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Mind the map? Mapping the academic, citizen and professional stakeholder views on buildings and heating behaviour in Spain

Elena López[a*], Sébastien Foudi[a] and Ibon Galarraga[a,b]

[a] Basque Centre for Climate Change (BC3), 48940 Leioa, Spain
[b] Economics for Energy, Doutor Cadaval 2, 3E, 36202 Vigo, Spain
*Corresponding author: elena.lopez@bc3research.org (E. López). Basque Centre for Climate Change (BC3), Building 1, 1st floor, Scientific Campus of the University of the Basque Country (UPV/EHU), 48940 Leioa, Spain. Tel.: +34 944 014 690

Email addresses: elena.lopez@bc3research.org (E. López); sebastien.foudi@bc3research.org (S. Foudi); ibon.galarraga@bc3research.org (I. Galarraga)

Abstract

The residential building sector is a major driver of current and future energy consumption and associated CO_2 emissions. The main use of energy by households is for heating. Consumers' heating behaviour results from the interactions of internal and external drivers, which makes it a complex system. We used Fuzzy Cognitive Mapping method to represent key drivers and interactions in that system. Maps were drawn up at three focus groups representing different social groups from Spain – academics, citizens and energy experts – in order to capture heterogeneity of behaviours. Maps seek to identify and set out the factors that influence heating costs as well as private and public adaptation measures to minimise them. The core common concepts of the maps deal with consumer behaviour regarding investment in energy efficiency technologies such insulation or thermostat, attitudes regarding the environment or the thermal comfort temperature, economic factors such as price and income and regulatory interventions. The most significant differences between the groups were that the academics and energy experts considered that taxes could improve energy savings. The results shown in this paper may be helpful in designing effective policies on heating consumption.

Keywords: consumer behaviour; fuzzy cognitive mapping; energy savings; low-carbon heating; energy policies; Spain.

Highlights:

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- Policy effectiveness for low-carbon heating consumption depends on behavioural aspects
- Academics and energy experts mention taxes as a way of reducing energy consumption
- Subsidies are effective tools for alleviating energy poverty for Spanish citizens
- Energy experts from Spain support environmental education policies
- Spanish citizens mention policies that can help them to understand energy bills

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 [1,2]. 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 [3,4]. In Spain, 18% of total energy consumption is accounted for by households and 44% of that energy goes into heating homes [5,6]. 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 [7].

Climate change and energy security require a 90-100% reduction in fossil fuel consumption in buildings by 2050 [8]. The technical requirement that new buildings in the European Union must be "nearly zero energy buildings" [9,10] as from 2021 is an important instrument for achieving this. Efforts to refurbish the existing building stock in Europe need to be stepped up [11] as close to 75% of buildings in the European Union are energy-inefficient [12]. 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) [13–15] but also the development of renewable energy sources [16].

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 [17–21]. Large differences in energy consumption in similar buildings have been observed, mainly due to the behaviour of their occupants [22–25]. Indeed, the behaviour of consumers may be more significant in explaining energy consumption than building characteristics or other factors [26].

The total reduction in residential energy consumption is the result of the interplay of technological change and household behaviour [27,28], but the financial capacity to invest in more energy-efficient equipment also plays a major role [29–31]. Indeed, significant investments are required to promote sustainability in buildings and housing [31]. For instance, Wang et al. [32] 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 [33] 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 [34,35]. Other research papers, such as Yeatts et al. [36], 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 [37,38]. It is therefore important not to ignore behavioural uncertainties in policy design [39]. Indeed, policy makers need to better understand consumers' behaviour to design effective energy saving strategies [40,41]. In addition, policy interventions are needed to overcome barriers [42], but they must be carefully designed to reflect specific national and local circumstances [43,44]. 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 [7,45], 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. [46] 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. [47] 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. [48] and Ruiz and Romero [49] 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 [50]. 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 [51,52].

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 [53–55]. This method is based on fuzzy graph structures to represent causal reasoning [54] 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 provides an overview of the literature on technological, environmental, behavioural and regulatory factors affecting residential heating systems. Section 3 presents a statistical overview of energy consumption on heating in Spain. Section 4 presents the methodology and a case study. Section 5 sets out the results and discusses the findings. Finally, Section 6 outlines implications for policy-making and business.

