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Universidad del País Vasco

Euskal Herriko Unibertsitatea

UNDERSTANDING ENERGY EFFICIENCY IN HOUSEHOLDS AND HOTELS IN SPAIN: A COMBINATION OF METHODS TO ACCOUNT FOR STAKEHOLDERS' VIEWS

PhD THESIS

Elena López Bernabé

Supervised by IBON GALARRAGA GALLASTEGUI & PEDRO LINARES LLAMAS

Tutor: Alberto Ansuategi Cobo

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Summary

The growing complexities of the current energy price crisis and environmental problems are leading to an acceleration in reductions in energy consumption. Stimulating the adoption of energy efficiency is one of the strategies formulated by the international community to reduce energy consumption and greenhouse gas emissions. Buildings in the EU are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions. Improving energy efficiency in buildings therefore plays a key role in attaining the ambitious goal of carbon-neutrality by 2050. Huge investments in energy efficiency are required to achieve energy savings and climate goals. However, despite its significant monetary benefits and environmental advantages, levels of EE in buildings are generally low. This is the so-called *energy efficiency gap*. Many reasons exist for it, which can be mainly grouped into market, behavioural and other failures. And different energy efficiency policy instruments can be used to address those failures.

If energy efficiency leads to significant reductions in energy consumption (and bills), why do residential and non-residential buildings invest so little in it? How should policy makers encourage investments in energy efficiency? What effective ways are there of making energy efficiency policies effective and accepted by all stakeholders? By answering these overarching research questions, the dissertation's main goal is to study the effects of energy efficiency policies and to understand how these policy instruments can be designed to promote effective, cheaper reductions in emissions and energy consumption in households and hotels, mainly in the context of Spain. To that end, this dissertation integrates and combines different methodologies, i.e. semi-quantitative approaches through the use of focus groups and surveys to understand behavioural complexity; and a quantitative econometric approach based on hedonic price method to provide evidence of the effectiveness of EE labels.

We find that the application of policy packages may be useful for less coercive policy instruments (especially for households) and for ambitious EE targets. Specifically, ambitious technical standards and specific regulation would ensure that energy is saved. Environmental education and information policies seem to be useful in helping consumers to make better decisions. Additionally, in the light of variation in policy acceptability for economic instruments, energy tax could be combined with subsidies or other revenue recycling schemes. Findings suggest that various policy instruments can be used to help achieve EE targets, but good policy design and excellent implementation are needed, considering behavioural complexity on the part of key stakeholders and features of the policy instruments.

Resumen extendido

En la situación de crisis energética que estamos viviendo, los principales retos a abordar son el aumento de precios de la energía y el cambio climático. En ese contexto, y la necesidad de encontrar soluciones para lograr los objetivos climáticos, una de las estrategias formuladas por la comunidad internacional para reducir el consumo de energía y las emisiones de CO2 es la eficiencia energética.

El sector de la edificación representa un 34% del consumo de energía final, siendo responsable de alrededor un tercio de las emisiones mundiales de CO2. La calefacción es el dominante en el consumo de los edificios a nivel mundial, y la mayoría de la energía utilizada es intensiva en combustibles fósiles. Además, otro de los promotores de las emisiones en el sector residencial es el aumento en el uso y la cantidad de electrodomésticos en los hogares. Mejorar la eficiencia energética en los edificios es clave para lograr los ambiciosos objetivos climáticos de cero emisiones para 2050.

Nótese que definimos la EE como el esfuerzo por reducir la cantidad de energía utilizada para proporcionar un determinado servicio y resulta ser una medida muy común para reducir los impactos ambientales asociados al consumo de energía. Sin embargo, a pesar de sus importantes beneficios monetarios y ventajas ambientales, se observan unos niveles bajos de inversión en eficiencia energética. Es decir, las personas invierten menos en EE de lo que, a primera vista parecería económicamente razonable. Esta paradoja es lo que se denomina como *brecha de eficiencia energética* o *paradoja de la eficiencia energética*. Las potenciales razones que explican esta desviación de la inversión óptima en eficiencia energética suelen clasificarse en tres grupos, principalmente en fallos de mercado, fallos de comportamiento y otros factores. Diferentes instrumentos de política de eficiencia energética pueden ser utilizados para direccionar estos fallos.

Objetivos

La presente tesis doctoral incorpora los diferentes factores que son esenciales para entender el marco actual de las políticas de eficiencia energética. Concretamente, el principal objetivo de esta tesis es comprender por qué se produce la falta de inversión en eficiencia energética en los hogares y en los hoteles en España, y entender cómo las políticas de eficiencia energética pueden ser diseñados para promover una reducción efectiva y más barata del consumo de energía y emisiones asociado al uso y compra de sistemas de calefacción y de electrodomésticos en los hogares. Además, esta tesis es un claro ejemplo de cómo integrar y combinar diferentes metodologías. Más concretamente, la investigación presentada en esta tesis busca ilustrar la necesidad de combinar diferentes métodos cualitativos y cuantitativos para mejorar la comprensión respecto al comportamiento en el campo de la eficiencia energética y proporcionar información para el diseño de políticas efectivas.

La tesis destaca la necesidad de una comprensión más profunda de las percepciones de diferentes grupos sociales. Con ese fin, los Capítulos 1, 2 y 3 integran métodos semi-cuantitativos mediante el uso de grupos de discusión y encuestas, empleando los modelos conocidos como Mapeo Cognitivo Difuso (o Fuzzy Cognitive Mapping, en inglés) y el modelo probit, para comprender la complejidad del comportamiento. Además, para promover efectivamente la eficiencia energética, el Capítulo 4 se basa en un análisis econométrico cuantitativo basado en el modelo de precios hedónicos, que sirve para ilustrar la efectividad de las etiquetas de eficiencia energética, que parecen ser una de las políticas más valoradas para superar las barreras de información y promover la inversión en eficiencia energética.

Visión de la industria hotelera en España sobre la valoración del atributo de eficiencia energética

El Capítulo 1 analiza las opiniones de la industria hotelera en España sobre los factores que afectan la valoración de eficiencia energética en la inversión de sistemas de calefacción y aire acondicionado. Para ello se aplica un modelo de respuesta binaria (modelo probit) para explorar qué barreras y factores influyen en la consideración de la eficiencia energética como un atributo importante en la decisión de compra. España ofrece un caso de estudio muy interesante en este sector debido a la importancia del turismo en el país y su importante consumo energético. Los resultados muestran que parece haber una brecha entre las creencias y las decisiones de compra de sistemas de calefacción y aire acondicionado energéticamente eficientes debido a las múltiples barreras. Es decir, una gran parte de la industria hotelera está dispuesta a tomar una oportunidad en sistemas energéticamente eficientes, pero sólo una un 6% informó que habían cambiado su sistema de calefacción y aire acondicionado. A nivel de recomendaciones políticas, el análisis muestra que, en base a las diferentes respuestas dependiendo de la zona climática, las políticas podrían ir dirigidas primero a aquellas áreas con clima continental donde los agentes parecen estar más preocupados por la eficiencia energética. La ausencia de conocimiento entre los dueños del hotel sobre los ahorros energéticos y monetarios que proporcionan los sistemas energéticamente más eficientes sugiere que instrumentos de política basados en la información, tales como etiquetas de eficiencia energética con información monetaria, auditorías energéticas y comentarios explicativos en la factura pueden ser necesarios. Los subsidios pueden también ayudar a superar la brecha entre las creencias y las decisiones de compra, pero también pueden agravar el efector rebote y el problema del agente principal. Esto sugiere que los subsidios podrían estar vinculados a la introducción de instrumentos de regulación más estrictos de rendimiento energético o impuestos sobre la energía. Impuestos a la energía también pueden ayudar a acentuar la actitud a favor de la eficiencia energética entre los propietarios actuales de sistemas de calefacción basados en combustibles fósiles, aunque también pueden ser necesarios subsidios para ayudar a superar el problema de racionalidad limitada.

Políticas de eficiencia energética efectivas teniendo en cuenta las percepciones de los hogares, académicos y expertos de energía

Los Capítulos 2 y 3 muestran la importancia de ampliar el debate sobre qué se puede hacer para reducir la factura de calefacción de los hogares, al incorporar las percepciones de agentes locales, tales como los hogares, así como la visión de expertos, como académicos y expertos en energía. Más específicamente, el Capítulo 2 proporciona un entendimiento cualitativo de las actitudes y opiniones sobre los obstáculos a los que se enfrentan los hogares en la vida cotidiana para reducir la factura de calefacción y las posibles soluciones y políticas que podrían apoyar y aceptar. El Capítulo 3 analiza la efectividad de las políticas de eficiencia energética con un enfoque integrador que incorpora las percepciones de todos los grupos analizados en el Capítulo 2. Entender las percepciones de todos los agentes sobre cómo interactúan los problemas relacionados con la energía proporciona un muy buen complemento para los modelos cuantitativos utilizados tradicionalmente en el diseño de políticas, porque las expectativas pueden afectar significativamente los resultados de las políticas (es decir, la eficiencia y eficacia de una política) y la aceptabilidad de dichas políticas. El mapa cognitivo utilizado para el análisis revela efectos directos e indirectos de determinados instrumentos de política sobre otros conceptos definidos, y permite identificar efectos que no son tan evidentes, los cuales deben tenerse en cuenta para diseñar políticas efectivas en la descarbonización del uso de calefacción.

La información revelada en el mapa cognitivo (Capítulos 2 y 3) confirma que los hogares prefieren políticas que no generen costes directos para ellos (por ejemplo, programas de educación e información o subsidios), en lugar de políticas que les suponga un coste directo (es decir, impuestos). Sin embargo, los académicos y expertos en energía parecen estar más a favor de introducir impuestos a la energía, quizás vinculados a subsidios, programas de educación e información y/o normas de regulación. Estas diferencias apuntan a dónde podrían enfocarse los políticos para hacer que las futuras políticas energéticas sean aceptadas y en consecuencia más efectivas. Por ejemplo, en base a la variación en la aceptabilidad política del impuesto a la energía, este instrumento económico podría combinarse con subsidios que permitan reducir el coste de la energía y, por lo tanto, el impuesto. Por ejemplo, un “impuesto centrado en sistemas de calefacción basados en combustibles fósiles”, vinculado a “subsidios” para reemplazar el sistema de calefacción podría dar lugar a un aumento en la inversión en sistemas de calefacción energéticamente más eficientes y también a una caída en los precios de la energía. Finamente, la combinación de instrumentos de política da como resultado una mayor reducción en el consumo de calefacción. Específicamente, los resultados muestran que lo que parece funcionar es una combinación de políticas (paquete de políticas) en lugar de una sola política aislada. Es decir, la aplicación de un paquete de políticas puede ser útil para instrumentos de política menos coercitivos (especialmente para los hogares) y para metas más ambiciosas de eficiencia energética. En particular, “normas técnicas” ambiciosas y “reglamentos específicos sobre el mantenimiento de los sistemas de calefacción” garantizarían el ahorro de energía. Además, “políticas de educación e información ambiental” parecen ser útiles para que los consumidores tomen mejores decisiones en eficiencia energética. También se cree que se necesita un “impuesto centrado en sistemas de calefacción que utilicen combustibles fósiles”, aunque puede ser difícil de conciliar dadas las preferencias de los hogares, en base al resultado de que los hogares prefieren subsidios a impuestos. Acorde a la literatura, los resultados del presente análisis demuestran que esta aversión fiscal se puede abordar mediante educación fiscal y reciclando los ingresos derivados de los impuestos.

Evidencia sobre la efectividad de la etiqueta de eficiencia energética

Adicionalmente, para promover la eficiencia energética de forma efectiva, el Capítulo 4 presenta un análisis cuantitativo el cual sirve como ilustración sobre la efectividad de la etiqueta de eficiencia energética, que parece ser una de los instrumentos de política más valorado para superar las barreras de información. Mediante la aplicación del método de precios hedónicos es posible estimar cuánto paga realmente el consumidor por el atributo de eficiencia energética en el mercado de electrodomésticos. Este análisis permite determinar cuánto de la variable precio es explicado por cada uno de los atributos de los bienes, estimando la importancia de cada atributo (tales como la marca, características técnicas, entre otros) y prestando especial atención al atributo de eficiencia energética. Estimar la disposición a pagar por el atributo de eficiencia energética es útil para ayudar a diseñar las políticas de incentivos y subsidios ampliamente utilizadas para respaldar la compra de electrodomésticos energéticamente eficientes. Los resultados sugieren que los consumidores realmente pagan una prima en el precio del 11% por lavadoras con el mayor nivel de eficiencia energética, en comparación con otras lavadoras con las mismas características, pero menor eficiencia energética. Esto supone unos 67€ del precio medio del mercado de lavadoras en España. Esta disposición a pagar por la eficiencia energética parece haber aumentado más del 5% entre 2012 y 2019. El análisis también muestra que otros atributos, tales como la marca, el lugar de venta, la velocidad de centrifugado las dimensiones son también muy importantes en la decisión de compra.

Conclusiones

La investigación presentada en esta tesis ha demostrado ser útil para ilustrar la necesidad de combinar diferentes métodos para mejorar la comprensión del comportamiento en el campo de la eficiencia energética. La tesis destaca la necesidad de una comprensión más profunda de las percepciones de diferentes grupos sociales. En cuanto a la promoción efectiva de la eficiencia energética, el enfoque cuantitativo utilizado sirve como ilustración de la eficacia de la etiqueta de eficiencia energética.

Queda mucho por hacer antes de obtener una imagen completa del sector de la edificación en el camino hacia la neutralidad climática para 2050, pero el análisis realizado en la presente tesis ha demostrado ser útil para promover políticas efectivas de eficiencia energética.

Se necesitan instrumentos económicos, especialmente para apoyar el despliegue de la transición en calefacción, pero existen diferencias en la aceptabilidad entre impuestos y subsidios por parte de los diferentes grupos sociales considerados en el análisis. Los impuestos sobre la energía parecen ser más efectivos para el ahorro de energía, ya que mantienen los precios de la energía más altos a largo plazo y disuaden el consumo de energía. Sin embargo, encontramos preferencias consistentes por los subsidios entre los hogares y los dueños de hoteles. Por ejemplo, dadas las diferencias entre las creencias y las decisiones de compra de sistemas de calefacción energéticamente eficientes en la industria hotelera, los formuladores de políticas deberían asegurarse de que exista un claro incentivo financiero para invertir en eficiencia energética. Al mismo tiempo, los hogares parecen más dispuestos a aceptar subsidios para invertir en eficiencia energética. Por tanto, el impuesto a la energía podría combinarse con subsidios o con otras ayudas procedentes del reciclaje de los ingresos de impuestos. Sin embargo, los subsidios también pueden agravar el efecto rebote. Como solución la literatura sugiere dirigir los subsidios exclusivamente a aquellos consumidores que, debido a restricciones relacionadas con los ingresos o acceso al capital, no invertirían en ausencia de estos subsidios. También se necesitan instrumentos de política de normas y regulación para respaldar la inversión en eficiencia energética de hoteles y hogares. La introducción de normas obligatorias y más estrictas de regulación sobre los niveles de eficiencia energética en todos los sistemas de calefacción y electrodomésticos garantizaría el ahorro de energía en todos los casos. Al mismo tiempo, mejorar la información disponible sobre los efectos ambientales y el ahorro de energía es otro campo importante para el diseño de políticas efectivas, especialmente si estos instrumentos de política están bien diseñados y se mantienen en el tiempo.

Finalmente, conocer el excedente en el precio que se paga en el mercado por el atributo de eficiencia energética es útil para diseñar las ayudas y programas de descuento ampliamente utilizados para incentivar la compra de electrodomésticos energéticamente eficientes, es decir, para establecer la justa cantidad necesaria de ser subvencionada. Además, el resultado sobre el aumento en la disposición a pagar por el atributo de eficiencia energética sugiere que los esfuerzos para mejorar la información y crear conciencia con respecto a la eficiencia energética y el cambio climático pueden estar siendo efectivos.

Outcomes from this thesis

Chapter 1

- **López-Bernabé, E.**, Foudi, S., Linares, P., Galarraga, I. 2021. Factors affecting energy-efficiency investment in the hotel industry: survey results from Spain. Energy Efficiency. 14. (4) DOI (10.1007/s12053-021-09936-1).

Chapter 2:

- **López-Bernabé, E.**, Foudi, S., Galarraga, I. 2020. Mind the map? Mapping the academic, citizen and professional stakeholder views on buildings and heating behaviour in Spain. Energy Research and Social Science. 69. DOI (10.1016/j.erss.2020.101587).

Chapter 3:

- **López-Bernabé, E.**, Linares, P., Galarraga, I. 2022. Energy-efficiency policies for decarbonising residential heating in Spain: A fuzzy cognitive mapping approach. Energy Policy. 171. DOI (10.1016/j.enpol.2022.113211).

Chapter 4:

- **López-Bernabé, E.**, de Ayala, A. and I. Galarraga (2022) Estimating the price premium of high energy-efficient washing-machines in Spain: A hedonic approach. BC3 Working Paper Series 2022-01. Basque Centre for Climate Change (BC3). Leioa, Spain.

Other publications:

- de Ayala, A., Foudi, S., Solà, M.d.M., **López-Bernabé, E.**, Galarraga, I. 2021. Consumers' preferences regarding energy efficiency: a qualitative analysis based on the household and services sectors in Spain. Energy Efficiency. 14. (1) DOI (10.1007/s12053-020-09921-0).

- Galarraga, I., **López-Bernabé, E.**, Ojeda, C., Solà, M.M. y de Ayala, A. 2022. La importancia de la eficiencia energética: evidencia reciente para España. *Submitted to Papeles de Economía Española.*

Presentation in conferences

- 5th April – 8th April 2022: assistance and presentation of the paper "Estimating the price premium of high energy-efficient washing-machines in Spain: A hedonic approach" at *World Sustainable Energy Days-Presentation at Young Energy Efficiency Researchers Conference*.

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- 29th June – 30th June 2021: assistance and presentation of the paper "Energy-efficiency policies for decarbonising residential heating in Spain: a fuzzy cognitive mapping approach" at the *XVI Congreso de la Asociación Española para la Economía Energética*.

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Introduction

We are approaching a decisive moment for tackling climate change, a great challenge of our times. Global assessments have shown how important reducing final energy demand can be in meeting international climate targets by easing pressure on the energy transition and reducing greenhouse gas (GHG) emissions (IEA, 2022a; IPCC, 2022; UNFCC, 2015). The EU has committed to cutting its GHG emissions and achieving net-zero GHG emissions by 2050 (EC, 2019). The rate of increase of GHG emissions has fallen in the past ten years, but they are still rising and are now 54% higher than in 1990 (IPCC, 2022). In this context, the global temperature will continue to rise, and during the 21st century global warming will exceed 1.5-2ºC unless there are major reductions in GHG emissions in the coming decades (IPCC, 2022).

The radical transformation of key sectors such as building is essential for the energy transition. This sector has a very large carbon footprint when indirect emissions are accounted for. In 2021 the operation of buildings accounted for 30% of global final energy consumption (the figure rises to 34% if final energy use associated with the production of cement, steel and aluminium is included). The buildings sector is therefore responsible directly and indirectly for around one-third of global C02 emissions (8% being direct emissions from buildings, 19% indirect emissions from the production of electricity and heat used in buildings and an additional 6% from the manufacture of cement, steel and aluminium used for building construction) (Figure 1) (IEA, 2022b). Drivers of these emissions include population growth, the inefficiency of newly constructed buildings, increases in the use, number and size of appliances and equipment and continued reliance on carbon intensive electricity and heat (IPCC, 2022; Lucon et al., 2014).

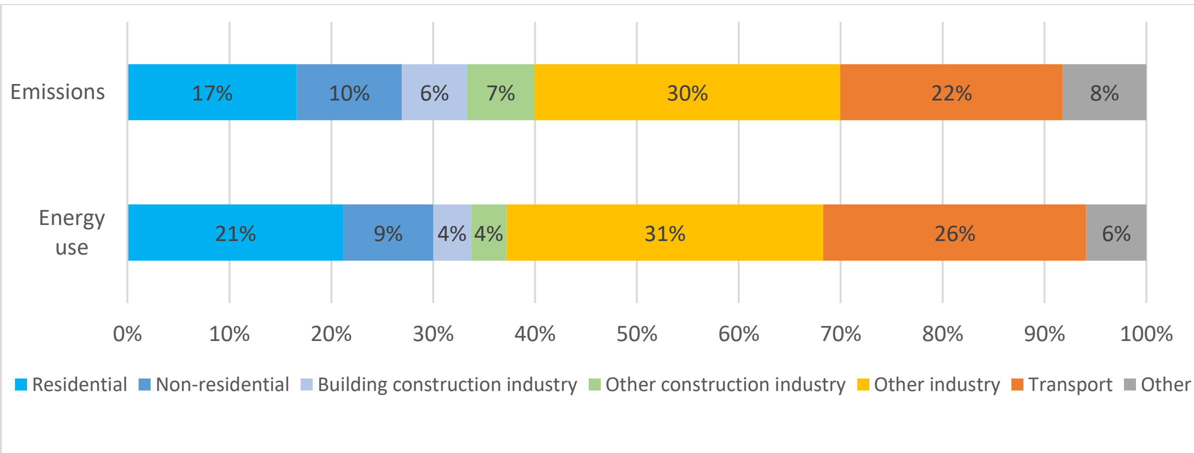

Figure 1. Global energy and process emissions and final energy consumption in the building sector, 2021. Source: Own work based on IEA (2022b). Note: Emissions include embodied emissions from new construction

An examination of emissions and energy demand trends in the building sector reveals that from 1990 to 2019 global CO2 emissions from buildings increased by 50%, while global final energy demand grew by 38% (with increases of 54% in non-residential buildings and 32% in residential ones) (IPCC, 2022)

(IPCC, 2022). Heating is the dominant end-use in residential buildings at global level (IEA, 2022c). In Europe, 62.8% of final energy consumption by households is for heating their homes, followed by water heating, cooking and connected and small appliances (Figure 2a). And most of the energy used for heating is fossil-fuel based (Figure 2b). Rapid changes are needed to bring global energy-related carbon dioxide emissions to net zero by 2050, in which the share of fossil fuels in the heating mix should drop to 45% (IEA, 2022c). It is clear that heating is one of the areas in which decarbonising is very important (Bouckaert et al., 2021; IEA, 2022c). It is also important to highlight that energy demand from connected and small appliances in residential buildings increased most (IPCC, 2022).

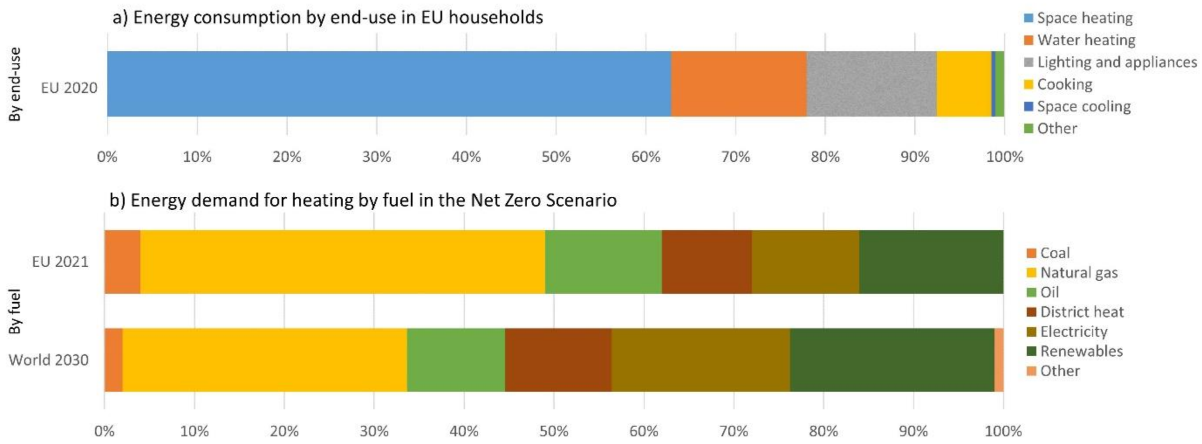

Figure 2. Global and EU energy consumption by end-use and fuel
Source: Own work based on Eurostat (2022) and IEA (2022c)

At the same time, building energy intensity (energy use per square metre) decreased by around 7% from 2010 to 2021, due to the development of building energy codes, additional and more stringent minimum energy performance standards (MEPS) for appliances and shifts to higher-efficiency heating technologies such as heat pumps (IEA, 2022b). Nevertheless, the buildings sector needs more rapid change to get on track with the net-zero emissions by 2050 scenario (Bouckaert et al., 2021). This means that the energy consumed per square metre in 2030 must be 35% less than in 2021 and carbon emissions from buildings operations need to drop by more than half by 2030 (IEA, 2022b). This calls for significant efforts to reduce energy demand through clean and efficient technologies, including leveraging the potential for behavioural change (IEA, 2022b).

Energy efficiency (EE) (broadly conceived as reduction in energy use per unit of service demand or economic activity) provides an opportunity to substantially reduce energy consumption and consequently GHG emissions. It is one of the main instruments for reducing household energy consumption (IPCC, 2022). Several studies have analysed the potential energy savings, avoided CO2 emissions and profitability of EE investments (Cattaneo, 2019; Fleiter et al., 2012; Labandeira et al., 2020). Across sectors, energy efficiency could deliver more than one-third of the total greenhouse gas emissions reduction within the IEA's Sustainable Development Scenario up to 2050 (IEA, 2022d). In the building sector, according to the latest report from IPCC (IPCC, 2022), EE also accounts for a substantial proportion of GHG emissions reduction by 2050. This includes changes in infrastructure (e.g. buildings that do not consume energy), changes in end-use technologies (e.g. more energy-efficient appliances) and behavioural and socio-cultural changes (climate control adjustments in buildings).

Investment in energy efficiency and clean technologies in the building sector is on the rise (around USD 215 billion annual investment by 2022) (see Figure 3), but this does not suffice to meet the levels required in the Net Zero Scenario (Bouckaert et al., 2021; IEA, 2022b). After years of stagnation, overall investment in energy efficiency measures in the buildings sector increased by more than 15% in 2021 (IEA, 2022b). However, growth in investment has already slowed in the first half of 2022, as construction and material costs have reached all-time highs and the direct stimuli that incentivised energy efficiency investment are decreasing in several countries in Europe (IEA, 2022b). To align with the Net Zero Scenario by 2050, investment in energy efficiency needs to rise from the average of around USD 200 billion in recent years to around USD 536 billion in 2030, mostly for in-depth building retrofits and efficient appliances (Bouckaert et al., 2021; IEA, 2022b). Accordingly, households globally could save USD 201 billion in avoided expenditure on fuels (IEA, 2022e). However, despite significant monetary benefits and environmental advantages, EE adoption levels are generally low, as illustrated by the so-called EE gap, which refers to situations in which economically beneficial investments are not made and/or apparently non-beneficial ones are made (Jaffe and Stavins, 1994a; Linares and Labandeira, 2010; Shama, 1983).

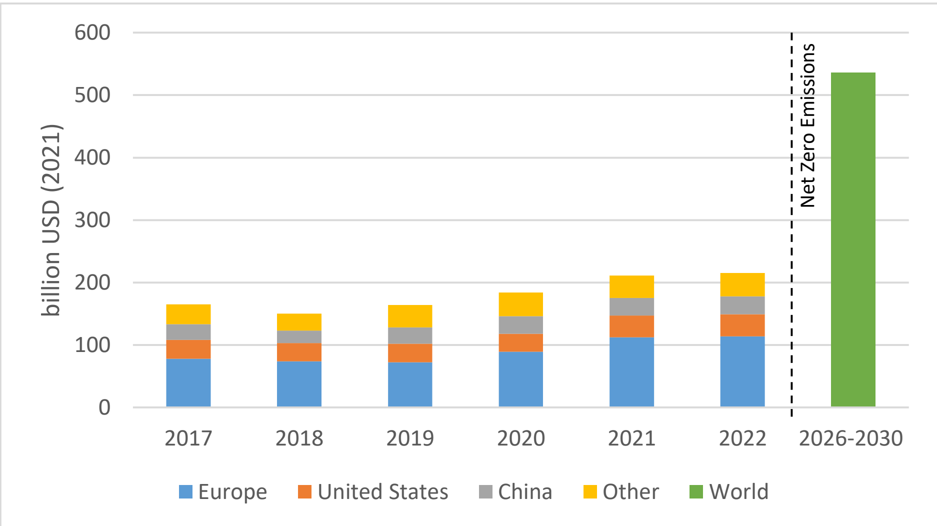

Figure 3. Annual investment in energy efficiency in the buildings sector in the Net Zero Scenario, 2017-2050
Source: (IEA, 2022b)

Recently, the European Parliament has united behind proposals to raise the EU's EE target for 2030. The European Green Deal (EC, 2019) is the EU's long-term growth plan to make Europe climate neutral by 2050, with a commitment to reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels. To implement these targets, the European Commission presented its Fit for 55 package of legislation in July 2021 (EC, 2021a). As part of the "Fit-for-55" Package, the European Union revised its Energy Efficiency Directive (REED) in July 2021 (EC, 2021b). The main changes in the REED proposal include (i) Member States having to ensure that at least 3% of public buildings are renovated each year to at least nearly zero-energy buildings (NZEB); (ii) an increase in the annual energy savings obligation for the period between 2024 and 2030, from 0.8% to 1.5%; and (iii) higher targets for reducing primary energy consumption (39%) and final consumption (36%) by 2030. This reduction in energy consumption corresponds to an increase in the EU energy efficiency target of 9% in 2030 compared to the projections of the 2020 reference scenario. To that end, the REED focuses on sectors with high energy savings potential, notably heating and cooling.

In May 2022, the Commission also published REPowerEU (EC, 2022a), a plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition. It proposes an increase in the EU energy efficiency target from 9% to 13% compared to the 2020 reference scenario. The Commission also published an EU Save Energy Communication (EC, 2022b) detailing short-term behavioural changes which could cut gas and oil demand by 5% and encouraging Member States to start specific communication campaigns targeting households and industry. Member states are also encouraged to use fiscal measures to encourage energy savings, such as reduced Value Added Tax rates on energy efficient heating systems, building insulation and appliances and products. Additionally, targeting energy-intensive sectors, the EU has just proposed including buildings in the EU Emission Trading System (EU ETS) to accelerate decarbonisation. However, that does not mean that targets will be easier to achieve, since many non-monetary and behavioural barriers remain.

To meet EU-wide targets, Spain has presented its national energy and climate plan 2021-2030 (NECP, 2020). Recently, in line with the latest communications by the Commission as mentioned above, a Royal Decree Law (14/2022) introduced a series of measures aimed at reducing energy consumption, such as limit heating and cooling temperatures in buildings for public use, among others.

Under this EU framework, the recent IPCC report highlights the importance of not just supply-side but also demand-side solutions in mitigation strategies (Action on demand, 2022). Changes in the behaviour of energy consumers play an important role in cutting C02 emissions and energy demand growth in the building sector. Behavioural changes may reduce global energy demand by 10% by 2050, reflecting changes in temperature settings for heating or reducing excessive hot water temperatures.

Without them cumulative emissions between 2021 and 2050 would be around 10% higher (Bouckaert et al., 2021). Considering all this, energy policies will be crucial in promoting societal changes in demand and reaching the ambitious energy saving targets mentioned above under the EU framework.

Energy-efficiency policy instruments can be classified into three main categories: (i) command and control instruments; (ii) economic instruments; and (iii) information instruments. There is a substantial body of research that analyses the impact of the different types (Labandeira et al., 2020). However, designing and implementing effective policies require an understanding and a consideration of the various perceptions held by key stakeholders. This research focuses on understanding why underinvestment in energy efficiency in households and in the hotel industry occurs and how public policies can be enhanced to address this major challenge. More concretely, the research presented in this thesis seeks to illustrate the need to combine different quantitative and qualitative methods to enhance understanding with respect to behaviour in the field of energy efficiency and provide insights for effective policies.

Objectives and structure

The research presented in this thesis has proven useful in illustrating the need to combine different methods to enhance understanding with respect to behaviour in the field of EE. The thesis highlights the need for a deeper understanding of the perceptions of key stakeholders. To that end, **Chapters 1**, **2** and **3** integrate semi-quantitative approaches through the use of focus groups and surveys to understand behavioural complexity, in a combination of probit and participatory Fuzzy Cognitive Mapping (FCM) methods. Additionally, to effectively promote EE, **Chapter 4** focuses on a quantitative econometric approach based on hedonic price method, which serves to illustrate the effectiveness of EE labels, which seem to be one of the most highly-valued EE policies for overcoming informational barriers. An overview of research topics, sectors and methodological approaches covered by the four chapters of this thesis is shown in Figure 4.

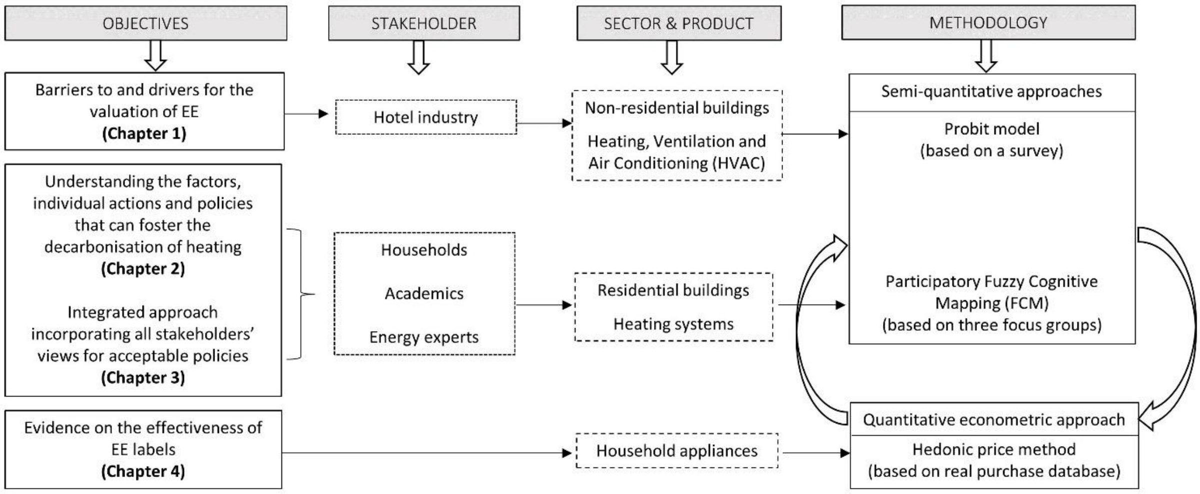

Figure 4. Summary of research topics in this thesis and methodology used

The primary motivation for this thesis is to provide a comprehensive assessment of the perceptions of key stakeholders. To that end, **Chapter 1** analyses the views of the hotel industry on the factors that affect energy efficiency ratings for investments in Heating, Ventilation and Air Conditioning (HVAC) systems. The discussion is based on the following research question:

> **RQ1**: What barriers influence the consideration of EE by hotels in Spain and what effect do various drivers have on the valuation of EE?

Chapters 2 and **3** set out to identify effective policies for energy efficiency in the residential heating sector, taking into account the view of households, academics and energy experts. More specifically, **Chapter 2** provides a qualitative understanding of the attitudes and opinions of households, the obstacles that they face in everyday life in reducing heating bills and potential solutions that they could identify and support. It also incorporates the knowledge of experts (academics and energy experts) on low-carbon heating behaviour. **Chapter 3** analyses the effectiveness of energy-efficiency policies with an integrational approach incorporating the views of all the stakeholders from Chapter 2. Understanding stakeholder perceptions of how energy related issues interact provides a very good complement for the more quantitative information traditionally used in policy design, because expectations may significantly affect policy outcomes (i.e. the efficiency and effectiveness of a policy) and the acceptability of policies. Both chapters base their discussions on the following research question:

> **RQ 2 and 3**: What can be done to ensure acceptable, effective energy-efficiency policies that accelerate decarbonisation in the household heating sector by incorporating the perceptions of different stakeholders?

Additionally, to effectively promote EE, a quantitative approach is used to illustrate the effectiveness of EE labels, which seem to be one of the most highly-valued EE policies for overcoming informational barriers. In this sense, **Chapter 4** provides some insights into the effectiveness of EE labels, estimating how much consumers actually pay in the market for them. More specifically, Chapter 4 seeks to address the following research question:

> **RQ 4**: How much do consumers actually pay for the EE attribute and other technical characteristics of washing machines in Spain?

Finally, the dissertation ends with an outline of the conclusions of the whole research project reported here, along with some suggestions for possible further research.

