et al (2019), who found that larger households were more likely to choose electricity. MEs for electricity and oil have remained constant over time, whereas MEs for gas substantially increased between 2019 and 2021 and decreased between 2021 and 2022. Thus, COVID has had the strongest effect, leading to a greater incentive to use gas by the larger households.

Education

Coefficients are always positive and significant for gas and oil (exception: not significant for oil in 2021). Therefore, a high education level is related to a higher probability to choose oil or gas rather than electricity. This is in line with Laureti and Secondi (2012), Braun (2010), Belaid and Massié (2022) and Michelsen and Madlener (2012), who found that a higher educational level is related to the choice of gas for heating, but in contrast to Braun (2010)(regarding oil), Decker and Menrad (2015), Bai et al (2023) and Chen (2021). MEs are all significant and positive but, since MEs for electricity are lower, a higher education level leads to a higher increase in the use of gas and oil than electricity. Although positive, MEs follow a downward trend, especially between 2019 and 2021 and for oil, suggesting a greater effect of COVID than the Ukraine war in this regard.

Building age

The sign for gas is positive and significant, whereas it is negative and significant for oil. Thus, more recent buldings are more likely to be heated with gas than electricity and more likely to use electricity than oil for heating. This is in line with Braun (2010), Laureti and Secondi (2012), Vaage (2000), Belaid and Massié (2022) and Liao and Chang (2002). MEs are positive for electricity and gas and negative for oil. Thus, more recent buildings are more likely to use electricity and gas. Oil for heating was mostly applied in old houses (Laureti and Secondi 2012), whereas new buildings more likely have gas (Michelsen and Madlener 2012) or electric heating (Vaage 2000, Liao and Chang 2002). The reduction in MEs between 2019 and 2021 for electricity and gas suggest that the impact of COVID has been greater than the Ukraine war.

Dwelling type

The negative sign for gas and positive one for oil (and significant) indicates that electricity for heating (versus gas) and oil (versus electricity) is more likely in detached than in non-detached dwellings (flats). MEs are all significant and negative for electricity and gas and positive for oil. Thus, detached dwellings are more likely to use oil and less likely to use electricity and gas than non-detached dwellings. Braun (2010) also found that gas was a more attractive option for row houses compared to detached houses and the opposite was found for oil. In contrast, a high preference for electric heating in apartment blocks was found in Vaage (2000). Belaid and Massié (2022) found that individual houses (compared to twin houses) were more likely to use electricity rather than gas because connecting to gas networks was challenging for individual houses. MEs are less positive for oil and less negative for electricity and gas in 2021 than in 2019. Changes between 2021 and 2022 are either non-existing (gas) or lower (electricity and oil).

Age

The coefficients for age are not significant. They are positive and significant for oil. Therefore, households with older members have a greater probability to use oil than electricity for heating than households with younger members, but age is not related to the choice of gas versus electricity. MEs are positive and significant for oil, but are not significant for electricity and gas. Thus, older people would more likely choose oil, but age is unrelated to the choice of electricity and gas. Our results are in contrast to Chen (2021), who found that aging increases the probability to choose electricity. However, they are in line with Belaid and Massié (2022), who showed that the choice of oil with respect to gas was unrelated to age but that aging reduced the probability of choosing electricity, maybe due to convenience (Liao and Chang 2002). Michelsen and Madlener (2012) found that older homeowners preferred oil, while younger ones were more open towards heat pumps, reflecting different risk aversions. Older families used more oil heating in Liao and Chang (2002).

MEs substantially decrease between 2019 and 2021 for oil. Thus, although the probability to choose oil increases with age both in 2019 and 2021, COVID has reduced such probability.

Nationality

The positive sign for most fuels and years suggests that the probability to choose gas or oil (with respect to electricity) is higher if the breadwinner is Spanish-born. MEs are negative for electricity and positive for oil and gas[20]. Thus, being Spanish increases the probability to use oil and gas and reduces the probability to use electricity. This variable has not received much attention in the literature. Belaid and Massié (2022) found that people of foreign nationality at birth rather than French were more likely to use electricity and other energies instead of gas. MEs do not follow a clear pattern over time.

Ownership

The sign of the coefficients is negative and significant for all years and fuels, suggesting that owning the dwelling increases the probability to use electricity rather than gas and oil (with respect to being a tenant). MEs are not significant for electricity and are negative and significant for gas and oil. Thus, owning the house does not influence the choice for electricity and negatively influences the choice for gas and oil. Our results are in contrast to Braun (2010), who found that owners preferred oil, and Laureti and Secondi (2012), who showed that owners were more likely to choose gas than families living in rented dwellings whereas owners were less prone to choose electricity. Belaid and Massié (2022) found that, compared to owners, tenants were more likely to use oil rather than gas. However, the choice between gas, electricity, and other sources was not significantly affected by occupancy status. MEs for gas

[20] MEs are not significant in 2019 (with the exception of oil).

become less negative and more negative for oil over the years. Thus, COVID and the Ukraine war have lowered the probability for owners to choose gas and oil.

Gender

Gender is unrelated to the choice of heating modes, since the coefficient is only significant (and negative) in 2022 for gas,. Compared to females, males more likely chose electricty rather than gas in 2022. MEs are only significant (and positive) for oil. Thus, being male increases the probability to use oil. The lack of statistical significance of gender is in line with Michelsen and Madlener (2012).

Table 6. Coefficients of the multinomial probit estimations (base outcome: electricity).