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 [56]. These factors affect household behaviour regarding energy consumption [57].

Household behaviour has a significant impact on energy use, especially in homes [58], 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 [33]. Several studies in the literature analyse factors related to the behaviour, attitudes and preferences of consumers [20,22,23,32,41,43]. These factors can be broken down as follows: (i) socioeconomic and demographic characteristics; (ii) residence characteristics; and (iii) environmental considerations [59].

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

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households has an impact on the energy consumed for space heating [60,61]. Additionally, households classified as energy-poor tend to use less energy for keeping warm in the winter due to a lack of financial resources [62,63]. In the case of Spain almost 10% of households are unable to keep their homes adequately warm [64]. Energy poverty in Spain is significant although slightly below the European Union average [63,65,66].

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 [59,67].

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 [33,68]. However, there are differences between pro-environmental attitudes and pro-environmental behaviour. Su et al. [69] 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 [70]. In other words, attitudes to the environment generally seem to be less important in explaining the replacement of heating systems than financial considerations [70]. 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 [70–72].

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 [73].

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%[1]. The INS (Spain's National Statistics Institute) reveals that a large proportion of houses in Spain

[1] Calculated according to data from the Ministry of Public Works [74]

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) [75].

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 [76] and the Renewable Energies Plan 2011-2020 [77] 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) [78], 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 [79].

Half of the buildings now standing in Spain were constructed before 1980, when building codes had no EE requirements [70]. 82% of households with heating have individual heating systems while central heating is found in only 8% [75]. 70% of households with heating have a thermostat or some other temperature regulating device. The most common heating system is that 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 [80]. 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 [78]. 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 [81].

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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 [70]. 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 [82].

4. Methodology

A literature review on energy research [83] reinforces the idea of incorporating qualitative methodologies to understand how human behaviour affects energy demand. Sovacool, B.K. [84] 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. [43] 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 [85,86]. 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 [43]. Hirsh and Jones [87] 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 [88,89]. 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. [51] focus on effective policy instruments for a sustainable energy transition in the biofuel industry in Italy using the FCM technique; and Papageorgiou et al. [90] analyse factors influencing the development of photovoltaic solar energy by means of FCM. For environmental policy, Doukas and Nikas [91] 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. [92] show how important information is for monitoring energy savings in buildings while Vergini and Groumpos [93] apply FCM to analyse the performance of Zero Energy Buildings. Very few studies have employed FCM for assessing EE policies [44,94]. Nikas et al. [94] introduce the ESQAPE FCM tool for assessing a broad EE policy framework in a pilot application in Greece. Finally, Song et al. [44] 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.

4.1 Fuzzy Cognitive Mapping

Qualitative methods such as FG are powerful instruments for understanding attitudes, opinions, expectations and practices [95] and can help to identify important concepts which may not be picked up by quantitative techniques [96,97].

In this paper we obtain cognitive maps using an FCM methodology. This is a participatory semi-quantitative method [53–55,98]. It comprises concepts that represent key drivers of a system, joined by directional edges or connections that represent causal links between concepts [99]. It enables unexpected effects to be identified [98]. To reflect the strength of those causal links, weights are assigned by participants to the arrows [53]. The method enables a quantitative analysis to be conducted on the links identified to support decision making [53,98]. 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 [98].

There are two main ways in which FCM can be built up [100,101]. 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 [102,103]. 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 [102,103]. 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. [98], 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 [54,55,99] 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 [104,105]. 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.

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 [2]. FG-Energy-experts was made up of four researchers and three stakeholders specialising in the field of energy[3]. 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 A, Table A.1)[4]. 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 [53,106]. Moreover, in large FGs there is a risk of creating subgroups with certain talkative individuals dominating the discussion [107]. 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 [108]. 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

[2] Conducted on December 20, 2017 in the city of Bilbao (Spain) with ten participants from the Basque Centre for Climate Change (BC3).
[3] Conducted on January 31, 2018 at the conference of the Spanish Association for Energy Economics (AEEE) in Zaragoza (Spain) with seven participants.
[4] Conducted on January 23, 2018 in the city of Bilbao (Spain) with eight participants recruited by the Spanish company CPS.

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[5].

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, 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[6]. 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).

[5] 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).