Chapter 1: Factors affecting energy-efficiency investment in the hotel industry: survey results from Spain [1]

[1] **López-Bernabé, E.**, Foudi, S., Linares, P., Galarraga, I. 2021. Factors affecting energy-efficiency investment in the hotel industry: survey results from Spain. Energy Efficiency. 14. (4) DOI (10.1007/s12053-021-09936-1).

1.1. Introduction

Buildings account for 40% of Europe's final energy consumption (EC, 2019; ODYSEE-MURE, 2018). Non-residential buildings[2] of different types, including hotels, account on average for 25% of energy consumption from the total European building stock, which makes them major contributors to overall CO_2 emissions (WBG, 2020). Moreover, non-residential buildings are on average 40% more energy-intensive than residential buildings; they also require more electrical energy than residential buildings (286 kWh/m^2 compared to 185 kWh/m^2) (D'Agostino et al., 2017).

Energy consumption in buildings varies from one European Union (EU) country to another. Differences may be explained by climate conditions, by building characteristics (e.g. building envelope, insulation level, etc.) and by social and cultural factors (lifestyle, habits, etc.) among others. Energy demand in non-residential buildings may also be influenced by economic growth and employment growth (Bertoldi et al., 2018).

Energy efficiency (EE) provides an opportunity to substantially reduce energy consumption and consequently GHG emissions from the services sector (Hrovatin et al., 2016; Liang et al., 2019; Schleich, 2009; Schlomann and Schleich, 2015) and also to reduce energy-related running costs in that sector (Mavrotas et al., 2003; Patel and Guedes, 2017; Sakshi et al., 2020). Several studies have analysed the potential energy savings, avoided CO_2 emissions and profitability of EE investments (Cattaneo, 2019; Fleiter et al., 2012). However, despite its significant monetary benefits and environmental advantages, EE adoption levels are generally low, as shown by the EE gap (Jaffe and Stavins, 1994a; Linares and Labandeira, 2010; Shama, 1983). A better understanding of barriers regarding large investments such as HVAC systems is particularly important in addressing this EE gap and encouraging more efficient purchases. In fact, studies exploring what barriers are most relevant to EE in the hotel industry provide important information for the design of effective policies for the promotion of energy EE (Schleich, 2009).

Spain provides a very interesting case study for this sector due to the importance of tourism in the country (INE, 2019; UNWTO, 2019) and its significant energy consumption. The wide range of climates and types of hotel industry establishment in the country also provide a chance to explore the connection of these factors with the adoption of energy-efficiency measures, thus providing insights for other countries where tourism is also a significant part of the economy.

[2] Non-residential buildings are more heterogeneous than residential ones. A BPIE (Buildings Performance Institute Europe) survey states that non-residential buildings in Europe can be divided into the following categories: wholesale & retail (28%), offices (23%), educational (17%), hotels and restaurants (11%), hospitals (7%), sport facilities (4%) and others (11%).

In Spain, 73% of the energy demand from buildings in 2017 (including residential and non-residential buildings) came from heating (40.4%) and electrical equipment (32.5%). Hot water accounted for 12.5%, air conditioning for 9% and cooking for 5.5% of consumption (ODYSEE-MURE, 2020). Focusing on non-residential buildings, 7% of the country's final energy consumption was attributable to restaurants and accommodation establishments (IDAE, 2017). Most of the energy used came from electricity (74%), followed by natural gas (17%) and petroleum products (7%), while renewables had a direct contribution of 2.4% (IDAE, 2017). The National Integrated Energy and Climate Plan 2021-2030 (PNIEC) (NECP, 2020), which defines the priorities for the energy transition, proposes measures to promote renewable energies and EE in heating systems among other points.

In that context, this study sets out (i) to analyse barriers that influence the consideration of EE by hotels in Spain; and (ii) to explore the effect of several drivers on the valuation of EE. The data used were collected expressly for this study from 200 hotels throughout Spain. The survey seeks to (i) assess the importance attributed to EE achieved through HVAC installation; and (ii) identify the most common barriers that prevent tourist establishments from investing in energy-efficient HVAC systems. A binary response model is estimated to explore whether these barriers and a set of other factors influence the consideration of EE in the purchasing decision, i.e. the consideration of EE as a *very important* attribute in the purchase of HVAC systems. Note that these barriers are analysed in isolation and no trade-off is allowed between them. That is, the analysis is *ceteris paribus*, so that it provides and understanding of the impact of one attribute when the rest remain constant. The results provide insights for policy-makers for effective incentives to encourage the adoption of energy-efficient HVAC systems so as to decarbonise energy consumed in heating and cooling at hotels.

The rest of paper is organised as follows. Section 1.2 offers an analysis of the barriers to the wider use of efficient HVAC systems, with a particular focus on non-residential buildings. Section 1.3 describes the survey and the econometric model. Section 1.4 presents and discusses the results. Finally, Section 1.5 concludes and outlines policy implications.

1.2. Barriers to energy efficiency

Barriers to the adoption of EE measures have been analysed previously in the relevant literature for both residential (Gerarden et al., 2017; Linares and Labandeira, 2010; Solà et al., 2020) and non-residential buildings (Cagno et al., 2013; Sorrell et al., 2004). Some of the main findings are described below.

Studies analysing the empirical relevance of barriers for EE in residential buildings have identified cognitive limitations, a lack of financial resources, the principal-agent problem and imperfect information problems as the most important barriers (Ramos et al., 2015; Stieß and Dunkelberg, 2013).

Given that the building sector is characterised by dualities in the use of buildings (residential vs. non-residential), some of the barriers for residential buildings also apply to non-residential ones. So, as proposed by Ramos et al. (2015), references to barriers for residential buildings are included in order to draw analogies and provide a more integrated view of barriers to achieving optimal EE levels in residential and non-residential buildings. Further research would be needed to find differences among how these and other barriers may affect residential and non-residential consumers. The heterogeneity of the households that make investment (or purchase) decisions and of the managers making equivalent decisions suggests that a whole new direction of research would be needed to answer this question.

1.2.1. Barriers to energy efficiency in non-residential buildings

Econometric assessments of barriers in non-residential buildings show that EE investment is driven not only by market and behavioural factors but also by the characteristics of firms, such as organisational factors, the products and services offered by a company, location and profitability. Specific sectors such as industry, commerce and services have been analysed previously (Fleiter et al., 2012; Schleich, 2009, 2004; Schleich and Gruber, 2008). Three categories of barriers to EE in organisations have been proposed in the literature: (i) market barriers; (ii) behavioural barriers; and (iii) organisational barriers (Cagno et al., 2013; Sorrell et al., 2004). A summary of these barriers is presented in Table 1. Nonetheless, some barriers may fall under more than one category (Sorrell et al., 2011). These barriers are linked below to variables included in this analysis.

Market barriers include two important groups: informational failures and other market failures. Informational failures are led by imperfect and asymmetric information. These terms refer to a lack of information on costs and energy saving equipment, unclear information by technology providers or poor-quality information as to the energy performances of different technologies. Hidden costs (low perceived profitability of EE investments, additional costs associated with energy-efficient technologies, etc.) and risk and uncertainty (uncertainty about future energy prices, technical risks, economic and technological uncertainties concerning the business, etc.) may also be part of the problem (Cagno et al., 2013). Other market failures are related to access to capital and the principal-agent problem.

Among behavioural barriers, consumers tend to use simple calculations because of bounded rationality (e.g. individuals and companies ignore changes in real energy prices and energy savings that can be made over the lifetime of a good) (Blasch et al., 2019; Cattaneo, 2019; Gillingham and

Palmer, 2014a). In addition, Blasch et al. (2018) indicate that consumers need not only specific energy-related and financial knowledge but also the cognitive skills to apply that knowledge, in what they call "energy-related financial literacy". Moreover, the characteristics of information (specific, simple, personalised, updated, credible or trustworthy) comprise another significant barrier to energy-efficiency investment (Cagno et al., 2013).

Among organisational barriers, power barriers comprise a lack of power and/or influence by those in charge of energy management (lack of energy experts and skills, lack of energy audits, conflicts of interest between individuals and departments with different ideas and values influencing decision-making, or time pressure leading to concentrate solely on core business) and culture barriers refer to a lack of organisational culture leading people to ignore energy issues (Cagno et al., 2013; Hrovatin et al., 2016; Palm, 2009).

Table 1. A summary of the major barriers in non-residential buildings

Category	Barriers	Description/Examples
Market		
Informational failures	Imperfect and/or asymmetric information	Lack of information on costs and energy saving equipment. Unclear information by technology providers. Poor-quality information as to the energy performances of different technologies.
	Hidden costs	Low perceived profitability of EE investments. Additional costs associated with energy-efficient technology.
	Risk and uncertainty	Uncertainty about future energy prices. Technical risks. Economic and technological uncertainties in the business.
Other market failures	Access to capital	EE investments are usually assigned lower priority than essential maintenance projects or strategic investments.
	Principal-agent problem	Managers who hold their posts for only a short time may have limited incentives to invest in energy-efficient projects.
Behavioural		
	Bounded rationality	Making satisfactory decisions rather than searching for optimum decision, following imprecise routines and rules of thumb. Moreover, firms seem to focus on the core production process rather than on ways to save energy costs.
	Characteristics of information	Information should be specific, simple, personalised, updated, credible and trustworthy.
Organizational		
	Power	Low status of energy management may lead to issues having a lower priority within organisations.
	Culture	Organisations may encourage EE investments by developing a culture characterised by environmental values.

Source: Own work adapted from Cagno et al. (2013), Hrovatin et al. (2016) and Schleich (2009).

Fleiter et al. (2012) summarise the main findings of empirical studies addressing the role of barriers for non-residential buildings. They find that the most frequent barriers are lack of information about energy consumption patterns and about EE measures, lack of time to analyse potentials for EE, priority setting within organizations and the principal-agent problem (Schleich, 2009; Schleich and Gruber, 2008).

1.2.2. Barriers to energy-efficient HVAC systems in the hotel industry

Although the barriers indicated in Table 1 appear to be the most significant at organisations, there are differences by sector and size (Olsthoorn et al., 2017b). Most barriers are more pronounced in less energy-intensive firms and in smaller firms (Schleich, 2004). The main barriers for small and medium enterprises (SMEs) are a lack of capital and the technical risk of halting production for energy-intensive SMEs. For less energy-intensive SMEs they are a lack of information and a lack of staff time (Fleiter et al., 2012). Moreover, the significance of these barriers varies from one type of EE measure and technology to another. For example, installing an HVAC system calls for higher investment costs and a greater degree of complexity and customisation than measures involving lighting. This in turn is associated with higher hidden costs (Olsthoorn et al., 2017b; Trianni et al., 2014). Specifically, Olsthoorn et al. (2017) conclude that the main barriers for heating replacement are the principal-agent problem, hidden costs (such as financing costs and other investment priorities) and lack of capital. As a result, many firms fail to perceive that investing in energy-efficient appliances reduces operating costs in the future by lowering energy costs.

This paper analyses the factors that influence the adoption of energy-efficiency HVAC systems, focusing on the impacts of different barriers. A distinguishing feature of this study is its focus on behaviour regarding energy consumption at establishments and on investment in green and energy-efficient equipment[3]. All this contributes to a better understanding of the EE gap in the hotel industry.

As regards behavioural failures, Fadzli Haniff et al. (2013) conduct a detailed review of HVAC scheduling techniques for buildings, analysing energy and cost savings obtained by changing practices. They demonstrate that advanced scheduling techniques (e.g. a combination of "ON" and "OFF" statuses and pre-cooling or pre-heating techniques) may be able to save up to 20% in energy and 20% in cost for HVAC systems used for heating and cooling buildings. Chedwal et al. (2015) estimate energy savings by applying advanced energy-efficiency HVAC systems in different categories of hotel buildings in India. They find that the payback period for replacing existing HVAC systems with grand source heat pumps (GSHP) is 5-7 years, and that such investments increase profits and make establishments more competitive in the tourism market (Cingoski and Petrevska, 2018). Considering the current context of climate change, increases in extreme temperatures will have consequences for energy demand in this

[3] "Green and energy-efficient equipment" means energy-conservation equipment, i.e. types of equipment which permit energy-saving.

sector, not only for heating but also for cooling (Biardeau et al., 2020), thus making these practices even more important.

To explain the EE gap, it is also important to consider energy consumption behaviour at hotels. Owners believe that energy consumption depends not only on the EE of the HVAC system but also on the behaviour of customers. Liang et al. (2019) find that there are barriers to changing behaviour towards energy savings due to attitudes such as inattention and myopia among customers who do not pay the marginal cost of their energy consumption. To address these failures, Tiefenbeck et al. (2019) conduct a field experiment that provides information on energy and water consumption in every shower taken through a smart meter fitted to the hotel room shower unit. They show that real time feedback is a cost-efficient policy instrument for promoting resource conservation among hotel guests.

Related to this, several studies find no significant link between pro-environmental attitudes and investment in EE or energy-saving actions (Hornsey et al., 2016; Kollmuss and Agyeman, 2002; Ramos et al., 2016a; Schleich et al., 2016; van der Linden, 2017), in other words that pro-environmental attitudes may not always translate into substantial pro-environmental action (Cattaneo, 2019). Moreover, Nauges and Wheeler (2017) suggest that pro-environmental attitudes may have a negative effect on environmental concerns because agents who invest in energy mitigation behaviour may feel less concerned about climate change. Other behavioural explanations include lifestyle categories that capture the energy culture of a company (i.e. how energy is perceived and what habits and routines are in place). This allows for a deeper understanding of how and why companies improve EE (Palm, 2009; Trianni et al., 2017). For the specific case of the hotel industry and investment in energy-efficient HVAC systems, Ramos et al. (2016) find that environmental concerns appear to be significantly less relevant for high-cost energy-efficient investments (such as HVAC systems), suggesting that there may be a trade-off between environmentally friendly behaviours and monetary costs.

1.3. Methodology

1.3.1. Survey deployment

Two hundred telephone interviews were conducted in December 2017 and January 2018 by CPS[4], a specialist polling company. Establishments were recruited so as to provide a representative sample of types of accommodation, climate areas, geographical locations and other characteristics such as star rating and number of rooms. Decision-makers from three types of accommodation – individual hotels, hostels and cottages – were interviewed to explore their attitudes to HVAC systems. A preliminary

[4] CPS is a market research and opinion polling company that collects market and consumer information in Spain (https://www.cps2000.com/)

test of the survey questionnaire was conducted. It included the three types of accommodation indicated plus international hotel chains, but the latter were left out of the final version because their decisions about HVAC systems were found to be centralised at their main offices and often unrelated to their geographical locations. The respondents targeted were individuals in charge of purchasing and investment decisions at the establishments. Seventy percent of the respondents were building owners and the rest had lease agreements. The establishments included in the survey were drawn from five main climate regions in Spain (Mediterranean, Atlantic, Continental, Subtropical and Mountain) and two types of surroundings (coast and inland). They also represented different star ratings. Establishments were also drawn from municipalities of different sizes. For a more detailed explanation of the characteristics of the sample, see Appendix 1A.

The final questionnaire was designed based on the results of eight in-depth interviews conducted with Spanish accommodation operators to identify the key factors in their purchasing decisions. The analysis of these in-depth interviews revealed that consumers do not focus solely on the energy intensity of goods but are influenced by many other factors (de Ayala et al., 2020). Consequently, the goal of this analysis is to explore the interactions of these factors with the consideration of EE in purchasing decisions and to test a large number of factors. A binary response model (probit model) is thus used to explore the effect of several drivers on the weight given to EE. This enables drivers or factors to be analysed in isolation, i.e. keeping the rest of the factors unchanged (*ceteris paribus*). Several earlier studies have used probit models for this type of approach in the energy context (Hrovatin et al., 2016; Liang et al., 2019; Olsthoorn et al., 2017b; Schlomann and Schleich, 2015). Other approaches in the literature, such as discrete choice experiments, do not keep other factors constant in order to analyse possible trade-off between a number of factors (Fleiter et al., 2012; Michelsen and Madlener, 2012; Schleich, 2009; Schleich and Gruber, 2008). Both types of approach are useful and complementary for shedding more light on the topic.

The questionnaire contains sections on (i) socio-demographic and economic characteristics; (ii) the characteristics of HVAC systems; (iii) the attributes of the decision whether to purchase HVAC systems; (iv) barriers to EE investment; (v) understanding and use of existing labels and simulated monetary labels; and (vi) environmental behaviour, including energy-saving habits and investments in green and energy-efficient equipment. More detailed information on the questionnaire, including all the questions, is presented in Appendix 1C.

1.3.2. Barriers considered in the survey

The survey conducted here captures most of the relevant barriers for non-residential buildings identified in subsection 1.2.1. Specifically, survey participants were asked to indicate their attitudes and beliefs concerning different market, behavioural and organisational barriers to EE. Respondents were asked to answer using a 4-point Likert scale ranging from “strongly disagree” to “strongly agree”. **Table 2** provides an overview of the fourteen barriers addressed in the survey.

Regarding market barriers, “EE does not vary” and “More energy consumption” reflect the low perceived profitability of EE. “More EE goods are less reliable” and “Uncertainty as to energy prices hinders EE investment” are expected to capture the risk and uncertainty related to investing in energy-efficient heating systems. “Loan access limits my purchases” and “Cannot afford to upgrade” capture the importance of external access to capital due to high interest rates, but also internal access to capital because EE investments are often classified as less urgent than essential maintenance projects or strategic investments. And “Effectiveness of energy consumption information” refers to measures to make guests aware of energy consumption, aligning the incentives for energy savings between managers and guests. Behavioural failures are measured using several barriers that account for bounded rationality in EE investment decisions. The survey also inquired about organisational barriers such as willingness to take a chance on new technologies and the comfort and environmental values of the establishments, thus capturing information on the scale of EE investments in the accommodation sector.

Table 2. Overview of the barriers addressed in the survey (N=191).

Category	Variable	Mean	SD	Description
Market				
Hidden costs	EE does not vary	3.32	0.68	Low perceived profitability of EE, considering that all new HVAC systems have similar EE levels.
	More energy consumption	2.24	0.72	The saving in EE would enable the services offered by the establishment to be expanded and more electrical appliances to be fitted, producing a rebound effect.
Risk and uncertainty	More EE goods are less reliable	2.07	0.56	More energy-efficient HVAC systems are less reliable.
	Uncertainty as to energy prices hinders EE investment	3.28	0.67	Uncertainty as to energy prices discourages investment in EE.
Access to capital	Loan access limits my purchases	2.89	0.89	Lack of access to loans (excluding loans from friends and family) prevents more energy-efficient choices from being made.
	Cannot afford to upgrade	3.18	0.76	The establishment cannot afford to upgrade the EE of its HVAC system.
Principal-agent problem	Effectiveness of energy consumption information	3.11	0.76	The establishment has effective measures to make guests aware of energy consumption.
Behavioural				
Bounded rationality	Understand energy consumption	2.37	0.67	Good understanding of the energy consumption of the HVAC system at the establishment.
	Understand money saved	2.55	0.77	Good understanding of how much money would be saved if the establishment bought a more energy-efficient HVAC system.
	Aware energy price	2.22	0.79	Awareness of energy prices, i.e. the prices of the energy sources (gas, heating oil, electricity) that the establishment uses.
	Would buy if peers do so	2.94	0.77	The establishment would be more likely to buy an energy efficient HVAC system if other establishments did likewise.
Organizational				
Power	Willingness to take a chance on new technologies	2.74	0.78	The establishment is willing to take a chance on new technologies to reduce its energy consumption.
Culture	EE upgrade improves comfort	2.70	0.76	EE upgrades increase the value of the establishment.
	Reduce environmental impact	3.10	0.74	Buying a more energy efficient HVAC system would reduce the establishment's environmental impact.

1.3.3. Econometric model

A binary response model is built up using a probit model (Greene, 2003; Wooldridge, 2002). The dependent variable represents the probability of hotels rating EE as a *very important* attribute of their HVAC investment decision. Based on the literature review in the previous section, we use explanatory variables from seven different categories referring to (i) geo-climatic areas; (ii) socio-economic characteristics; (iii) technical characteristics of HVAC systems; (iv) specific attributes of HVAC systems such as price, brand reliability, performance and noise; (v) barriers to investing in energy-efficient HVAC systems; (vi) knowledge and perception of monetary information labels; (vii) environmental behaviour; and (viii) habits for energy savings and investment in green equipment. The general specification of the probit model applied can be expressed as follows:

$$\begin{aligned}\Pr\,(\mathrm{Y}=1\mid\mathrm{X}) = \beta_1 &\\ &+ \beta_2 \text{GeoClimatic areas}\\ &+ \beta_3 \text{Socioeconomic characteristics} + \beta_4 \text{ HVAC technical characteristics}\\ &+ \beta_5 \text{HVAC specific attributes} + \beta_6 \text{Barriers to EE}\\ &+ \beta_7 \text{Monetary information label} + \beta_8 \text{Environmental behaviour}\\ &+ \beta_9 \text{ Habits\&Investment} + \varepsilon \qquad (1)\end{aligned}$$

where Y is "Energy Efficiency is a *very important* attribute in the purchasing decision", X contains explanatory variables and $\varepsilon \sim N(0,1)$ is the error term. The elements of the vector of parameters $[\beta_1, \dots, \beta_9]$ are reported as the marginal effects of the explanatory variables on the consideration of EE, with all other attributes remaining unchanged (*ceteris paribus*). With binary independent variables, marginal effects measure a discrete change, i.e. how predicted probabilities change as the binary independent variable changes from 0 to 1. For a continuous independent variable, it measures the amount of change in the probability of considering EE produced by a 1-unit change of the independent variable as very important.

The explanatory variable "Barriers to EE" includes the market, behavioural and organisational barriers described above in subsection 1.3.2. All the barriers described in Table 2 were tested and the selection of the final model presented in Table 3 is based on the Akaike Information Criterion.

1.4. Results and discussion

1.4.1. Descriptive statistics

Descriptive statistics are used to describe and discuss the findings for the full sample in more detail regarding energy-efficiency considerations for the purchase of HVAC systems and to explain their socio-demographic background.

1.4.1.1. Socio-demographic and economic characteristics of establishments

The socio-demographic and economic characteristics of an establishment may influence the adoption of EE HVAC. The establishments surveyed have been running on average for 17 years, with a range from 1 to 86 years. The average number of rooms is 26, but the range is wide: from 1 to 434. The average occupancy rate of rooms is 80% during the high season and 40% during the low season. In 2017 most establishments considered that their businesses were financially sound and they did not envisage or anticipate financial problems in the future[5]. On a scale from 1 (“I am having major financial difficulties”) to 10 (“My financial situation is very comfortable”), the average score is 6 for the present situation and 7 for expectations for the following 5 years (Appendix 1B).

1.4.1.2. Technical characteristics and specific attributes of HVAC

The HVAC systems used vary from one establishment to another, with more than one type of system in some cases (e.g. cottages with reverse cycle air conditioning system and fireplaces or wood stoves). 27% of establishments have combined HVAC systems, 72% have separate heating systems and 18% also have separate cooling systems. The energy sources used for separate heating systems are heating oil (39%), electricity (18%), biomass (17%), natural gas (13%), propane (9%) and renewable energies such as photovoltaic and geothermal energy (4%). Combined systems and separate cooling systems use electricity. On average, HVAC systems were installed 10 years ago, with a range from 1 to 65 years.

HVAC systems are not a recent innovation in the Spanish hotel industry and the willingness to upgrade the EE of systems is low. Only 6% of respondents reported that they had upgraded to a more energy-efficient HVAC system in the last five years and 94% reported that they did not plan to upgrade their HVAC systems in the next five years. They stated that their current HVAC was working properly and assigned less importance to other reasons (e.g. building infrastructure problems, limits on access to loans, the current HVAC covers the needs of the establishment). This may be considered as a limitation in the analysis.

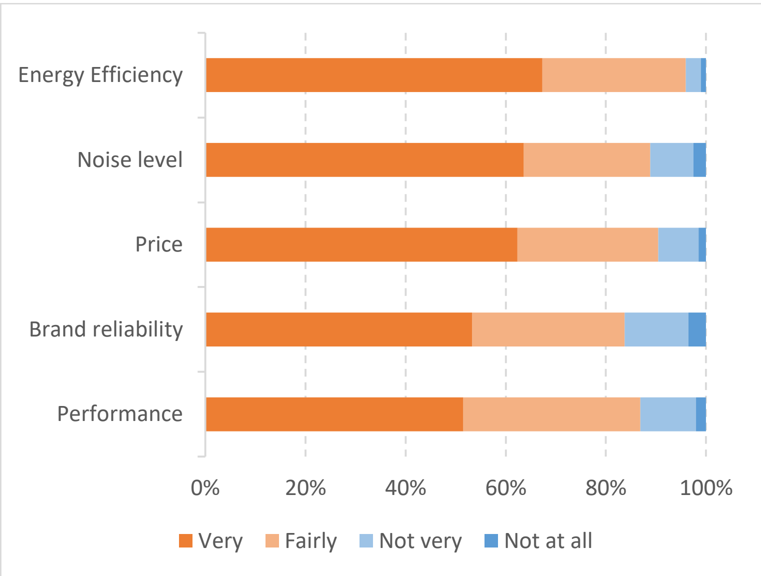

Figure 5. Importance of the attributes of HVAC systems in purchasing decisions for establishments in Spain

[5] Note that the survey was conducted well before the COVID-19 crisis.

Energy efficiency is the attribute most frequently rated as important in choosing an HVAC system (Figure 5). 67% of respondents rate it as a *very important* attribute. Other attributes less highly rated than energy efficiency[6] are also classed as important in purchasing decisions: noise level (decibels) is ranked second (64% rate it as *very important*), followed by price (62%). Brand reliability (i.e. durability and technical & maintenance support) and performance (such as automatic control, temperatures adjustable according to outside temperature and humidity level, heat recovery and integrated heating and cooling functions) are also rated as *very important* by at least 50% of respondents.

1.4.1.3. Barriers to energy-efficient HVAC systems

The three families of barriers identified in the literature were investigated in the survey and in the preliminary in-depth interviews (see Figure 6) using fourteen statements.

Regarding market barriers, the vast majority of respondents were found to believe in the reliability of energy-efficient equipment: about 83% disagreed or strongly disagreed with the idea that more energy-efficient HVAC systems were less reliable. This is supported by Peruzzi et al. (2014), who reveal the importance of reliability for HVAC systems, especially for those systems that must guarantee uninterrupted service. 67% of respondents answered that lack of access to loans was an important barrier limiting their energy-efficient HVAC purchases. It is also important to consider that about 61% of respondents strongly or slightly believed that specific measures could make customers more aware of and more responsible regarding their energy consumption. As for behavioural barriers, 38% of respondents knew how much energy their equipment consumed and 34% were aware of energy prices, but only 7.5% strongly agreed that they understand how much money they would save if they bought a more energy-efficient HVAC system. Concerning organisational barriers, about 39% of respondents strongly agreed that they were willing to take a chance on new technology to reduce their energy consumption and only 30% of respondents stated that they could not afford to buy a new, energy-efficient HVAC system. It is also important to highlight that about 43% of respondents strongly agreed that buying a HVAC system with more energy-efficient properties would reduce their environmental impact.

[6] Student's t-tests report significant heterogeneity in the rating of attributes according to a test on the variance and indicate that the average rating of energy efficiency differs from that of brand reliability and performance with a 95% confidence level and from that of price and noise with a 90% confidence level.

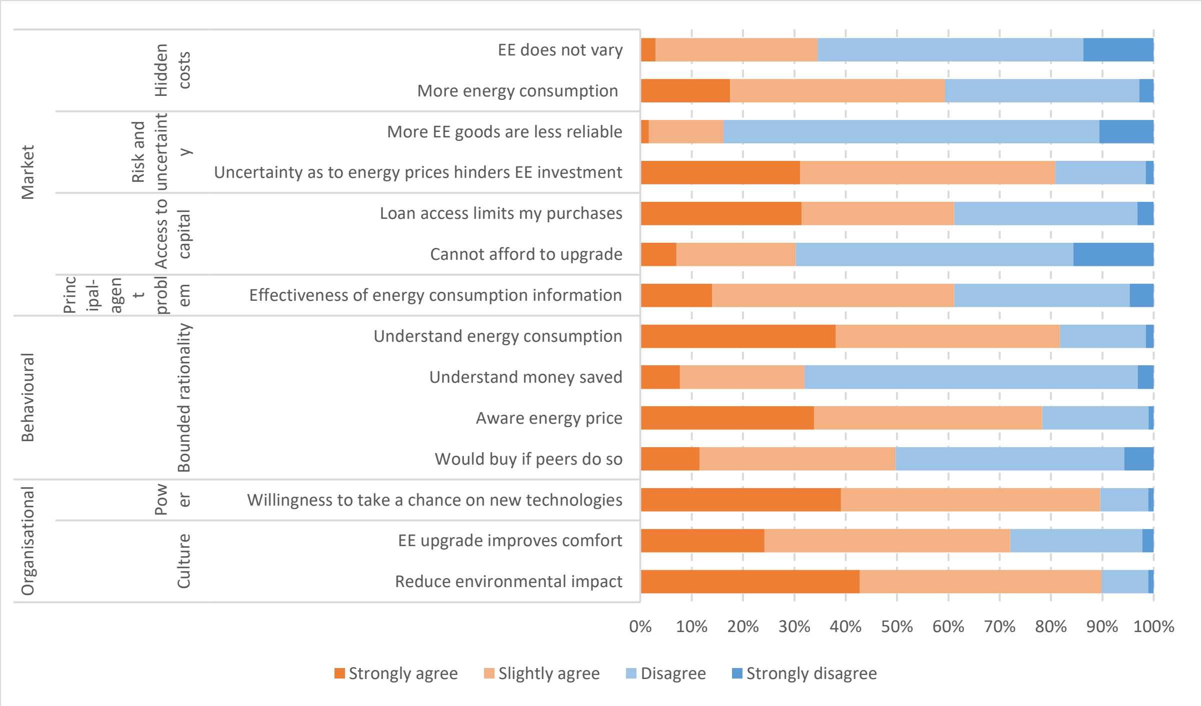

Figure 6. Agreement with drivers and barriers for energy-efficient HVAC systems for hotel establishments in Spain
Note: The respondents indicated their agreement to several statements on a scale with the four ordered response categories "strongly agree", "slightly agree", "disagree", and "strongly disagree".

1.4.1.4. The role of energy efficiency labels

Several studies highlight the importance of labelling schemes in preventing informational failures and consequently addressing the EE gap (Carroll et al., 2016; Lucas and Galarraga, 2015). We therefore also analyse the role of ecodesign[7] and energy labelling[8] regulations used in HVAC systems. According to Fig. 3 and 4, in the case of both heating and cooling systems only half the respondents (i.e. 100 respondents) acknowledged the existence of the energy label and/or technical specifications label. 70% of those respondents who were aware of the ecodesign and energy labelling of heating systems stated that these labels had influenced past purchasing decisions for heating systems (see Figure 7), and 74% of those aware of ecodesign and energy labelling of cooling systems stated that these labels had influenced past purchasing decisions for such systems (see Figure 8). In addition, 97% of the

[7] The first ecodesign regulation was implemented in 1992 for new hot-water boilers fired with liquid or gaseous fuels (92/42/EEC) and later extended to energy-using products (2005/32/EC). The latest ecodesign regulation, published in 2016 (2016/2281/EU) implementing Directive 2009/125/EC, summarises the most relevant information on energy performance, EE and the emission of nitrogen oxides from air heating and cooling products, high temperature process chillers and fan coil units.
[8] Most heating and cooling products are also covered by energy labelling regulations and use technical labels which include information on the energy rating of their cooling and heating functions and indications of their hourly or annual energy consumption and their noise levels. The information on the label and its design vary depending on product regulations: 2002/31/EC for air conditioners, repealed by 626/2011/EU; 811/2013/EU for space heaters and combination heaters; 2015/1186/EU for local space heaters, 2015/1187/EU for solid fuel boilers; all of them supplementing Directive 2010/30/EU.

respondents agreed with the statement that their company considered energy efficiency labels when purchasing heating and cooling systems. That is, their answers to this question were not directly linked to past purchasing decisions being conditioned by the label. In fact, they may be reflecting future preferences too.

Several studies of the effectiveness of energy labelling suggest different ways of improving such labels, so it is important to understand how consumers use the information on the labels in their purchasing decisions (Heinzle and Wüstenhagen, 2012a; Stadelmann and Schubert, 2018). In this regard, the responses in the study reported here indicate a high level of agreement about understanding of and trust in existing energy-efficiency labels.

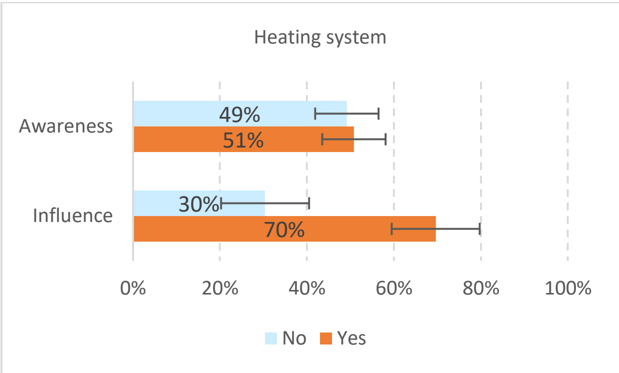

Figure 7. Awareness and influence of ecodesign and energy labelling regulations with 95% confidence intervals. "Influence" data refers to those respondents who are aware of both types of regulation

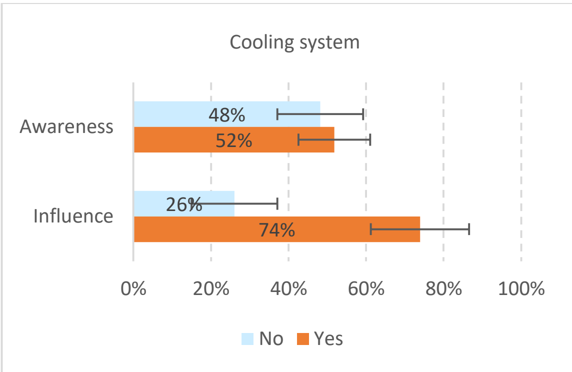

Figure 8. Awareness and influence of ecodesign and energy labelling regulations with 95% confidence intervals. "Influence" data refers to those respondents who are aware of both types of regulation

This study also analyses the role of labels in HVAC systems with energy-cost information and incorporate those statements into the survey presented in subsection 1.3.2. 90% of hotel owners think that labels with additional monetary information are more understandable and trustworthy (85%) than existing EE labels, and 92% of respondents said that these labels would influence their purchasing decisions. In fact, most respondents believed that a label with additional monetary information would be more helpful in understanding how much energy was consumed by an HVAC system (89%) and calculating how much it cost to run (88%). Finally, 30% of respondents believed that there was a risk of labels potentially being manipulated by manufacturers.

1.4.1.5. Hotel owners' attitudes towards the environment

Lastly, this study includes attitudes and beliefs about environmental issues. 86% of respondents stated that they were concerned or extremely concerned about the environment. Habits for energy savings and investments in green and energy-efficient equipment were measured using a survey question validated by the OECD (OECD, 2011). Regarding energy saving behaviour, we analyse how often establishments implement the following practices in their business: automatic control of HVAC systems or regular information to promote responsible consumption of energy and water by workers. Answers were classified into the following categories: "Never", "Occasionally", "Often" and "Always". The responses indicate a high level of recognition of these practices. Specifically, 37.5% of respondents stated that they always automatically controlled the use of HVAC systems in rooms (e.g. by using smart key cards, smart thermostats or on/off programming). 71% also answered that they always provided information on energy consumption to promote responsible energy consumption among workers.

In regard to other energy-efficiency investments, this study analyses whether establishments have invested or not in green and energy-efficient equipment, with the following response categories: "Yes", "No", "Already equipped, more than 10 years ago", and "Not possible/feasible in my establishment". It is important to note that 66% of respondents have energy-efficient appliances (e.g. minibars or TVs) installed. All respondents except one were also found to have invested in LED lighting. 70% of establishments stated that they had invested in energy-efficient windows and thermal insulation of walls and roofs. 60% said that they had sensors for controlling lights and temperature in common areas. Finally, respondents were asked to indicate whether they had invested in solar panels for electricity generation or for heating water. Such investments were found to be much less common, with only 23.5% of establishments equipped with this technology. According to Caird et al. (2008), this may be explained by barriers such as uncertainty as to the performance and reliability of the technology.

1.4.2. Factors influencing the importance assigned to EE as an attribute

The factors influencing the rating of EE as a *very important* attribute were explored in a probit model. The results are presented in Table 3. All categories of factors have an influence on the probability of the value EE very importantly.