	GAS			OIL/COAL		
	2019	2021	2022	2019	2021	2022
ENPOV	0.105*	0.317***	0.209***	0.221***	0.022	0.183***
Temperature	1.689***	1.186***	1.788 ***	1.208 ***	1.768 ***	1.173 ***
Rural	-0.381 ***	0.357 ***	-0.419 ***	0.388***	-0.350***	0.435***
Householdsize	0.047***	0.050***	0. 075***	0.051***	0.075***	0.051***
Education	0.244***	0.148 ***	0.226 ***	0.010	0.238 ***	0.090 **
Buildingage	0.339 ***	-0.372 ***	0.266 ***	-0.383***	0.333 ***	-0.349 ***
Dwellingtype	-0.497 ***	1.058 ***	-0.487 ***	0.944 ***	-0.486 ***	0.976 ***
Age	0.039	0.194 ***	0.017	0.119 ***	0.058	0.168 ***
Nationality	-0.036	0.218 **	0.235***	0.391 ***	0.218***	0.245**
Ownership	-0.281***	-0.268***	-0.294 ***	-0.402***	-0.250 ***	-0.433 ***
Gender	-0.014	0.021	0.017	0.043	-0.073**	0.033

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively (*p < 0.05, **p < 0.01, ***p < 0.001).

Table 7. Marginal effects (ME) of the multinomial probit estimations.

	ELECTRICITY			GAS			OIL/COAL		
	2019	2021	2022	2019	2021	2022	2019	2021	2022
ENPOV	-0.044***	-0.045***	-0.015	-0.009	0.034**	-0.022	0.054***	0.011	0.037***
Temperature	-0.105***	-0.131***	-0.112***	0.569***	0.615***	0.622***	0.174***	0.165***	0.165***
Rural	0.013***	0.007***	0.003***	-0.144***	-0.181***	-0.152***	0.088***	0.091***	0.096***
Householdsize	-0.007***	-0.009***	0.008***	0.007**	0.196***	0.020***	0.004*	0.003*	0.004*
Education	0.022***	0.017***	0.017***	0.143***	0.136***	0.137***	0.050***	0.017***	0.032***
Buildingage	0.283***	0.032***	0.018***	0.193***	0.179***	0.183***	-0.584***	-0.060***	-0.060***
Dwellingtype	-0.045***	-0.030***	-0.035***	-0.289***	-0.279***	-0.279***	0.194***	0.188***	0.182***
Age	-0.012	-0.003	-0.008	-0.002	0.002	0.012	0.032***	0.024***	0.029***
Nationality	0.004	-0.041***	-0.029**	-0.008	0.039**	0.051***	0.051***	0.054***	0.030*
Ownership	-0.007	0.008	0.003	-0.135***	-0.124***	-0.108***	-0.064***	-0.084***	-0.098***
Gender	0.013**	0.005	0.010	0.015*	0.009	-0.016*	0.015**	0.010*	0.015**

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively (*p < 0.05, **p < 0.01, ***p < 0.001).

The results and the main policy implications are summarised in Table 8. Heating with electricity is less likely to be used in energy poor, larger, more educated, older and tenant households, in more recent and non-detached dwellings (flats) and in dwellings located in the coldest regions and urban areas. Therefore, our findings suggest that electrification of heating should be supported especially in those households and dwellings.

Table 8. Summary of results and policy implications.

Variable	Results	Policy implications
ENPOV	Being energy poor increases the probability to use gas and oil to heat the homes with respect to using electricity for heating purposes.	Support electrification of heating in energy poor households. Mitigating energy poverty has a positive side effect in the decarbonised energy transition.

Temperature	The colder the region where the dwelling is located, the more likely that gas and oil will be chosen instead of electricity.	Support the electrification of heating particularly in the coldest regions.
Rural	If the town where the dwelling is located is a rural one, the probability to use electricity and oil is higher than in case the town is a non-rural one.	Support the electrification of heating especially in the most urban locations.
Householdsize	The greater the size of the househouseld is, the more likely that gas or oil will be chosen (vs. electricity).	Support the electrification of heating especially in the larger households.
Education	The higher the educational level of the breadwinner is, the higher the probability that oil or electricity will be chosen (vs. electricity).	Unclear policy recommendations.
Buildingage	More recent buildings are more likely to have gas for heating (than electricity) and more likely to have electricity than oil.	Support the electrification of heating especially in new buildings.
Dwellingtype	Detached dwellings are more likely to have electricity for heating (vs. gas) and oil (vs. electricity) than collective dwellings (non-detached, flats).	Support the electrification of heating particularly in non-detached dwellings (flats).
Age	Households with older members have a higher probability to use oil for heating than electricity (with respect to younger members) but age is not related to the choice of gas versus electricity.	Support the electrification of heating particularly in the households with older members.
Nationality	The probability to choose gas or oil for heating (versus electricity) is greater if the breadwinner is Spanish.	Unclear policy recommendations.
Ownership	Owning the dwelling leads to a greater probability to use electricity for heating than gas and oil (versus being a tenant).	Support the electrification of heating particularly in rented houses (tenants).
Gender	There isn't a statistically significant relationship between gender and the choice of heating sources.	Unclear policy recommendations.

They also suggest that COVID (2021) and the Ukraine war (2022) have likely influenced the decision to use different heating choices by Spanish households. They have aggravated energy poverty and thus, have negatively affected the electrification of heating and, in turn, the decarbonized energy transition. However, the impact of COVID has clearly been greater.

A higher energy poverty level (as experienced by Spain) clearly increases the probability of choosing oil for heating. This suggests that decarbonisation and mitigation of energy poverty are synergistic, i.e. reducing energy poverty reduces the probability to choose a highly carbon-intensive heating fuel (oil/coal) and increases the probability to use a cleaner one (electricity). The ME is lower in 2022 than in 2019 and 2021, suggesting that such probability to choose oil for heating has decreased after COVID and the Ukraine war. However, the more pronounced impact in this context can be attributed to COVID. Indeed, the ME strongly decreases between 2019 and 2021, and slightly increases between 2021 and 2022.