[6] 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.

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.

5. Results and discussion

The final maps obtained from each focus group are presented in Fig. 1, Fig. 2 and Fig. 3. 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 final maps were obtained by calculating the average of the weights given individually by all members taking part in each FG.

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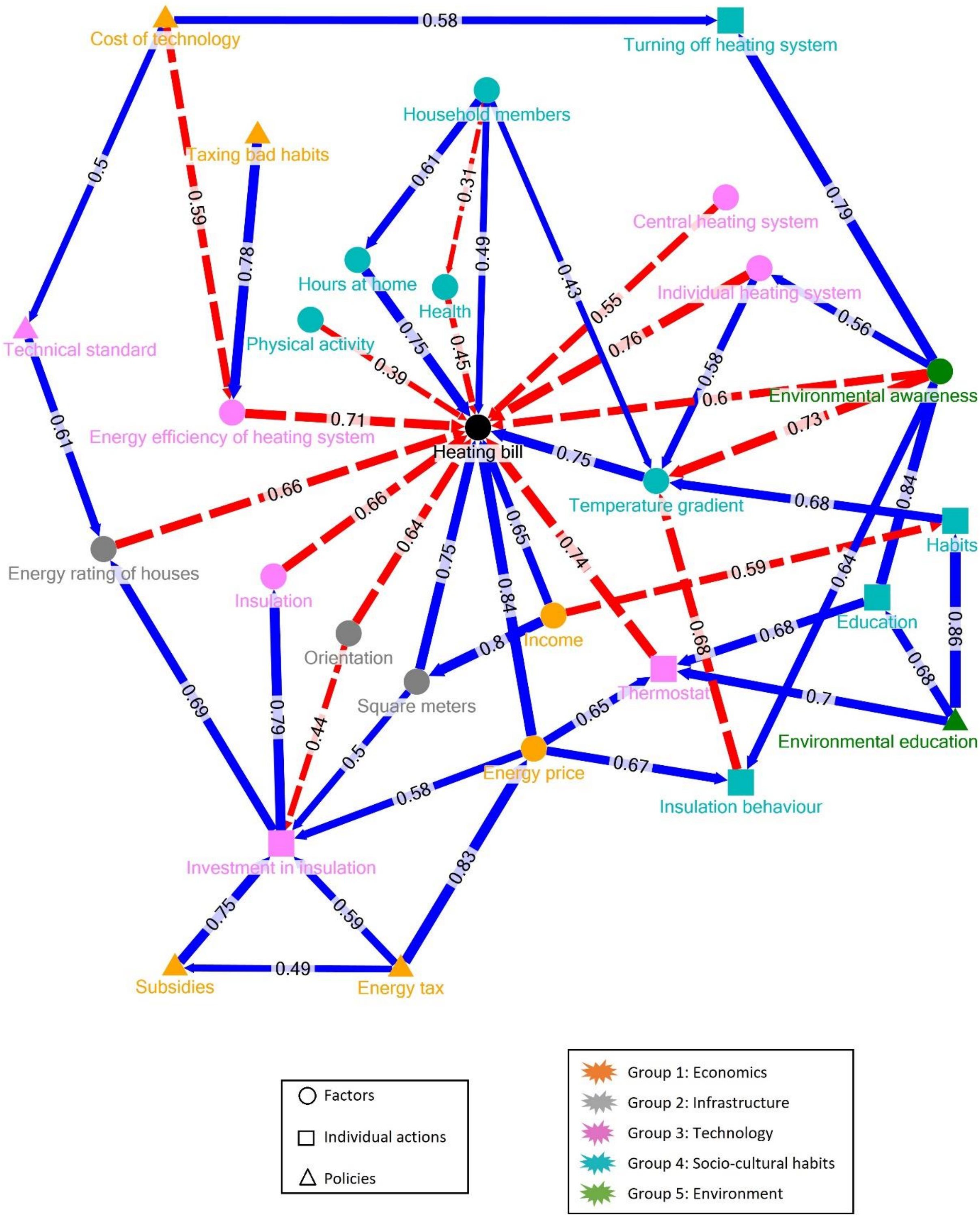

Fig. 1. Graphic showing weights assigned by FG-Academics. Blue lines represent positive connections and red dotted lines negative connections between concepts.