Table 3. Marginal effects of the EE attribute for hotels & similar establishments in Spain

	Marginal effects	Standard error	P>|z|
Geo-climatic areas			
Mediterranean (inland and coast)	-reference		
Atlantic (inland and coast)	0.0485	0.142	0.733
Continental (inland)	0.283**	0.102	0.005
Subtropical (inland and coast)	0.105	0.149	0.484
Mountain (inland)	0.00263	0.159	0.987
Socioeconomic characteristics			
Hotel	-reference-		
Hostel (=1 yes)	0.204**	0.082	0.013
Cottage (=1 yes)	0.0884	0.126	0.482
Owners of the building (=1 if yes)	-0.0722	0.133	0.588
Number of years in operation	0.00278	0.002	0.265
Occupancy rate in high season (range 0-100)	0.00561**	0.002	0.009
HVAC Technical characteristics			
HVAC system with natural gas (=1 yes)	-0.103	0.153	0.502
HVAC system with propane (=1 yes)	0.380**	0.141	0.007
HVAC system with heating oil (=1 yes)	0.0577	0.113	0.610
HVAC system with electricity (=1 yes)	-0.243**	0.100	0.015
Heating system with biomass (=1 yes)	-0.0838	0.103	0.418
HVAC system with geothermal (=1 yes)	-0.164	0.245	0.504
Heating-only system (=1 yes)	0.0825	0.106	0.435
HVAC-specific attributes			
Price (=1 if very important)	0.192**	0.088	0.029
Brand reliability (=1 if very important)	0.243***	0.078	0.002
Performance (=1 if very important)	0.269**	0.088	0.002
Noise (=1 if very important)	0.138	0.088	0.117
Barriers to energy-efficient HVAC systems			
Market barriers			
Loan access limits my purchases (=1 if strongly agree)	-0.0788	0.097	0.419
Effectiveness of energy consumption information (=1 if strongly agree)	0.141	0.130	0.280
Behavioural barriers			
Understand energy consumption (=1 if strongly agree)	-0.0961	0.091	0.290
Organisational barriers			
Willingness to take a chance on new technologies (=1 if strongly agree)	0.171*	0.094	0.069
Monetary information label			
Understandable (=1 if strongly and slightly agree)	-0.0658	0.121	0.588
Trustworthy (=1 if strongly and slightly agree)	-0.0886	0.108	0.411
Influence on purchasing decision (=1 if strongly and slightly agree)	0.0397	0.120	0.740
Helpful to understand how much energy is consumed by HVAC (=1 if strongly and slightly agree)	0.259**	0.123	0.035
Environmental behaviour			
Concern for the environment (=1 if extremely concerned)	0.154*	0.082	0.061
Habits for energy savings			
HVAC automatic control (=1 if always)	0.176*	0.076	0.020
Information (=1 if always)	-0.0666	0.090	0.457
Investments in green and energy-efficient equipment			
EE Appliances (=1 if yes)	-0.0661	0.075	0.379
EE windows (=1 if yes)	-0.164	0.086	0.056
Wall and roof insulation (=1 if yes)	-0.186*	0.082	0.023
Light sensors (=1 if yes)	0.0813	0.075	0.280
Solar panels (=1 if yes)	0.0706	0.082	0.389
Observations	191		
LR chi2(16)	112.18		
Prob > chi2	0.0000		
Pseudo R2	0.4919		
Log likelihood	-61.53		

Note: ***, ** and * indicate significance at 1%, 5% and 10% level. Robust standard errors are used in the probit model.

Establishments in areas with a continental climate are 28% more likely to value EE as a *very important* attribute than those located in a Mediterranean climate. Managers of establishments in areas characterised by hot summers and cold winters are more interested in EE as it might reduce energy-related running costs of air conditioning and heating. The type of establishment also plays a significant role: hostels are 20% more likely to value EE as a *very important* attribute than hotels. This may be because small establishments are more concerned about energy bills, given that they have lower personnel costs and higher energy costs than larger hotels. Another reason may be that the level of insulation in hostels is lower. Financial soundness was found to be significantly correlated with occupancy rates during the high season. The latter variable was used to avoid collinearity in the regression to capture the income situation. Establishments with higher occupancy rates and thus higher energy consumption are more likely to value EE as a *very important* attribute. For example, those with an 80% occupancy rate[9] are 45% more likely to do so. The possible reason is that higher occupancy establishments may have higher energy costs and so they may recoup EE investments more rapidly. We find no evidence of barriers to access to capital in the rating of EE.

Some technical characteristics of HVAC systems have a significant impact on ratings. Establishments with HVAC systems that run on propane are 38% more likely to value EE as a *very important* attribute. In terms of energy price, a comparison of the energy sources considered in this study reveals that propane costs more than natural gas but less than heating oil and electricity for heating (EIA, 2020). The higher price of propane may lead owners to use energy-efficient equipment so as to reduce their HVAC bills. Nevertheless, buildings in Spain are less likely to have propane-fired HVAC systems than buildings in other countries (e.g. the United States) (EIA, 2011), which suggests that effects involving this technology should be interpreted with caution. On the other hand, establishments that use electricity are 24% less likely to rate EE as a *very important* attribute. This may be for two reasons: one is that establishments which use electricity are relatively unconcerned about EE and the other is that energy consumption in these establishments is lower than energy consumption in other establishments.

Attributes of HVAC systems such as price, brand reliability and performance are also important determinants of the decisions made by establishments. Specifically, respondents who consider price as a *very important* attribute are 19% more likely to value EE as a *very important* attribute. One interpretation of this positive relationship concerns the budget constraints of consumers. Consumers with a binding budget constraint rate price (namely low prices) and EE as important in reducing

[9] This corresponds to the average and median rates of occupancy.

running costs. Energy-efficient goods are more expensive, so these consumers are less likely to buy such goods. This budget constraint explains EE campaigns with financial incentives to buy energy-efficient goods. Other studies show that energy-efficient equipment is more price-elastic than regular equipment (Coad et al., 2009; Galarraga et al., 2011a). Other attributes, such as brand reliability and performance, also significantly affect the rating of EE, to a similar extent to prices[10]. Indeed, respondents who rate the brand reliability and performance of HVAC systems as a *very important* attribute are 24% and 27% more likely, respectively, to rate EE as a *very important* attribute. Brand reliability and performance are thus as important as price is in the rating of EE. These findings provide evidence that consumers prefer energy-efficient HVAC systems which also have good performance and good brand reliability. This could indicate that they may be considering EE as a proxy for quality, i.e. considering the ability of HVAC systems to fulfil a specific requirement.

The attitude towards specific barriers as regards EE also helps to explain why EE is rated as *very important*. Respondents who strongly agree with taking a chance on new technologies to reduce their energy consumption are 17% more likely to rate EE as a *very important* attribute. This result, combined with the intention to upgrade HVAC systems, however, seems to indicate a gap between beliefs and purchasing decisions due to the barriers to EE adoption reviewed above. Indeed, 40% of respondents indicated that they were willing to take a chance on new technologies to reduce their energy consumption, but only 6% reported that they planned to change their HVAC systems. Similar results are observed in household energy-efficiency choices. Damigos et al. (2020) find no evidence that this same belief increases the purchase of energy-efficient refrigerators.

In regard to the role of monetary information labels, we find that hotel owners who state that a label with additional monetary information would be more helpful than the current label are 26% more likely to rate EE as a *very important* attribute.

Environmental concerns are also a factor in explaining EE in the hotel industry. On average, owners more concerned about the environment are 15% more likely to rate EE as a *very important* attribute. This finding is consistent with those of other studies such as Damigos et al. (2020) and Shen (2008), who show that the importance of EE is positively affected by the pro-environmental behaviour of the respondents. Energy-saving habits positively influence the probability of rating EE as a *very important* attribute, as expected from other studies (Palm, 2009). Indeed, establishments that always control the use of HVAC systems in rooms automatically (e.g. using smart key cards or on/off programming) are 18% more likely to rate EE as a *very important* attribute. This result supplements the existing

[10] A test of equality of marginal effects for brand, performance and price fails to reject it.

literature on EE measures in the service sector, which finds that factors affecting the adoption of high-cost technologies such as HVAC systems also affect the adoption of low-cost measures (e.g. switching off lights whenever possible or managing and controlling energy use) (Schlomann and Schleich, 2015).

Interestingly, we find that establishments with thermal insulation in walls and roofs are 19% less likely to rate EE as a *very important* attribute. This seems to indicate a negative feedback from non HVAC-related EE investment in the rating of EE. Establishments which invest in insulation have lower heating and cooling consumption, so their need for energy-efficient HVAC systems, or the savings brought by them, is lower. This may lead them to under-rate the EE attribute. Moreover, it would make sense for owners to scale down the importance of this attribute for the future once major action towards it has been taken. Another potential explanation is that establishments which undertake substantial environmental actions such as investing in insulation and energy-efficient windows feel less motivated to adopt further pro-environmental measures. They believe that their investment in thermal insulation of walls and roofs has already helped to mitigate climate change. This result supports previous findings on environmental concerns and energy mitigation behaviour (Nauges and Wheeler, 2017; van der Linden, 2017). For example, Nauges and Wheeler (2017) find that adoption of mitigation behaviour may have a negative effect on a household's climate change concerns.

1.5. Conclusions

HVAC systems are major consumers of energy in the hotel industry, and reducing and decarbonising energy consumption on heating and cooling is crucial for the energy transition. EE provides an important pathway for reducing energy consumption, generating energy savings and reducing energy expenses. However, it is often observed that investments in EE are lower than they should be. The analysis reported here, based on a survey of the hotel industry, identifies factors that influence the EE choices of Spanish accommodation owners and contributes to the literature exploring the barriers to EE investment in that industry.

The main results of this study are that hotel accommodation owners rate EE highly in their purchasing decisions but that several barriers limit the importance attributed to EE and thus their investment in EE. Those factors are related to the market and to individual behavioural and organisational factors.

There is evidence of lack of information and bounded rationality, because only a third of all respondents know how much energy their equipment consumes and what the price of energy is. Results also show that the decision of whether to purchase HVAC seems to be affected by existing energy labels, and establishments believe that a label with additional monetary information would be more understandable and helpful in understanding how much energy is consumed by HVAC systems and in calculating how much HVAC would cost to run.

The market price of goods also influences how highly EE is rated by owners. Lower prices would help to increase the importance attributed to EE, and other attributes reflecting the quality of goods, such as brand reliability and performance in terms of services provided, also positively influence EE.

Organisational factors such as the importance attributed to new technologies and environmental concerns are also a factor in explaining EE in the hotel industry, although there is a gap between beliefs and purchasing decisions.

Climate considerations, information and the technical characteristics of establishments affect how highly the energy-efficiency attribute is rated. A negative feedback effect is detected from investment in other EE goods but not in HVAC-related equipment. Establishments with thermal insulation in walls and roofs are less likely to rate EE as a *very important* attribute. However, those that always control the use of HVAC systems in rooms automatically (e.g. by using smart key cards or on/off programming) are more likely to rate EE as a *very important* attribute.

This research has several policy implications. To design the right EE policy one must account for the potential responses by agents, and the analysis reported here helps identify the drivers to which they may or may not respond. This is consistent with the findings of Blasch et al. (2018), who analyse the concept of “energy-related financial literacy” (which measures the level of energy-related knowledge and cognitive abilities that consumers need in order to take decisions with respect to investment for the production of energy services and their consumption). One of the points brought to light by our survey is the lack of knowledge among owners of hotel establishments about the energy and monetary savings provided by more energy-efficient equipment. This clearly indicates that it is of interest to use information-based policy instruments such as labels, energy audits and feedback on bills. This is reinforced by the fact that many owners do value the information provided by labels, and would like that information to be included.

This analysis also shows that different responses may be obtained in different climates: policies could be directed first at those areas, such as continental climates, where agents are more responsive to EE concerns. Also, in terms of directing policies, interaction with building retrofitting also needs to be accounted for, given that interest in EE HVACs decreases when buildings have been thermally insulated.

Energy taxes help reduce free-riding and rebound effects, and may also help accentuate pro-energy-efficiency attitudes among current owners of HVAC systems based on fossil fuels. Energy demand measured trough the occupancy rate is found to influence the rating of EE positively. A higher associated cost for energy would therefore reinforce the importance given to EE help owners reconsider their currently low willingness to upgrade HVAC systems, though subsidies may also be required to help overcome the bounded rationality problem. Subsidies may also help overcome the gap between beliefs and purchasing decisions.

Finally, the fact that EE is strongly linked with price, brand reliability and performance means that those who invest in cheaper, low-quality equipment seem less likely to rate EE highly. Here the introduction of stricter, mandatory EE standards across the board would ensure that energy is saved even in such cases.

However, it is worth remarking once again that our study addresses potential barriers to the adoption of EE but is not able to measure how they translate into under-investment in EE, given the low replacement rate in the sample. This would be of course a very welcome element for improving policies, and to determine the real consequences of these barriers. Further research is ongoing in this area.

Chapter 2: Mind the map? Mapping the academic, citizen and professional stakeholder views on buildings and heating behaviour in Spain [11]

[11] **López-Bernabé, E.**, Foudi, S., Galarraga, I. 2020. Mind the map? Mapping the academic, citizen and professional stakeholder views on buildings and heating behaviour in Spain. Energy Research and Social Science. 69. DOI (10.1016/j.erss.2020.101587).

2.1. Introduction

In Spain, as in the rest of Europe, current household energy consumption remains a major driver of total energy consumption and CO_2 emissions (European Commission, 2016; Eurostat, 2019a). Households use energy for various purposes: space and water heating, space cooling, cooking, lighting, electrical appliances and other end uses. The main use of energy in households is for heating (EEA, 2016; Hecher et al., 2017). In Spain, 18% of total energy consumption is accounted for by households and 44% of that energy goes into heating homes (European Commission, 2018; Eurostat, 2018a). Socioeconomic development, architectural design, climate and environmental awareness are some of the main factors underlying energy consumption on heating and cooling in Spanish residential buildings (De Boeck et al., 2015).

Climate change and energy security require a 90-100% reduction in fossil fuel consumption in buildings by 2050 (IEA, 2017). The technical requirement that new buildings in the European Union must be "nearly zero energy buildings" (Annunziata et al., 2013; Ecofys, 2014) as from 2021 is an important instrument for achieving this. Efforts to refurbish the existing building stock in Europe need to be stepped up (Tagliapietra et al., 2019) as close to 75% of buildings in the European Union are energy-inefficient (Buildings Performance Institute Europe, 2018). If the target is to be reached all the existing buildings need to be renovated by 2050. These actions in new buildings and renovations require not only improvements in energy efficiency (EE) (Alberini and Bigano, 2015; de Miguel et al., 2015; Olsthoorn et al., 2017a) but also the development of renewable energy sources (Cansino et al., 2011).

The technology-based approaches mentioned above can be supplemented by an understanding of the behavioural aspects of energy use and energy saving. Several studies note that behavioural aspects of consumer choices need to be better understood to fully assess what drives consumer decisions and to design better energy policies (Dubois et al., 2019; Knobloch et al., 2017; Metcalfe, 2016; Niamir et al., 2020; Tsoka et al., 2018). Large differences in energy consumption in similar buildings have been observed, mainly due to the behaviour of their occupants (Guerra-Santin and Itard, 2010; Schweiker and Shukuya, 2010; Terés-Zubiaga et al., 2018; Wolff et al., 2017). Indeed, the behaviour of consumers may be more significant in explaining energy consumption than building characteristics or other factors (IEA, 2013).

The total reduction in residential energy consumption is the result of the interplay of technological change and household behaviour (Blasch et al., 2017; Mauri et al., 2019), but the financial capacity to invest in more energy-efficient equipment also plays a major role (Achtnicht and Madlener, 2014;

Alberini et al., 2013; Kastner and Stern, 2015). Indeed, significant investments are required to promote sustainability in buildings and housing (Kastner and Stern, 2015). For instance, Wang et al. (2011) analyse the influence of the high cost of energy efficient appliances, arguing that the cost of appliances may constrain willingness to make energy savings. Michelsen and Madlener (2012) show that cost aspects or a financial grant influence energy heating system choice in Germany. Other papers show that heterogeneity of preferences with respect to cost aspects influences the choice of energy appliances (Banfi et al., 2008; Claudy et al., 2011). Other research papers, such as Yeatts et al. (2017), focus on barriers to the use of energy-efficient technologies in buildings. They show that cost and capital constraints are barriers to the use of energy-efficient technologies.

Policies are needed to influence consumer behaviour and lifestyle (Moezzi and Janda, 2014; Topouzi et al., 2019). It is therefore important not to ignore behavioural uncertainties in policy design (Li, 2017). Indeed, policy makers need to better understand consumers' behaviour to design effective energy saving strategies (Lesic et al., 2018; Li et al., 2017). In addition, policy interventions are needed to overcome barriers (Purkus et al., 2017), but they must be carefully designed to reflect specific national and local circumstances (Geels et al., 2016; Song et al., 2020). For the specific case of effective heating policies it is vital to understand what factors influence citizens' choices and energy use behaviour for heating. The objective of this paper is twofold: (i) to learn more about the determinants of household energy consumption for heating in Spain; and (ii) capture views from three different groups of stakeholders (academics, citizens and energy experts) on what policies can effectively help to reduce heating energy costs.

From a methodological point of view, various analyses and methodologies have been applied to assess energy performance in residential buildings (De Boeck et al., 2015; Swan and Ugursal, 2009), but most of the studies that analyse consumer behaviour use data from questionnaires on real or hypothetical decisions. Several studies have been published on the specific case of residential building in Spain. Labandeira et al. (2005) propose a regression model and develop an energy demand system for residential energy consumption that provides various findings for Spain. For example, a significant relationship is found between spending on different energy goods and place of residence, household composition and the work status of the household head. Gálvez et al. (2016) study residential demand for basic household services in Spain. Their results show that demand for electricity and drinking water is less sensitive to variations in prices and household income than that for natural gas. Domínguez et al. (2012) and Ruiz and Romero (2011) estimate EE improvement measures for Spanish residential buildings and show that design measures (such as adding insulation to the façade or increasing openings in south-facing outside walls) differ for different types of weather. These studies mostly focus on specific parameters that influence the actual energy performance of a building. But it is not enough to identify and recommend the policy measures that might most effectively modify the current unsustainable energy consumption. In the energy transition context, there is still a general lack of knowledge of what policy strategies should be implemented in order to direct consumer behaviour towards sustainability (Morone et al., 2019). The need to capture a general framework of cause-effect relationships to understand consumer behaviour is particularly relevant in identifying policy strategies that could encourage sustainable consumption practices (Falcone et al., 2018; Ziv et al., 2018).

Fuzzy Cognitive Mapping (FCM) is used in this study to overcome the lack of information needed to design effective policies. This paper seeks to understand consumers' heating behaviour and perceptions and the knowledge of experts on private and public adaptation policies for low-carbon heating behaviour. To that end, we apply FCM to elicit the system that interconnects intrinsic factors and policy instruments (Jetter and Kok, 2014; Kosko, 1986; Özesmi and Özesmi, 2004). This method is based on fuzzy graph structures to represent causal reasoning (Kosko, 1986) and it enables the drivers of heating expenditure to be depicted and the interactions between them from behavioural to policy-related factors. The method engages different participants from different social groups in a shared thinking process. In this research, we analyse the transition towards low-carbon heating in Spain. We develop three separate maps for households, academics and energy-experts. Our reason for working with these three groups is to gather a broader picture of the topic by working with users, researchers and those who are actually managing the energy system. Three sequential questions were asked in each Focus Group (FG): (i) "What basic heating facts, elements or components influence the amount of your heating bill?"; (ii) "what individual measures could help to reduce your heating bill, that is, things or individual actions that could really change your heating consumption?"; and (iii) "what policies could politicians implement to bring down heating bills?"

Participants provided a qualitative understanding of the attitudes and opinions of households, the obstacles that they face in everyday life and potential solutions that they could identify and support. This study could help to provide recommendations for policy actions that could effectively change current unsustainable heating consumption practices.

The paper is organised as follows. Section 2.2 provides an overview of the literature on technological, environmental, behavioural and regulatory factors affecting residential heating systems. Section 2.3 presents a statistical overview of energy consumption on heating in Spain. Section 2.4 presents the methodology and a case study. Section 2.5 sets out the results and discusses the findings. Finally, Section 2.6 outlines implications for policy-making and business.

2.2. Factors influencing household heating behaviour

The structure of the economy and socio-cultural and environmental factors have an impact on energy demand. In household energy demand, energy choices and consumption are driven by socio-economic conditions, environmental factors and cultural factors (Danlami et al., 2014). These factors affect household behaviour regarding energy consumption (Cayla et al., 2011).

Household behaviour has a significant impact on energy use, especially in homes (Wei et al., 2014), so it is most important to obtain a better understanding of how energy consumers behave, particularly against the background of climate change, security of energy supply and increasing energy prices (Michelsen and Madlener, 2012). Several studies in the literature analyse factors related to the behaviour, attitudes and preferences of consumers (Geels et al., 2016; Guerra-Santin and Itard, 2010; Li et al., 2017; Niamir et al., 2020; Schweiker and Shukuya, 2010; Wang et al., 2011). These factors can be broken down as follows: (i) socioeconomic and demographic characteristics; (ii) residence characteristics; and (iii) environmental considerations (Karytsas and Theodoropoulou, 2014).

The socioeconomic and demographic characteristics likely to affect behaviour include household income, household size and number of children. Several studies show that the annual income of households has an impact on the energy consumed for space heating (Schuler et al., 2000; Vaage, 2000). Additionally, households classified as energy-poor tend to use less energy for keeping warm in the winter due to a lack of financial resources (Hills, 2012; Phimister et al., 2015). In the case of Spain almost 10% of households are unable to keep their homes adequately warm (Eurostat, 2019b). Energy poverty in Spain is significant although slightly below the European Union average (Bouzarovski and Tirado Herrero, 2017; Phimister et al., 2015; Thomson and Snell, 2013).

Building characteristics that have been found to influence spending on heating include the type of house (size or number of bedrooms), the year of construction and retrofits to improve EE (Al Qadi et al., 2018; Karytsas and Theodoropoulou, 2014).

In terms of environmental concerns, environmental friendliness considerations, climate protection, indoor air quality and health aspects motivate homeowners to opt for new, innovative renewable-energy-based heating systems (Michelsen and Madlener, 2012; Sopha and Klöckner, 2011). However, there are differences between pro-environmental attitudes and pro-environmental behaviour. Su et al. (2019) demonstrate that personal environmental awareness is not statistically significant in the intention to adopt cleaner residential heating technologies. Moreover, no effect of environmental attitudes (such as acceptance of taxes on the most pollutant fuels in technology adaption) has been found for Spanish households (Ramos et al., 2016b). In other words, attitudes to the environment generally seem to be less important in explaining the replacement of heating systems than financial considerations (Ramos et al., 2016b). However, households with eco-friendly behaviour such as daily recycling or participation in environmental policy activism are more likely to invest in EE measures and to adopt daily habits conducive to energy saving (Gillingham et al., 2012; Maruejols and Young, 2011; Ramos et al., 2016b).

Other factors that help explain non-optimal behaviour on energy consumption are a lack of knowledge about energy saving measures, capital constraints, time preference, the principal-agent problem and uncertainty as to the effectiveness of measures (Markandya et al., 2015).

2.3. An overview of energy consumption for heating in Spain

Between 2001 and 2008 there was a construction boom in Spain that increased the stock of residential buildings by 17%. The number also increased in the following period, 2008-2018, though only by 4.65%[12]. The INS (Spain's National Statistics Institute) reveals that a large proportion of houses in Spain have insulation such as blinds, double windows, etc. However, only 40% of houses in Spain have specific additional insulation such as external or cavity wall insulation and roof insulation. 46% of households in Spain are located in blocks of flats, in buildings with 2 to 5 floors and medium size dwellings (66-120m^2) (IDAE, 2012).

Currently in Spain there are three main planning tools that define priorities in energy policy matters: the Action Plan on Energy Saving and Efficiency 2014-2020 (IDAE, 2011) and the Renewable Energies Plan 2011-2020 (IDAE, 2010) are intended to help the country transition towards a more sustainable energy system where autochthonous renewable energy sources play a bigger role in meeting energy demand and that demand is moderated by energy saving and efficiency policies. The third tool is the National Integrated Energy and Climate Plan 2021-2030 (PNIEC) (MITECO, 2019), which has been designed with the goal of decarbonising the economy by 2050.

More specifically, Spain's building legislation is linked to the Energy Performance of Buildings Directive (EPBD). Spain has implemented a Technical Building Code (CTE) and a Regulation on Thermal Installations in Buildings (RITE) which establishes EE and renewable energy requirements for new buildings and major renovations (Yearwood Travezan et al., 2013).

Half of the buildings now standing in Spain were constructed before 1980, when building codes had no EE requirements (Ramos et al., 2016b). 82% of households with heating have individual heating systems while central heating is found in only 8% (IDAE, 2012). 70% of households with heating have a thermostat or some other temperature regulating device. The most common heating system is that

[12] Calculated according to data from the Ministry of Public Works (Ministerio de Fomento, 2018)

of conventional boilers, which can be found in nearly half of Spanish households. More efficient equipment such as condensing boilers is not yet widespread, though its presence has increased in recent years. Changes in the energy sources used for heating have been detected in recent years, with a decrease in solid fuels and natural gas in favour of renewables, mainly biomass (IDAE, 2017). More specifically, 16% of energy used for heating consumption in 2015 came from renewable energies, and that figure is expected to increase to 20% by 2020 (MITECO, 2019). The EE of heating (in terms of energy demand per square meter) improved in Spain from 2005 to 2016 by an average of 2% per year (ODYSEE-MURE, 2015).

In terms of investment in EE and pro-environmental attitudes, Spanish households in higher income groups and at higher education levels are more likely to invest in EE in general but not to adopt energy-saving habits. Households with older members are less likely to invest in EE and show fewer eco-friendly habits (Ramos et al., 2016b). For instance, 15% of Spanish households do not turn off heating systems at night and 9% do not turn them off when away from home for more than a day. Another point to highlight is that people with lower incomes use less heating and are more likely to turn off heating systems at night and when they are away (INE, 2018).

2.4. Methodology

A literature review on energy research (Sovacool, 2014a) reinforces the idea of incorporating qualitative methodologies to understand how human behaviour affects energy demand. Sovacool, B.K. (Sovacool, 2014b) shows that energy studies combining quantitative and qualitative methods may achieve more social impact because they incorporate technical and social processes and include diverse actors. In this sense, there are several studies which analyse low-carbon transitions combining quantitative and qualitative methodologies. For example, Geels et al. (2016) merge integrated assessment model-based analyses with two qualitative methodologies. This approach generates more comprehensive, more useful assessments, bridging general plans with information about actor strategies and real-world initiatives. Other papers address the problem of integrating different analytical approaches with the aim of developing a more complete analysis of sustainability transitions (Doukas et al., 2018; Turnheim et al., 2015). Some of these papers integrate insights from behavioural economics with other more traditional quantitative approaches and prove to be very useful for effectively responding to the challenging questions related to climate change and energy transitions (Geels et al., 2016). Hirsh and Jones (2014) highlight the importance of the linkages between energy, culture and society for energy transition. Technology innovation depends, for example, on how people use that technology. These approaches which integrate quantitative and qualitative techniques are in line with other studies (Antosiewicz et al., 2019; Nikas et al., 2018). Both use FCM with stakeholders to explore risks of the energy transition, in Poland and Greece respectively.

FCM has been applied in previous studies in the field of energy to bridge the gap between modellers and policy makers. For renewable energy, for example, Falcone et al. (2018) focus on effective policy instruments for a sustainable energy transition in the biofuel industry in Italy using the FCM technique; and Papageorgiou et al. (Papageorgiou et al., 2020) analyse factors influencing the development of photovoltaic solar energy by means of FCM. For environmental policy, Doukas and Nikas (Doukas and Nikas, 2020) provide a critical review of publications assessing climate policies based on participatory processes, including FCM. Other studies focus on EE policies but limit their scope to building behaviour. For example, Mpelogianni et al. (Mpelogianni et al., 2015) show how important information is for monitoring energy savings in buildings while Vergini and Groumpos (Vergini and Groumpos, 2015) apply FCM to analyse the performance of Zero Energy Buildings. Very few studies have employed FCM for assessing EE policies (Nikas et al., 2019; Song et al., 2020). Nikas et al. (Nikas et al., 2019) introduce the ESQAPE FCM tool for assessing a broad EE policy framework in a pilot application in Greece. Finally, Song et al. (2020) analyse the green transition in the construction sector in China. They use the ESQAPE FCM tool to study the relationship between green policies implemented and possible risks identified.

2.4.1. Fuzzy Cognitive Mapping

Qualitative methods such as FG are powerful instruments for understanding attitudes, opinions, expectations and practices (Bader and Rossi, 2002) and can help to identify important concepts which may not be picked up by quantitative techniques (Clifton and Handy, 2003; Sovacool et al., 2018).

In this paper we obtain cognitive maps using an FCM methodology. This is a participatory semi-quantitative method (Jetter and Kok, 2014; Kosko, 1986; Olazabal et al., 2018a; Özesmi and Özesmi, 2004). It comprises concepts that represent key drivers of a system, joined by directional edges or connections that represent causal links between concepts (Kok, 2009). It enables unexpected effects to be identified (Olazabal et al., 2018a). To reflect the strength of those causal links, weights are assigned by participants to the arrows (Jetter and Kok, 2014). The method enables a quantitative analysis to be conducted on the links identified to support decision making (Jetter and Kok, 2014; Olazabal et al., 2018a). Moreover, FCMs enable the views of different participants to be factored in and a belief system to be constructed, in our case for heating behaviour, that can then be used to analyse scenarios (Olazabal et al., 2018a).

There are two main ways in which FCM can be built up (Gray et al., 2015; Langfield-Smith, 1992). One combines information obtained from individual interviews and the other obtains information from a selected group of agents through a series of workshops or FGs. We opted for the FG approach as we were interested in generating a consensual understanding of the topic. The maps are built up jointly by a selected group of agents through FGs. The main advantages of this approach are that it reduces misunderstanding, increases coherency and facilitates knowledge exchange (S. A. Gray et al., 2014; Olazabal et al., 2018b). However, a disadvantage is that participants are focused on reaching consensus, which may limit the number of beliefs, ideas or thoughts which are specific to individuals (S. A. Gray et al., 2014; Olazabal et al., 2018b). The weights were recorded on an individual basis in order to represent individual heterogeneity relative to the importance given to connections between concepts. It was observed during a pilot focus group that disagreements about whether to include concepts were due more often to the weights given to the links (essentially for the first order relations) than to the presence of the concepts in the common map. Those people who tended not to include concepts did so with those that had a weak connection (i.e. small weight). This behaviour is also reported in Olazabal et al. (2018a), where individuals tend to prioritise concepts with strong connections in their individual mental maps. Recording weights a posteriori and individually enables participants to express their own beliefs regarding links and the importance of the concepts. Of course, this also allows some time to adequately draw the visual map with the required program and minimise potential misunderstandings.

Three FGs were organised to try to determine the main factors that explain heating bills in Spain. Each targeted a different population, so as to test for potential differences: one comprised academics (FG-Academics), another ordinary citizens (FG-Citizens) and the third energy experts (FG-Energy-experts).

The FCM model is commonly used for scenario building (Kok, 2009; Kosko, 1986; Özesmi and Özesmi, 2004) when a single integrated map is constructed. Our study captures views from three different groups of stakeholders (academics, citizens and energy experts), so we provide three different maps and make no effort to integrate them into a single one. This paper does not presume that creating different maps is associated with simulation, but rather illustrates the differences between the three groups, paying attention to qualitative differences between different stakeholders. This is done to better understand different motivations and practices in heating consumption in an attempt to shed light on why actual energy savings are usually lower than estimated or expected (Galvin and Sunikka-Blank, 2017, 2016). Further research would be needed to aggregate the three maps into one. Preparing a homogenised map and undertaking simulation exercises lie outside the scope of this paper but will be part of future research.

2.4.2. The data collection process

The data were collected in two phases: a number of focus groups were arranged to draw the mental maps and each participant was subsequently contacted individually in order to weight connections on the digitised map of his/her FG.

The recruitment and composition of the FG were motivated by the goals of (i) assembling knowledge, expertise and perceptions from different social and professional groups; and (ii) having people confront each other in the same FG so as to reach a consensus. We designed three focus group profiles: a group comprising academics, a group of energy-experts and a group of citizens. The members of FG-Academics were selected on the basis of their expertise in the field of environmental science, climate change and possibly energy [13]. FG-Energy-experts was made up of four researchers and three stakeholders specialising in the field of energy[14]. FG-Citizens comprised citizens with different ages, types of residence, numbers of family members and children, locations (urban and rural), levels of income and work statuses (for more details see Appendix 2A)[15]. Note that with the method used in this research participants had to reach a consensus based on their individual opinions. This requires the group of participants to be small so as to reduce misunderstanding and facilitate knowledge exchange (Hobbs et al., 2002; Jetter and Kok, 2014). Moreover, in large FGs there is a risk of creating subgroups with certain talkative individuals dominating the discussion (Malhotra, N. K. and Birks, D. F., 2007). Also note that there is only one group member from a rural location in FG-Citizens: most of Spain's population live in urban areas and the population of rural areas is decreasing at a significant rate (Eurostat, 2018b). All these reasons suggest that although the findings may be consistent with general trends in the Spanish population, caution should be exercised in directly extrapolating the results. Each discussion lasted around 2 hours. The discussions were fully video recorded and transcribed. As usual in analyses of this type, only the participants of FG-Citizens were remunerated for their participation. In the other two groups remuneration was not required. To build up the visual maps we used NodeXL Basic[16].

Data collection during the focus groups involved 4 steps. In the first step participants were asked to list and represent the factors or concepts that influenced their heating bills: "*What are the basic heating facts, elements or components that influence the amount of your heating bill? (for example,*

[13] Conducted on December 20, 2017 in the city of Bilbao (Spain) with ten participants from the Basque Centre for Climate Change (BC3).
[14] Conducted on January 31, 2018 at the conference of the Spanish Association for Energy Economics (AEEE) in Zaragoza (Spain) with seven participants.
[15] Conducted on January 23, 2018 in the city of Bilbao (Spain) with eight participants recruited by the Spanish company CPS.
[16] NodeXL Basic is a free, open-source template for Microsoft Excel. It is freeware downloadable from https://archive.codeplex.com/?p=nodexl (Last accessed July 11, 2018).

energy price or orientation of the building)". In step 2, participants set out individual actions (measures) which could reduce their heating consumption: *"What individual measures could help to reduce your heating bill? (i.e. things or individual actions that can really change your heating consumption, such as lifestyle changes or investment in insulation)"*. In step 3, the participants listed policy measures that the government could implement to bring down heating bills: "*What policies could politicians implement to bring down heating bills?"* These concepts (also known as nodes) are divided into three categories –factors, individual actions and policy measures – and make up the elements or entities of the system analysed. In step 4 participants established connections between all the concepts: positive connections indicating that one concept increases (or decreases) in the same direction as others were represented in blue; negative connections indicating opposite directions (i.e. when one increases the other decreases and vice versa) were represented in red.

In the second phase, participants assigned weights of between 0 and 1 to indicate the strength of the connections between two concepts on the maps. Weights close to 0 represent weak connections and those close to 1 represent stronger connections. For technical reasons, participants were contacted individually one week after the FG session to assign the weights[17]. Collecting the weights assigned by individuals enabled us to account for heterogeneity between individuals. An ex-post statistical treatment of these weights (average, standard deviation) helped to assign the trend of each link (average) and indicate how consensual it was (standard deviation).

The discussion in the FG-Energy-experts was conducted according to the same steps indicated above for FG-Academics and FG-Citizens, but with some differences. The main difference was that in FG-Energy-experts connections were not centralised via the concept of "heating bill". The main reason for this was to create a map with more connections between the different factors mentioned by the participants so as to get more variability in the network.

2.5. Results and discussion

The final maps obtained from each focus group are presented in Figures 9, 10 and 11. The concepts in the maps are broken down into three concept categories in line with the questions answered: factors, individual actions and policies. These are then colour coded into 5 topics: economics, infrastructure, technology, socio-cultural habits and environment. The weights assigned to each interaction in the

[17] It was not feasible to digitise the maps during the focus groups so that each participant could have a map in hand to assign weights. Each of them was subsequently contacted by phone to participate. Participants received the digital map of their FG by email with instructions. In 3 out of the 8 cases for FG-citizens the analysist met the participants to help them complete the process. We received 21 maps with weights out of the 25 participants.

final maps were obtained by calculating the average of the weights given individually by all members taking part in each FG.