A similar picture is observed for gas, with positive MEs, i.e. a higher energy poverty level has increased the probability to choose gas for heating. In contrast to oil, however, the ME is greater in 2021 than in 2019, suggesting that COVID increased the probability that the energy poor chose gas. The lack of statistical significance in 2022 indicates that, similarly to oil, the war in Ukraine has not affected the choice of heating sources as much as COVID.

Regarding electricity, the negative MEs indicate that the opposite picture compared to oil and gas emerges. Higher energy poverty levels reduce the probability to choose electricity as the heating source (although MEs are only significant in 2021), confirming the aforementioned conclusion that energy poverty and the decarbonised energy transition are synergistically related.

Regarding the other explanatory variables, COVID and the Ukraine war have not affected (no substantial change between 2019, 2021 and 2022) temperature, rurality (for gas and oil/coal), household size (for electricity and oil/coal), nationality and gender. However, MEs clearly differ for the rest of variables in 2021 or 2022.

Variables with clearly different MEs only between 2019 and 2021 (suggesting an impact of COVID) are *household size* for gas (a higher probability to use gas by larger households), *building age* (a lower probability to use gas and electricity in recent buildings), *dwelling type* (a lower probability to use oil and a higher probability to use electricity in detached dwellings) and *age* (a lower positive effect of aging on oil).

Those variables with clearly different MEs between 2019 and 2021 and also between 2021 and 2022 (suggesting an impact of COVID and the war in Ukraine in the same direction) are *rural* (only for electricity, leading to a lower probability to use electricity by rural households) and *ownership* (leading to a greater probability to use oil and gas by tenants).

Education clearly has different MEs between 2019 and 2021 and also between 2021 and 2022, but in different directions (suggesting a different effect of COVID and the war in Ukraine). Therefore, there is a lower probability to use oil by the most educated households between 2019 and 2021, but a greater probability between 2021 and 2022.

5. Conclusions and policy recomendations.

The heating sector plays a crucial role in the decarbonization of the energy system. As stressed by Sovacool et al (2021), it is imperative that climate policy researchers and practitioners grapple with the decarbonization of heat, a difficult task given the path dependencies involved (Bertelsen et al 2020).

This paper has connected three crucial issues affecting countries worldwide: decarbonisation of energy systems, COVID/Ukraine war and energy poverty. Our results show that being energy poor reduces the probability to choose electricity compared to more carbon-intensive fuels and that the COVID/Ukraine war have likely influenced the probability to use different heating choices by Spanish households. Those two events have aggravated energy poverty, with a negative impact on the electrification of heating and the decarbonized energy transition. However, the impact of COVID has been greater than the Ukraine war in this regard.

Some explanatory variables have an impact on the probability to choose different heating types and those two events have had a clear effect on such probability. Electric heating is less likely to be used in energy poor, larger, more educated, older and tenant households, in more recent and non-detached dwellings (flats) and in dwellings located in the coldest regions and in urban locations. COVID or the Ukraine war have had a negative effect on the probability to use electric heating in rural and larger households, owners, less educated households and more recent buildings and flats.

Our findings suggest that energy poverty hampers the decarbonised energy transition, in which the electrification of energy uses plays a crucial role. Thus, reducing energy poverty reduces the probability to choose highly carbon-intensive fuels for heating, i.e., mitigating energy poverty comes with an additional benefit: supporting the decarbonized energy transition. Some policies may kill two birds with one stone although, in line with the Tinbergen rule (one instrument is needed per policy goal, Tinbergen 1952), policies to address each policy goal should be different. Thus, a policy mix is required which combines instruments to mitigate energy poverty and instruments to support electric heating.

Whereas the literature on instruments to mitigate energy poverty is relatively large, the literature on policies to encourage electrification with a focus on different types of households and dwellings, including the energy poor, is not. Therefore, we focus on the later, considering the determinants of electric heating found in this article.

In general, measures to encourage the uptake of electric heating can fall in several realms: regulatory, economic and information instruments. Many barriers affect the ways in which people currently heat their homes that need to be overcome (Rosenow et al 2023). Therefore, a policy mix approach that address several dimensions should be adopted: measures aimed at economic factors, which may include grants, low interest loans and tax reductions, should be combined with those aimed at emotional or cognitive aspects (environmental awareness), which may include information campaigns, demostracion and regulatory measures. A mix of carrots (subsidies or soft loans for adopting electric heating, scrap bonuses and information campaigns) and sticks (requirement to phase-out oil heating) would be appropriate in this regard.

Regulatory instruments may focus on the prohibition of heating oil, particularly in the context of renovation strategies. Indeed, prohibitions on fossil fuel heating in favour of low-carbon alternatives have increased (Rosenbloom et al. 2020, Sunderland and Gibb 2022). For example, the French government recently prohibited the installation of heating equipment using oil, combined with subsidies to change the heating system (Belaid and Massié 2022)[21]. The European Commission RepowerEU Plan proposes to ban the installation and replacement of fossil-fuel boilers from 2029.

Economic instruments (subsidies and taxes) can also be adopted. Grants can be directed to the switch to electric heating equipment or subsidised electricity rates can be provided for those using electric heating equipment. Subsidies should particularly target lower-income households, the ones which are most at risk of being locked into fossil fuel reliance (Sunderland and Gibb 2022). An interesting possibility is to give a scrap bonus if one replaces the old heating system with an electric one (similarly to that provided by car manufacturers to promote sales of new cars)(Decker and Menrad 2015).