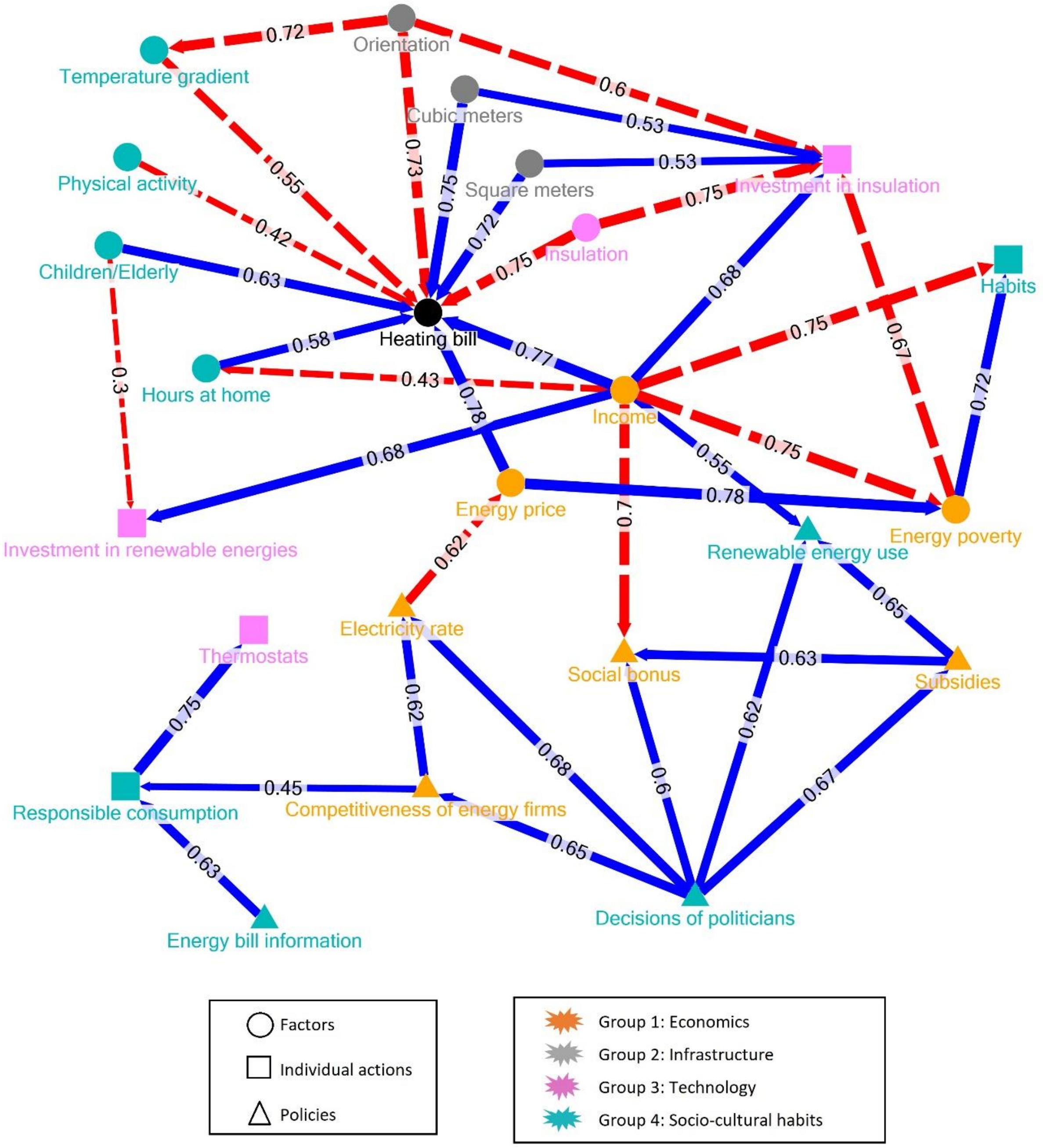

Fig. 2. Graphic showing weights assigned by FG-Citizens. Blue lines represent positive connections and red dotted lines negative connections between concepts.