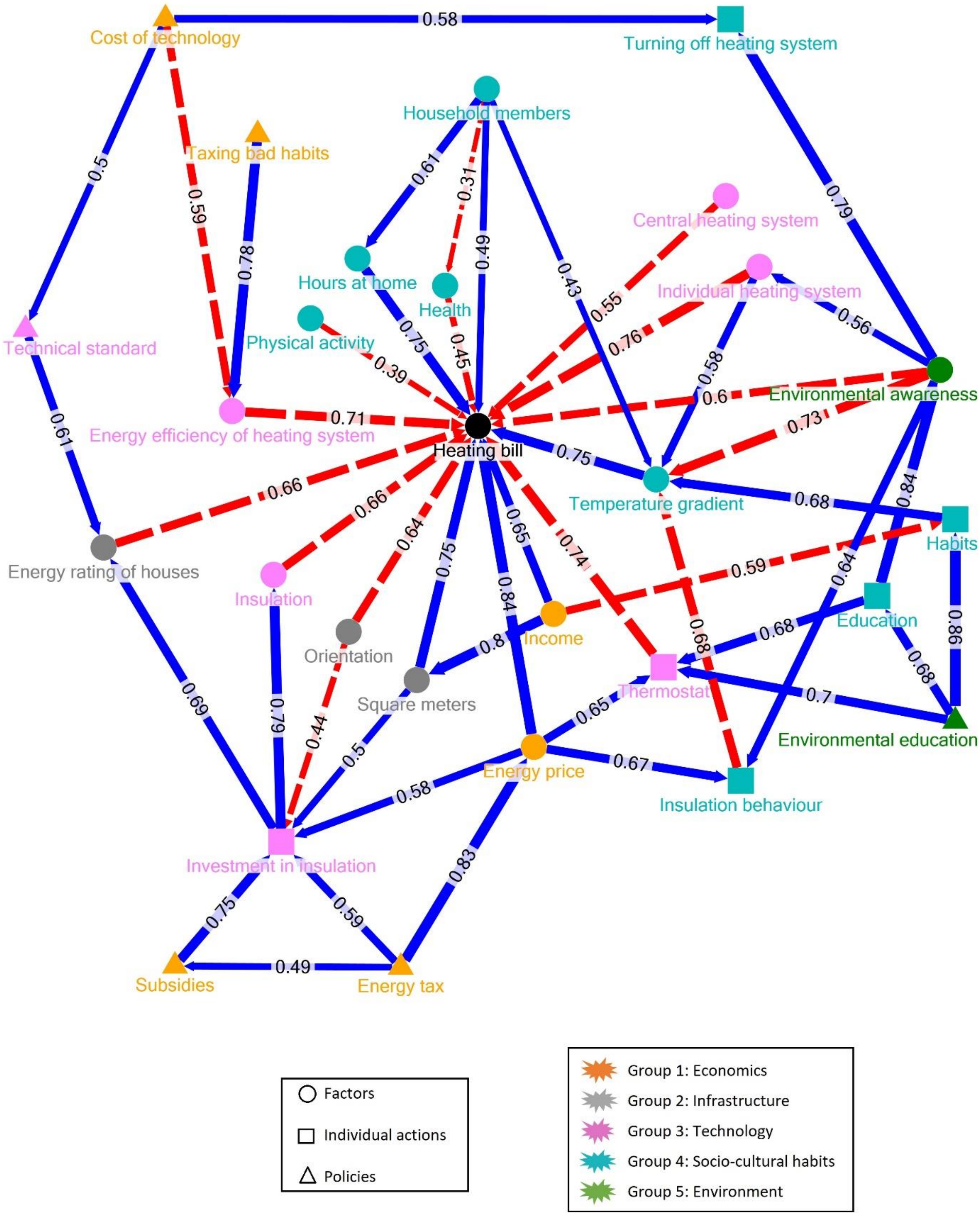

Figure 9. Graphic showing weights assigned by FG-Academics. Blue lines represent positive connections and red dotted lines negative connections between concepts

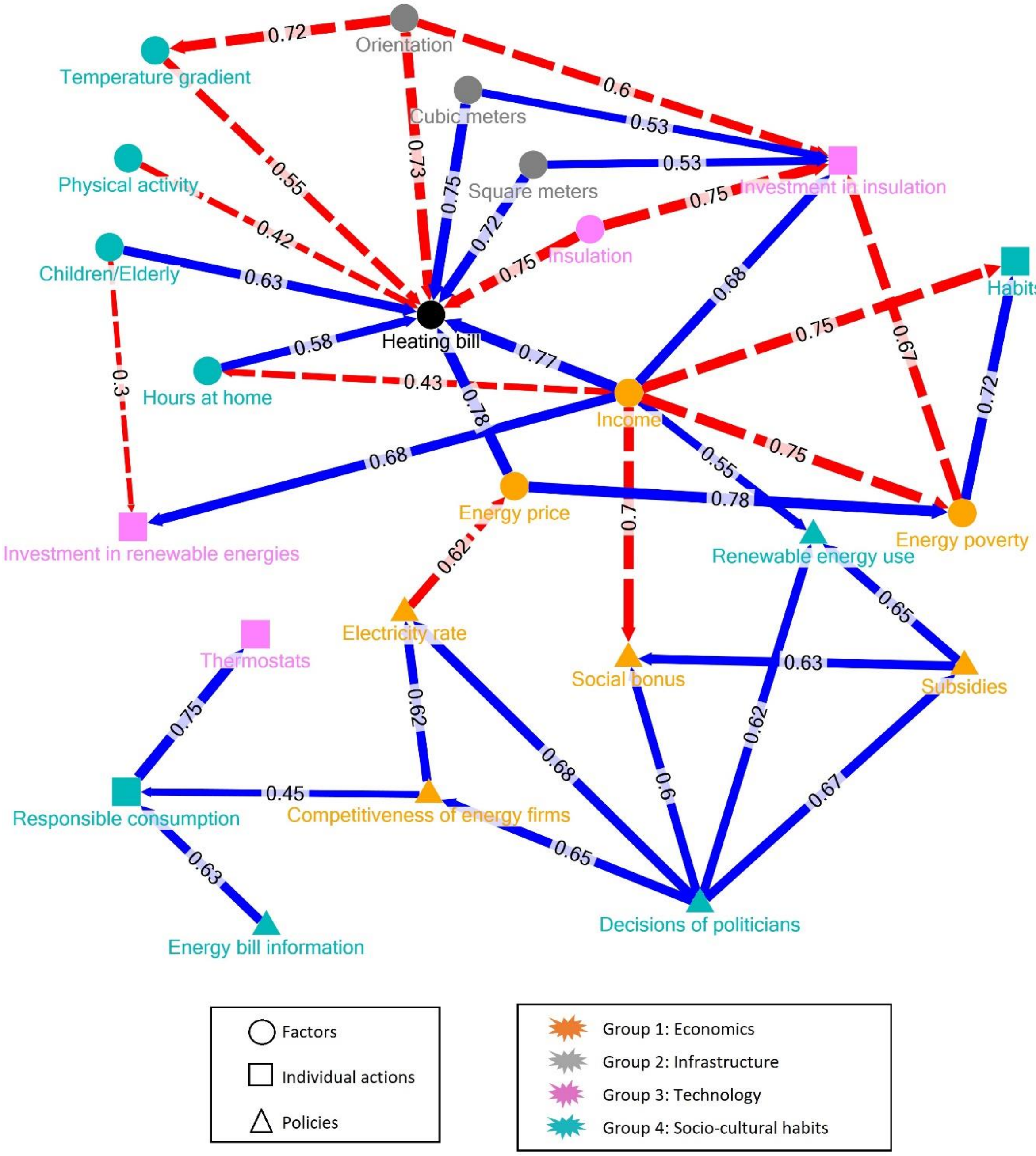

Figure 10. Graphic showing weights assigned by FG-Citizens. Blue lines represent positive connections and red dotted lines negative connections between concepts

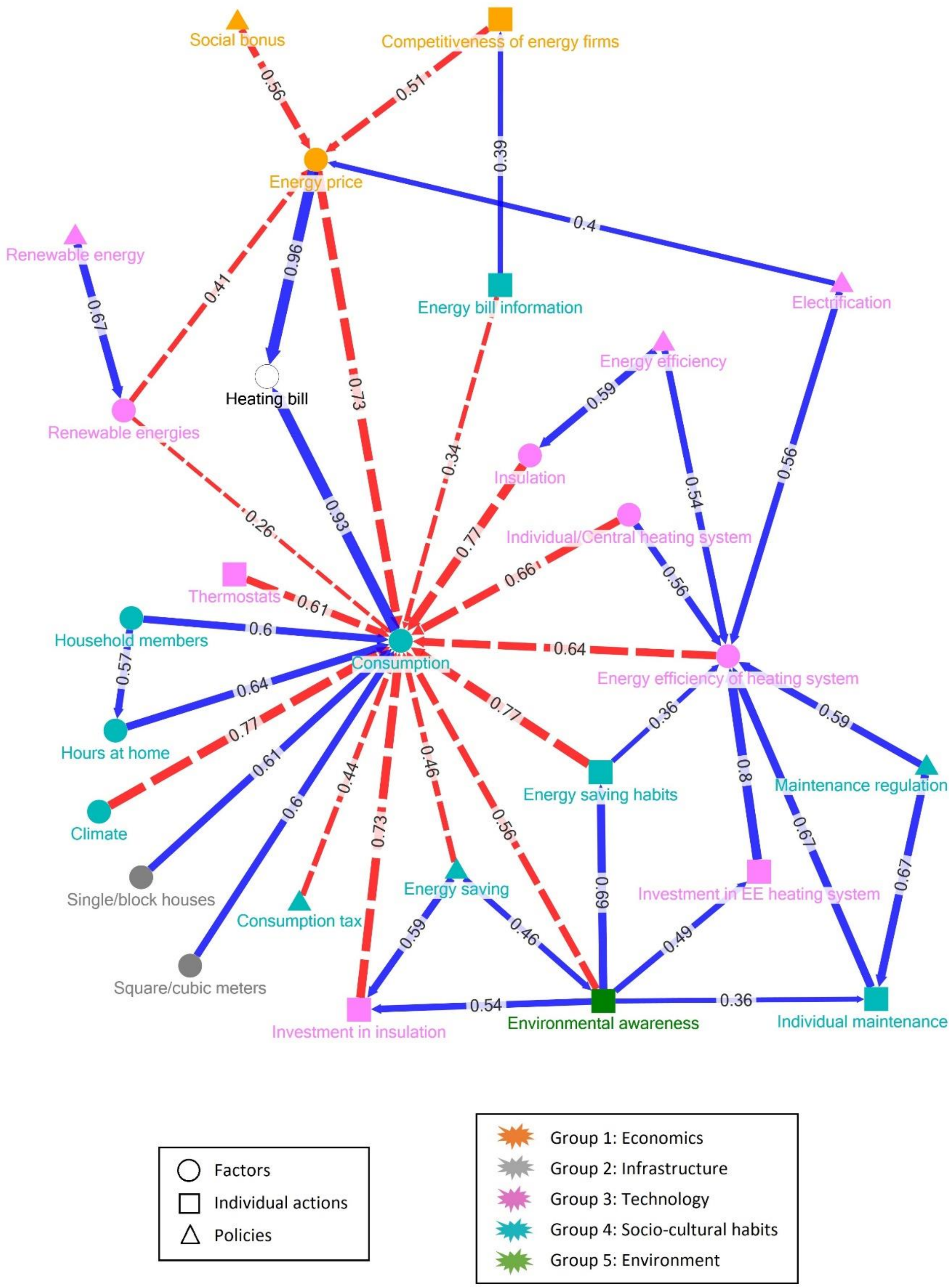

Figure 11. Graphic showing weights assigned by FG-Energy-experts. Blue lines represent positive connections and red dotted lines negative connections between concepts

Factors such as household incomes and energy prices are included under the topic of economics. They are positively connected with heating bills, which means that as incomes or prices rise energy bills will increase, with all other connections remaining unchanged (i.e. *ceteris paribus*). In the building infrastructure category, insulation and orientation both show negative connections with heating bills, i.e. the more insulation buildings have, the smaller their bills are, and the more south-facing (oriented towards the sun) they are, the lower their bills are. Size in square meters and cubic meters shows a positive connection with heating bills, which means that, *ceteris paribus*, houses with more rooms pay more for heating. Variables related to lifestyle, such as the temperature gradient (i.e. the difference between indoor and outdoor temperatures) and physical activity at home have, *ceteris paribus*, a negative connection with heating bills. Other factors, such as the number of household members and children have, *ceteris paribus*, a positive connection with heating bills. Technological issues include the efficiency level of heating systems, building EE ratings and the level of temperature control, which is greater for individual heating systems than for central heating systems. All these variables were identified as having negative connections with heating bills.

Participants were asked what individual actions could reduce energy consumption on heating. They all mentioned investment in insulation and also considered that good practices in thermal insulation (e.g. use of blinds, opening windows to air rooms, etc.) were also important for reducing energy consumption. Another individual action considered by FG-Academics and FG-Energy-experts was environmental awareness, with information being shown on the impact of individual heating consumption on emissions of CO_2 and other pollutants in order to improve knowledge and perception of environmental problems and climate change. Participants thought that this would help to promote sustainable energy practices by families and neighbours. Following the connections on the maps, this behavioural aspect of environmental awareness is linked to environmental education policies (see Fig.1). The use of thermostats was indicated by all FG. The participants also considered that habits at home could influence energy consumption on heating. For example, they argued that heating consumption on cold days could be reduced by wearing warmer clothes while at home. Another strategy mentioned was not to turn on the heating system when one is not planning to stay at home for long (the "*Hours at home"* concept).

Public policy instruments for achieving more sustainable heating behaviours were also analysed. In this part of the FG we found significant differences between the three groups. On the one hand, FG-Academics and FG-Energy-experts believed that subsidies and energy taxes could be effective in increasing investment in insulation, and that education on energy saving and the environment was needed in order to change habits at home. On the other hand, FG-Citizens attributed more importance to the role of energy policies focused on subsidies for people suffering financial hardships and for the installation of renewable energy systems and policies to help people understand energy bills. A further analysis of what policy instruments might be most effective is given below.

For instance, it can be observed that taxing bad habits and/or fossil fuels for heating encourages the use of *energy-efficient heating systems* and consequently leads to a reduction in *energy consumption*. Moreover, such taxes encourage households to increase *investment in insulation*, thus improving the conditions of buildings and consequently reducing *energy bills*. Energy tax revenues can also be used to provide *subsidies* or rebate schemes, for instance for the use of *renewable energy* or for other policies such as the *social bonus*. Environmental education policies could shift the *habits of consumers* towards energy saving and thus bring about a reduction in *energy bills*. Following the connections on the maps, this policy feeds into the behavioural aspect of environmental awareness and habits of consumers. Other interesting ideas include the role of energy companies. Some citizens thought that greater competition between energy firms could lead to a reduction in final energy prices. Competitiveness was considered as a policy by citizens because they introduced energy market regulation and how it influences decisions into the discussion. It is important to highlight although the energy market in Spain is being deregulated the regulator still plays a major role. Additionally, there seems to be some potential in policies for helping people understand energy bills, which could lead to more responsible consumption *habits*.

It is important to consider certain differences between the three FGs (see Table 4). Environmental issues were only mentioned in the FG-Academics and FG-Energy-experts. Note also that the participants in FG-Energy-experts discussed the blend of technologies for electricity generation from a mix of renewable energy resources to meet heating energy needs. Another difference is that only the FG-Citizens included in their map the issue of people who found it hard to pay their energy bills. The policies mentioned by the participants in the FG-Academics and FG-Energy-experts differed from those in the FG-Citizens in that they took a particularly positive view of taxation. That is, they considered that taxes on bad habits (e.g. setting very high temperatures, thermostats running all day even when the house is empty and low EE) could be very effective, while citizens made no mention of this. This is consistent with economic literature, which shows that the general public tend to express substantially greater support for subsidies than for taxes (Heres et al., 2017). This is partly attributable to the fact that people do not support taxes because they are worried that they will not see the benefits of the revenues (Cherry et al., 2012; Heres et al., 2017). Indeed, other studies show that public acceptance of taxes is greater if the use of revenues is clearly specified beforehand (Carattini et al., 2018). In addition, Kallbekken and Sælen (2011) suggest that to make taxation more acceptable to the public it is important to ensure that people understand and believe that taxes will have positive environmental consequences.

Table 4. Concepts mentioned in the three FG organised according to thematic issues

	Thematic issues							
							Policies	
	Economics	Infrastructure	Socio-cultural habits	Technology	Environment	Energy poverty	Subsidies	Taxes
FG-Academics	✓	✓	✓	✓	✓		✓	✓
FG-Citizens	✓	✓	✓	✓		✓	✓	
FG-Energy-experts	✓	✓	✓	✓	✓		✓	✓

An interesting point to consider is how participants assign weights to connections. The information is provided in a numerical format that can only be interpreted relative to other numbers (Kok, 2009).

By focusing on the strongest and weakest connections given by participants, it is possible to show some differences between the FGs. For example, for individual actions mentioned by participants in FG-Academics the highest score was 0.84, connecting *education* and *environmental awareness*. In policies, one of the strongest connections was that between *taxing bad habits* and *energy efficiency heating systems,* with a score 0.78. The lowest score was 0.49, for the connection between *energy tax* and *subsidies*. This is evidence that academics attribute more importance to policies related to taxing bad habits. In FG-Citizens there is a strong connection between thinking in terms of *subsidies* and *decisions of politicians* (0.67) or *subsidies* and *renewable energy use* (0.65). Additionally, a policy to *understand energy bills* is strongly connected to *responsible consumption* (0.63). In FG-Energy-experts there is a strong connection between *environmental awareness* and *energy saving habits* in individual actions (0.69). Other policy connections with high scores are *maintenance regulation of the heating system* with *individual maintenance* (0.67) and *renewable energy policies* with *the use of renewable energies for heating systems* (0.67). It is noteworthy that policies are assigned similar levels of importance by academics, citizens and energy experts, though academics consider that individual actions such as changing habits by programming thermostats or investing in insulation may play a more important role than policies. For the energy experts, individual measures and policies play similar roles in achieving more sustainable heating behaviour.

We calculate the average of the weights given by all participants (see Figure 12). Participants express stronger connections more often than they do weaker ones. In FG-Academics, 84% of connections are weighted at more than 0.5. For FG-Citizens and FG-Energy-experts the figures are 78% and 70% respectively. Energy experts are more parsimonious than academics and citizens in rating how far a concept could influence bills, especially for those policy concepts that can reduce energy consumption directly. Energy experts and academics also tend to give slightly more importance to *individual actions* than to *policies* for reducing bills. On average they assign greater weights to *individual actions* than citizens, who prefer to rely on national *policies* that help them directly to reduce their energy bills. The standard deviation of the weights represented in Figure 12 illustrates the heterogeneity of participants regarding the importance given to connections. Although participants form a consensus when drawing up the map, their opinion regarding the influence (weight) of the concepts on the map varies.

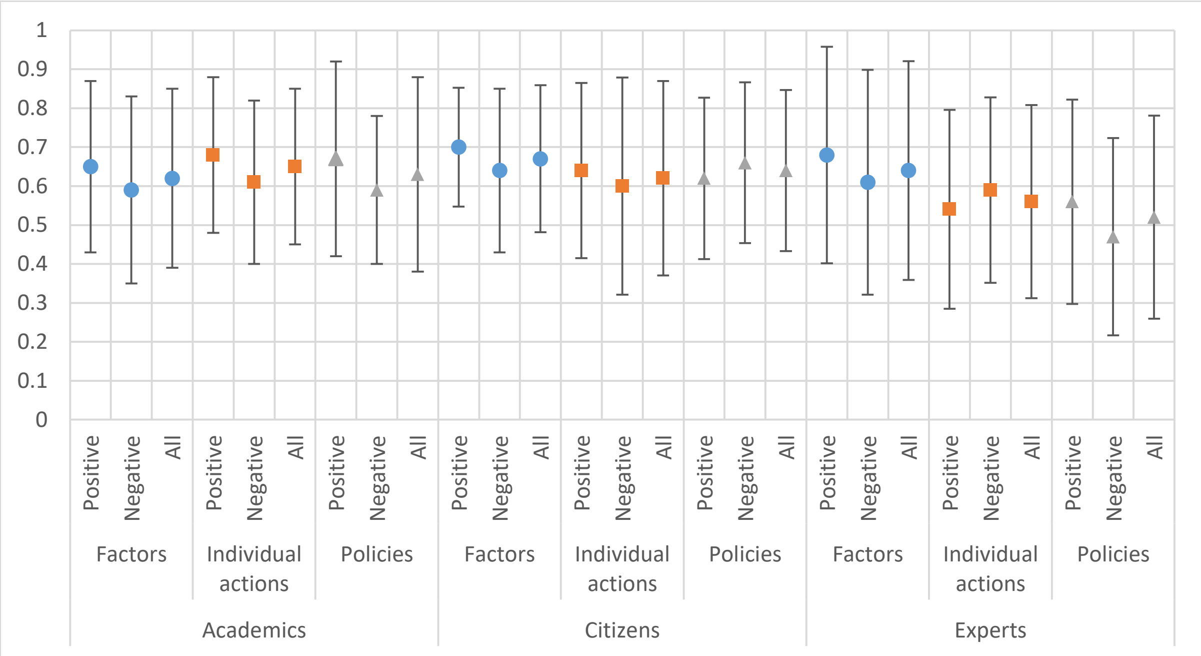

Figure 12. Mean of connections with standard deviation

The complexity of the maps, reflected here in the number of concepts and connections, can vary with occupational background (Olazabal et al., 2018a). Our study seems to confirm this (Table 5). Academics and energy experts provide more concepts and connections than citizens. Citizens' maps are denser[18]: they see a great many causal relationships between concepts. Participants are observed to tend to provide more positive than negative connections. Indeed, 64% of connections in all FGs are positive. An analysis of how concepts relate to each other (Appendix 2B) reveals that the top 5 core concepts in the network on the FG-Academics map are investment in insulation, temperature gradient and thermostat, energy price and environmental awareness. For citizens, the core concepts are income and energy poverty, investment in insulation, decisions of politicians and energy price. And for energy experts the top 5 are consumption, energy efficiency of heating system, energy price, investment in insulation and environmental awareness. The core concepts of the maps therefore deal with consumer behaviour regarding investment in EE technologies (insulation, thermostat) and attitudes or preferences (regarding the environment or the thermal comfort temperature), economic factors such as price and income and regulatory interventions. Appendix 2C provides information on the importance of other concepts for each FG.

[18] "Density" is defined in Appendix 2B.

Table 5. Figures for number of concepts, connections and density index

	Number of concepts	Number of connections	Density (D)
FG-Academics	30	50	0.056
FG-Citizens	25	38	0.061
FG-Energy-experts	28	41	0.052

The description of multiple-order connections allows us to illustrate and show relationships that are less obvious, as shown by Olazabal et al. (2018a). In other words, the large number of connections between concepts mean that it is often difficult to fully identify higher-order connections at first glance. Analyses of these interdependencies are very useful in revealing direct and indirect effects between concepts and highlighting connections with not so evident effects. For example, the Academics believe that policies based on *environmental awareness* would require improvements in *education* (positive connection), which would result in an increase in the use of *thermostats* (positive connection), thus leading to a reduction in *heating bills* (negative connection). Energy experts believe that an increase in *energy saving policies* would lead to an increase in *environmental awareness*. This would generate an improvement in *habits* in terms of energy consumption and thus lead to a reduction in *heating consumption*. Energy experts also believe that an increase in *energy efficiency of heating systems* could lead to a reduction in *energy consumption* if it is accompanied by *energy savings habits*. In this sense, energy experts mention the so-called rebound effect (Galarraga et al., 2013; Jaffe and Stavins, 1994b; Kounetas and Tsekouras, 2008; Linares and Labandeira, 2010; Sunikka-Blank and Galvin, 2012). This effect refers to when an improvement in EE fails to reduce energy demand because greater EE leads to increases in energy consumption as a result of lower energy costs. Citizens believe that *income*, *energy poverty* and *political decisions* not only directly influence heating bills but may also have indirect impacts on the rest of the concepts that they mention, plus impacts on other policies (social bonus, subsidies, renewable energy use) and on lifestyle (habits and temperature gradient).

2.6. Conclusions

Understanding the behaviour of consumers is very important in designing a policy that can facilitate the transition towards low-carbon heating systems. In this paper we seek to enhance understanding of consumer behaviour by considering different views from academics, citizens and energy experts. We capture knowledge and experiences with an FCM technique to better draw causal connections between factors and highlight differences between the three groups. A simulation exercise of policy interventions to promote low carbon behaviours lies outside the scope of this paper.

All three groups consider that not just economic variables such as energy price and income but also technological variables such as insulation or thermostat are determinants of heating bills. Other factors mentioned include socio-cultural factors, habits and preferences regarding the thermal comfort temperature by day and by night. Environmental awareness is another major concept which explains heating related attitudes and behaviours. Regulatory interventions are a further factor of intervention to be considered regarding the energy market price, energy poverty and environmentally responsible consumption.

A notable difference between groups in terms of the policy instruments that occupy a core location on the maps is that academics seem to support environmental education policies directly, e.g. the showing of information on the impact of individual heating consumption on emissions of CO_2 and other pollutants and its effect on the environment. FG-Energy-experts point rather to energy saving policy. This policy is connected to individual actions by consumers such as investment in insulation but also to environmental awareness. Citizens expect regulatory interventions by politicians to influence low carbon behaviours.

The most significant differences between the groups arise in regard to the use of taxes and the importance assigned to energy poverty. Academics and energy experts consider that taxes could be used to reduce energy consumption through policies such as taxing bad habits in energy consumption or taxes on fossil fuels. Citizens do not mention taxes at all but focus on the role of subsidies in helping alleviate energy poverty, in line with different quantitative and qualitative studies mentioned above. Moreover, citizens mention the situation of those who find it hard to pay their energy bills, i.e. the issue of energy poverty. They also express a strong preference for policies that could help them to understand energy bills better. All these differences can be noted to help tailor policies and make progress in regard to the acceptability of policies to promote low carbon behaviours in the residential buildings sector.

Perspectives for further research could include using a larger group of citizens or experts to assess the effect of attitudes and preferences of heating consumption and better account for individual heterogeneity, both at the time of building the map and when recording the weights between concepts. Extension to other expert groups such as architects and building material or heating technicians could contribute to the co-design of low carbon heating behaviours for both individuals and buildings.

Chapter 3: Energy-efficiency policies for decarbonising residential heating in Spain: a fuzzy cognitive mapping approach [19]

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3.1. Introduction

Providing heating for homes, industry and other applications accounted for around half of global final energy consumption in 2021 (IEA, 2021), and that consumption accounted for 40% of energy-related greenhouse gas emissions (GHG) (IRENA et al., 2020). Heating in residential buildings accounted for 64% of the European Union's (EU) final energy consumption in 2019 (Eurostat, 2021). Given the EU's commitment to cut its GHG emissions by at least 50% and towards 55% by 2030 (compared to 1990 levels) and to achieve net-zero GHG emissions by 2050 (EC, 2019), the decarbonisation of residential heating plays an important role in fulfilling EU climate and energy goals (Nijs et al., 2021). To address that decarbonisation, the residential sector would have to undergo the greatest reduction in energy demand for heating and cooling, ranging between 19% and 23% by 2030 (compared to 2015) (EC, 2020a). To reach this target, the EU has emphasised the following main areas: energy efficiency (building renovation, efficiency of heating and cooling supply), the phase-out of fossil fuel-based boilers and increasing the share of renewable energy heating systems (Braungardt et al., 2021). These actions require target-oriented policies (Nijs et al., 2021) and other national policies to address challenges and barriers specific to each Member State (Toleikyte and Carlsson, 2021).

Decarbonising heating is a complex challenge with many interdependent factors (e.g. technological, behavioural, economic, socio-cultural, institutional) (Csutora et al., 2021; Knobloch et al., 2019; Narula et al., 2020) and one that involves many stakeholders (consumers, builders, firms, policy-makers) (Gago et al., 2012). To meet this challenge, the preferences of all the stakeholders involved need to be factored into the analysis so that better policies can be designed (Falcone et al., 2021; Lange and Cummins, 2021) and the effectiveness of those policies can be maximised. Common knowledge from stakeholder participation can bring all stakeholders involved to a more conscious behaviour so as to better support and accept policy levels for energy transition (Falcone, 2018; Falcone et al., 2021; Itten et al., 2021). Additionally, the literature on governance suggests that participation by different stakeholders in the decision-making process can be an effective tool for resource management (Lange and Cummins, 2021) because it can harness the power of diverse perspectives, build coalitions and promote cooperation rather than competition (Sovacool and Martiskainen, 2020; Sovacool and Van de Graaf, 2018). In this regard, the heating transition must take place from a governance point of view, involving multiple stakeholders none of whom have decisive power (Smith et al., 2005). The importance of local stakeholders in achieving energy transitions was noted in the 2015 Paris Agreement (Falcone et al., 2021; Galende-Sánchez and Sorman, 2021; UNFCC, 2015). Indeed, the empowerment and engagement of citizens are seen as strategic to meeting the EU's energy targets in the clean energy transition (EC, 2019; Wahlund and Palm, 2022).

The literature on participatory approaches recognises the need to identify the roles and perspectives of local stakeholders. For example, Mendonça et al. (2009) and Sperling et al. (2011) demonstrate that local stakeholder participation is an effective tool in supporting structural, cultural and practical changes in energy planning in Denmark (Falcone et al., 2021). A case study on the implementation of a renewable energy project in Switzerland shows that the personal values of local stakeholders and their interests must be represented during the decision-making process (Díaz et al., 2017). Lange and Cummins (2021) find that civil society is missing from the negotiation process for a renewable energy project in Ireland, and that added cost could have been avoided if community stakeholders had been more engaged in the planning process from an early stage and if place-based understanding had been considered more strongly. In this sense, (Itten et al., 2021) show that sustainable heating projects need to be supported by clear political commitment, as it may otherwise be difficult for individual members of the community to step up to leadership roles. Local stakeholders are thus key actors in transforming perceptions into tangible experiences on energy transition, fostering social acceptability and motivating technological choices (Falcone et al., 2021; Sisto et al., 2018).

However, the understanding and consideration of stakeholders' perceptions about the decarbonisation of residential heating is still quite limited. Approaches that examine household decision-making processes concerned with residential heating show the importance of behavioural aspects, given the heterogeneity of household characteristics and perceptions (Kastner and Stern, 2015; Levesque et al., 2019; Wolff et al., 2017). These factors, uncertainties and behaviours explain some of the barriers to energy-efficiency improvements. For instance, a look at the main barriers to heating replacement (cognitive limitations, the principal agent problem, financing costs and other investment priorities and lack of capital) reveals that it is unlikely that all households will choose the same cost-optimal solution (Knobloch et al., 2021). These barriers (Gerarden et al., 2017; Gillingham and Palmer, 2014a; Jaffe and Stavins, 1994b; Linares and Labandeira, 2010; Ramos et al., 2015) and particularities must be taken into account if a proper understanding is to be obtained. In that context, considering that different stakeholders may have different scopes and perceptions may help to address these particularities and the major barriers. To further the low-carbon residential heating transition, a participatory process needs to be established that enables stakeholders to (i) define the main drivers for and barriers to heat decarbonisation; (ii) assess measures which could decarbonise heating consumption; (iii) propose policies; and (iv) assess impacts through scenario simulation.

Contributions in this field have concentrated mainly on including representations of household behaviour and preferences (Knobloch et al., 2021; Sovacool and Martiskainen, 2020). However, to our knowledge there are no broad-based studies that seek to learn how households perceive the different policy instruments that may be used to promote sustainable heating.

This paper sets out to fill that gap by employing a policy fuzzy inference simulation that incorporates the preferences of all stakeholders involved. Such a methodological approach can help to understand the complexity and interactivity of the current heating system and identify the most influential policies with a view to steering the decarbonisation of residential heating.

In this regard, our research shows the importance of broadening the debate on heating transition by incorporating the perceptions of expert stakeholders such as academics and energy experts. Academics and universities can contribute new designs, criteria, approaches and concepts (Fischer and Newig, 2016; Goess et al., 2015; Shahvi et al., 2021). Energy experts are also considered key actors because they bring competitive products and services to the market (Sorman et al., 2020). Based on the literature, the perceptions of energy experts can be used as sensors, to locate synergies and potential bottlenecks around the energy transition, such as institutional and regulatory systems or infrastructures unsuitable for change (Foxon et al., 2010; Smith et al., 2005).

For this purpose, we use the so-called Fuzzy Cognitive Mapping (FCM) method for policy simulation. It is built upon a paper already published (López-Bernabé et al., 2020). By applying the FCM method, we seek to understand the different perceptions of stakeholders about energy efficiency policy instruments and provide some insights for effective policy design. FCM is a participatory, semi-quantitative technique in which a weighted causal network of a situation or system is produced by an interviewee or selected group of agents (Groumpos, 2010; Jetter and Kok, 2014; Kosko, 1986). That is, it enables a map of complex concepts to be drawn up based on the perceptions that the participants may have on certain issues, topics and relationships, thus bringing to light interesting findings with respect to the expected behaviour of participants. López-Bernabé et al. (2020) show that the determinants of heating bills include not just economic variables such as energy price and income but also technological energy-efficiency variables such as investment in insulation or the use of thermostats or other temperature regulating devices. They also find differences between the views of the three groups, and show that the policies mentioned by academics and energy experts differ from those mentioned by households. For example, academics and energy experts consider that taxes could be used to reduce energy consumption through policies such as taxing bad habits in energy consumption or taxes on fossil fuels. Households do not mention taxes at all but focus on the role of subsidies in helping alleviate energy poverty. Another difference is that academics and energy experts seem to support environmental education policies directly while households say very little about them. In the light of this, we set out here to answer the question of what policy instruments might be most effective in bringing about a low-carbon transition in the household heating sector.

Our survey was carried out in Spain, as we deem it an interesting case from which many insights can be extrapolated to other European countries. Demand for heating is lower in Spain than in many other parts of Europe due to a warmer climate. Just 42% of the energy demand from residential buildings in 2019 came from heating (IDAE, 2021a), but the country still provides a very interesting case study for the deployment of low-carbon residential heating strategies. The main reasons are that, unlike the EU average, where natural gas is the most widely used fuel for residential heating, Spain uses several different energy sources. In 2019, 40% of the energy used for residential heating came from biomass and around 1% from other renewables (mainly solar thermal and, to a lesser extent, geothermal). Oil and petroleum products accounted for 28%, natural gas for 23%, electricity for 7% and other fossil fuels for 0.9% (IDAE, 2021a). As a case study, Spain provides insights for countries with similar heating consumption patterns (e.g. Greece, which uses several different fuels, mainly natural gas (16%), oil and petroleum products (46%) and biomass (31%)). These data show that if biomass is discounted then renewables are one of the smallest supply sources for residential heating in Spain. Thus, Spain can provide insights for countries in eastern and southern Europe with no plan to ban any type of fossil fuel heating systems but with ambitious national measures for the decarbonisation of residential buildings (Nijs et al., 2021).

Our study also provides many useful recommendations for Spanish policy-makers. The national policies and measures towards decarbonisation of buildings presented in the National Energy and Climate Plan (Toleikyte and Carlsson, 2021) indicate that there is no specific plan to phase out fossil fuel heating systems in Spain and there are no forecasts for the share of renewable technologies in heating and cooling. Nonetheless, the country plans to promote ambitious building renovation targets to 2030 with thermal envelope systems and renovation of thermal heating and air conditioning systems. The insights provided by the paper on stakeholders' perceptions will be essential for deploying these actions efficiently and effectively.

The paper is structured as follows. Section 3.2 reviews literature associated with the policy instrument options available for decarbonising heating. Section 3.3 describes the research methodology. Section 3.4 presents and discusses the results. Section 3.5 concludes.

3.2. Policy interventions for decarbonising heating

Political attention and support for heating decarbonisation seems limited despite the large proportion of final energy consumption in the EU accounted for by heating. In 2016, the European Commission proposed an EU heating and cooling strategy to explore the main issues and challenges and integrate efficient heating and cooling into EU energy policies (EC, 2016). More recently, the decarbonisation of heating in buildings has been addressed across key EU legislation including (i) the Energy Performance of Buildings Directive (EPBD) (Directive 2018/844/EU); (ii) the Renewable Energy Directive (Directive 2018/2001/EU); the Energy Efficiency Directive (Directive 2012/27/EU); and the Ecodesign Regulation (813/2013/EU) implementing the Ecodesign Directive (2009/125/EC). The EPBD is currently under revision (EC, 2021c) with the aim of introducing provisions to support the objectives of the Renovation Wave Strategy (EC, 2020b). The aim is to increase actions and investments with the target of at least doubling the annual energy renovation rate of buildings by 2030 and to foster deep retrofits. It was (and still is) considered as an opportunity to lead a green economic recovery from the crisis sparked by the coronavirus pandemic, supporting Small and Medium Enterprises (SMEs) and local jobs (BPIE, 2020). The revision of the Renewable Energy and Energy Efficiency Directives (EC, 2021d, 2021e) seeks to set quantitative requirements for minimum levels of energy from renewable sources in buildings and support the phase-out of fossil-fuel boilers in regional and local planning. The EU also highlights the application and further development of ecodesign and energy labelling measures to support the phase-out of fossil fuels for heating in buildings through strengthened requirements for heating system efficiency across all technologies (Braungardt et al., 2021). Additionally, the EU has just proposed including buildings in the EU Emission Trading System (EU ETS) to accelerate decarbonisation. However, that does not mean that targets will be easier to achieve, since many non-monetary and behavioural barriers remain.