Subsidies to support the replacement of heating systems may be particularly effective in the Spanish context, given the relatively lower average income levels in the EU context (between 29.000€-31.000€) and the difficulties to change the heating system by the oldest and youngest segments of the population, given their limited investment capability and heating consumption habits (ADL 2023).

Increasing taxes on gas and reducing them on electricity is another alternative to encourage the uptake of electric heating (Decker and Menrad 2015). Rosenow et al (2023) analysed taxes and levies for heating fuels in five European countries (including Spain) and concluded that electricity is overtaxed whereas oil, coal and gas are significantly undertaxed. This “results in heating systems relying on electricity being more costly than other options” (Rosenow et al 2023, p.6)[22]. Thus, switching from fossil-fuel to electric heating is disincentivized and lowering taxes on electricity and increasing them for fossil fuels would make electricity more attractive.

[21] In contrast, there is no specific plan to phase out fossil fuel heating systems in Spain (López-Bernabé et al 2022).
[22] For Spain, they conclude that “when recalculating all excise duties and levies into an implicit carbon tax, Spain levies an implicit carbon tax of €13 per tonne on gas, €36 per tonne on oil, and an additional €427 per tonne on electricity on top of the explicit carbon tax of €80 in the EU ETS. When a shadow cost for NOx, PM2.5 and PM10 is also included in the comparison, Spain seems to undertax gas and oil by 92% and 80% respectively, while overtaxing electricity by 330% excluding the EU ETS and 397% including the EU ETS” (Rosenow et al 2023, p.6).

However, this may have negative distributional effects on the poorest segments of the population that need to be assessed[23].

Both subsidies and taxes are not without problems. The former may be problematic from the public deficit and additionality viewpoints[24]. The latter could be problematic from an equity point of view. Increasing heating prices may be socially rejected, particularly if it negatively affects low-income households.

Finally, information and education campaigns may play an important role in addressing the non-economic rationale of households to adopt electric heating. These campaigns can place different economic (costs, convenience) and non-economic (environmental protection, comfort) aspects at their core, depending on the specific type of electric heating system being promoted and the household type. In particular, households should be made aware of the environmental benefits of electric heating to increase its attractiveness. Indeed, the greatest potential for the heating transition in Spain lies in environmental education and information (López-Bernabé et al 2022) and information strongly influences the choice of heating systems in this country (Ortega-Izquierdo et al 2019).

COVID and the Ukraine war have provided added reasons to improve the affordability of electricity as an element to support electric heating and increase energy independency. The surge in electricity and gas prices and the inflationary pressures caused by the latter conflict have negatively impacted consumers' energy bills (Belaid and Massié 2022).

Energy and climate policy measures targeting electric heating should consider the heterogeneity of homeowners by considering behavioral aspects as well as framework conditions on the individual, home and regional level (Michelsen and Madlener 2012). Thus, complementary to the above, some policies may be addressed to specific households. Those policies may be directed to the energy poor, supporting the electrification of heating through investment subsidies, soft loans, tax reduction schemes or scrap bonuses.

Our approach has identified drivers of electric heating which can be addressed by policies. Focusing on specific determinants will help policy makers to design-target oriented policy measures to encourage electric heating. In particular, our findings suggest that electrification of heating should be supported especially in energy poor, larger, oldest and tenant households, in new and non-detached dwellings (flats) and in dwellings located in the coldest regions. In addition, the negative incentives to use electricity in given types of households as a result of COVID and/or the Ukraine war suggest that, if the aim is to transition towards electric heating, policy interventions should be targeted at specific household types to mitigate those negative effects, i.e., rural households, tenants and the less educated (only regarding COVID).

Some of the limitations of this paper refer to our dataset. Cross-sectional data do not allow a true study of dynamics and we disregard the attributes (cost and quality) of different heating alternatives (such as device and fuel costs and safety levels). Furthermore, we use electric heating as an aggregated category which includes different technologies, with different characteristics and costs. Emotional (i.e., psychological and cognitive) factors influencing the adoption of different heating systems have not been researched in this article. Finally, this paper provides an analysis of a single country. The general findings, arguments and policy

[23] As Rosenow et al (2006, p.9) themselves argue "the majority of low-income households heat with fossil fuels and more often live in poorly insulated homes, unable to keep warm".

[24] For example, Michelsen and Madlener (2012) found that the grant provided by the German Federal Office of Economics and Export Control did not play a role in the decision-making process for certain renewable energy heating systems and that the grant was not economically efficient since the homeowners would have bought such heating system anyway.

implications may be applicable only to very similar contexts (Southern European countries) and not to countries where heating habits and/or systems are very different from those in Spain. However, the analysis of energy poverty and heating choices at household level unavoidably requires a national approach, since economic, institutional and climatic conditions are necessarily different across countries and policies need to take these differences into account. Furthermore, the original analysis of the interaction between COVID/Ukraine war, heating choices and energy poverty makes it a valuable contribution which can be replicated in other countries with similar databases.

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APPENDIX

Table A1. Coefficients of the multinomial estimations (base outcome: electricity).