Residential heating in Spain has received limited attention from policy-makers. Specifically, Spain has implemented two specific pieces of legislation: (i) a Technical Building Code (CTE), which sets energy-efficiency and renewable energy requirements; and (ii) a Regulation on Thermal Installations in Buildings (RITE), which regulates the energy efficiency of new and existing heating, ventilation and air conditioning (HVAC) systems and water heaters (Collado and Díaz, 2017; Yearwood Travezan et al., 2013). Spain has recently presented its revised national energy and climate plan (NECP, 2020) to help meet EU-wide targets. Additionally, under the EPBD Spain updated its Long Term Strategy for Energy Renovation in the Building Sector in 2020 (ERESEE, 2020). As part of the renovation wave initiative, substantial reductions in energy consumption on heating are expected to result from improved building insulation and renovation of thermal heating systems in 30,000 houses per year on average. However, when it comes to phasing out fossil-fuel heating systems, Spain has no nationwide plan to ban all fossil-fuel boilers. Similar trends can be found in other eastern and southern European countries. Focusing on the targets for increasing the use of renewable sources, the plan is for the share of renewables to increase from 18% in 2020 to 31% in 2030, with biomass as the dominant technology, followed by heat pumps (NECP, 2020). This plan forecasts that the contribution of heat pumps is expected to increase from 629 to 3,523ktoe from 2021 to 2030. However, no forecasts for other renewable technologies are provided.

In that context, the shift towards a decarbonised heating supply calls for energy-efficiency policy instruments (Lowes et al., 2020; Lowes and Woodman, 2020). There is a substantial body of research that analyses the impact of different types of energy-efficiency policy instruments (for a review, see Labandeira et al., 2020). That literature reveals that a policy package can be more effective, efficient and more popular than individual policies (Givoni et al., 2013; Howlett and del Rio, 2015; Kern et al., 2017; Rogge and Reichardt, 2016). Givoni et al. (2013) define a policy package as "a combination of policy measures designed to address one or more policy objectives, created in order to improve the effectiveness of the individual policy measures, and implemented while minimizing possible unintended effects, and/or facilitating interventions' legitimacy and feasibility in order to increase efficiency". Indeed, several studies have argued for the need to combine different policy instruments and proposed policy packages or so–called policy mixes. For example, Bennear and Stavins (2007) focus on the combination of a wide range of policy instruments to regulate energy efficiency in the USA. Fesenfeld (2020) shows that policy packaging can increase support for climate policies. Lehmann (2012) provides a review of economic studies analysing the use of multiple policies to overcome single pollution problems. Focusing on the design of energy-efficiency policies in buildings, Gago et al. (2012) propose a policy package for dealing with the main obstacles to the adoption of energy-efficiency measures in buildings. Knobloch et al. (2019) find that policy mixes are more effective than single policy instruments. Specifically, they show that the combination of a carbon tax with subsidies and procurement policies for renewables is more effective in encouraging a switch to low-carbon technologies. On that basis, our paper contributes to the literature on energy-efficiency policy instrument assessment as well as to the design of policy packages for fostering energy efficiency in heating, which can certainly support effective, efficient policy-making. To that end, the paper proposes a participatory method for the design of policy interventions for the heating transition which factors in the perceptions of different stakeholders.

Policy targets which are technically feasible and socially desirable need to factor in heterogeneity in household behaviour and preferences (e.g. differences in consumer and investment behaviour) (Knobloch et al., 2021). Moreover, the particular characteristics and the barriers to energy-efficiency improvements highlighted in the Introduction suggest that there is a need for intervention from public authorities to design effective energy-efficiency policies. The many factors that policy makers need to consider when undertaking that task include the views of consumers and their potential reactions to policies. By factoring in the perceptions of different stakeholders, this paper seeks to enhance understanding of what works in terms of decarbonisation policies.

3.3. Methodology

3.3.1. Fuzzy Cognitive Mapping

The FCM model is used in a similar way to that in Falcone et al. (2019) and Falcone and De Rosa (2020). FCM is a participatory modelling approach employed to determine the behavioural complexity of a system through causal reasoning (Falcone and De Rosa, 2020). FCM also enables stakeholders to show their perceptions and expectations, and policy-makers to advance their understanding of priorities in a transparent manner (Papageorgiou et al., 2009; Sisto et al., 2018). In this sense, scientific literature recognizes that FCM makes for greater public acceptance and effectiveness of policy interventions, because the approach is based on full and equal involvement of all stakeholders (Falcone et al., 2019). The importance of participatory modelling approaches has been recognised in several research fields in terms of helping to find solutions due to its ability to engage stakeholders and incorporate valuable first-hand knowledge such as perceptions and expertise (Falcone and De Rosa, 2020; Özesmi and Özesmi, 2004; Shahvi et al., 2021). There are many participatory modelling techniques, including system dynamics, Bayesian networks, Agent-Based Modelling and Fuzzy Cognitive Mapping (FCM) among others (Voinov and Bousquet, 2010). They are all powerful tools for identifying solutions to a given problem, normally related to supporting decision-making processes, policy design, regulation or management (Penn et al., 2013). We have opted for FCM[20], which has been applied in many different areas such as the food sector (Morone et al., 2019), water management (Shahvi et al., 2021; Solana-Gutiérrez et al., 2017), municipal waste management (Falcone and De Rosa, 2020), urban transformation and resilience (Olazabal and Pascual, 2016), climate change (Reckien, 2014) and the energy transition (Falcone et al., 2019, 2018). FCM offers various advantages over the other participatory research methods mentioned (Table 6). However, it must also be noted that FCM is designed to be a simple, transparent tool, so it has some disadvantages and uncertainties (Table 7).

[20] Due to the complex nature of our case study, i.e. analysing how policy instruments can facilitate the transition towards low-carbon residential heating, we require a method which enables stakeholders' knowledge and perceptions to be integrated, capturing the social, economic, political, environmental and engineering domains (Penn et al., 2013). Furthermore, analysis and considerations of indirect effects between concepts in a system are crucial to provide insight for risk management. In this sense, FCM has been used to understand complex systems more efficiently, making it a useful tool for decision makers. FCM also offers the ability to assess the effects of different policy options through FCM-built scenarios (Jetter and Kok, 2014; Kosko, 1986; Özesmi and Özesmi, 2004).

Table 6. Main advantages of FCM compared to other participatory modelling techniques

	FCM	Other participatory modelling technique
	It is applicable even when limited data is available.	System dynamic models
		They require a variety of empirical datasets (Shahvi et al., 2021)
	Ability to include variables in models which may be not well-defined and to model relationships between variables that are not known with certainty but can be described in degrees such as “a little” or “a lot” (Özesmi and Özesmi, 2004). In other words, FCM uses a combination of network analysis and subjective information from stakeholders to provide an inclusive, fully-complex view.	Bayesian Belief Networks
		They are typically used to quantitatively assess the map defining conditional probabilities for each variable included in the network and do not handle feedback (Barbrook-Johnson and Penn, 2021; Voinov and Bousquet, 2010).
Advantages	It reveals direct and indirect effects between concepts and highlights connections with effects which are less evident, enabling unexpected effects to be identified. This allows for more freedom to represent and analyse sophisticated relationships.	Causal Loop Diagrams
		They are also used qualitatively to visualise the complexity of a system. They identify potential nodes but ensure a map structure consistent with the method (Barbrook-Johnson and Penn, 2021). In fact, in most participatory modelling techniques stakeholders participate in framing and repeatedly assessing detailed systems produced by expert modellers, whereas FCM engages with stakeholder groups so that they produce models/systems themselves (Penn et al., 2013).

Table 7. Main disadvantages of using FCM

	FCM
Disadvantages	It does not provide inferential statistical tests or represent temporal dynamics easily, i.e. it cannot model transition behaviour (Özesmi and Özesmi, 2004). As stated by Shahvi et al. (2021), the semi-quantitative values of FCM mean that it is not easy to implement common calibration methods used for quantitative models; instead the steady-state condition (equilibrium condition of the system) is considered as the calibrated form of these systems (Kok, 2009).
	Another perceived drawback of FCM is the abnormal fluctuations of weights that sometimes occur in trials to bring the systems into steady-state mode (Groumpos, 2017).
	The main drawback of FCM-built scenarios lies in the interpretation of causal relationships, due to the complementarity of stories developed by different stakeholders and simulated creative thinking (Kok, 2009).

Considering all these strengths and weaknesses of FCM and despite its not being sufficiently quantitative to facilitate a link with other mathematical models, the value-added of the method arises from the possibility of having a full-complexity view of all stakeholders and perceived effects. This makes the method highly appropriate for this case study in which we wish to incorporate different stakeholder’s perceptions on energy consumption for heating, highlighting connections with non-obvious effects to design effective policies for heating transition.

For the purpose of this analysis, we use four complementary methodological stages (Figure 13). We use three separate maps built up to understand perceptions from different stakeholders regarding the factors that explain heating bills in Spain. These three maps, recently published in López-Bernabé et al. (2020), were drawn up at three focus groups representing different social groups – academics, households and energy experts – in order to capture heterogeneity of behaviour. The second stage involves data processing to produce an aggregate map. In the third stage we conduct a network analysis of that aggregate map. Finally, stage 4 is based on so-called fuzzy inference or policy simulations, characterised by the identification of effective policy packages. In this, we use the FC Mapper tool[21].

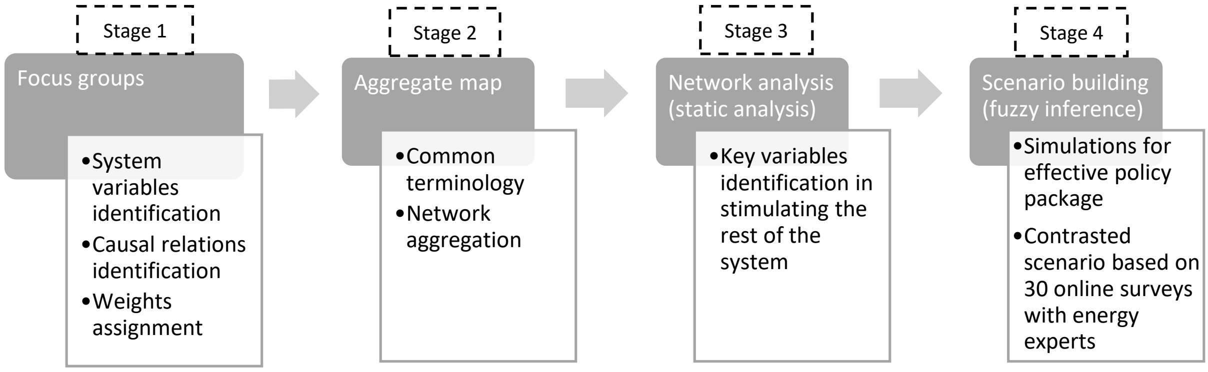

Figure 13. Methodological framework

The four complementary methodological steps used in this approach (stages 1, 2, 3 and 4 in Figure 13) are explained step by step below.

3.3.2. Stage 1 – Focus groups

Each focus group prepared a map of the determinants for reducing energy consumption for heating and thus heating bills in Spain. The data collection processes for the three separate focus groups are summarised in Table 8.

[21] FCMapper is an FCM analysis tool based on MS Excel. It is freeware downloadable from http://www.fcmappers.net/joomla/ (Last accessed May 17, 2021).

Table 8. Research process for the three separate maps

1. Framing research question	
	The heating case study used in this paper was developed within the framework of ENABLE.EU[a]. Participants received information about the amount of energy consumed for heating in Spain and energy-related greenhouse gas emissions. The research question was designed to elicit the attitudes and opinions of key stakeholders as to what can be done to reduce residential heating bills and how; the obstacles that they face in everyday life; and potential solutions that they could identify and support. Each focus group session lasted around 2 hours. Note that with the method used in this research participants had to reach a consensus based on their individual opinions. This requires the group of participants to be small so as to reduce misunderstanding and facilitate knowledge exchange.
2. Three face-to-face focus groups	
Academics	Conducted on December 20, 2017 in the city of Bilbao (Spain) with ten participants from the Basque Centre for Climate Change (BC3). Participants were selected on the basis of their expertise in the field of environmental science, climate change and possibly energy (for more details about socio-demographic characteristics of participants see Appendix 3B).
Households	Conducted on January 23, 2018 in the city of Bilbao (Spain)with eight participants recruited by the Spanish company CPS. Participants comprised households with different ages, types of residence, numbers of family members and children, locations (urban and rural), levels of income and work statuses (for more details see Appendix 3A).
Energy experts	Conducted on January 31, 2018 at the conference of the Spanish Association for Energy Economics (AEEE) in Zaragoza (Spain) with seven participants. This focus group was made up of four researchers and three stakeholders specialising in the field of energy. They were contacted by e-mail (for more details about socio-demographic characteristics of participants see Appendix 3C).
3. Data collection process	
Identification of system variables (these concepts, also known as nodes, make up the elements or entities of the system analysed)	Step 1. Participants were asked to list and represent the factors or concepts that influenced their heating bills. "What are the basic heating facts, elements or components that influence the amount of your heating bill? (for example, energy price or orientation of the building)"
	Step 2. Participants set out individual actions (measures) which could reduce their heating consumption. "What individual measures could help to reduce your heating bill? (i.e. things or individual actions that can really change your heating consumption, such as lifestyle changes or investment in insulation)"
	Step 3. The participants listed policy measures that the government could implement to bring down heating bills. "What policies could politicians implement to bring down heating bills?"
Identification of causal relations	Participants were asked to provide a personal opinion as to the possible presence of links between system variables, and a consensus was reached among all the participants. Positive connections indicate that a concept increases (or decreases) in the same direction as others; negative connections indicate opposite directions (i.e. when one increases the other decreases and vice versa). The discussion in the three focus groups was conducted using the same steps indicated in this table, but with some differences. The main difference was that in focus group with energy experts, connections were not centralised via the concept of "heating bill". The main reason for this was to create a map with more connections between the different factors mentioned by the participants so as to get more variability in the network.

Recording weights a posteriori and individually	The weights assigned to causal relations were recorded on an individual basis in order to represent individual heterogeneity relative to the importance assigned to connections between concepts. Specifically, participants were contacted individually one week after the focus group session to assign weights of between 0 and 1 indicating the strength of the connections between two concepts on the maps. Weights close to 0 represent weak connections and those close to 1 represent stronger connections. Recording weights a posteriori and individually enables participants to express their own beliefs regarding links and the importance of the concepts. Of course, this also allows some time to adequately draw the visual map with the required program and minimise potential misunderstandings.
4. Limitations	
	It can be argued that different focus groups may lead to relatively different findings (e.g. more variability in the variables and weights) but for qualitative analysis it is well documented that the most important factors can be covered in one well-structured focus group (Krueger and Casey, 2008). Based on this, a diversified composition of each focus group profile was preferred to running a second or third focus group with participants with the same diversified profiles.

[a] ENABLE.EU – ENABLE.EU (enable-eu.com)

3.3.3. Stage 2 - Aggregate map

The three stakeholder maps drawn up by the three different groups – academics, households and energy experts – are combined into one cognitive map. Individual maps offer the experiential knowledge of individuals, capturing many details of specific parts of the system. Homogenised or aggregated maps, on the other hand, offer an integrated view, combining perspectives and therefore better capturing the complexity of an entire system. The combination of different perspectives and views helps to understand how elements from the system may interact and discover cross-sectoral interactions and potential unintended effects (Olazabal et al., 2018a). The weighted average method is used to combine the three separate FCMs into a single collective FCM. This technique consists of averaging numerical values for every given interconnection (Gray et al., 2014). According to Olazabal et al. (2018), the construction of an aggregate map involves several steps. Those steps are detailed in Table 9.

Table 9. Detailed process of constructing an aggregate map

Steps	Process	Examples
Data treatment	- Maintain original meaning and connotations - Validate changes with notes/recording and/or with participants.	- "Outdoor temperature", "Indoor temperature" were all renamed/reworded as "temperature gradient" - "Children and elderly at home" was renamed as "Vulnerable person" - When a concept was renamed using an antonym the signs of the connections were reversed. - Other concepts in the individual maps were redundant or not well defined, and were therefore deleted (e.g. "renewable energy policies" and "energy saving policies" were left out of the final version because they do not refer to specific policy instruments and have no significant influence on the other concepts in the network). Concepts and links can be removed with no need to change the rest of the system because the effect of each concept antecedent is independent of the effects of the other concept antecedents (Carvalho, 2013).
Homogenisation	- Selection of a consistent terminology across maps. - Choice of level of detail: grouping and ungrouping of concepts. o During this process there were some conflicting links, i.e. links between concepts were checked to avoid inconsistency in relationships and some sign changes were required.	- "Insulation" and "Energy rating houses" were grouped as "Efficiency of dwellings and certificates". - "Environmental and energy savings information" was ungrouped as "Environmental education and information" and "Education on energy savings" - Additionally, the analysts considered changing specific concepts defined by participants as individual actions to policies (e.g. "Education on energy savings")
Network aggregation	- Building up the augmented matrix from individual matrices o Define how the weights are averaged when grouping concepts. This applies to individual matrices and to the augmented matrix. o Identify potential incoherencies: two concepts connected with different directions or with different weight signing.	- In our case, weights were generally averaged. Then we built up the augmented matrix using R code, as developed by Olazabal et al. (2018). This code uses individual maps as its source and calculates the final aggregate map. In other words, individual networks were merged with equal impacts and weights on equal links were averaged (Reckien, 2014).

3.3.4. Stage 3 - Network analysis

To explore the system configuration characterised by the links between variables (i.e. the static analysis), we conducted a network analysis of the aggregate map. To that end, and based on network theory, some key network indices were considered to assess the system architecture and the relevance of certain variables in stimulating the rest of the system (Özesmi and Özesmi, 2003). In our static analysis, relevant information is provided by (i) the centrality index, which denotes the individual importance of one concept relative to others in the network; (ii) the out-degree index, which measures the degree of influence of one concept on others; and (iii) the in-degree index, which measures the degree of dependency of one concept on others in the network.

3.3.5. Stage 4 - Scenario building

Focusing on policy simulation based on fuzzy inference, FCM enables the answers to "what if" questions to be estimated, e.g. what happens to our system if specific policy instruments change (Carvalho, 2013). The participation of stakeholders in providing their knowledge contributes to the credibility of the scenarios (Kok, 2009). As noted above, results from scenarios can be used to generate new policies because they are built up based on the integrated perspectives of stakeholders (Jetter and Kok, 2014).

Two specific steps can be identified in scenario building and modelling policy interventions: (i) the dynamic behaviour of the network without external influences; and (ii) the policy intervention simulation, i.e. what would happen in the system if different policy instruments were implemented (Falcone and De Rosa, 2020; Lopolito et al., 2020). First, the steady-state vector or system equilibrium is calculated using a specific algorithm (see Appendix 3D). Steady-state calculations provide the rankings of variables in comparison to each other. To calculate this steady-state, simulations were run by multiplying an initial state vector or activation vector with all variables set to 1 (baseline scenario) by the square weight matrix, whose rows and columns are labelled by the variables of the aggregate map, until the values of the system variables stabilised (Kontogianni and Papageorgiou, 2012). In this study the FCM reached its steady-state in no more than 21 iterations. Steady-state calculation is used to perform a qualitative comparison between variables, i.e. the steady-state value taken by the variable x under the baseline scenario reflects its importance within the system according to people's knowledge (Solana-Gutiérrez et al., 2017). Second, once the steady-state condition is obtained, some of the policy instruments are selected by setting them to their maximum values (normally 1). The simulation is performed by applying the procedure described above, with the difference that only variables representing a specific policy instrument are set to 1 for each iteration step. The effect of the policy instrument analysed is assessed by calculating the percentage of variation between the steady-states of variables representing the policy objectives with and without the policy intervention.

The literature on household energy-efficiency policy instruments (Labandeira et al., 2020; Markandya et al., 2015; Ramos et al., 2015) indicates that policy instruments can be classified into four main categories: (i) command and control instruments (e.g. building codes, minimum energy efficiency requirements); (ii) economic instruments (e.g. tax, subsidies); (iii) information instruments (e.g. certificates, labels, energy audits); and (iv) governance. Table 10 shows the policy instruments of our aggregate map classified according to the literature.

Table 10. Classification of policy instruments

Command and control instruments	**Technical standard**: Imposition of specific construction standards on new dwellings, or on boilers, making them more energy-efficient. For example, improvements in technical building codes that seek to achieve lower or near- zero energy consumption.
	Prosumer: Support renewable energy consumption for residential heating, i.e. highlight the role of renewable energy consumers for heating so that renewable energy consumers can produce, store, consume and sell their own energy to the grid.
	Energy-saving regulation: Compulsory boiler maintenance every 4 years. In this case, combustion improves and performance is higher.
	Electrification: Heating electrification supported by renewable energy is likely to be a major option for low-carbon heating.
Economic instruments	**Subsidies**: Promotion of economic incentives to use renewable energy sources or to purchase energy-efficient systems such as heat pumps.
	Social bonus: Discount in power and in energy consumption considering climate differences (see article 15 of Royal Decree 15/2018 in Spain regarding the thermal social bonus) with the need to incorporate requirements for the type of energy source used.
	Taxing bad habits: A carbon tax could be applied to the use of inefficient boilers. This would increase heating bills. Moreover, this specific tax could lead to more efficient behaviour, for example, investment in insulation.
	Taxing fossil fuel used for heating: Introduce a carbon tax for heating fuels.
	Tax on consumption: Progressive rates with the aim of penalising energy consumption on heating (the more used, the higher the price).
	Competition between firms: Rates offered by energy companies. In other words, an option to choose the rate that best suits your consumption habits, i.e. the rate that best suits the consumer's needs, e.g. how much and when they consume.
Information instruments	**Environmental education and information**: Make people who live with you aware of the importance of saving energy, not only for economic reasons but for other environmental issues.
	Education on energy savings: It is suggested that energy companies could give more information about energy consumption on heating bills. The need for help to understand bills is also mentioned.
Governance	***Governance***: Participants ultimately speak of political will. Specifically, they mention the influence of politicians and the policies that they are willing to implement, including a common understanding of the responsibilities and powers of different institutions and actors, ensuring they are able to deliver outcomes required.

Each concept defined as policy instrument in the aggregate map was changed by setting a desirable value for it[22]. In our case, each policy instrument defined in the aggregate map was set at 1 separately. The aim was to identify specific and hidden connections to obtain a better understanding of the application of isolated policy instruments.

3.4.1. Scenario contrasted with energy experts

Then, based on the relevance of the policy packages (identified in Section 3.2), an additional FCM scenario was built up by simulating several policy instruments together. Data for this additional FCM scenario were obtained from thirty interviews conducted by email in August 2019 with members of the Spanish Association for Energy Economics (AEEE) with expertise in energy efficiency. The aim was to get a comprehensive picture of the application of policy mixes or packages (i.e. combinations of instruments) defined by energy efficiency experts to foster energy efficiency in residential heating. The questionnaire was designed on the basis of the policy instruments mentioned by the participants in the aggregate map drawn up by the three groups (academics, households and energy experts). The main goal of the questionnaire was to compare the policy instruments obtained from the aggregate map with the specific views of people working in the area of energy efficiency. The questions sought to determine which of the policy instruments included in the aggregate map were most important in the view of energy experts, and what other policy instruments could complement them. Accordingly, the questionnaire contained questions on (i) selection of policy instruments; (ii) ranking of policy instruments; and (iii) additional policy instruments to be considered.

3.4. Results and discussion

3.4.1. Network analysis

The aggregate map drawn up based on the knowledge of the three stakeholder groups is shown in Figure 14. To visualise our integrated map we used NodeXL Basic[23]. FCMs are converted to square matrices whose elements are every link weight (Özesmi and Özesmi, 2004). Link weights are placed at the intersection cell of each concept shown twice on the matrix, as the cause in the rows and as the effect in the columns (Reckien, 2014).

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[22] A variable may be set to 1 for a highly desirable condition or to 0 for a low condition at each iteration step.
[23] NodeXL Basic is a free, open-source template for Microsoft Excel. It is freeware downloadable https://archive.codeplex.com/?p=nodexl from the Social Media Research Foundation https://www.smrfoundation.org/ (Last accessed July 30, 2021).

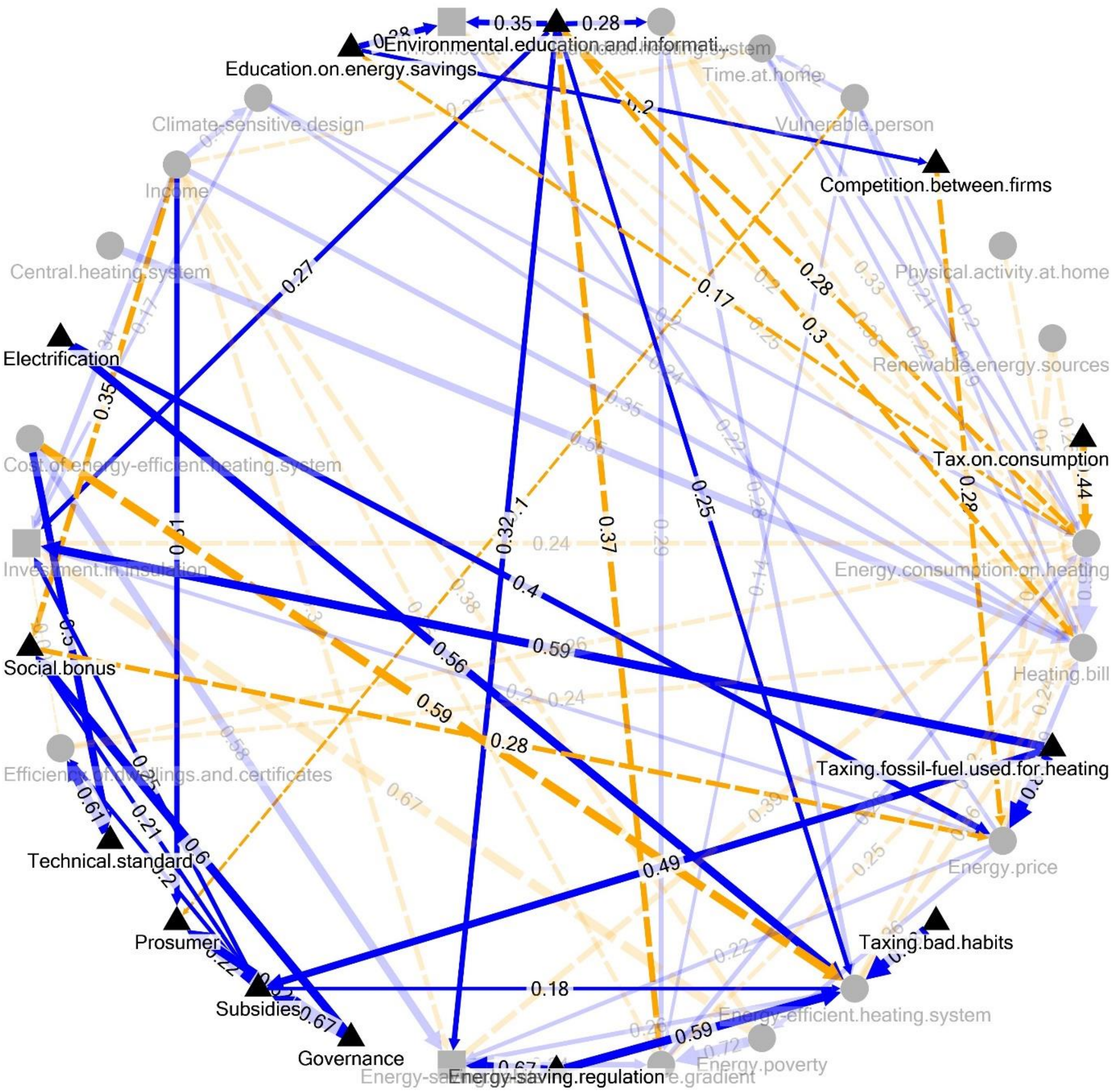

Figure 14. Network aggregated from the maps of the three stakeholder groups (academics, households and energy experts). Blue lines represent positive connections and orange dotted lines negative connections between nodes. Links with policy instruments are highlighted.

The map is composed of 32 nodes (or concepts, C) and 82 connections. Each connection has a weight that represents the strength of the link. Nodes are classified as (i) circles; (ii) squares; and (iii) triangles. Circles represent factors that influence heating bills, i.e. the basic heating facts, elements and components that influence the amount of heating bills. Squares represent individual actions which could reduce heating consumption; and triangles represent policy instruments that the government could implement to reduce heating bills. Arrows show direction and weight (between 1 and 0) according to the strength of the links between connected concepts (Kosko, 1986) derived from the perceptions of participants in the three focus groups. Links can be positive (when one concept increases so does the other) or negative (when one increases, the other decreases) (Kok, 2009).

We analysed three basic indices of FCMs to characterise the role of each concept in our system. The centrality index is based not only on the number of connections but also on their weight. On that basis, the centrality of a concept indicates how closely connected it is to other concepts in the system. The in-degree and out-degree indices measure whether a concept mainly influences or is influenced by the system. This information is reported in Appendix 3E. According to the stakeholders' knowledge, the top 3 central concepts are "energy consumption on heating", "heating bill" and "energy-efficient heating system". "Energy consumption on heating" and "energy-efficient heating system" both influence and are influenced by the system. This highlights their importance in the structure of the FCM and their role in creating interdependence between the other concepts included on the map. On the other hand, "heating bill" is a receiver concept (zero out-degree), meaning that it has little influence on the system. Focussing on how policy instruments relate to each other and to other nodes, our analysis reveals that the top 3 core policy instruments in the network on the aggregate map are "environmental education and information", "subsidies" and "taxing fossil-fuel used for heating". "Environmental education and information" and "taxing fossil-fuel used for heating" both have a strong influence on the values of other concepts in the system (zero in-degree), i.e. they are both connected to other concepts with a large number of highly weighted connections and are influencers of the system. "Subsidies" are also central to the system, both influencing and being influenced by it.

3.4.2. Scenario analysis

Applying the fuzzy inference algorithm discussed in subsection 3.3.4. and Appendix 3D, the first goal was to explore residential energy consumption on heating according to the integrated perspectives of stakeholders without external disturbances i.e. to calculate the steady-state of the variables as reported in Figure 15. This analysis shows that the most important variables according to the integrated knowledge of stakeholders are "energy-efficient heating systems" and "energy-saving habits", followed by "temperature gradient", "investment in insulation" and "subsidies". The use of "thermostats" or "efficiency of dwellings and certificates" and "social bonuses" are also assumed to play a leading role in promoting the transition of residential heating towards sustainability. Surprisingly, the income is the least significant in the system.

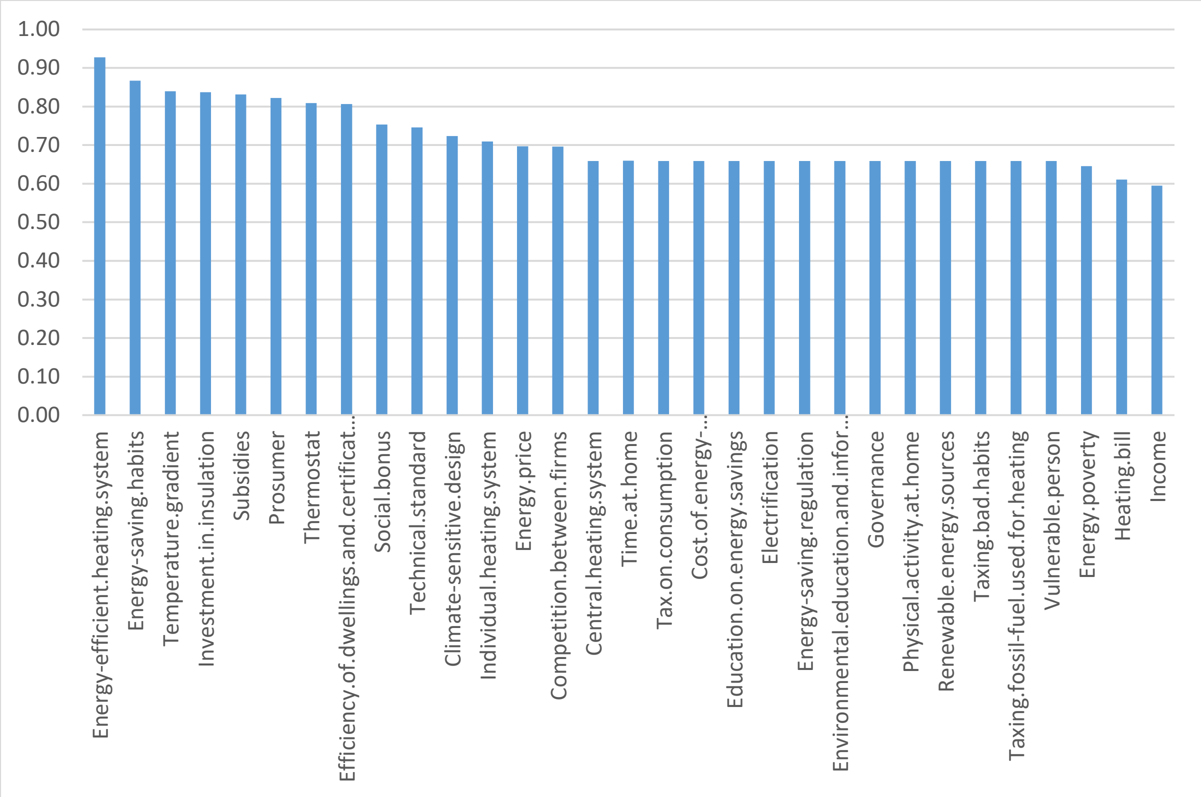

Figure 15. Steady-state values

The next points to be considered are what policies could be implemented to decarbonise residential heating and what would happen if specific policy instruments were reinforced by policy makers. Scenarios were tested by changing the value of each policy instrument defined by each stakeholder group to the highest level of influence. For example, scenario 1 tests the “technical standard” policy instrument, keeping the value of this instrument at one for every iteration phase. Scenario 2 tests the policy instrument called “prosumer”, keeping its value at one for every iteration phase. FCM is simulated several times, once for each policy instrument defined by the different stakeholder groups, and the impacts are shown on the aggregate map. The results for each policy instrument in each scenario are shown in Tables 11-16 as the difference between the performance of each instrument and the no-policy case. The sign of the figures shows whether the impact increases (green) or decreases (orange), and the larger the value, the larger the perceived impact. Note that impacts of certain policy instruments on others can also be analysed and are highlighted in grey. These are usually second-order effects which are not always easy to interpret and should therefore be studied with caution.

Table 11. Command and control instruments

	Command and control instruments			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Technical standard	Prosumer	Energy-saving regulation	Electrification
Efficiency of dwellings and certificates	2.68%	0.00%	0.00%	0.00%
Energy-efficient heating system	0.00%	0.00%	1.36%	1.26%
Energy consumption on heating	-0.12%	0.00%	-0.24%	-0.22%
Energy poverty	0.00%	0.00%	0.00%	0.27%
Energy price	0.00%	0.00%	0.00%	3.49%
Energy-saving habits	0.00%	0.00%	2.67%	0.10%
Heating bill	-0.24%	0.00%	-0.23%	0.10%
Income	0.00%	0.00%	-0.01%	0.00%
Investment in insulation	0.00%	0.00%	0.00%	0.08%
Temperature gradient	0.00%	0.00%	0.14%	0.04%
Thermostat	0.00%	0.00%	0.00%	0.14%

Table 11 shows that "technical standards" are expected to positively impact the efficiency of dwellings and certificates, and hence reduce consumption and heating bills. "Energy-saving regulations" are perceived to produce more energy-efficient heating systems but also to result in better energy-saving habits, which in turn should reduce consumption and heating bills. Finally, "electrification" is expected to produce benefits in regard to energy poverty and promote more efficient systems, but also to increase energy prices and heating bills, according to the stakeholders' knowledge. Curiously, it is expected to increase investments in insulation and temperature gradients as well as thermostats. Temperature gradient and thermostats refer to impacts on lifestyle such as improving the thermal comfort temperature (the difference between indoor and outdoor temperatures) and changing habits by programming thermostats. In this sense, Csutora et al. (2021) test the ability to control indoor temperature and quantitative findings contrasted with the expectations expressed by focus groups, and conclude that culture and established habits play a very important role in determining heating temperatures. According to our analysis, stakeholders believe that the "prosumer" policy instrument has no great impact on other variables.

Table 12. Combination of scenarios 1 and 3

	Scenario 5
Efficiency of dwellings and certificates	2.68%
Energy-efficient heating system	1.36%
Energy consumption on heating	-0.35%
Energy-saving habits	2.67%
Heating bill	-0.47%
Income	-0.01%
Temperature gradient	0.14%

Stakeholders perceive that a combination of the "energy-saving regulations" and "technical standard" policy instruments (see Table 12) should lead to an increase in energy-efficiency requirements such as efficiency of dwellings and certificates, energy-efficient heating systems and energy-saving habits. Note that the effects of the two policy instruments run in the same direction, so the total effect is reinforced, resulting in a much stronger impact on heating bills and energy consumption.

Table 13. Economic instruments

	Economic instruments					
	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11
	Subsidies	Social bonus	Taxing bad habits	Taxing fossil-fuel	Tax on consumption	Competition between firms
Efficiency of dwellings and certificates	0.61%	0.00%	0.00%	0.09%	0.00%	0.00%
Energy-efficient heating system	0.22%	0.00%	1.69%	0.04%	0.00%	0.00%
Energy consumption on heating	-0.06%	0.08%	-0.09%	-0.42%	-2.35%	0.10%
Energy poverty	0.00%	-0.15%	0.00%	0.53%	0.00%	-0.18%
Energy price	-0.06%	-1.89%	0.00%	6.88%	0.00%	-2.34%
Energy-saving habits	0.00%	-0.05%	0.00%	0.20%	0.00%	-0.07%
Heating bill	-0.09%	-0.14%	-0.22%	0.46%	-0.68%	-0.17%
Income	0.00%	0.00%	0.00%	-0.01%	0.00%	0.00%
Investment in insulation	0.65%	-0.04%	0.00%	3.11%	0.00%	-0.05%
Prosumer	0.62%	0.00%	0.00%	0.09%	0.00%	0.00%
Social bonus	0.80%	0.00%	0.00%	0.12%	0.00%	0.00%
Subsidies	0.00%	0.00%	0.00%	2.53%	0.00%	0.00%
Temperature gradient	0.00%	-0.02%	0.00%	0.07%	0.00%	-0.02%
Thermostat	0.00%	-0.08%	0.00%	0.27%	0.00%	-0.09%

Table 13 shows that key stakeholders perceive that "subsidies" should result in an increase in the efficiency of dwellings and certificates, energy-efficient heating systems and investment in insulation, but also a drop in energy prices. This is in line with Hesselink and Chappin (2019), who suggest that subsidies help to encourage the adoption of alternative heating technologies. These impacts are thought to be particularly useful in reducing consumption and heating bills, but to a lesser extent than command and control instruments.

Considering the current context of the application of a "social bonus" in Spain, which means a discount in both power and energy consumption, stakeholders perceive that this policy instrument should directly reduce heating bills. In fact, consumers may perceive that their energy consumption is being subsidised so, according to economic theory, one might expect a decrease in energy-saving habits, investment in insulation and use of thermostats.

Focusing on taxation as a policy instrument (scenarios 8, 9 and 10), stakeholders' views suggest that "taxing bad habits" should produce a positive impact on energy-efficient heating systems, thus reducing consumption and heating bills by an amount similar to that for command and control instruments. "Taxing fossil-fuel" is thought to produce greater effects on energy prices than on energy-efficiency improvements (i.e. energy-saving habits or investment in insulation), resulting in an increase in heating bills. The efficiency of heating systems is perceived to not change much. Finally, a "tax on consumption" is expected to decrease consumption substantially (by more than any other policy instrument), thus resulting in the largest reduction in heating bills observed so far.

"Competition between firms" is expected to have a negative impact on energy-saving habits, investment in insulation and the use of thermostats, but is also expected to decrease energy prices and heating bills.

Table 14. Information instruments

	Information instruments	
	Scenario 12	Scenario 13
	Environmental education and information	Education on energy savings
Climate sensitive design	0.01%	0.00%
Competition between firms	0.00%	1.79%
Energy-efficient heating system	0.66%	0.00%
Energy consumption on heating	-1.95%	-1.01%
Energy poverty	-0.02%	-0.01%
Energy price	0.00%	-0.13%
Energy-saving habits	1.34%	0.00%
Heating bill	-4.20%	-0.48%
Income	0.15%	0.00%
Individual heating system	2.40%	0.00%
Investment in insulation	1.40%	0.00%
Prosumer	0.01%	0.00%
Social bonus	-0.01%	0.00%
Temperature gradient	-1.88%	0.00%
Thermostat	2.07%	2.23%
Time at home	-0.01%	0.00%

Table 14 shows that stakeholders expect "environmental education and information" to produce more energy-efficient heating systems, but also to result in better energy-saving habits, the use of individual rather than central heating systems and investment in insulation and the use of thermostats. This in turn is expected to reduce consumption and heating bills substantially (by more than any other policy instrument considered here), probably because of the combination of the instruments.

“Education on energy saving” is expected to decrease energy prices, consumption and heating bills. It is also expected to result in more competition between firms and an increase in the use of thermostats.

Table 15. Governance instruments

	Scenario 14
	Governance
Efficiency of dwellings and certificates	0.12%
Energy-efficient heating system	0.04%
Energy poverty	-0.03%
Energy price	-0.34%
Energy-saving habits	-0.01%
Heating bill	-0.04%
Investment in insulation	0.12%
Prosumer	3.40%
Social bonus	4.45%
Subsidies	3.36%

Table 15 shows that governance is expected to positively impact the efficiency of dwellings, promoting efficient systems and investment in insulation. It is also expected to decrease energy prices and heating bills. A negative impact on energy poverty and energy-saving habits is also perceived.

Table 16. This scenario is inspired by energy-efficiency experts from AEEE, based on a survey considering all the policies defined from scenario 1 to scenario 14

	Scenario 15
Climate-sensitive design	0.01%
Efficiency of dwellings and certificates	3.22%
Energy-efficient heating system	2.05%
Energy heating consumption	-2.64%
Energy poverty	0.51%
Energy price	6.84%
Energy-saving habits	3.89%
Heating bill	-4.22%
Income	0.13%
Individual heating system	2.40%
Investment in insulation	4.67%
Prosumer	0.63%
Social bonus	0.79%
Temperature gradient	-1.67%
Thermostat	2.32%
Time at home	-0.01%

Note: The policy instruments ranked (i) “Energy-saving regulations”; (ii) “Environmental education and information; (iii) “Subsidies”; (iv) “Taxing fossil-fuel used for heating”; and (v) “Technical standards” were set to 1.

When several instruments are combined as proposed by energy experts, most positive impacts are reinforced, as shown in Table 16. This policy package scenario is perceived to increase energy prices but expected to have a large impact on energy-efficiency improvements (efficiency of dwellings and certificates, energy-efficient heating system, investment in insulation and the promotion of individual heating systems). It is also expected to promote energy-saving habits and thus reduce energy consumption on heating and heating bills. This combination is perceived to achieve the largest reduction in energy consumption and heating bills observed for any policy instrument, be it command and control, economic or information-based, according to the stakeholders' perceptions.

3.4.3. Main findings

Our findings provide several insights for effective policy design in reducing carbon dioxide emissions from residential heating. Stakeholders' perceptions of "technical standards" and "energy-saving regulations" show that they can be expected to have little impact on heating bills and energy consumption. However, combining the two policy instruments (scenario 5) adds together and hence reinforces their effects, resulting in a much stronger impact on heating bills and energy consumption. There is some potential here for correcting market failures due to imperfect information. For example confidence could be created, leading to improvements in investment in energy-efficient heating systems.

Economic policy instruments such as subsidies and social bonuses are perceived to reduce heating bills but to a lesser extent than command and control instruments. Specifically, our results reveal that the "social bonus" is perceived to increase energy consumption on heating, as might be expected according to economic theory. In this regard, Galarraga et al. (2013) show that when subsidies are introduced to reduce energy bills by promoting the purchase of energy-efficient appliances, they may generate a rebound effect in terms of an increase in the total number of appliances and consequently an increase in energy consumption. Other papers also show that perception may play an important role in the acceptability and effectiveness of policies. For instance, Kallbekken et al. (2011, 2010) and Kallbekken and Sælen (2011) find that consumers substantially support subsidies more than taxes, even in situations in which the final outcome of both policies may be similar. This may be because participants expect a subsidy to increase their own payoffs more than a tax, rather than because it is expected to be more effective in changing behaviour (Heres et al., 2017).

Public acceptance of environmental policies is likely to depend on the perceived effectiveness of those policies and on the expected personal gains if they are implemented (Kallbekken and Sælen, 2011). A comparison of scenarios based on tax policy instruments (scenarios 8, 9 and 10) shows that, according to stakeholders' perceptions, a "tax on consumption" is expected to decrease consumption by a substantial amount, which would also result in lower heating bills. This result strongly supports the hypothesis that taxes become significantly more acceptable when there is more complete information (Heres et al., 2017). In our case, the information revealed by the cognitive map (direct and indirect effects of certain policy instruments on other concepts defined, and connections which have non-obvious effects) increases support for taxes relatively more than support for subsidies.

Stakeholders assign the greatest potential for the heating transition to "environmental education and information", whose ability to reduce heating bills is the greatest of any of the policy instruments considered here. This is not totally unexpected, although the literature is not always clear with respect to which instruments are more effective. For example, Filippini et al. (2014) find that financial incentives and energy performance standards play an important role in promoting energy-efficiency improvements in the EU residential sector, while informative measures such as labelling and education campaigns show no significant effects. Csutora et al. (2021) also find that providing more meaningful information does not trigger public support. Their findings from contrasting qualitative assumptions with quantitative results show that too little or too much information may result in a failure to save energy, depending on the country (e.g. Hungarians were extremely negative about getting meaningful information compared to other countries). In terms of energy conservation, people prefer practical advice to energy consumption related data. Other approaches point to a central role for informational instruments in different sectors (Falcone and De Rosa, 2020; Ramos et al., 2015). For the specific sector of households, information feedback tools are commonly used and can be effective, but only if they are carefully designed (Ramos et al., 2015).

In scenario 15, which combines several instruments as proposed by energy experts, most positive impacts are reinforced and the reduction obtained in energy consumption and heating bills is the largest of any of the policy scenarios. For example, "subsidies" for replacing fossil-fuel-fired heating systems are perceived to encourage energy-efficiency improvements, promoting energy-efficient heating systems. But this is unlikely to be sufficient according to the stakeholders' knowledge. Considering the proposed policy package, a "tax focused on fossil-fuel used for heating" is also believed to be needed, i.e. a carbon tax which ensures that costs related to carbon dioxide emissions are assigned individually and not shifted to society in general. An interesting example of the use of public incentives and carbon taxation is the case of Finland, where financial incentives for heating system renovations were promoted for all households, while taxes on fossil fuels continued to rise. This encouraged a switch away from fossil-fuel heating systems towards cleaner systems such as heat pumps (Sovacool and Martiskainen, 2020). Command and control policy instruments and information instruments are also perceived to play a fundamental role in the heating transition. Specifically, "energy saving regulations", "technical standards" and "environmental education and information" policy instruments are expected to be most effectively addressed under this combination of policy instruments, based on stakeholders' perceptions.

3.5. Conclusions and policy implications

As the single largest energy consumer in residential buildings, heating plays an important role in decarbonisation in many countries, and particularly in Spain. The challenge of decarbonising residential heating calls for an effective policy and research response and energy-efficiency policies are key in the transition. However, those policies need to be well designed and implemented as there are many examples of policies which do not produce the expected outcomes. It is thus essential to enhance the understanding of policy impacts and design features. Of course, there are usually differences between the planned design and the implementation features of certain policies for many reasons, and perceptions and/or acceptability of policies can often explain many of those differences. Therefore, taking into consideration the views of stakeholders on what policies should be used and how they can contribute makes for a highly interesting contribution to the analysis of policy interventions; a contribution that complements well the information that economic theory and more traditional economic modelling may provide. Also note that a powerful reason for choosing the heating sector for this analysis is that the residential heating sector has three particular characteristics: (a) heating systems are long-lived; (b) they can be very costly; and (c) a great many agents may be involved in the decision to install and use them.

This paper focuses on residential heating in Spain, but the general arguments used here are likely also to be applicable to other countries with similar characteristics such as Eastern or Southern European countries.

In particular, we analyse the effectiveness of energy-efficiency policies here by incorporating the perceptions of different stakeholders. Understanding stakeholder perceptions of how energy related issues interact provides a very good complement for the more quantitative information traditionally used in policy design, because expectations may significantly affect policy outcomes (i.e. the efficiency and effectiveness of a policy) and because they affect the acceptability of those policies.

This analysis is carried out using the so-called FCM method, a participatory method which captures the diversity of perspectives and opinions that drive heating decarbonisation and has proven very useful in many research areas for the reasons explained above. Here, we integrate the views of three separate groups of stakeholders (academics, households and energy experts) in an attempt to better understand how stakeholders may interact with policy instruments. These same groups were analysed separately in earlier work to obtain a thorough understanding of the differences and similarities in their views. Integrating the views of all three groups to provide a much closer interpretation of reality is the added value that we offer in this paper. This integration also enables us to analyse the expected impact of different policy instruments together in policy packages. Note that a policy package can be more effective, more efficient and more popular than individual policies.

This paper clearly shows that integrating views provides a richer picture of how perceptions may influence the impacts of different policies. Specifically, FCM reveals direct and indirect effects of certain concepts on others and highlights connections which have non-obvious effects that should be considered in designing policy interventions. Bearing in mind this broad range of views from academics, households and energy experts and their perceptions as to effects, we identify the main factors, individual measures and policy instruments that may facilitate the transition in residential heating. FCM is also used for scenario assessment to better understand the strength of policy instruments and interactions between the concepts used to explain the residential heating transition. These outcomes can be very useful tools for policy-making processes.

The specific findings that have emerged from the policy simulation can be summarised as follows. For command and control instruments, when policy instruments comprising energy-saving regulations and technical standards are combined the effects are perceived to be greater than when those instruments are used in isolation. This policy package or policy mix is expected to have a much stronger impact on heating bills and energy consumption. Regarding the choice of economic instruments, a potentially important misconception emerges: consumers seem to underestimate the effectiveness of taxes compared to the effectiveness of subsidies, although the evidence is relatively scarce. Our analysis indicates that when all views are integrated, taxes are expected to be more effective than subsidies, which is indeed what economic theory teaches us. In fact, according to stakeholder views, a direct "tax on consumption" would result in the largest reduction in heating consumption, far greater than that obtained by taxing fossil fuels or other measures. The information revealed by the cognitive map (direct and indirect effects of certain policy instruments on other concepts defined, and connections which have non-obvious effects) increases support for taxes relatively more than it increases support for subsidies. Note also that perceived effectiveness matters as it is an important determinant of acceptability (Kallbekken and Sælen, 2011). In this regard, our results support the idea that the perceived effectiveness of energy policies may be significantly correlated with the acceptability of those policies (Heres et al., 2017).

With regard to information instruments, the greatest potential for the heating transition is expected to lie in "environmental education and information", which can reduce heating bills by more than any other single policy instrument considered here, according to the combined views of the stakeholders groups.

Finally, the combination of several instruments (in so-called policy packages or mixes), as proposed by the energy experts consulted during this research, results in the greatest reduction in energy consumption and heating bills of any policy instrument analysed. This can be attributed to the fact that the effects are added together and hence reinforced, making the impact of a policy package much more evident. In addition, other literature also suggests that policy packages enable more than just one policy target to be addressed.

However, there are several caveats in regard to the work reported this paper. On the one hand, we are using a semi-quantitative methodology whose results need to be handled with care and are not easily extrapolated to other contexts. These results, and the lessons learnt, may be applicable only to very similar contexts and not to countries where heating habits and/or systems are very different from those in Spain. On the other hand, the method is based on perceptions so it does not substitute but rather complements other more analytical and modelling approaches also needed for good policy design. Finally, although great care was put into inviting broad groups of heterogeneous stakeholders, there is always a risk of selection bias when deciding on the specific participants to be invited to each group.

In any event, FCM is a sound, appropriate research methodology for incorporating more qualitative information into traditional policy analysis, and in combination with other approaches it can substantially enhance the understanding of what works, what does not and why. From qualitative research based on focus group discussions, it can be argued that different focus groups may lead to relatively different findings. However, it is well documented that the most important factors can be covered in one well-structured focus group (de Ayala et al., 2020; Krueger and Casey, 2008). The method outlined in this paper can also be used to explore many other policy combinations such as combinations of subsidies and taxes and more complete policy packages with several other instruments together by combining informational, command and control and market instruments. But we believe that the results shown here are a good example of the usefulness of the research technique proposed.

Chapter 4: Estimating the price premium of high energy-efficient washing-machines in Spain: A hedonic approach [24]

[24] **López-Bernabé, E.**, de Ayala, A. and I. Galarraga (2022) Estimating the price premium of high energy-efficient washing-machines in Spain: A hedonic approach. BC3 Working Paper Series 2022-01. Basque Centre for Climate Change (BC3). Leioa, Spain.

4.1. Introduction

With rising living standards, the number of household appliances is growing rapidly, as is household electricity consumption (Wang et al., 2021). In the context of climate change and the plans of the European Union to transition to a clean, carbon-neutral economy by 2050 (EC, 2019), the household sector is one of those that needs to be addressed urgently. Household energy consumption accounts for around 26% of final energy consumption in Europe (Eurostat, 2021) and 17% in Spain (IDAE, 2021b). It also accounted for around 17% of global energy-related carbon dioxide emissions in 2019 (UN, 2020). More specifically, appliances represent one of the main sources of household energy consumption (IDAE, 2021a). In the EU, household appliances and lighting account for 57% of total residential end-use electricity consumption (Eurostat, 2019a). In Spain the figure is about 62%[25]. They are therefore very important products for energy-saving efforts.

Energy Efficiency (EE) provides an opportunity to substantially reduce household energy consumption (Linares and Labandeira, 2010)[26]. Several studies have analysed the potential energy savings, avoided CO2 emissions and profitability of energy-efficiency investments in the household sector (Cattaneo, 2019; Ramos et al., 2016a, 2015; Stieß and Dunkelberg, 2013).

However, despite the potentially significant monetary benefits and environmental advantages of EE, its adoption levels are generally low, as illustrated by the literature on the EE gap (Jaffe and Stavins, 1994a; Linares and Labandeira, 2010; Shama, 1983). This gap can be explained by various failures and factors such as market failures (including information failures), behavioural failures and/or other factors (e.g. social norms, procrastination or personal experience) (Solà et al., 2020).

For the case of appliances, the fact that consumers do not observe the amount of electricity consumed by the appliance in question contributes to the EE gap. As a result, EE in the appliances market gives rise to several problems related to information, which is (i) frequently imperfect and asymmetric; (ii) almost always hard to obtain; and (iii) generally constrained for consumers to operating costs (Ramos et al., 2015; Solà et al., 2020).

The relevant literature has analysed several policy instruments for addressing these barriers (Cattaneo, 2019; Gillingham et al., 2009, 2006; Gillingham and Palmer, 2014b; Labandeira et al., 2020; Ramos et al., 2016a). The policy instrument most commonly used to reduce informational failures is

[25] The Institute for Diversification and Energy Saving in Spain (known by its Spanish acronym IDAE) classified electricity consumption into the following categories in 2019: appliances (62.8%), lighting (11.74%), cooking (9.29%), domestic hot water (7.47%), heating (7.37%) and air conditioning (2.33%).

[26] The Energy Efficiency Directive (2018/2002/EU) sets a target of at least 32.5% EE by 2030 and the Spanish National Energy and Climate Plan envisages a 39.5% improvement by 2030 (NECP, 2020).

the EE label[27]. These labels provide information on the energy consumption of energy-related products and on their EE levels, among other technical information (e.g. energy consumption, volume or capacity, noise level and water consumption). They are intended to provide consumers with the information that they need to make energy-efficient purchases.

With mandatory minimum standards for EE, energy labelling regulations encourage manufacturers to use more energy-efficient technologies. This effectively changes the distribution of household appliances with different energy consumption levels in the current market (Wang et al., 2021). However, there are still arguments as to the effectiveness of EE label policy for purchasing decision making on energy-efficient appliances, because of the EE gap mentioned above (Galarraga et al., 2011a; Wang et al., 2021).

This paper focuses on the EE label for washing machines in Spain. This market provides a very interesting case study due to the substantial electricity consumption of washing machines, which were ranked third among all the appliances used in 2019, accounting for around 11% of total energy demand from appliances[28].

The energy-efficiency label for washing machines provides standardised information on electricity use, on how energy-efficient a washing machine is and on other resource consumption such as water consumption, rated capacity, spin-drying efficiency class and noise level. Directive 95/12/EC(EC, 1995) on washing machines has been amended several times. For a more detailed explanation of the EU regulation on the energy performance of household appliances, see Schleich et al., (2021).

This paper estimates how much consumers actually pay on the washing machines market in Spain for the EE label. To that end, we use real purchase data for 2019 and apply the well-known hedonic price method to calculate the marginal price differential due to improvements in EE.

Estimating the price-premium is useful with a view to adequately designing the widely used rebate schemes that seek to support the purchase of high-efficiency appliances. Comparing those premiums over time could also provide an idea as to whether the actual willingness-to-pay (WTP) for EE is increasing or not. There are many factors that could explain an increase in the premium paid, such as policies and other efforts to promote EE. Apart from energy labels, those policies include smart meters

[27] The energy-efficiency label for household appliances has been in place for almost 30 years at EU level, regulated by Directive 92/75/EEC(EEC, 1992). On that basis, the EU published implementing directives for refrigerators in 1994 (94/2/EC), washing machines in 1995 (95/12/EC), washing machines and washer dryers in 1996 (96/60/EC) and dishwashers in 1997 (97/17/EC).

[28] The distribution of electricity consumption by appliances in Spain in 2019 was the following: refrigerators (30.6%), TVs (12.2%), washing machines (11.8%), stand-by (10.7%), ovens (8.3%), computers (7.4%), dishwashers (6.1%), freezers (6.1%), dryers (3.3%) and other equipment (3.5%) (IDAE, 2021a).

and information feedback tools and energy audits (Cattaneo, 2019; Solà et al., 2020). Other factors refer to changes over time in the price of electricity and even supply-side factors such as standards for EE, technological progress and similar (e.g. encouraging manufacturers to drive technological innovation by using more energy-efficient technologies due to the mandatory minimum standards for EE) (Schleich et al., 2021). In any event, an increase in the EE premium can be interpreted as positive for the general goal of increasing the adoption of EE and reducing energy consumption.

The paper is organised as follows: Section 4.2 reviews the existing literature on energy-efficiency label premiums for household appliances. Section 4.3 explains the hedonic price method, the data used and the regression model specified for the estimation. Section 4.4 presents and discusses the main results and Section 4.5 concludes.

4.2. Review of the literature

Research into understanding consumer reactions to EE improvements in different markets has been growing in recent years, due to both the implementation of EE labels and growing concern for the environment and climate change. There are several studies that analyse the effectiveness of EE labels in different product markets such as appliances (Faure et al., 2021; Galarraga et al., 2011b, 2011a; Lucas and Galarraga, 2015; Schleich et al., 2021; Zhang et al., 2021), dwellings (Brounen and Kok, 2011; Copiello and Donati, 2021; de Ayala et al., 2016; Fuerst and Warren-Myers, 2018; Walls et al., 2017), and cars (Alberini et al., 2014; Arawomo and Osigwe, 2016; Galarraga et al., 2020, 2014).

For the appliances market, there is a substantial body of research analysing the effect of EE levels on purchasing decisions for different appliances (washing machines, refrigerators, dishwashers, air conditioners, air purifiers and TVs) and in several countries (e.g. Spain, Germany, Switzerland, China, South Korea, the United States and India). Table 17 provides an overview of these empirical studies organised by types of appliance, country and method.

Table 17. Research on EE label premiums for household appliances in different countries

Appliance type	Country	EE price premium	Method	Year	Reference
Washing machine	Spain	4.15% (19.79€)	Hedonic price model	2012	(Lucas and Galarraga, 2015)
	China	15.9% (424.76 RMB)	Discrete-choice experiment	2017	(Zha et al., 2020)
	Switzerland	30% (455€)	Discrete-choice experiment	2004	(Sammer and Wüstenhagen, 2006)
Dishwasher	Spain	4% (19.28€)	Hedonic price model	2012	(Lucas and Galarraga, 2015)
		15% (80€)	Hedonic price model	2009	(Galarraga et al., 2011a)
Refrigerator	Spain	12.6% (86.18€)	Hedonic price model	2012	(Lucas and Galarraga, 2015)
		8.9% (58.56€)	Hedonic price model	2009	(Galarraga et al., 2011b)
	China	28.1% (1162RMB)	Hedonic price model	2018	(Zhang and Tao, 2020)
		21.63% (757 RMB)	Discrete-choice experiment	2006	(Shen and Saijo, 2009)
		23.09% (731.16 RMB)	Discrete-choice experiment	2017	(Zha et al., 2020)
	United States	26.17%-36.60% ($249.82-$349.30)	Discrete-choice experiment	2009	(Ward et al., 2011)
		6.66%-10.66% ($95-$152)	Structural demand model	2008	(Houde, 2014)
		Over 28% (Over $200)	Discrete-choice experiment	2009	(Li et al., 2016)
	India	35% ($100)	Discrete-choice experiment	2015	(Jain et al., 2018a)
Air conditioner	China	12.4% Around (703RMB)	Hedonic price model	2018	(Zhang et al., 2021)
		8.12% (276 RMB)	Discrete-choice experiment	2006	(Shen and Saijo, 2009)
		9.4% (400RMB)	Discrete-choice experiment	2013	(Zhou and Bukenya, 2016)
	India	24% ($126.24)	Discrete-choice experiment	2015	(Jain et al., 2018a)
		36% ($137)	Discrete-choice experiment	2015	(Jain et al., 2018b)
Air purifier	Korea	9.1% (40,000 KRW)	Discrete-choice experiment	2018	(Kim et al., 2019)
Television	Korea	19.1% (359.27€) No premium after using difference-in-differences and fixed-effect models.	a. Hedonic price model b. Discrete-choice experiment	2012	(Park, 2017)
	Germany	15.8% (150€)	Discrete-choice experiment	2009	(Heinzle and Wüstenhagen, 2012b)

Source: Own work.
Notes:
€: Euro, the official currency of 19 of the 27 member states of the European Union. This group of states is known as the Eurozone.
$: United States dollar, the official currency of the United States and several other countries.
RMB: Renmimbi, the currency of the Republic of China.
KRW: Korean Republic won, the official currency of South Korea.

For the specific case of washing machines, research on EE label premiums has been carried out in different countries. For instance, Lucas and Galarraga (2015) use the hedonic price method to calculate the premium for the most energy-efficient washing machines in Spain. They find that those with the highest energy–efficiency label (A+++) had a premium of 4.15% compared to those with lower EE in 2012. Results from other studies that conduct DCEs in other countries find, for instance, that the premium on A-level energy-efficiency washing machines was about 30% compared to C-level washing machines in Switzerland in 2004 (Sammer and Wüstenhagen, 2006). Zha et al.(2020) show that the price premium paid by Chinese consumers for each increase in the energy-efficiency level of washing machines was 15.9% of the mean prices in 2017.

In Spain, several studies have used the hedonic price model to calculate the price premium on different appliances. In addition to the specific research on washing machines market mentioned before, Galarraga et al. (2011a) and Lucas and Galarraga (2015) also analyse the dishwashers market and find that the premium paid for energy-efficiency was 15% in 2012 and 4% in 2009. Galarraga et al. (2011b) and Lucas and Galarraga (2015) conduct a similar investigation for refrigerators and find that those with the highest energy-efficiency label had a premium of 8.9% in 2012 and 12.6% in 2009.

Other studies quantifying the energy-efficiency price premium differ in terms of the appliances and countries covered. For example, the EE price premium for refrigerators is found to range from 22% to 28% in China (Shen and Saijo, 2009; Zha et al., 2020; Zhang and Tao, 2020), from 7% to 37% in the United States (Houde, 2014; Li et al., 2016; Ward et al., 2011) and to be close to 35% in India (Jain et al., 2021, 2018a). For air conditioners a price premium ranging from 9% to 12% is found in China (Shen and Saijo, 2009; Zhang et al., 2018; Zhou and Bukenya, 2016) and close to €110 in India (Jain et al., 2018a). In Korea, Kim et al. (2019) estimate a price premium of 9% for air purifiers in 2018. Park (2017) uses a hedonic price model analysis and finds a 19% premium for TVs in Korea. However, no premium is found when a discrete-choice experiment is used. Finally, Heinzle and Wüstenhagen (2012) find a price premium of 19% for the highest energy-efficiency TV on the EU label scale (A to G) in 2012 in Germany.

As can be seen from this literature review, the studies considered all generally find a positive price premium for EE but its extent varies across countries, product categories and years and depending on how EE is measured.

4.3. Methodology

4.3.1. The hedonic price method

As can be seen from Table 1, the literature uses either the DCE methodology or the hedonic price method to estimate the price premiums for EE. DCEs are based on subjective data as they enable hypothetical decisions on appliance choice to be estimated (McFadden, 1974; Theil, 1970). A major drawback, however, is that there could be a gap between consumers' WTP and the actual prices they accept because data do not come from a real purchase situation (Zhang et al., 2021). In comparison, the hedonic price model relies on observed market data or on household surveys in which participants are asked to report their past appliance purchase decisions (Schleich et al., 2021). The price premiums considered therefore reflect what consumers actually pay in the market for the EE attribute.

The hedonic price technique is commonly used to estimate how much of the price of a good is explained by each different attribute of that good (Rosen, 1974). This method enables the relationship between a product's price and its different attributes to be analysed by generating a bundle of implicit prices for all attributes. In other words, by using this method the price of a good can be broken down into the prices of its different attributes (Ankamah-Yeboah et al., 2016; Bockstael and McConnell, 2007; Schamel, 2012; Soler et al., 2019). The method assumes that different goods are differentiated by the number of characteristics (attributes) that they have. It enables the price difference between two goods of different EE levels to be estimated *ceteris paribus*, i.e. while controlling the rest of the attributes (Galarraga et al., 2011a). It is usually interpreted in the literature as the price premium of the EE attribute or the actual WTP of consumers for EE when they purchase an appliance (Galarraga et al., 2011a). Thus, the WTP for (or actual cost of) the EE attribute reflects the preference for or degree of recognition of that attribute (Fernández et al., 2019; He et al., 2019; Zhang et al., 2021).

In this paper we estimate how much consumers actually pay on the washing machine market for the EE attribute in Spain. A complete description of this technique can be found in Braden and Kolstad(1991) and Rosen(1974).

The hedonic price method has been widely applied to analyse the effects of product attributes on product prices in the housing (Copiello and Donati, 2021; de Ayala et al., 2016), car (Galarraga et al., 2014) and appliances markets (see Section 4.2), among others.

4.3.2. Data

Data were collected online in Spain by a specialist polling company (CPS[29]) between June 2018 and May 2019. They cover market prices and related product-attribute information on 322 washing-machine models from 18 different brands. Data were collected from online catalogues (18%) and the websites of various stores (82%).

The period when the largest number of price observations were made was May 2019[30] (19% from June 2018, 27% from November 2018, 24% from January 2019 and 30% from May 2019). Given that the 322 washing-machine models were sold on more than one store's website, the final number of market price observations was 739, distributed as follows: *catalogue* (107 observations), *El Corte Ingles* (224 observations), *Mediamarkt* (104 observations), *Carrefour* supermarkets (232 observations) and *Eroski* supermarkets (72 observations). The average washing machine price was €612.60[31]. The data also contained related product-attribute information such as *EE level, brand* and other specific technical characteristics such as weighted water consumption in litres per year *(water consumption)*, rated capacity in kilograms *(capacity)*, spin-drying efficiency class (*Spin-drying efficiency performance A, B or C)* and airborne noise emissions during the washing and spinning phases expressed in decibels (*noise speed spin*). Table 18 describes each of the variables used in our hedonic model together and their summary statistics.

[29] CPS is a market research and opinion polling company that collects market and consumer information in Spain (https://www.cps2000.com/)

[30] This increase in the number of price observations may be due to two reasons: (i) some brands could be offering their models to more stores than previously; and/or (ii) the stores themselves may have decided to put more models of washing machines on sale.

[31] The average washing machine price differs from one store to another. Specifically, washing machines from *Catalogue* were on average 18% more expensive than washing machines from *El Corte Ingles* (€833.36 compared to €638.42). The average washing machine price at *Carrefour* was €489.79 and that of *Eroski* was €578.68. And the average price at *Mediamarkt* was €530.40.

Table 18. Variables selected and summary statistics

Variable	Codification	Description	Obs.	Mean (Std. dev)	Range [Min; Max]
Dependent variable					
Ln (price)	Quantitative	Log of the market price of the washing-machine	739	612.60 (290.18)	[206; 2,349]
Independent variables					
EE level					
High energy-efficient level	Dummy	Whether label is A+++ and a reduction of energy consumption from 10% to 70%	739	0.55 (0.50)	[0; 1]
Store					
Catalogue	Dummy	Whether the store is Catalogue	739	0.14 (0.35)	[0; 1]
El Corte Inglés	Dummy	Whether the store is El Corte Inglés	739	0.30 (0.46)	[0; 1]
Supermarkets	Dummy	Whether the store is Eroski and Carrefour	739	0.41 (0.49)	[0; 1]
Technical attributes					
Spin-drying efficiency performance A	Dummy	Whether spin-drying performance of the washing machine is A	739	0.16 (0.37)	[0; 1]
Spin-drying efficiency performance B	Dummy	Whether spin-drying performance of the washing machine is B	739	0.67 (0.47)	[0; 1]
Spin-drying efficiency performance C	Dummy	Whether spin-drying performance of the washing machine is C	739	0.12 (0.33)	[0; 1]
Width	Quantitative	The width of the washing machine measured in millimetres	739	581.09 (59.62)	[400; 850]
Depth	Quantitative	The depth of the washing machine measured in millimetres	739	577.55 (49.11)	[340;850]
Height	Quantitative	The height of the washing machine measured in millimetres	739	849.29 (31.03)	[550; 990]
Water consumption	Quantitative	Weighted annual water consumption of the washing machine measured in litres per year	734	10,145 (1,182)	[6,400; 17,000]
Colour	Dummy	Whether the washing machine is white	739	0.81 (0.40)	[0; 1]
Capacity	Quantitative	The capacity of the washing machine measured in kilogramme	738	7.98 (1.34)	[4; 17]
Load type	Dummy	Whether the washing machine has front-load type	739	0.93 (0.26)	[0; 1]
Noise speed spin	Quantitative	The noise speed spin of the washing machine measured in decibels	730	74.55 (2.77)	[66; 82]
Built-in	Dummy	Whether the washing machine can be integrated into the wall	739	0.06 (0.23)	[0; 1]

Notes:
Obs.: Observations.
For dummy variables, a value of 1 is assigned if the feature was present and 0 otherwise.

EE in our database is represented on a scale ranging from A+++ (the most efficient) to D (the least efficient) based on the EU Energy Labelling Directive (2010/30/EU) for household appliances in force at the time. The database includes information on higher energy-efficiency levels based on extra information on reductions in energy consumption of between 10% and 70% compared to A+++ energy-efficiency level, divided into the following levels: 70%; 60%; 55%; 50%; 40%; 30%; 20%; and

10%. This information on energy consumption reduction is added to the mandatory energy label at points of sale, e.g. A+++ level minus 10% energy consumption, or A+++ level minus 20% energy consumption, etc.

90.39% of the sample is accounted for by A+++ level products, 7.98% by A++ and 1.62% by A+. The high proportion of A+++ washing machines in the sample led us to decide to focus our analysis on the most energy-efficient washing machines in the sample, i.e. those classed as A+++ with a reduction in energy consumption of 10% to 70% in KWh (*high energy-efficient level*). These machines account for 54.67% of the total sample (see Figure 16).