2019

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Iteration 0:   log likelihood = -20625.528
Iteration 1:   log likelihood = -20596.671
Iteration 2:   log likelihood = -20596.611
Iteration 3:   log likelihood = -20596.611

Multinomial probit regression                   Number of obs =  20,817
                                                Wald chi2(33) = 9496.46
Log likelihood = -20596.611                     Prob > chi2   =  0.0000
```

ENERCAL2	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
1						
ENPOV	-.1850599	.064412	-2.87	0.004	-.3113051	-.0588147
TEMPERATURE	-1.124821	.0358144	-31.41	0.000	-1.195015	-1.054626
municipio	.0535271	.0444329	1.20	0.228	-.0335599	.1406141
TAMANO	.0182316	.0150606	1.21	0.226	-.0112866	.0477497
educ	-.5961497	.037328	-15.97	0.000	-.6693112	-.5229881
buildingage	-.4918783	.037653	-13.06	0.000	-.5656767	-.4180798
dwellingtype	.500418	.0393564	12.72	0.000	.423281	.5775551
Age	.0050194	.0414537	0.12	0.904	-.0762284	.0862673
NATIONALITY	-.1287237	.0773441	-1.66	0.096	-.2803154	.022868
VIVIENDAPROP	.5169025	.0504588	10.24	0.000	.4180051	.6157999
GENDER	-.1521275	.0361689	-4.21	0.000	-.2230173	-.0812377
_cons	1.483988	.0977657	15.18	0.000	1.292371	1.675606
2	(base outcome)					
3						
ENPOV	.1055276	.0639472	1.65	0.099	-.0198065	.2308618
TEMPERATURE	1.689562	.0424055	39.84	0.000	1.606449	1.772676
municipio	-.3811551	.0446848	-8.53	0.000	-.4687357	-.2935745
TAMANO	.0474205	.0151193	3.14	0.002	.0177872	.0770538
educ	.2449638	.0353136	6.94	0.000	.1757503	.3141772
buildingage	.3394719	.0364596	9.31	0.000	.2680124	.4109314
dwellingtype	-.4975927	.041542	-11.98	0.000	-.5790134	-.4161719
Age	.0396186	.0415557	0.95	0.340	-.0418291	.1210663
NATIONALITY	-.0364972	.0815421	-0.45	0.654	-.1963168	.1233225
VIVIENDAPROP	-.2817013	.0513567	-5.49	0.000	-.3823586	-.181044
GENDER	-.0141045	.0358671	-0.39	0.694	-.0844026	.0561936
_cons	-.7140269	.1040846	-6.86	0.000	-.9180289	-.5100248
4						
ENPOV	.3176666	.0664131	4.78	0.000	.1874992	.4478339
TEMPERATURE	1.186618	.0483595	24.54	0.000	1.091835	1.281401
municipio	.3571728	.0457909	7.80	0.000	.2674244	.4469213
TAMANO	.0509896	.0171316	2.98	0.003	.0174122	.084567
educ	.1487785	.0407359	3.65	0.000	.0689375	.2286194
buildingage	-.3722184	.0425314	-8.75	0.000	-.4555784	-.2888584
dwellingtype	1.058566	.0435769	24.29	0.000	.9731565	1.143975
Age	.1942541	.0452057	4.30	0.000	.1056527	.2828556
NATIONALITY	.218264	.1028876	2.12	0.034	.0166079	.41992
VIVIENDAPROP	-.2680561	.0638427	-4.20	0.000	-.3931855	-.1429266
GENDER	.0218551	.0406731	0.54	0.591	-.0578627	.1015729
_cons	-1.776467	.127341	-13.95	0.000	-2.02605	-1.526883

2021

```
Iteration 0:   log likelihood = -24092.645
Iteration 1:   log likelihood = -24055.408
Iteration 2:   log likelihood = -24055.314
Iteration 3:   log likelihood = -24055.314

Multinomial probit regression                  Number of obs =   24,631
                                               Wald chi2(33) = 11551.79
Log likelihood = -24055.314                    Prob > chi2   =   0.0000
```

ENERCAL2	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
1						
ENPOV	-.067775	.0565968	-1.20	0.231	-.1787026	.0431527
TEMPERATURE	-1.240732	.033487	-37.05	0.000	-1.306365	-1.175099
municipio	.1893989	.0412931	4.59	0.000	.1084658	.2703319
TAMANO	-.0042589	.0140089	-0.30	0.761	-.0317158	.0231979
educ	-.5206742	.0339326	-15.34	0.000	-.5871808	-.4541676
buildingage	-.520191	.0355089	-14.65	0.000	-.5897872	-.4505947
dwellingtype	.430425	.0365159	11.79	0.000	.3588551	.5019948
Age	-.0519907	.039564	-1.31	0.189	-.1295347	.0255534
NATIONALITY	.014867	.0747853	0.20	0.842	-.1317095	.1614436
VIVIENDAPROP	.5004825	.0477909	10.47	0.000	.4068141	.5941509
GENDER	-.0548286	.0333703	-1.64	0.100	-.1202331	.010576
_cons	1.320664	.0908889	14.53	0.000	1.142525	1.498803
2	(base outcome)					
3						
ENPOV	.209886	.0550962	3.81	0.000	.1018995	.3178724
TEMPERATURE	1.788518	.0389695	45.90	0.000	1.712139	1.864897
municipio	-.4198474	.0405833	-10.35	0.000	-.4993892	-.3403057
TAMANO	.0756797	.0137647	5.50	0.000	.0487015	.102658
educ	.2261858	.0319246	7.08	0.000	.1636147	.2887569
buildingage	.2665953	.0335759	7.94	0.000	.2007878	.3324027
dwellingtype	-.4875922	.0376195	-12.96	0.000	-.561325	-.4138594
Age	.017888	.0385772	0.46	0.643	-.0577219	.0934979
NATIONALITY	.2359117	.0795385	2.97	0.003	.080019	.3918044
VIVIENDAPROP	-.2944586	.0476505	-6.18	0.000	-.3878519	-.2010654
GENDER	.0171742	.0322542	0.53	0.594	-.0460428	.0803913
_cons	-1.068126	.0974577	-10.96	0.000	-1.25914	-.8771129
4						
ENPOV	.2215562	.0589255	3.76	0.000	.1060645	.337048
TEMPERATURE	1.208704	.0445759	27.12	0.000	1.121337	1.296071
municipio	.3806427	.0419312	9.08	0.000	.2984591	.4628263
TAMANO	.0512256	.0156436	3.27	0.001	.0205647	.0818865
educ	.010033	.0366594	0.27	0.784	-.0618181	.0818842
buildingage	-.3837519	.0391585	-9.80	0.000	-.460501	-.3070027
dwellingtype	.9443597	.0396377	23.82	0.000	.8666712	1.022048
Age	.1193899	.0420123	2.84	0.004	.0370474	.2017325
NATIONALITY	.3913264	.1040498	3.76	0.000	.1873925	.5952602
VIVIENDAPROP	-.4020258	.0608604	-6.61	0.000	-.5213101	-.2827415
GENDER	.0437228	.0366846	1.19	0.233	-.0281777	.1156234
_cons	-1.835212	.1224258	-14.99	0.000	-2.075162	-1.595262

2022