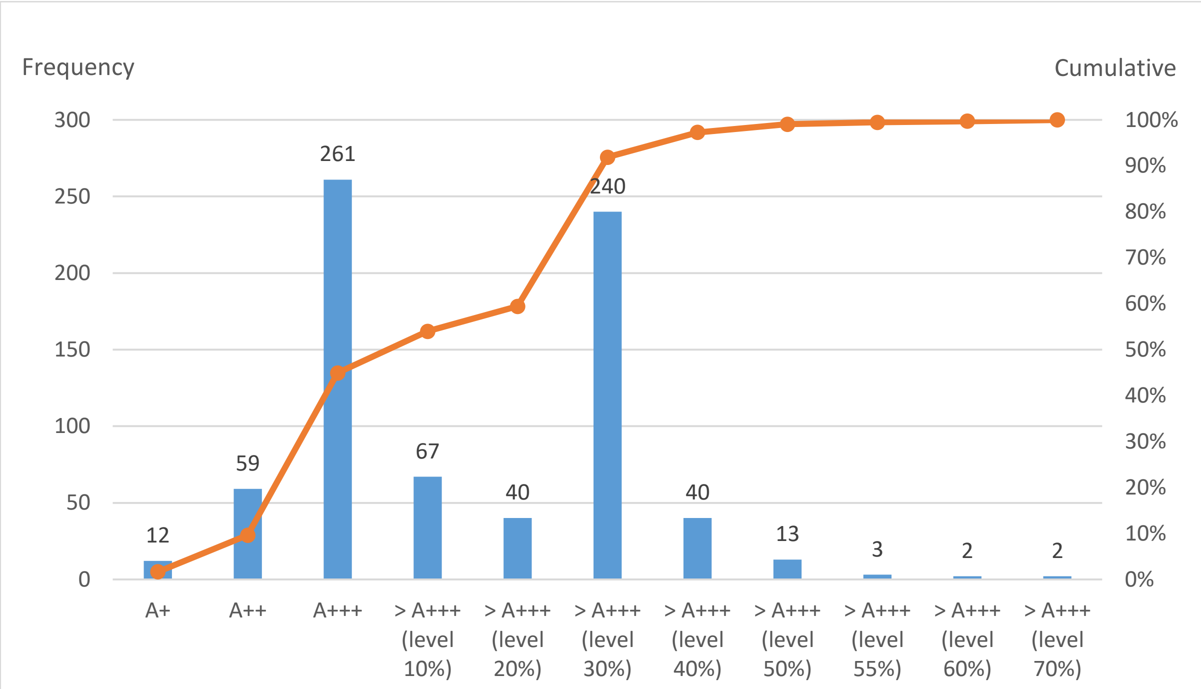

Figure 16. EE label distribution

Note: > A+++ with different % levels refers to higher energy-efficiency levels based on extra information about reductions in energy consumption from 10% to 70% compared to A+++ energy-efficiency level.

Regarding the *brand* attribute, half the washing machines belong to the following brands: *SIEMENS* (14%), *BALAY* (13%), *AEG* (8%), *SAMSUNG* (8%) and LG (7%). The other half is accounted for by the remaining brands (*WHIRPOOL, ZANUSSI, INDESIT, BEKO, MIELE, SMEG, CANDY, HAIER, TEKA, HOOVER* and *CORBERO*). We consider each of the 17 brands as a dummy variable, given that it represents numerous factors such as design, reputation and reliability[32] (Galarraga et al., 2011a; 2011b; Lucas

[32] A preliminary test was conducted with brands into low, medium and advanced according to durability in the product ranking offered by the OCU (Spanish Organization of Consumers and Users). However, this classification was not included in the final version because “brand” is not just durability but also the sum of numerous factors such as design, reputation and reliability. Accordingly, the seventeen brands included in this study are coded as dummy variables.

and Galarraga, 2015). The 17 different brands of washing machines included in this study are listed separately in Table 19 together with their summary statistics.

Table 19. Brands and summary statistics

Variable	Codification	Description	Obs.	Mean (Std. dev)	Range [Min; Max]
AEG	Dummy	Whether the brand is AEG	739	0.77 (0.27)	[0; 1]
BALAY	Dummy	Whether the brand is BALAY	739	0.13 (0.33)	[0; 1]
BEKO	Dummy	Whether the brand is BEKO	739	0.35 (0.18)	[0; 1]
CANDY	Dummy	Whether the brand is CANDY	739	0.02 (0.15)	[0; 1]
CORBERO	Dummy	Whether the brand is CORBERO	739	0.01 (0.10)	[0; 1]
HAIER	Dummy	Whether the brand is HAIER	739	0.02 (0.14)	[0; 1]
HISENSE	Dummy	Whether the brand is HISENSE	739	0.01 (0.08)	[0; 1]
HOOVER	Dummy	Whether the brand is HOOVER	739	0.01 (0.12)	[0; 1]
INDESIT	Dummy	Whether the brand is INDESIT	739	0.05 (0.21)	[0; 1]
LG	Dummy	Whether the brand is LG	739	0.07 (0.25)	[0; 1]
MIELE	Dummy	Whether the brand is MIELE	739	0.03 (0.18)	[0; 1]
SAMSUNG	Dummy	Whether the brand is SAMSUNG	739	0.08 (0.26)	[0; 1]
SIEMENS	Dummy	Whether the brand is SIEMENS	739	0.14 (0.35)	[0; 1]
SMEG	Dummy	Whether the brand is SMEG	739	0.03 (0.16)	[0; 1]
TEKA	Dummy	Whether the brand is TEKA	739	0.16 (0.13)	[0; 1]
WHIRPOOL	Dummy	Whether the brand is WHIRPOOL	739	0.06 (0.24)	[0; 1]
ZANUSSI	Dummy	Whether the brand is ZANUSSI	739	0.05 (0.22)	[0; 1]

Notes:
Obs.: Observations.
For dummy variables, a value of 1 is assigned if the feature was present and 0 otherwise.

The following variables representing technical characteristics were included in the model: *Spin-drying efficiency performance (sdp)* level *(ranging from the most efficient level, A, to the least, C), Depth* (in millimetres), *Height* (in millimetres), *Water consumption* (in litres per year), *Colour* (white or non-white), *Capacity* (in kilogrammes), *load type* (front-load or top-load), *High-speed spin noise* (in decibels) and Built-in[33].

[33] The dataset contained other valuable information such as extra-silent motor, extra rinse, Sensofresh technology, start/pause or home connect arrangements, among others, which however were not reported for many of the models and were therefore discarded from the analysis.

16% of the washing machines in the sample are in the highest-efficiency class (A) in *spin-drying efficiency performance (sdp)*, 67% are in class B and 12% in class C. The average *width*, *depth* and *height* are 581, 578 and 849 millimetres respectively. The average water consumption is 10.145 litres per annum and the *high-speed spin noise* level is 74.55 decibels. As many as 92.56% of the washing machines currently on the market are *front-load*. *White* washing machines account for 80.65% of the total. The *Capacity* of washing machines ranges from 1 to 17kg., with 7, 8, 8.5 and 9 kg models accounting for more than 84%. *Built-in* washing machines account for only 5.82%.

4.3.3. The regression model

A logarithmic transformation of the original prices (*lnprice*) is used as the dependent variable and regressed on different explanatory variables referring to different attributes. The log-linear function is chosen for different reasons. First, it is appropriate in view of the dichotomous nature of most of our explanatory variables (Galarraga et al., 2011a). Second, many other research studies in different fields use this function (Zhang et al., 2021). And third, it gives a useful explanation of the regression coefficient of independent variable, i.e. the percentage change in price when the independent variable increases by one (Galarraga et al., 2011a; Wooldridge, 2008; Zhang et al., 2021).

The general specification of the simple semi-log-linear model estimated is indicated in Eq. (1):

$$lprice_i = \propto + \beta \sum x_i + \varepsilon_i \qquad (1)$$

where $lprice$ is the logarithm of the washing machine price, $\propto$ is a constant, x_i is the vector containing the attributes and technical characteristics of the washing machine. The vector of coefficients associated with the explanatory variables is β and the error ε is assumed to be uncorrelated with x_i. The estimated hedonic-price equation applied can be expressed as follows:

$$\begin{aligned} lprice_i = \propto &+ \beta_1 HighEElevell_i + \beta_2 Catalogue_i + \beta_3 El\ Corte\ Ingles_i \\ &+ \beta_4 Supermarkets_i + \beta_5 Brand_i + \beta_6 sdpA_i + \beta_7 sdpB_i + \beta_8 sdpC_i \\ &+ \beta_9 Depth_i + \beta_{10} Height_i + \beta_{11} Water\ Consumption_i + \beta_{12} Colour_i \\ &+ \beta_{13} Capacity_i + \beta_{14} Load\ type_i + \beta_{15} Noise\ speed\ spin_i \\ &+ \beta_{16} Built - in_i + \varepsilon_i, \end{aligned} \qquad (2)$$

where the vector x_i contains explanatory variables related to (i) stores (*Catalogue, El Corte Ingles, Supermarkets*); (ii) Brand (AEG, BALAY, ..., ZANUSSI)[34]; (iii) EE level (*high energy-efficiency level*); and (iv) technical attributes (*sdpA, sdpB, sdpC*, *Depth, Height, Water Consumption, Colour, Capacity, Load type, High-speed spin noise, Built-in*) (see Table 2 and Table 3). Using this model, it is possible to estimate how much consumers actually pay for the washing machine with the highest EE level (i.e.

[34] Table 19 provides a description of each brand included in Eq. (2) together with summary statistics.

high energy-efficiency level). Note that the prices analysed include demand side and supply side factors because they are the equilibrium prices, i.e. the prices at which a consumer can buy a certain appliance.

4.4. Results and discussion

The hedonic price method enables us to estimate, *ceteris paribus (*i.e. when all other attributes and technical characteristics remain the same), the price premium of washing machines with the highest energy-efficiency level. This is done by estimating Eq. 1 by ordinary least squares (OLS) with robust standard errors using STATA software (Ver.13.1). The regression results for the hedonic price model are shown in Table 20[35]. The adjusted R-squares value of almost 0.8 suggests that the model fits the data well and explains a large proportion of the variation in price[36].

[35] We also explored a second hedonic-price model considering discounts in prices which vary depending on different factors, e.g. stock available in store. All other explanatory variables are unchanged. In this case, the price premium for high energy-efficient washing machines was found to be insignificant. This could be because discounts on price prevail in purchasing decisions, so that energy efficiency and rest of the attributes and technical characteristics are no longer significant. The full set of estimates is available from the authors upon request.

[36] A multicollinearity analysis is conducted and no multicollinearity problem is found among the selected explanatory variables. The minimum variance inflation factor (VIF) for all variables is 1.19 and the maximum is 8.46. The mean VIF in the model is lower than 10. Thus, the assumption of collinearity between variables is rejected.

Table 20. Results of hedonic price model

Variable		Coefficient	Std. error	P>|z|
EE level				
	High energy-efficient level	0.110***	0.023	0.000
Stores				
	Catalogue	0.183***	0.028	0.000
	El corte ingles	0.154***	0.023	0.000
	Supermarkets	-0.061***	0.023	0.007
Brand				
	Aeg	0.108***	0.033	0.001
	Balay	-0.115	0.027	0.000
	Beko	-0.271***	0.043	0.000
	Candy	-0.105*	0.059	0.076
	Corbero	-0.256***	0.078	0.001
	Haier	-0.278***	0.055	0.000
	Hisense	-	-	-
	Hoover	-0.125*	0.070	0.074
	Indesit	-0.185***	0.045	0.000
	Lg	-0.252***	0.039	0.000
	Miele	0.495***	0.048	0.000
	Samsung	-0.001	0.047	0.983
	Siemens	0.062**	0.027	0.021
	Smeg	0.364***	0.051	0.000
	Teka	-0.088	0.063	0.157
	Whirpool	-0.103***	0.038	0.008
	Zanussi	0.056	0.044	0.196
Technical attributes				
	sdpA	0.327***	0.051	0.000
	sdpB	0.100**	0.043	0.021
	sdpC	0.015	0.045	0.738
	Width	-0.000	0.000	0.197
	Depth	0.001***	0.000	0.000
	Height	0.001***	0.000	0.001
	Water consumption	0.000	0.000	0.101
	Colour	-0.155***	0.020	0.000
	Capacity	0.081***	0.012	0.000
	Load type	0.010	0.054	0.855
	Noise spin speed	-0.032***	0.004	0.000
	Built-in	0.310***	0.041	0.000

Note: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

The results show a significant, positive effect of *high energy-efficiency level* on price, i.e. the *highest energy-efficiency level* of washing machines (A+++ label with extra information about energy consumption savings between 10% and 70%) is valued at a price premium of 11% compared to washing machines with the same characteristics but lower EE levels (A+++, A++, A+). That is, *ceteris paribus*, the price of washing machines is 11% higher when the highest level of EE is included. This is equivalent to €67 out of the average washing machine price of €612.60.

Our price premium estimate is consistent with the previous literature, where a positive price premium for EE is found in all cases with some differences in size depending on type of appliance, country and year analysed, as reviewed in Section 4.2. Moreover, it is important to bear in mind that the EE attribute does not represent the same EE level in all studies, so comparisons should be made with caution. Figure 17 shows the price-premium for EE (in percentages) of different household appliances in several countries and different years.

Recall that Lucas and Galarraga (2015) find that in 2012 washing machines with the highest energy–efficiency label (in this case A+++) in Spain were sold with a price premium of 4.15% (€19.79) compared to those with lower EE. Changes in the design of the label prevent a direct, straightforward comparison from being made but one could argue that the price premium for high energy-efficiency washing machines in Spain has increased, as the new estimate is more than double the previous one. This apparent increase in the premium may be explained by three reasons: (1) efforts to enhance information and raise awareness with respect to EE and climate change may have proved effective and significantly increased consumers' WTP for EE (Ramos et al., 2015); (2) the EE label is now well-known and more highly rated as an instrument for providing information about the EE level of washing machines and thus promoting energy-efficient choices (de Ayala et al., 2020; de Ayala and Solà, 2022); and (3) changes driven by technological progress, standards for EE and consumers' perceptions of electricity price (i.e. the expected electricity price) may also have encouraged investment in energy efficient appliances (Schleich et al., 2021).

The price premium estimated in other countries for high energy-efficiency washing machines is greater than that estimated in Spain. Sammer and Wüstenhagen (2006) estimate a price premium of 30% for A level energy-efficient washing machines in Switzerland in 2004. This difference can perhaps be explained by standards of living and by the price of electricity in Switzerland. Zha et al.(2020) show that the average WTP of Chinese consumers for each increase in the energy-efficiency level of washing machines was 16% in 2017.

A comparison of our estimate with those for other types of appliance reveals that the price premium trend for EE in washing machines is in general systematically lower than for refrigerators and TVs[37]. This may be explained by the fact that although washing machines are among the most important appliances in the home (de Ayala et al., 2020) they may be less used than others such as refrigerators or TVs (IDAE, 2021a). In fact, refrigerators were ranked first in Spain out of all the appliances used in 2019, followed by TVs and washing machines (IDAE, 2021a). This might be because refrigerators are used 24/7 all year round (Zha et al., 2020), so there is more incentive to invest in EE (del Mar Solà et

[37] There is an exception of three cases in which the price-premium estimates for refrigerators are similar to our price premium estimation for washing machines: 8.66% on average in the United States in 2008 (Houde, 2014); 8.9% in Spain in 2009 and 12.6% in Spain in 2012 (Galarraga et al., 2011b; Lucas and Galarraga, 2015).

al., 2021). EE seems to be key for energy savings in the case of refrigerators, while energy use in the home may be more important for reducing the energy consumption of washing machines (de Ayala et al., 2020; del Mar Solà et al., 2021; Pollitt and Shaorshadze, 2011; Trotta, 2018).

The price-premium estimates for dishwashers and air purifiers are in the range of washing machines (between 4% and 15% for dishwashers and 9.1% for air purifiers). However, for air conditioners price premiums vary substantially (between 8% and 36%) depending on the country and year analysed.

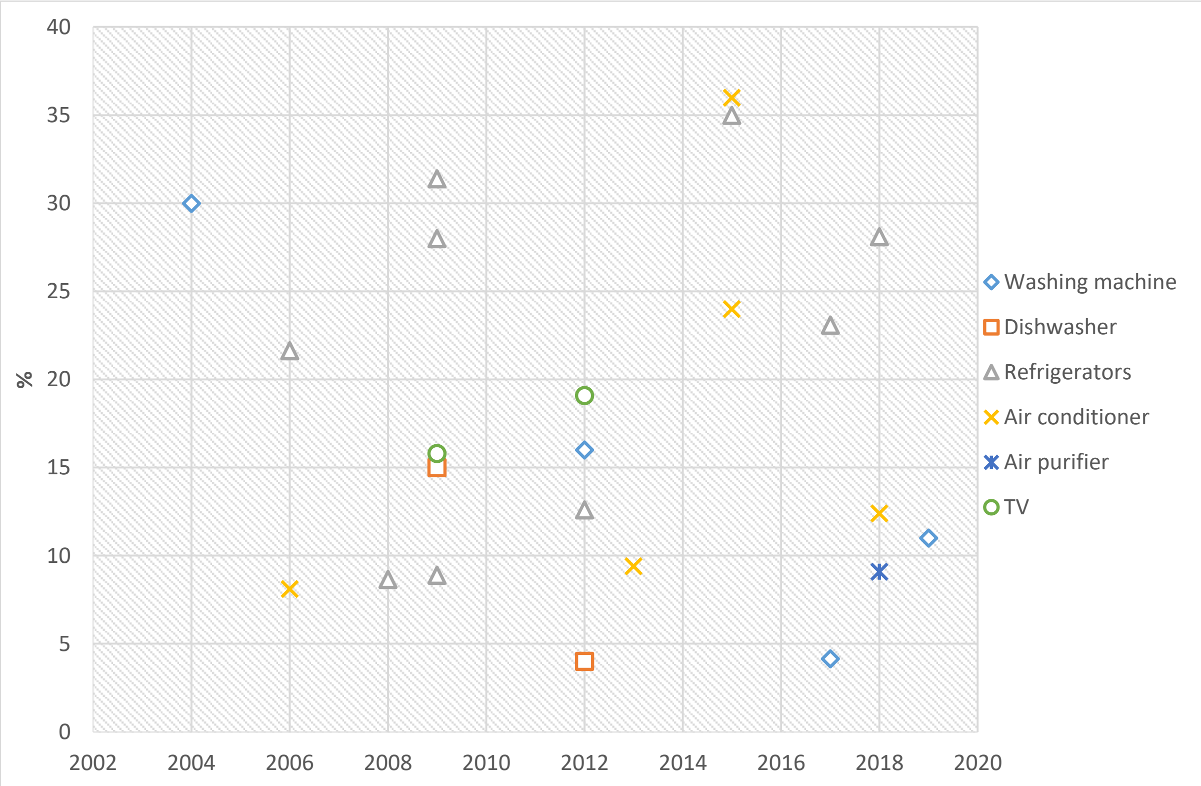

Figure 17. Price premiums (%) for high energy-efficiency level estimated for different types of household appliance

Our results also show that product prices may vary substantially from one point of sale to another. In particular, *ceteris paribus*, washing machines bought via an online *catalogue* or at *El Corte Ingles* website are 18% and 15% more expensive, respectively. This last price premium is in line with Lucas and Galarraga (2015), who find that the *El Corte Ingles* website sells washing machines at higher prices (14%). However, washing machines sold on *supermarket* websites cost 6% less than at the other stores analysed.

Brand has the highest price premium. We find that, all else being equal, customers who buy the *MIELE* brand (considered as an advanced brand according to average product prices) are willing to pay a premium of 49%, followed by *SMEG (36%), AEG* (11%) and *SIEMENS* (6%). However, *BEKO, HAIER, CORBERO, INDESIT, HOOVER, WHIRPOOL* and *CANDY* are considered as low-prestige brands (OCU, 2021), and have a negative effect on prices (ranging from 10% to 27%) all else being equal. These price premiums for brands are in line with a study conducted in Spain in 2012 (Lucas and Galarraga, 2015) (for a more detailed comparison of brand-based price premiums in Spain, see appendix 4A). In this regard, Sammer and Wüstenhagen (2006) estimate that customers are willing to pay a premium of 86% for the most popular brands (VZug and Miele) compared with no-name washing machines. Finally, literature analysing other appliances in other countries finds that prices of foreign products are much higher than those of domestic products (Zhang et al., 2021; Zhang and Tao, 2020). Specifically, Zhang et al.(2021) show that the price of foreign-brand air conditioners is 47% higher than that of Chinese-made units. Zhang and Tao(2020) reveal that foreign refrigerator prices are 71% higher than those of domestic Chinese products and that the prices of low, medium, and advanced brand refrigerators increase by around 63% with increases in market positioning.

In terms of technical attributes of washing machines, class A *spin drying performance* (*sdpA*) has a significant positive effect on price. Prices for machines with high drying efficiency (class A spin drying efficiency) are around 33% higher than for classes B and C, *ceteris paribus*. For washing machines with class B spin drying efficiency the proportion of the price explained is 10%. These results are compatible with those of Lucas and Galarraga (2015), who find that washing machines with *sdpA* cost more than the others in Spain (*sdB* or *sdpC*). *Width* seems not to be an important attribute for buyers of washing machines, while *depth* and *height* have a positive, albeit very small, effect on price. One possible reason is that most washing machines that cannot be built into the wall tend to have standard dimensions. *Water consumption* does not seem to be a major factor in purchases either. The literature seems to be conclusive with respect to the significance of this attribute. For example, Sammer and Wüstenhagen (2006) estimate a negative impact of water consumption on the purchase of high energy-efficiency washing machines, but Lucas and Galarraga (2015) and Zha et al. (2020) find no significant effects for this attribute.

However, built-in washing machines are 31% more expensive that non-built in units with all else being equal. Also, white washing machines cost 15.5% less than non-white ones, all else being equal. Washing machines with a higher *capacity* seem to be more expensive (8.1%). A similar result was found for washing machines in Spain in 2012 (Lucas and Galarraga, 2015) and elsewhere in 2017 (Zha et al., 2020). *High-speed spin noise* has a negative effect consistent with the fact that noiseless washing machines tend to be more slightly more expensive (3.2%). Finally, l*oading type* seems not to be an important attribute.

4.5. Conclusions and policy implications

Household appliances in Spain accounted for about 62% of residential electricity consumption in 2019 so there is a need to improve their EE. EE provides an opportunity to substantially reduce household energy consumption and to meet the substantial energy-saving targets that authorities worldwide are aiming for. In this context, many countries have introduced EE labels as a key policy for attaining energy and climate policy targets. This policy instrument is expected to induce consumers to purchase more energy-efficient products through the provision of observable, consistent, credible information.

Using market data for 2019 in Spain, this study estimates how much consumers actually pay for the EE attribute, with all other attributes of appliances assumed to remain the same. To that end, we apply the hedonic price method, which enables us to calculate the marginal price differential due to improvements in EE. Our findings provide some insights into the effectiveness of EE labels for washing machines in recent years compared with the price premium estimated previously in Spain for the same appliances. We also compare our findings with similar studies analysing different appliances in different countries and years.

The hedonic method suggests that the price premium paid in the market for washing machines with the highest energy-efficiency level is 11% of the final price, i.e. €67 out of the estimated average price for washing machines on the Spanish market. Changes in the design of the EE label and the fact that EE levels are not exactly the same prevent a direct, straightforward comparison from being made, but our figure is much higher than the price premium estimated in 2012.

In most countries the price premium for EE on washing machines is systematically lower than for refrigerators, but for other appliances (e.g. air conditioners, air purifiers and TVs) it is slightly higher. This makes perfect sense, as consumers may have more incentive (and therefore be more willing) to pay more for EE in appliances which are used more frequently.

The information obtained with respect to WTP for different attributes may be also useful to appliance manufacturers. We find that brand reputation has the highest premium (49%), but brands considered as low-prestige negatively affect prices. This is in line with the previous literature, which suggests that the price premium of a specific appliance increases as the market positioning of the brand increases.

Specific technical characteristics also have significant effects. Attributes such as high *spin drying performance* (*sdpA*), *Built-in* and *higher capacity* seem to have a significant positive effect on the price of washing machines (33%, 31% and 8.1%, respectively), whereas white machines and *high-speed spin noise* have negative impacts of 15.5% and 3.2%, respectively.

Our findings have clear policy implications. First, knowing the precise premium paid on the market for the EE attribute is useful in designing the subsidy and rebate schemes widely used to encourage the purchase of efficient appliances. In addition, one similar studies could be run every few years to learn how the price premium is evolving and see what kind of measures and policies have been taken during that time. This is part of the information needed to understand whether policies and other efforts to promote EE are proving effective or not. Secondly, the increase in the price premium for high-energy efficiency washing machines in Spain (roughly estimated at 5%) suggests that efforts to enhance information and raise awareness with respect to EE and climate change may have become effective and significantly increased consumers' willingness to pay for EE. Moreover, the EE label for appliances is widely established in the appliances market, consumers are aware of it and take it more and more into account when buying. Of course, many other supply-side factors (such as new standards for EE and technological progress) and electricity prices may also explain this increase. In any case, the figures estimated are consistent with most research on price premiums for EE. All studies tend to find a positive premium in all cases but with some differences in size depending on the type of appliance, country and year analysed. These differences in the price premium are likely to reflect differences in national policies promoting the dissemination of energy-efficient appliances, such as information and awareness campaigns, rebates and taxes, plus other supply side factors such as technological progress and standards for EE. Likewise, electricity price differences may lead to different financial incentives to adopt more EE appliances across countries. Finally, the estimated differences in price premiums across countries suggest that cultural and environmental factors may also play an important role in purchasing decision-making by consumers.

Chapter 5: Conclusions

Energy efficiency is a key factor in the fight against climate change and in reducing energy consumption. However, despite its significant monetary benefits and environmental advantages, EE adoption levels are generally low, as shown by the EE gap. This thesis applies a combination of participatory and quantitative methodologies to enhance understanding of how to effectively promote EE in the building sector and for HVAC and other household appliances. Specifically, the findings presented here are particularly important in addressing the EE gap and providing insights for effective policies. The results from the views of different stakeholders (Chapters 1 and 2), obtained via surveys and the so-called FCM are contrasted with an integrative approach incorporating all stakeholders (Chapter 3). A quantitative assessment (Chapter 4) is also undertaken to better understand how highly consumers value the energy efficiency attribute.

- **The views of the hotel industry on the factors that affect the energy efficiency rating for investments in HVAC systems (Chapter 1)**

Results from Chapter 1, based on a survey for the hotel industry, identify factors that influence the EE choices of Spanish accommodation owners and contribute to the literature exploring the barriers to EE investment in that sector. The main finding from this survey is that there seems to be a gap between beliefs and purchasing decisions for energy-efficient HVAC system due to multiple barriers to EE. Indeed, 40% of hotel owners indicated that they were willing to take a chance on new technologies to reduce their energy consumption, but only 6% reported that they planned to change their HVAC systems. The most common barriers affecting the consideration of EE by hotels in Spain are lack of access to loans, the principal-agent problem (e.g. owners value the need for specific measures which could make customers more aware of and more responsible in regard to their energy consumption), the bounded rationality problem (i.e. only 7.5% strongly agreed that they understand how much money they would save if they bought a more energy-efficient HVAC system) and organisational barriers (e.g. willingness to take a chance on new technologies and the comfort and environmental values of establishments).

EE is the attribute most frequently rated by accommodation owners as very important in choosing an HVAC system. Other, less highly rated attributes also classed as important in purchasing decisions are noise level (decibels), followed by price, brand reliability (i.e. durability and technical & maintenance support) and performance (such as automatic control, temperatures adjustable according to outside temperature and humidity level, heat recovery and integrated heating and cooling functions).

These findings have several policy implications:

(i) This analysis shows that different responses may be obtained by decision makers in different climate areas: policies could be directed first at areas such as continental climates, where agents seem to be more responsive to EE concerns. That is, establishments in areas with a continental climate are more likely to value EE as a very important attribute than those located in a Mediterranean climate. This may be because energy costs in a continental climate (characterised by hot summers and cold winters) are much higher than in other climates.

(ii) The survey hotel industry reveals a lack of knowledge among hotel owners about the energy and monetary savings provided by more energy-efficient equipment. This clearly suggests that information-based policy instruments such as labels, energy audits and feedback on bills may be needed. This is reinforced by the fact that many owners do value the information provided by labels, and would like monetary information to be included. Most of the hotel owners interviewed think that labels with additional monetary information are more understandable and trustworthy than existing EE labels. In fact, most respondents said that a label with additional monetary information would be more helpful in understanding how much energy was consumed by an HVAC system and calculating how much it cost to run.

(iii) Subsidies may help overcome the gap between beliefs and purchasing decisions, but they may also exacerbate free-riding and rebound effects. Analysing the rebound effect, we find that when establishments invest in insulation this may lead them to under-rate the EE attribute. In fact, around 60% of the sample consider that the saving in EE would enable the services offered by the establishment to be expanded and more electrical appliances to be fitted, producing a rebound effect. This suggests that subsidies could be linked to the introduction of stricter energy performance standards or energy taxes.

(iv) Energy taxes may also help accentuate pro-energy-efficiency attitudes among current owners of fossil-fuel-fired HVAC systems. Our results confirm that a higher associated cost for energy would reinforce the importance given to EE, encouraging owners to reconsider their currently low willingness to upgrade HVAC systems, though subsidies may also be required to help overcome the bounded rationality problem.

(v) Finally, related to command and control instruments, the fact that EE is strongly linked with price, brand reliability and performance means that those who invest in cheaper, low-quality equipment seem less likely to rate EE highly. Here, the introduction of stricter, mandatory EE standards across the board would ensure that energy is saved even in such cases.

- **Identifying effective policies for energy efficiency in the residential heating sector, accounting for the views of households, academics and energy experts (Chapters 2 and 3)**

One of the main challenges for effective policy design is the acceptability of measures, so understanding the views of different stakeholders is essential. This thesis seeks to understand consumers' heating behaviour and perceptions and the knowledge of experts on private and public adaptation policies for low-carbon heating behaviour. To that end, a participatory method based on Fuzzy Cognitive Mapping is used to try to separate their views and understanding of the factors, individual actions and policies that may directly affect heating bills. This method is based on fuzzy graph structures to represent causal reasoning. It enables the drivers of heating expenditure to be depicted, along with the interactions between them from behavioural to policy-related factors.

Looking at the various perceptions of key stakeholders in Spain, households, academics and energy experts all consider that not just economic variables such as energy price and income but also technological variables such as insulation and thermostats are determinants of heating bills. Other factors mentioned include socio-cultural factors, habits and preferences regarding the thermal comfort temperature by day and by night. Focusing on what policy instruments might be most effective in successfully nudging people towards highly energy-efficient heating choices, we find differences between the groups. The policies mentioned by academics and energy experts differ from those mentioned by households. Based on focus group discussions, academics and energy experts seem to support "environmental education policies" directly, e.g. the showing of information on the impact of individual heating consumption on emissions of CO_2 and other pollutants and their effects on the environment. Households, however, say very little about them. Academics and energy experts also consider that taxes could be used to reduce energy consumption through policies such as "taxing bad habits in energy consumption" or "taxes on fossil fuels". Households do not mention taxes at all but focus on the role of "subsidies" in helping alleviate energy poverty and economic barriers. Specifically, households attribute more importance to the role of energy policies focused on subsidies for people suffering financial hardships and for the installation of renewable energy systems. Households also mention information policies to help people understand energy bills.

All these differences can be noted to help tailor policies and make progress in regard to the acceptability of policies to promote low carbon behaviour in the residential building sector. For example, this research confirms that households prefer policies that do not lead to direct costs for them (i.e. education and information programmes, subsidies) rather than policies which cost them directly (i.e. taxes). However, academics and energy experts seems to be more in favour of introducing energy taxes, perhaps linked to subsidies, education and information programmes and standards. These differences point to where policy-makers might focus in making future energy policies more acceptable. The acceptability of taxes versus subsidies has long been studied in other areas of economics. These findings are in line with previous literature (Cherry et al., 2012; Heres et al., 2017).

The fact that previous research finds differences between stakeholders in policy preferences reinforces the importance of contrasting those differences using an integrative participatory approach. Unlike Chapter 2, where perceptions are analysed separately, Chapter 3 integrates all views into a common methodological framework. This makes for a deeper understanding of the expected impact of energy-efficiency policies. Indeed, considering various groups of stakeholders and the combinations of their interests represented during the decision-making process can be an effective tool for making future EE policies more acceptable. To that end, a Fuzzy Cognitive Mapping approach is applied to integrate the views of key stakeholders in Spain (academics, households and energy experts). This analysis reveals direct and indirect effects of certain concepts on policies and highlights connections which have non-obvious effects that should be considered in designing effective EE policies on heating transition.

Stakeholders assign great potential to "environmental education and information policy" because it is expected not just to produce more energy-efficient heating systems but also to result in better energy-saving habits, the use of individual rather than central heating systems and investment in insulation and the use of thermostats. In terms of command control policy instruments, "technical standards" are expected to positively impact the efficiency of dwellings and certificates, while "energy-saving regulations" are perceived to favour more energy-efficient heating systems and better energy-saving habits. Additionally, stakeholders perceive that a combination of "technical standards" and "energy saving regulations" policy instruments would reinforce their effects, resulting in a much stronger impact on heating bills and energy consumption. Regarding economic instruments, the results when all views are integrated indicate that taxes are expected to be more effective than subsidies, which is indeed what economic theory teaches us. In fact, a direct tax on consumption would result in a major reduction in heating consumption. However, the finding that households prefer subsidies to energy taxes in the previous analysis is particularly interesting. In this sense, efforts to implement EE policies through energy taxes may lead to a backlash from households. In the light of variation in the policy acceptability of energy tax, this economic instrument could be combined with subsidies which enable energy cost, and thus tax, to be reduced. For example, a "tax focused on fossil fuel used for heating" (i.e. a carbon tax which ensures that costs related to carbon dioxide emissions are assigned individually and not shifted to society in general) linked to "subsidies" for replacing fossil fuel fired heating systems could result in an increase in energy-efficient heating systems and investment in insulation, but also a drop in energy prices.

Finally, in terms of helping to find solutions, combining economic policy instruments with other instruments (command and control and information policy instruments) results in the largest reduction in heating consumption. Specifically, a policy package inspired by energy-efficiency experts and based on the policy instruments defined by all stakeholders in Chapter 2 is perceived to increase energy prices but expected to have a large impact on energy-efficiency improvements, promoting energy-saving habits and thus reducing energy consumption on heating. This policy package includes (i) "energy-saving regulations"; (ii) "environmental education and information"; (iii) "subsidies"; (iv) "taxing fossil fuel used for heating"; and (v) "technical standards".

Several policy implications arise from this analysis. Overall, what seems to work is a policy mix rather than a single policy in isolation. This research highlights that the application of a policy package may be useful for less coercive policy instruments (especially for households) and for ambitious EE targets. In particular, ambitious "technical standards" and "specific regulations about maintenance of heating systems" would ensure that energy is saved. Additionally, "environmental education and information policies" seem to be useful to consumers in making better decisions. "A tax focused on fossil fuel used for heating" is also believed to be needed, although it may be difficult to reconcile with household preferences. This tax aversion can be dealt with through fiscal education and revenue recycling (Kallbekken et al., 2011). Findings from policy packages also reveal that to increase the acceptability of energy taxes they should be combined with "subsidies" (e.g. transfers for replacing fossil-fuel-fired heating systems).

- **Evidence on the effectiveness of energy-efficiency labels and insights into how such a policy instrument should be designed (Chapter 4)**

In an attempt to supplement semi-quantitative methods with a quantitative approach, this thesis estimates how much consumers actually pay on the market for EE labels. The contrast between the results of stakeholder perception analysis that include the views of the hotel industry, academics, households and energy experts (Chapters 1, 2 and 3) and the results of this quantitative analysis (Chapter 4) are useful to help design better EE policies. Contrasting the two types of analysis may be useful because it enhances understanding of the views of key stakeholders about behavioural factors behind energy consumption. This can shed light on the main barriers to and effects of certain policy instruments. This analysis uses a hedonic price method to provide evidence on the effectiveness of energy-efficiency labels implemented in the appliance sector. Estimating the price-premium is useful to help design the widely used rebate schemes that seek to support the purchase of high-efficiency appliances. Additionally, comparison of premiums over time could also provide an idea as to whether actual willingness-to-pay (WTP) for EE is increasing or not.

The results are found to be in line with the views of stakeholders. EE labels are a key policy for attaining energy and climate policy targets. They are expected to induce consumers to purchase more energy-efficient products through the provision of observable, consistent, credible information. Our results suggest an increase of roughly 5% in the price premium for high energy-efficiency washing machines in Spain. This means that efforts to enhance information and raise awareness with respect to EE and climate change may have been effective and significantly increased consumers' willingness to pay for EE.