```
Iteration 0:   log likelihood = -19850.036
Iteration 1:   log likelihood = -19818.569
Iteration 2:   log likelihood = -19818.482
Iteration 3:   log likelihood = -19818.482

Multinomial probit regression                   Number of obs =  20,585
                                                Wald chi2(33) = 9828.15
Log likelihood = -19818.482                     Prob > chi2   =  0.0000
```

ENERCAL2	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
1						
ENPOV	-.0092502	.0605285	-0.15	0.879	-.1278839	.1093836
TEMPERATURE	-1.280038	.0361994	-35.36	0.000	-1.350987	-1.209088
municipio	.1145996	.0447323	2.56	0.010	.0269258	.2022734
TAMANO	-.0115936	.0150734	-0.77	0.442	-.041137	.0179497
educ	-.5306275	.0371732	-14.27	0.000	-.6034856	-.4577694
buildingage	-.4217964	.0388694	-10.85	0.000	-.4979789	-.3456139
dwellingtype	.4542451	.0399653	11.37	0.000	.3759146	.5325756
Age	-.0540381	.0431607	-1.25	0.211	-.1386315	.0305552
NATIONALITY	-.0259603	.075468	-0.34	0.731	-.1738749	.1219542
VIVIENDAPROP	.4765434	.0512	9.31	0.000	.3761933	.5768935
GENDER	-.0598144	.0363431	-1.65	0.100	-.1310456	.0114168
_cons	1.424465	.0944186	15.09	0.000	1.239408	1.609523
2	(base outcome)					
3						
ENPOV	.0227913	.0608038	0.37	0.708	-.0963819	.1419644
TEMPERATURE	1.768028	.0431669	40.96	0.000	1.683423	1.852634
municipio	-.3505313	.0443709	-7.90	0.000	-.4374966	-.2635659
TAMANO	.0755923	.0149102	5.07	0.000	.0463688	.1048158
educ	.2380977	.0350964	6.78	0.000	.1693099	.3068854
buildingage	.3338311	.0370445	9.01	0.000	.2612251	.406437
dwellingtype	-.4868115	.0414082	-11.76	0.000	-.5679701	-.405653
Age	.0589342	.0424881	1.39	0.165	-.0243409	.1422094
NATIONALITY	.2186102	.0807458	2.71	0.007	.0603514	.376869
VIVIENDAPROP	-.2500082	.0513294	-4.87	0.000	-.3506121	-.1494044
GENDER	-.073745	.035329	-2.09	0.037	-.1429886	-.0045015
_cons	-1.022889	.1020721	-10.02	0.000	-1.222946	-.8228309
4						
ENPOV	.1831447	.0645821	2.84	0.005	.0565661	.3097233
TEMPERATURE	1.173653	.049271	23.82	0.000	1.077084	1.270222
municipio	.4357706	.0458833	9.50	0.000	.3458409	.5257002
TAMANO	.0515985	.0170651	3.02	0.002	.0181515	.0850455
educ	.0905071	.0404844	2.24	0.025	.011159	.1698551
buildingage	-.3490444	.043717	-7.98	0.000	-.4347281	-.2633607
dwellingtype	.9767081	.0438699	22.26	0.000	.8907246	1.062692
Age	.1689711	.0465693	3.63	0.000	.077697	.2602452
NATIONALITY	.2455589	.1020508	2.41	0.016	.0455431	.4455747
VIVIENDAPROP	-.4337923	.0669076	-6.48	0.000	-.5649288	-.3026558
GENDER	.0331894	.0404861	0.82	0.412	-.0461619	.1125407
_cons	-1.768796	.1249321	-14.16	0.000	-2.013658	-1.523934

Table A2. Marginal effects of the multinomial estimations (base outcome: electricity).

2019

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
ENPOV						
_predict						
1	-.0895966	.0145907	-6.14	0.000	-.1181938	-.0609994
2	-.0077173	.0118781	-0.65	0.516	-.030998	.0155634
3	.0341903	.0146326	2.34	0.019	.0055109	.0628698
4	.0631236	.0092879	6.80	0.000	.0449196	.0813276
TEMPERATURE						
_predict						
1	-.6378281	.0089358	-71.38	0.000	-.6553418	-.6203143
2	-.1057351	.0070039	-15.10	0.000	-.1194625	-.0920076
3	.5693966	.010049	56.66	0.000	.5497009	.5890923
4	.1741665	.0071744	24.28	0.000	.1601049	.1882281
municipio						
_predict						
1	.0435359	.0102846	4.23	0.000	.0233784	.0636934
2	.01302	.0081797	1.59	0.111	-.0030118	.0290519
3	-.1449099	.010414	-13.91	0.000	-.1653211	-.1244988
4	.088354	.0064981	13.60	0.000	.075618	.10109
TAMANO						
_predict						
1	-.0046826	.0034835	-1.34	0.179	-.0115101	.0021448
2	-.0079652	.0028023	-2.84	0.004	-.0134575	-.0024729
3	.0079093	.0035154	2.25	0.024	.0010193	.0147993
4	.0047385	.0025328	1.87	0.061	-.0002258	.0097028
educ						
_predict						