These findings have important policy implications. First, knowing the precise premium paid on the market for the EE attribute is useful in designing the subsidy and rebate schemes widely used to encourage the purchase of efficient appliances, i.e. in establishing the right amount to be subsidised. In addition, similar studies could be run every few years to learn how the price premium is evolving and learn more about the connection between its evolution and the policies implemented during that time. This is part of the information needed to understand whether policies and other efforts to promote EE are proving effective or not. Secondly, the increase in the price premium for high-EE washing machines in Spain (estimated at roughly 5%, as the difference between our analysis and earlier similar efforts) suggests that efforts to enhance information and raise awareness with respect to EE and climate change may have been effective and significantly increased consumers' willingness to pay for EE. Moreover, the EE label is widely established in the appliances market, consumers are aware of it and take it more and more into account when buying. But it must also be acknowledged that the increase in the premium could be due to several other supply-side factors (such as new standards for EE and technological progress) and/or increasing electricity prices.

- **Final remark**

The research presented in this thesis has proven useful in illustrating the need to combine different methods to enhance understanding of behaviour in the field of EE. The thesis highlights the need for deeper understanding of the perceptions of key stakeholders. As regards effectively promoting EE, the quantitative approach used illustrates the effectiveness of EE labels, which seem to be one of the most highly valued EE policies for overcoming informational barriers. A lot remains to be done before a complete picture is obtained of the building sector on the path to climate neutrality by 2050, but the analysis undertaken has proven useful in effectively promoting effective EE policies.

The understanding and consideration of stakeholders' perceptions as to the decarbonisation of heating in buildings suggest that a number of policy practices are particularly effective across hotels and households. First, economic instruments are needed especially to support deployment of the heating transition but there are differences between energy taxes and subsidies in terms of acceptability. Energy taxes seem to be more effective for energy savings since they keep energy prices higher in the long term and discourage energy consumption. However, we find consistent preferences for subsidies among households and other consumers. For example, given the differences between beliefs and purchasing decisions in regard to energy-efficient HVAC systems in the hotel industry, policymakers should ensure that there is a clear financial incentive to invest in such systems. At the same time, households appear more willing to accept subsidies to encourage energy-efficiency improvements. In the light of variation in the acceptability of policies for different economic instruments, energy tax could be combined with subsidies (as argued in Galarraga et al. (2016), Galarraga et al. (2013)) or with other revenue recycling schemes (Kallbekken et al., 2011), which result in lower effective energy prices. This combination may positively affect the acceptability of taxes. However, subsidies may also exacerbate free-riding and rebound effects. As a solution, the literature suggests addressing subsidies exclusively at those customers who, due to constraints related to income or access to capital, would not make investments in the absence of policies (Labandeira et al., 2020; Schleich, 2019).

Second, command and control instruments are also needed to support deployment of the heating transition at hotels and households. The fact that EE is strongly linked with price, brand reliability and performance means that those who invest in cheaper, low-quality equipment seem less likely to rate EE highly. Here, the introduction of stricter, mandatory EE standards across the board would ensure that energy is saved even in such cases. For residential heating, energy-saving regulations and technical standards are perceived to produce more energy-efficient heating systems but also to result in better energy-saving habits, which in turn should reduce consumption and heating bills.

At the same time, improving the information available about environmental effects and energy savings for establishment owners and households is another promising field of action for the design of effective policies, especially if they are well designed and they remain in place for long enough (Ramos et al., 2015). HVAC systems have higher upfront costs, but information on lifetime energy savings is not considered. Providing owners with monetary information, for example through EE labels with energy-related running costs, can help reduce their upfront costs. For households, information feedback tools through feedback on energy bills may result in better energy-saving habits.

Finally, according to EE stakeholder perceptions, the hedonic price method shows that consumers actually pay a price premium of 11% for high energy-efficiency washing machines compared to machines with the same characteristics but lower EE. Other specific attributes such as brand, place sold, spin-drying performance and built-in washing machines are also very important in purchasing decision-making. Given that purchasing decisions are made by assessing the full set of attributes, energy-efficient investments require the continued expansion of policies considering all of them. This suggests that confidence in technology improvements provided by markets is feasible if supported by well-designed policies.

- **Limitations and future research**

The following limitations and avenues for future research emerge from each of the chapters of this thesis:

(i) The analysis in Chapter 1 is constrained by a limit on the replacement rate of energy-efficient HVAC systems in the sample. Further research is needed on owners who have upgraded to a more energy-efficient HVAC system in recent years, so as to be able to measure how they translate under–investment in EE.

(ii) Chapters 2 and 3 have limitations primarily associated with their participatory approach. It can be argued that different focus groups may lead to relatively different findings. This limitation can be addressed by using a larger group of households or experts to better accounting for individual heterogeneity. Households, as end users of products, are key in the energy transition. Considering their endogenous, heterogeneous and control-averse behaviour, future research should explore new policy scenarios that give greater weight to household perceptions. Additionally, extending expert groups to include architects, building material and heating technicians could contribute to the co-design of low carbon heating behaviours.

(iii) Finally, Chapter 4 has limitations primarily associated with the perceptions of electricity prices. Given the current energy crisis and soaring prices, it is important to analyse whether the perception of these high electricity prices could have influenced the premium paid for EE. The fact of heterogeneous behaviour by consumers reinforces the importance of compensatory measures. In this sense, future work should examine how the price premium is distributed across different levels of income. There are also many other factors that could influence the apparent increase in the premium, such as changes produced by technological progress and efforts to enhance information and raise awareness with respect to EE and climate change. In this regard, it would be interesting to compare the price premium with actual electricity cost savings from energy-efficient washing machines. The market responses of manufacturers could also be included, e.g. to estimate what manufacturers think they can get for EE by including the changing level of competition or concentration in the market as additional explanations of the trend in the value of EE.

Appendices

Appendix 1A: Detailed information on hotel industry establishments

Geo-climatic areas	Mediterranean		Atlantic		Continental	Subtropical		Mountain
	Coast	Inland	Coast	Inland	Inland	Coast	Inland	Inland
	8%	13%	7%	14%	21.5%	6.5%	8.5%	21.5%

Type of accommodation	Hotel	Hostel	Cottage
	33.5%	33.5%	33%

	Hotel	Hostel	Cottage
Star-rating	Five Gold Star 1.49% Four Gold Star 25.37% Three Gold Star 29.85% Two Gold Star 23.88% One Gold Star 19.40%	Three Silver Star 1.49% Two Silver Star 50.75% One Silver Star 47.76%	Five “Wheat ears” 1.52% Four “Wheat ears” 4.55% Three “Wheat ears” 16.67% Two “Wheat ears” 15.15% One “Wheat ears” 15.15% Not defined 46.97%

Number of rooms	From <10 to >150			From <5 to >25			From <3 to >7		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
	58.42	6	434	15.15	3	42	15.15	3	28

Appendix 1B: Descriptive statistics for dependent and explanatory variables (N=191)

Variable	Unit	Mean	SD	Min	Max
Type of accommodation	Number 1= Hotel 2= Hostel 3= Cottage	1.99	0.82	1	3
Climate	Number 1=Mediterranean (coast & inland) 2=Atlantic (coast & inland) 3=Continental (coast & inland) 4=Subtropical (coast & inland) 5=Mountain (inland)	2.95	1.44	1	5
Owners of the building (=1 if yes)	0/1 dummy	0.88	0.33	0	1
Number of years in operation	Number	16.72	15.27	1	86
Occupancy rate in high season	%	79.99	17.84	10	100
Current financial situation	Number	6.40	1.62	2	10
Future financial situation	Number	7.22	1.58	2	10
EE as a *very important* attribute	0/1 dummy	0.67	0.47	0	1
HVAC system with natural gas	0/1 dummy	0.13	0.33	0	1
HVAC system with propane	0/1 dummy	0.10	0.30	0	1
HVAC system with heating oil	0/1 dummy	0.36	0.47	0	1
HVAC system with electricity	0/1 dummy	0.58	0.50	0	1
Heating system with biomass	0/1 dummy	0.15	0.36	0	1
HVAC system with geothermal	0/1 dummy	0.01	0.10	0	1
Heating-only system	0/1 dummy	0.72	0.45	0	1
Price (=1 if very important)	0/1 dummy	0.62	0.49	0	1
Brand reliability (=1 if very important)	0/1 dummy	0.53	0.50	0	1
Performance (=1 if very important)	0/1 dummy	0.51	0.50	0	1
Noise (=1 if very important)	0/1 dummy	0.63	0.48	0	1
Access to loans limits my purchases (=1 if strongly agree)	0/1 dummy	0.30	0.46	0	1
Understand the energy consumption (=1 if strongly agree)	0/1 dummy	0.38	0.49	0	1
Take a chance on new technologies (=1 if strongly agree)	0/1 dummy	0.38	0.49	0	1
Effectiveness of energy consumption information (=1 if strongly agree)	0/1 dummy	0.14	0.34	0	1
Understandable (=1 if strongly and slightly agree)	0/1 dummy	0.85	0.36	0	1
Trustworthy (=1 if strongly and slightly agree)	0/1 dummy	0.79	0.41	0	1
Influence on purchasing decision (=1 if strongly and slightly agree)	0/1 dummy	0.87	0.34	0	1
Helpful to understand how much energy is consumed by HVAC (=1 if strongly and slightly agree)	0/1 dummy	0.83	0.38	0	1
Concern for the environment (=1 if extremely concerned)	0/1 dummy	0.43	0.50	0	1
Automatic control (=1 if always)	0/1 dummy	0.38	0.49	0	1
Regular information to promote responsible consumption of energy and water (=1 if always)	0/1 dummy	0.71	0.45	0	1
EE Appliances (=1 if yes)	0/1 dummy	0.58	0.50	0	1
EE windows (=1 if yes)	0/1 dummy	0.60	0.49	0	1
Wall and roof insulation (=1 if yes)	0/1 dummy	0.56	0.50	0	1
Sensors (=1 if yes)	0/1 dummy	0.59	0.49	0	1
Solar panels (=1 if yes)	0/1 dummy	0.24	0.43	0	1

Appendix 1C: Full questionnaire for hotel industry establishments in Spain

Screening	**Category of answer / Coding**
Type of accommodation	1 (Hotel); 3 (Hostel); 4 (Cottage)
Climate zones	1 (Mediterranean-Coast); 2 (Mediterranean-Inland); 3 (Atlantic-Coast); 4 (Atlantic-Inland); 5 (Continental-Coast); 6 (Continental-Inland); 7 (Subtropical-Inland); 8 (Mountain-Inland)
Do you own the building or does your establishment operate in the building under a lease agreement?	1 (Owner); 2 (lease agreement)
Are you the person in charge of making the decision whether to purchase HVAC systems?	1 (Yes); 0 (No)
HVAC Technical characteristics	
Please indicate the type of HVAC system at your establishment	
Reverse cycle air conditioning system (cold and hot air)	0 (No); 1 (Yes)
Heating-only system (wall radiator, portable radiator, fireplace or wood stove, underfloor heating)	0 (No); 1 (Yes)
Cooling-only system (fixed or portable)	0 (No); 1 (Yes)
Ceiling fan	0 (No); 1 (Yes)
Other	[Open text]
Energy source used for HVAC system:	
Natural gas	0 (No); 1 (Yes)
Propane	0 (No); 1 (Yes)
Heating oil	0 (No); 1 (Yes)
Electricity	0 (No); 1 (Yes)
Biomass	0 (No); 1 (Yes)
Solar energy	0 (No); 1 (Yes)
Geothermal energy	0 (No); 1 (Yes)
Other	[Open text]
How old is your HVAC system?	
Reverse cycle air conditioning system (cold and hot air)	[Open text]
Heating-only system, wall radiator	[Open text]
Heating-only system, portable radiator	[Open text]
Heating-only system, fireplace or wood stove	[Open text]
Heating-only system, underfloor heating	[Open text]
Cooling-only system, fixed	[Open text]
Cooling-only system, portable	[Open text]
Ceiling fan	[Open text]
Other systems	[Open text]
Attributes of the purchasing decision	
Has your establishment changed its HVAC system in the *last five years*?	0 (No); 1 (Yes); -999 (Don't know /No answer)
[if Q5=NO] Why?	
Our HVAC system works properly	0 (No); 1 (Yes); -999 (Don't know / No answer)
Because the infrastructure of the building makes it difficult	0 (No); 1 (Yes); -999 (Don't know / No answer)
Lack of access to finance	0 (No); 1 (Yes); -999 (Don't know / No answer)
I consider that the current HVAC system is the most efficient	0 (No); 1 (Yes); -999 (Don't know / No answer)
The current HVAC system was installed recently	0 (No); 1 (Yes); -999 (Don't know / No answer)
I have other refurbishments planned and cannot afford also to change the establishment's HVAC systems	0 (No); 1 (Yes); -999 (Don't know / No answer)
Because the current HVAC system covers the needs of our establishment	0 (No); 1 (Yes); -999 (Don't know / No answer)
Other	[Open text]
[if Q5=1] For what purpose?	

To modernize the HVAC system	0 (No); 1 (Yes); -999 (Don't know / No answer)
To switch to a more efficient HVAC system	0 (No); 1 (Yes); -999 (Don't know / No answer)
To install a reversible system (heating, hot water and air conditioning)	0 (No); 1 (Yes); -999 (Don't know / No answer)
To change the energy source used by the HVAC system	0 (No); 1 (Yes); -999 (Don't know / No answer)
Other	[Open text]
Do you intend to change the current HVAC system at your establishment in the *next 5 years*?	0 (No); 1 (Yes); -999 (Don't know / No answer)
Please rate the importance of each of the following characteristics when buying an HVAC system	
Price	1 (not at all important); 2 (not very important); 3 (fairly important); 4 (very important); -999 (Don't know/ No answer)
Energy efficiency / Energy consumption	1 (not at all important); 2 (not very important); 3 (fairly important); 4 (very important); -999 (Don't know/ No answer)
Brand reliability (durability, technical & maintenance support, etc.)	1 (not at all important); 2 (not very important); 3 (fairly important); 4 (very important); -999 (Don't know/ No answer)
Performance (hot and cool air, remote control, etc.)	1 (not at all important); 2 (not very important); 3 (fairly important); 4 (very important); -999 (Don't know/ No answer)
Noise	1 (not at all important); 2 (not very important); 3 (fairly important); 4 (very important); -999 (Don't know/ No answer)
Attitudes towards EE (exploring costs and benefits)	
Please state whether you disagree or agree with the following statements in relation to energy efficiency:	
Buying a more energy efficient HVAC system would reduce my establishment's environmental impact	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
All new HVAC systems have similar EE levels	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
More energy-efficient HVAC systems are less reliable	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
I am willing to take a chance on new technologies to reduce my establishment's energy consumption	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
Lack of access to loans (excluding loans from friends and family) prevents us from making more energy-efficient choices	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
I have a good understanding of the energy consumption of the HVAC system at the establishment	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
I am aware of energy prices, i.e. the price of the energy sources (gas, heating oil, electricity) that our establishment uses	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
I understand how much money I would save if my establishment bought a more energy-efficient HVAC system	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)

My establishment would be more likely to buy an energy-efficient HVAC system if other establishments also do so	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
My establishment cannot afford to upgrade the EE of our HVAC system	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
EE upgrades increase the value of the establishment	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree);-999 (Don't know/ No answer)
The saving in EE would enable us to expand the services offered by our establishment and fit more electrical appliances	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree);-999 (Don't know/ No answer)
The establishment has effective measures to make the customer aware of energy consumption	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree);-999 (Don't know/ No answer)
Uncertainty as to the price of energy discourages investment in energy efficiency	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree);-999 (Don't know/ No answer)
Understanding and use of existing labels and simulated monetary labels	
Are you aware of the Energy Label and Data Sheet for HVAC systems?	0 (No); 1 (Yes)
Did the Energy Label and/or Data Sheet affect your choice of an HVAC system?	0 (No); 1 (Yes); -998 (Not applicable); -999 (Don't know)
Please state whether you disagree or agree with the following statements in relation to the information provided in the Energy Efficiency label and Data Sheets for HVAC systems:	
It is understandable	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It is trustworthy	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It is manipulated by sellers	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It influences my choice of an HVAC system	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It helps me to understand how much energy an HVAC system consumes	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It helps me calculate how much an HVAC system will cost to run	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
Imagine an energy label with energy cost information for HVAC systems, e.g. "It is estimated that the lifetime energy cost of an HVAC system that consumes 4,000 kWh (10 years) is €5,000". In relation to this new information, please state whether you disagree or agree with the following statements:	
It would be understandable	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It would be trustworthy	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It would be manipulated by sellers	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It would influence my choice of an HVAC system	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)

It would help me to understand how much energy an HVAC system consumes	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
It would help me calculate how much an HVAC system will cost to run	1 (strongly disagree); 2 (slightly disagree); 3 (slightly agree); 4 (strongly agree); -999 (Don't know/ No answer)
Environmental concerns	
Please rate how concerned your establishment is about the environment (for example, pollution, global warming and climate change)	1 (not concerned); 2 (slightly concerned); 3 (concerned); 4 (extremely concerned); -999 (Don't know/ No answer)
Habits for energy savings	
How often does your establishment perform the following in your day to day operations?	
Automatic control of HVAC systems in rooms, for example, smart key cards, programming the power button to turn on and off, smart thermostats, etc.	1 (never); 2 (occasionally); 3 (often); 4 (always); -999 (Don't know/No answer)
Periodic information to promote responsible consumption of water and energy among workers	1 (never); 2 (occasionally); 3 (often); 4 (always); -999 (Don't know/No answer)
Investments in green and energy-efficient equipment	
Has your business installed any of the following items for energy savings in the last 10 years?	
Top-rated energy-efficient electronic devices (e.g. TVs, computers)	1 (yes); 2 (no); 3 (already equipped, more than 10 years ago); 4 (not possible / feasible in my building)
Low-energy light bulbs (compact fluorescent, LED)	1 (yes); 2 (no); 3 (already equipped, more than 10 years ago); 4 (not possible / feasible in my building)
Energy-efficient windows (e.g. double or triple glazed windows)	1 (yes); 2 (no); 3 (already equipped, more than 10 years ago); 4 (not possible / feasible in my building)
Thermal insulation of walls/roof	1 (yes); 2 (no); 3 (already equipped; more than 10 years ago); 4 (not possible / feasible in my building)
Sensors for controlling the switching on and off of lights in common areas	1 (yes); 2 (no); 3 (already equipped; more than 10 years ago); 4 (not possible / feasible in my building)
Solar panels	1 (yes); 2 (no); 3 (already equipped, more than 10 years ago); 4 (not possible / feasible in my building)
Socio-economic characteristics	
How would you describe your current income on a scale from 1 to 10, where 1 means that your establishment is having financial difficulties and 10 means that it is financially very sound	1 (The lodging has financial difficulties); 2; 3; 4; 5; 6; 7; 8; 9; 10 (The lodging has a very good financial situation); -999 (Don't know / No answer)
How would you describe your incomes during the next five years on a scale from 1 to 10, where 1 means that your establishment is expected to have financial difficulties and 10 means that it is expected to be financially very sound	1 (The lodging will have financial difficulties); 2; 3; 4; 5; 6; 7; 8; 9; 10 (The lodging will have a very good financial situation); -999 (Don't know / No answer)
Hotel star rating	1 (Five gold stars); 2 (Four gold stars); 3 (Three gold stars); 4 (Two gold stars); 5 (One gold star) -998 (Not applicable)
Hostel star rating	6 (Three silver stars); 7 (Two silver stars); 8 (One silver star); -998 (Not applicable)
Cottage star rating	9 (One wheat ear); 10 (Two wheat ears); 11 (Three wheat ears); 12 (Four wheat ears); 13 (Five wheat ears); 14 (Not specified); -998 (Not applicable)
Years in business	[open text]
Number of rooms	[open text]
Months of high season and low season: January, February, March, April, May, June, July, August, September, October, November, December	0 (No); 1 (Yes)
What is the average occupancy rate in high and low season? (%)	[open text]

Appendix 2A: Socio-demographic characteristics of participants in FG-Citizens

		Participant							
		1	2	3	4	5	6	7	8
Gender	Male	x	-	-	x	-	x	-	-
	Female	-	x	x	-	x	-	x	x
Education	No educ. qualifications	-	-	-	-	-	-	-	-
	Primary school	x	-	-	-	-	x	x	-
	High school	-	x	-	-	x	-	-	x
	Higher education	-	-	x	x	-	-	-	-
Heating system	Central	-	x	x	-	-	-	-	-
	Individual	x	-	-	x	x	-	x	x
	Other	-	-	-	-	-	x	-	-
Age	25-44	-	34	42	-	-	-	-	-
	45-64	56	-	-	49	-	45	-	54
	≥65	-	-	-	-	65	-	72	-
Type of dwelling	Owner-occupied	x	-	x	x	x	-	x	x
	Rented	-	x	-	-	-	x	-	-
Municipality	Urban	x	x	x	-	x	x	x	x
	Rural	-	-	-	x	-	-	-	-
Members	No children	-	-	x	-	-	-	-	x
	With children	-	x	-	x	-	x	-	-
	Elderly	x	-	-	-	x	-	x	-
Members of household	1	-	-	-	-	-	-	-	x
	2	-	-	x	-	-	-	x	-
	3	x	x	-	-	x	-	-	-
	4	-	-	-	x	-	x	-	-
	≥5	-	-	-	-	-	-	-	-
Employment status	Unemployed	x	x	-	-	-	x	-	-
	Employed	-	-	x	x	-	-	-	x
	Retired	-	-	-	-	x	-	x	-
Income	<€1,000	-	-	x	-	-	-	-	-
	€1,001-€1,500	x	x	-	-	-	-	-	x
	€1,500-€2,500	-	-	-	-	x	x	x	-
	>€2,500	-	-	-	x	-	-	-	-

Appendix 2B: Fuzzy Cognitive Mapping Indicators

FCM can be described using various indicators such as density, centrality, the out-degree and the in-degree.

Density, D, is an indicator of connectivity which analyses how connected or sparse maps are. It is calculated as per equation (1) by dividing the number of actual connections (C_i C_j) by the number of potential connections (Özesmi and Özesmi, 2004).

$$D = \frac{\sum C_i\ C_j}{N\ (N-1)} \tag{1}$$

where N is the total number of concepts and C_i and C_j the connections.

Centrality, C_{ti} denotes the individual importance of a concept (Olazabal and Reckien, 2015) relative to other concepts in the network. It is calculated as per equation (2). It is the sum of a concept's out- and in-degrees (O_i and I_I respectively).

$$C_{ti} = O_i + I_i \tag{2}$$

O_i is a the out-degree of a concept. It is a measure of the influence of one concept C_i on other concepts in the network (Özesmi and Özesmi, 2004). It is calculated as per equation (3) by adding up the absolute weights, w_{ik} of all outgoing connections of a particular concept.

$$O_i = \sum_{k=1}^{k} w_{ik} \tag{3}$$

I_i is the in-degree of a concept. It is a measure of the dependency of a concept on other concepts in the network. It is calculated as per equation (4) by adding up the absolute weights, w_{ki} of all incoming connections of a concept.

$$I_i = \sum_{k=1}^{k} w_{ki} \tag{4}$$

More specifically, the out-degree measures the degree of influence of a concept on others, that is, it reflects the total connections exiting from a concept. The in-degree measures the degree of dependency of a concept on other concepts of the network, showing the total connections entering a variable. Centrality is the sum of in- and out-degrees, and illustrates the importance of a concept relative to other concepts. These indicators reveal the roles of the single variables in our system. Based on the values of in- and out-degree indicators, concepts with a positive in-degree and 0 out-degree are named "receivers", as they receive input from the rest of the variables in the system. Concepts with positive in- and out-degrees both receive and send input and are known as "transmitters" (Morone et al., 2019).

Appendix 2C: Centrality network analysis

FG-Academics			
Concepts	**Out-degree**	**In-degree**	**Centrality**
Investment in insulation	1.48	3.55	5.03
Environmental awareness	3.32	0.84	4.16
Temperature gradient	0.75	3.1	3.85
Energy price	2.74	0.83	3.57
Thermostat	0.74	2.03	2.77
Energy rating of houses	1.35	1.3	2.65
Environmental education	2.24	0	2.24
Education	1.52	0.68	2.2
Habits	0.68	1.45	2.13
Energy efficiency of heating system	0.71	1.37	2.08
Square meters	1.25	0.8	2.05
Income	2.04	0	2.04
Insulation behaviour	0.68	1.31	1.99
Energy tax	1.91	0	1.91
Individual heating system	1.34	0.56	1.9
Household members	1.84	0	1.84
Cost of technology	1.67	0	1.67
Insulation	0.66	0.79	1.45
Turning off heating system	0	1.37	1.37
Hours at home	0.75	0.61	1.36
Subsidies	0.75	0.49	1.24
Technical standard	0.61	0.5	1.11
Orientation	1.08	0	1.08
Taxing bad habits	0.78	0	0.78
Health	0.45	0.31	0.76
Central heating system	0.55	0	0.55
Physical activity	0.39	0	0.39

FG-Citizens			
Concepts	**Out-degree**	**In-degree**	**Centrality**
Income	5.5	0	5.5
Investment in insulation	0	3.8	3.8
Decisions of politicians	3.3	0	3.3
Energy poverty	1.4	1.6	3
Energy price	1.6	0.6	2.2
Orientation	2	0	2
Subsidies	1.3	0.7	2
Responsible consumption	0.8	1.1	1.9
Electricity rate	0.6	1.3	1.9
Social bonus	0	1.9	1.9
Renewable energy use	0	1.9	1.9
Competitiveness of energy firms	1.1	0.7	1.8
Insulation	1.6	0	1.6
Habits	0	1.5	1.5
Temperature gradient	0.6	0.7	1.3
Cubic meters	1.3	0	1.3
Square meters	1.2	0	1.2
Hours at home	0.6	0.4	1
Investment in renewable energies	0	1	1
Children/Elderly	0.9	0	0.9
Thermostat	0	0.8	0.8
Energy bill information	0.6	0	0.6
Physical activity	0.4	0	0.4

FG-Energy-experts			
Concepts	**Out-degree**	**In-degree**	**Centrality**
Consumption	0.93	10.19	11.12
Energy efficiency of heating system	0.64	4.08	4.72
Energy price	1.69	1.88	3.57
Environmental awareness	2.64	0.46	3.1
Investment in insulation	0.73	1.13	1.86
Energy saving habits	1.13	0.69	1.82
Individual maintenance	0.67	1.03	1.7
Energy saving	1.51	0	1.51
Insulation	0.77	0.59	1.36
Renewable energies	0.67	0.67	1.34
Investment in EE heating system	0.8	0.49	1.29
Maintenance regulation	1.26	0	1.26
Individual/Central heating system	1.22	0	1.22
Hours at home	0.64	0.57	1.21
Household members	1.17	0	1.17
Energy efficiency	1.13	0	1.13
Electrification	0.96	0	0.96
Competitiveness of energy firms	0.51	0.39	0.9
Climate	0.77	0	0.77
Energy bill information	0.73	0	0.73
Renewable energy	0.67	0	0.67
Single/block houses	0.61	0	0.61
Thermostat	0.61	0	0.61
Square/cubic meters	0.6	0	0.6
Social bonus	0.56	0	0.56
Consumption tax	0.44	0	0.44

Appendix 2D: Descriptive statistics

FG-Academics	Variable	Obs	Mean	Standard deviation	Std. Err.
FACTORS	Positive	88	.654	.22	.023
	Negative	88	.587	.24	.025
	All	176	.621	.23	.017
MEASURES	Positive	96	.674	.20	.020
	Negative	32	.609	.21	.037
	All	128	.658	.20	.018
POLICIES	Positive	88	.668	.25	.027
	Negative	8	.587	.19	.067
	All	96	.661	.25	.025

FG-Citizens	Variable	Obs	Mean	Standard deviation	Std. Err.
FACTORS	Positive	42	.717	.15	.023
	Negative	42	.621	.21	.032
	All	84	.669	.19	.021
MEASURES	Positive	36	.65	.22	.037
	Negative	30	.613	.28	.051
	All	66	.633	.25	.031
POLICIES	Positive	66	.614	.21	.025
	Negative	12	.658	.21	.060
	All	78	.620	.21	.023

FG-Energy-experts	Variable	Obs	Mean	Standard deviation	Std. Err.
FACTORS	Positive	63	.654	.28	.035
	Negative	42	.638	.29	.044
	All	105	.648	.28	.027
MEASURES	Positive	56	.536	.26	.034
	Negative	42	.588	.24	.037
	All	98	.558	.25	.025
POLICIES	Positive	63	.562	.26	.033
	Negative	21	.486	.25	.055
	All	84	.543	.26	.028

Appendix 3A: Socio-demographic characteristics of participants in focus groups with households

		Participant							
		1	2	3	4	5	6	7	8
Gender	Male	x	-	-	x	-	x	-	-
	Female	-	x	x	-	x	-	x	x
Education	No formal education qualifications	-	-	-	-	-	-	-	-
	Primary school	x	-	-	-	-	x	x	-
	Secondary school	-	x	-	-	x	-	-	x
	Higher education	-	-	x	x	-	-	-	-
Age	25-44	-	34	42	-	-	-	-	-
	45-64	56	-	-	49	-	45	-	54
	≥65	-	-	-	-	65	-	72	-
Employment status	Unemployed	x	x	-	-	-	x	-	-
	Employed	-	-	x	x	-	-	-	x
	Retired	-	-	-	-	x	-	x	-
Income	<€1,000	-	-	x	-	-	-	-	-
	€1,001-€1,500	x	x	-	-	-	-	-	x
	€1,500-€2,500	-	-	-	-	x	x	x	-
	>€2,500	-	-	-	x	-	-	-	-
Type of dwelling	Owner-occupied	x	-	x	x	x	-	x	x
	Rented	-	x	-	-	-	x	-	-
Municipality	Urban	x	x	x	-	x	x	x	x
	Rural	-	-	-	x	-	-	-	-
Members	No children	-	-	x	-	-	-	-	x
	With children	-	x	-	x	-	x	-	-
	Elderly	x	-	-	-	x	-	x	-
Members of household	1	-	-	-	-	-	-	-	x
	2	-	-	x	-	-	-	x	-
	3	x	x	-	-	x	-	-	-
	4	-	-	-	x	-	x	-	-
	≥5	-	-	-	-	-	-	-	-
Heating system	Central	-	x	x	-	-	-	-	-
	Individual	x	-	-	x	x	-	x	x
	Other	-	-	-	-	-	x	-	-

Appendix 3B: Characteristics of participants in focus group of academics

Participant	Gender	Number of dwellings	Type of dwelling	Household size	Municipality	Heating system
1	Male	1	Owner-occupied	2	Urban	Individual-Natural gas
2	Male	1	Owner-occupied	2	Urban	Central-Fossil fuel
3	Male	1	Owner-occupied	4 (2 children)	Urban	Central with individual control-Natural gas
4	Male	1	Owner-occupied	2	Rural	Individual-propane and wood stove
5	Female	1	Owner-occupied	2	Urban	Individual-Natural gas
6	Female	1	Rented	2	Rural	Individual-Natural gas
7	Male	1	Owner-occupied	3 (1 child)	Urban	Individual-Natural gas
8	Male	1	Owner-occupied	5 (3 children)	Urban	Individual-Natural gas-Energy efficient boiler in terms of nitrogen oxides and particulate emissions

Appendix 3C: Characteristics of participants in focus group of energy experts

Participant	Gender	Profile	Number of dwellings	Type of dwelling	Household size	Municipality	Heating system
1	Male	Researcher	1	Owner-occupied	2	Urban	Individual-Natural gas
2	Female	Researcher	1	Owner-occupied	3 (1 child)	Urban	Central with individual control-Natural gas
3	Male	Stakeholder specialising in the field of energy	1	Owner-occupied	4 (2 children)	Urban	Central with individual control-Natural gas
4	Male	Stakeholder specialising in the field of energy	2	Owner-occupied	4 (2 children)	Urban Rural	Individual-Natural gas
5	Male	Researcher	1	Owner-occupied	1	Urban	Central-Fossil fuel
6	Male	Researcher	1	Owner-occupied	5 (3 children)	Urban	Individual-Natural gas
7	Male	Stakeholder specialising in the field of energy	1	Owner-occupied	3 (1 child)	Urban	Individual-Natural gas

Appendix 3D: Fuzzy inference and simulation process

For scenario analysis, a vector of initial values of variables (A) is multiplied by the adjacency matrix of the aggregate FCM using the following function (Kontogianni and Papageorgiou, 2012):

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j=1 \\ j\neq i}}^{n} A_j^{(k)} w_{ji}\right) \quad (1)$$

where $A_i^{(k+1)}$ is the value of concept C_i at simulation step k+1, $A_i^{(k)}$ is the value of concept C_j at step k, w_{ji} is the weight of the interconnection between concept C_j and concept C_i and f is a threshold function commonly used in FCM which normalises the values at each step in the interval [0,1] and its mathematical type is:

$$f = \frac{1}{1+e^{-mx}} \quad (2)$$

where m is a real positive number and x is the value $A_i^{(k)}$ at the equilibrium point. A concept is activated by making its vector element 1 or 0 with [1] activated concepts and [0] non-activated concepts. If a concept has an activation value of 0, it does not contribute in the next iteration whereas an activation value of 1 means that it does contribute in the next iteration.

Appendix 3E: Centrality network analysis

Here is a list of the 32 concepts consolidated in the aggregated map alongside measures of their centrality. Concepts found to have zero out-degree or zero in-degree are classified as receivers or transmitters, respectively. The concept of in (or out)-degree is the sum of the absolute interaction weights.

Concepts	**Concept group**	**Out-degree**	**In-degree**	**Centrality**	**Concept type**
Energy consumption on heating	Factor	0.93	4.00	4.93	
Heating bill	Factor	0.00	4.75	4.75	Receiver
Energy-efficient heating system	Factor	0.68	3.49	4.17	
Energy price	Factor	1.42	2.20	3.62	
Energy-saving habits	Individual action	0.99	2.09	3.08	
Income	Factor	2.65	0.25	2.90	
Investment in insulation	Individual action	0.24	2.48	2.72	
Temperature gradient	Factor	0.76	1.86	2.62	
Environmental education and information	Policy	2.42	0.00	2.42	Transmitter
Subsidies	Policy	1.06	1.16	2.22	
Energy poverty	Factor	1.39	0.64	2.03	
Taxing fossil fuel used for heating	Policy	1.91	0.00	1.91	Transmitter
Governance	Policy	1.89	0.00	1.89	Transmitter
Cost of energy-efficient heating system	Factor	1.67	0.00	1.67	Transmitter
Individual heating system	Factor	1.28	0.28	1.56	
Social bonus	Policy	0.28	1.16	1.44	
Thermostat	Individual action	0.45	0.95	1.40	
Efficiency of dwellings and certificates	Factor	0.50	0.81	1.31	
Energy-saving regulation	Policy	1.26	0.00	1.26	Transmitter
Prosumer	Policy	0.00	1.25	1.25	Receiver
Technical standard	Policy	0.61	0.50	1.11	
Climate-sensitive design	Factor	0.61	0.40	1.01	
Electrification	Policy	0.96	0.00	0.96	Transmitter
Time at home	Individual action	0.43	0.42	0.85	
Vulnerable person	Factor	0.83	0.00	0.83	Transmitter
Taxing bad habits	Policy	0.78	0.00	0.78	Transmitter
Education on energy savings	Policy	0.75	0.00	0.75	Transmitter
Renewable energy sources	Factor	0.67	0.00	0.67	Transmitter
Central heating system	Factor	0.55	0.00	0.55	Transmitter
Competition between firms	Policy	0.28	0.20	0.48	
Tax on consumption	Policy	0.44	0.00	0.44	Transmitter
Physical activity at home	Individual action	0.20	0.00	0.20	Transmitter

Appendix 4A: Detailed comparison of brand-based price premiums in Spain

Brands	Coefficient **(Lucas and Galarraga, 2015)**	Coefficient of this research
AEG		+0.11***
BALAY	-0.08***	-0.11
BEKO	-0.24***	-0.27***
BOSCH	+0.05*	
CANDY	-0.11***	-0.10*
CORBERO	-0.13***	-0.26***
HAIER	-0.24***	-0.28***
HOOVER		-0.12*
INDESIT	-0.19***	-0.18***
LG		-0.25***
MIELE	+0.74***	+0.49***
SAMSUNG	-0.12***	
SIEMENS	+0.13***	+0.06**
SMEG		+0.36***
TEKA	-0.08*	
WHIRPOOL	-0.09***	-0.10***
ZANUSSI	-0.14***	

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

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