1	-.2162809	.008878	-24.36	0.000	-.2336815	-.1988802
2	.0223278	.0066404	3.36	0.001	.0093129	.0353428
3	.1435734	.0082958	17.31	0.000	.127314	.1598328
4	.0503796	.0060946	8.27	0.000	.0384344	.0623248
buildingage						
_predict						
1	-.1637123	.008996	-18.20	0.000	-.1813442	-.1460804
2	.0283743	.0067794	4.19	0.000	.015087	.0416616
3	.193776	.0086791	22.33	0.000	.1767653	.2107866
4	-.058438	.0063981	-9.13	0.000	-.0709781	-.0458979
dwellingtype						
_predict						
1	.1413122	.0091943	15.37	0.000	.1232918	.1593327
2	-.0457313	.0073926	-6.19	0.000	-.0602206	-.0312419
3	-.2898383	.0096345	-30.08	0.000	-.3087216	-.270955
4	.1942573	.0063002	30.83	0.000	.1819092	.2066054
Age						
_predict						
1	-.0171556	.0095372	-1.80	0.072	-.0358481	.001537
2	-.0125298	.007681	-1.63	0.103	-.0275842	.0025246
3	-.0026492	.0096349	-0.27	0.783	-.0215334	.0162349
4	.0323346	.00655	4.94	0.000	.0194969	.0451723
NATIONALITY						
_predict						
1	-.0470686	.0177651	-2.65	0.008	-.0818875	-.0122496
2	.0043874	.0150188	0.29	0.770	-.025049	.0338237
3	-.0084571	.0191005	-0.44	0.658	-.0458933	.0289792
4	.0511382	.0160639	3.18	0.001	.0196536	.0826228
VIVIENDAPROP						
_predict						
1	.2064651	.0116801	17.68	0.000	.1835726	.2293577
2	-.0071048	.0095565	-0.74	0.457	-.0258352	.0116255
3	-.1351647	.0119727	-11.29	0.000	-.1586307	-.1116987
4	-.0641956	.0098299	-6.53	0.000	-.0834619	-.0449293
GENDER						
_predict						
1	-.0435927	.0084032	-5.19	0.000	-.0600628	-.0271227
2	.0131308	.0066727	1.97	0.049	.0000525	.0262092
3	.0151625	.0083562	1.81	0.070	-.0012153	.0315404
4	.0152994	.0060194	2.54	0.011	.0035016	.0270972

2021

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
ENPOV						
_predict						
1	-.0600799	.0121676	-4.94	0.000	-.0839279	-.0362319
2	-.0251219	.0104342	-2.41	0.016	-.0455726	-.0046712
3	.0556993	.0129819	4.29	0.000	.0302552	.0811434
4	.0295025	.0085522	3.45	0.001	.0127404	.0462646
TEMPERATURE						
_predict						
1	-.6493041	.0081147	-80.02	0.000	-.6652086	-.6333996
2	-.1315099	.0065991	-19.93	0.000	-.1444438	-.1185759
3	.6151336	.0096964	63.44	0.000	.596129	.6341383
4	.1656803	.0068858	24.06	0.000	.1521845	.1791762
municipio						
_predict						
1	.0827697	.0090822	9.11	0.000	.0649688	.1005705
2	.0077678	.0075597	1.03	0.304	-.0070489	.0225845
3	-.1828979	.0097556	-18.75	0.000	-.2020185	-.1637773
4	.0923605	.0061453	15.03	0.000	.0803159	.104405
TAMANO						
_predict						
1	-.0143683	.0030996	-4.64	0.000	-.0204435	-.0082932
2	-.0092741	.0025873	-3.58	0.000	-.0143451	-.0042031
3	.0196641	.003326	5.91	0.000	.0131452	.0261831
4	.0039783	.0023845	1.67	0.095	-.0006952	.0086519
educ						
_predict						
1	-.1719593	.0076499	-22.48	0.000	-.1869529	-.1569657
2	.0179596	.0060518	2.97	0.003	.0060983	.029821
3	.1369014	.0077601	17.64	0.000	.121692	.1521108
4	.0170982	.0056292	3.04	0.002	.0060651	.0281313
buildingage						
_predict						
1	-.1522792	.0081023	-18.79	0.000	-.1681595	-.136399
2	.0324004	.0063279	5.12	0.000	.0199979	.0448028
3	.1799507	.0082806	21.73	0.000	.1637209	.1961805
4	-.0600718	.0060636	-9.91	0.000	-.0719562	-.0481875
dwellingtype						
_predict						
1	.1215975	.0081381	14.94	0.000	.1056471	.137548
2	-.0305283	.0068335	-4.47	0.000	-.0439218	-.0171348
3	-.2794058	.0090663	-30.82	0.000	-.2971755	-.2616362
4	.1883366	.0058967	31.94	0.000	.1767792	.1998939
Age						
_predict						
1	-.0240299	.008674	-2.77	0.006	-.0410307	-.0070291
2	-.0032699	.0072612	-0.45	0.652	-.0175017	.0109619
3	.0029835	.009246	0.32	0.747	-.0151383	.0211052
4	.0243163	.0062427	3.90	0.000	.0120808	.0365518
NATIONALITY						
_predict						
1	-.0517732	.0170495	-3.04	0.002	-.0851897	-.0183568
2	-.0418548	.01461	-2.86	0.004	-.0704898	-.0132198
3	.0394848	.020048	1.97	0.049	.0001915	.078778
4	.0541433	.0171723	3.15	0.002	.0204861	.0878004
VIVIENDAPROP						
_predict						
1	.2002318	.0105506	18.98	0.000	.179553	.2209105
2	.0083495	.0090357	0.92	0.355	-.0093602	.0260592
3	-.1244495	.0115782	-10.75	0.000	-.1471424	-.1017567
4	-.0841317	.0097288	-8.65	0.000	-.1031998	-.0650637
GENDER						
_predict						
1	-.0199273	.0074359	-2.68	0.007	-.0345014	-.0053533
2	.0005386	.0060875	0.09	0.930	-.0113926	.0124698
3	.0090532	.0078212	1.16	0.247	-.006276	.0243824
4	.0103356	.0055995	1.85	0.065	-.0006393	.0213105

2022

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
ENPOV						
_predict						
1	-.0173331	.013463	-1.29	0.198	-.04372	.0090538
2	-.00951	.0113544	-0.84	0.402	-.0317643	.0127443
3	-.0051205	.0143438	-0.36	0.721	-.0332338	.0229928
4	.0319636	.0090998	3.51	0.000	.0141283	.0497989
TEMPERATURE						
_predict						
1	-.6747475	.0090286	-74.73	0.000	-.6924432	-.6570518
2	-.1123995	.0071887	-15.64	0.000	-.1264891	-.09831
3	.6220962	.0104929	59.29	0.000	.6015304	.6426619
4	.1650508	.007246	22.78	0.000	.150849	.1792527
municipio						
_predict						
1	.0521968	.0101442	5.15	0.000	.0323146	.0720791
2	.0039123	.0082604	0.47	0.636	-.0122778	.0201023
3	-.152764	.0105588	-14.47	0.000	-.1734588	-.1320691
4	.0966548	.0064768	14.92	0.000	.0839606	.1093491
TAMANO						
_predict						
1	-.0168162	.0034437	-4.88	0.000	-.0235658	-.0100666
2	-.0083855	.0028006	-2.99	0.003	-.0138746	-.0028964
3	.0206291	.0035694	5.78	0.000	.0136332	.027625
4	.0045726	.0025095	1.82	0.068	-.000346	.0094911
educ						
_predict						
1	-.1872607	.0086462	-21.66	0.000	-.2042069	-.1703144
2	.0170741	.0066608	2.56	0.010	.004019	.0301291
3	.1373826	.008455	16.25	0.000	.120811	.1539542
4	.032804	.0059889	5.48	0.000	.021066	.044542
buildingage						
_predict						
1	-.1417716	.0091086	-15.56	0.000	-.1596242	-.1239189
2	.018832	.007005	2.69	0.007	.0051024	.0325616
3	.1832338	.0090146	20.33	0.000	.1655656	.2009021
4	-.0602943	.0065128	-9.26	0.000	-.0730591	-.0475294
dwellingtype						
_predict						
1	.1318246	.0091667	14.38	0.000	.1138581	.1497911
2	-.0351429	.0075235	-4.67	0.000	-.0498886	-.0203971
3	-.2791612	.0098541	-28.33	0.000	-.2984748	-.2598476
4	.1824795	.0062888	29.02	0.000	.1701536	.1948053
Age						
_predict						
1	-.0339356	.0097947	-3.46	0.001	-.0531328	-.0147384
2	-.0085927	.0079786	-1.08	0.281	-.0242304	.007045
3	.0128899	.0101102	1.27	0.202	-.0069257	.0327054
4	.0296384	.0066893	4.43	0.000	.0165276	.0427492
NATIONALITY						
_predict						
1	-.0526246	.0175687	-3.00	0.003	-.0870586	-.0181905
2	-.0291507	.0147393	-1.98	0.048	-.0580392	-.0002621
3	.0516606	.0199429	2.59	0.010	.0125732	.090748
4	.0301146	.0160337	1.88	0.060	-.0013108	.06154
VIVIENDAPROP						
_predict						
1	.1954868	.0117061	16.70	0.000	.1725433	.2184302
2	.0037065	.0097276	0.38	0.703	-.0153592	.0227722
3	-.1087852	.0123617	-8.80	0.000	-.1330137	-.0845567
4	-.090408	.0103195	-8.76	0.000	-.1106338	-.0701823
GENDER						
_predict						
1	-.00889	.0083431	-1.07	0.287	-.0252423	.0074622
2	.0102657	.0066773	1.54	0.124	-.0028215	.0233529
3	-.0164945	.0084591	-1.95	0.051	-.0330741	.0000851
4	.0151188	.0059502	2.54	0.011	.0034566	.026781

Table A3. Classification tables.

2019

ENERCAL2	ENERCAL2_pred 1	3	4	Total
1	4,809	1,272	829	6,910
2	1,131	1,393	345	2,869
3	630	6,496	612	7,738
4	359	1,199	1,742	3,300
Total	6,929	10,360	3,528	20,817

2021

ENERCAL2	ENERCAL2_pred 1	3	4	Total
1	5,284	1,340	827	7,451
2	1,323	1,707	399	3,429
3	604	8,512	723	9,839
4	380	1,569	1,963	3,912
Total	7,591	13,128	3,912	24,631

2022

ENERCAL2	ENERCAL2_pred 1	3	4	Total
1	4,711	1,113	736	6,560
2	1,044	1,421	344	2,809
3	493	6,866	678	8,037
4	314	1,201	1,664	3,179
Total	6,562	10,601	3,422	20,585