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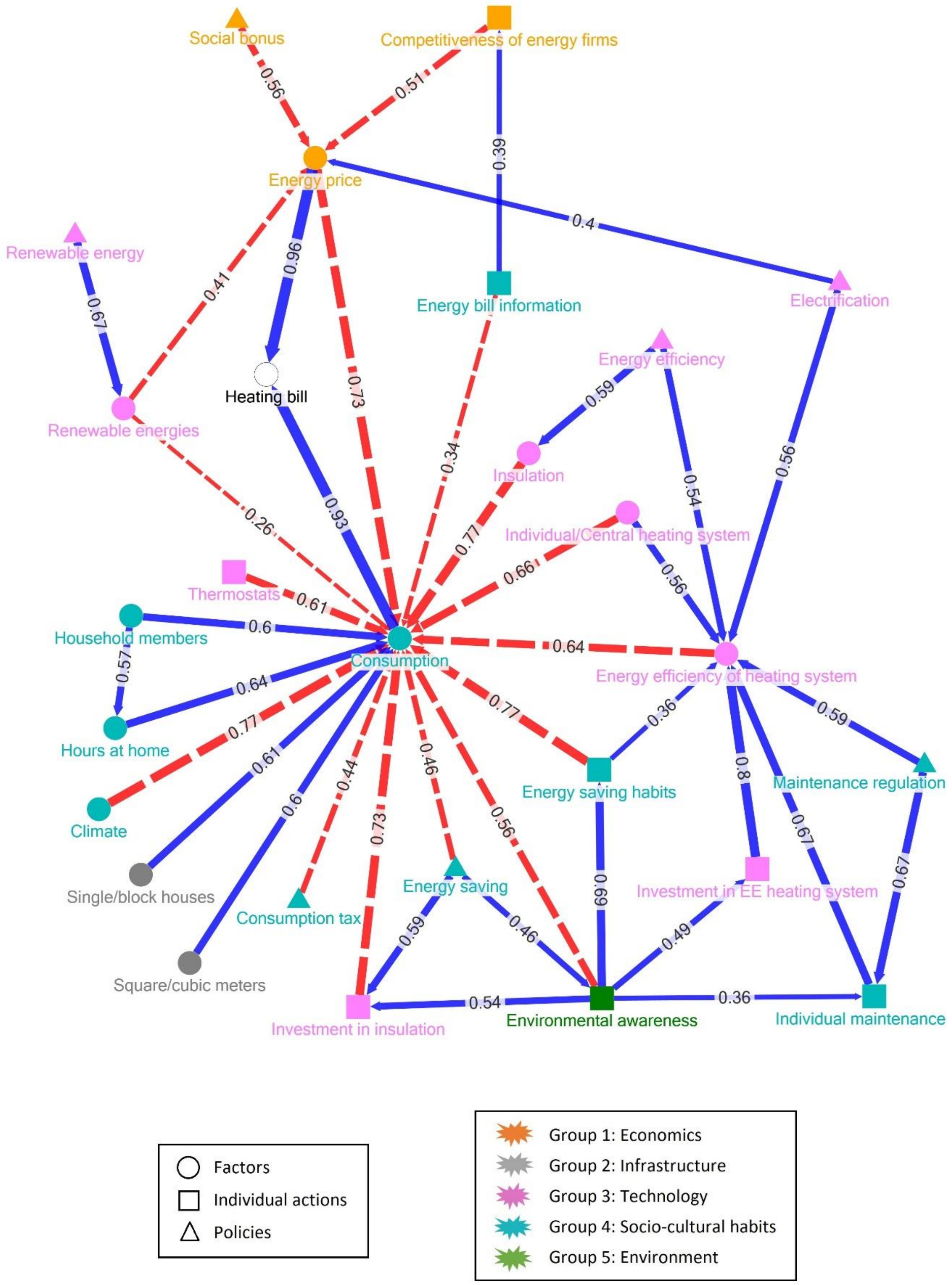

Fig. 3. Graphic showing weights assigned by FG-Energy-experts. Blue lines represent positive connections and red dotted lines negative connections between concepts.

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 1). 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 [109]. 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 [109,110]. Indeed, other studies show that public acceptance of taxes is greater if the use of revenues is clearly specified beforehand [111]. In addition, Kallbekken and Sælen [112] 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 1

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 [99].

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 Fig. 4). 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 Fig. 4 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.

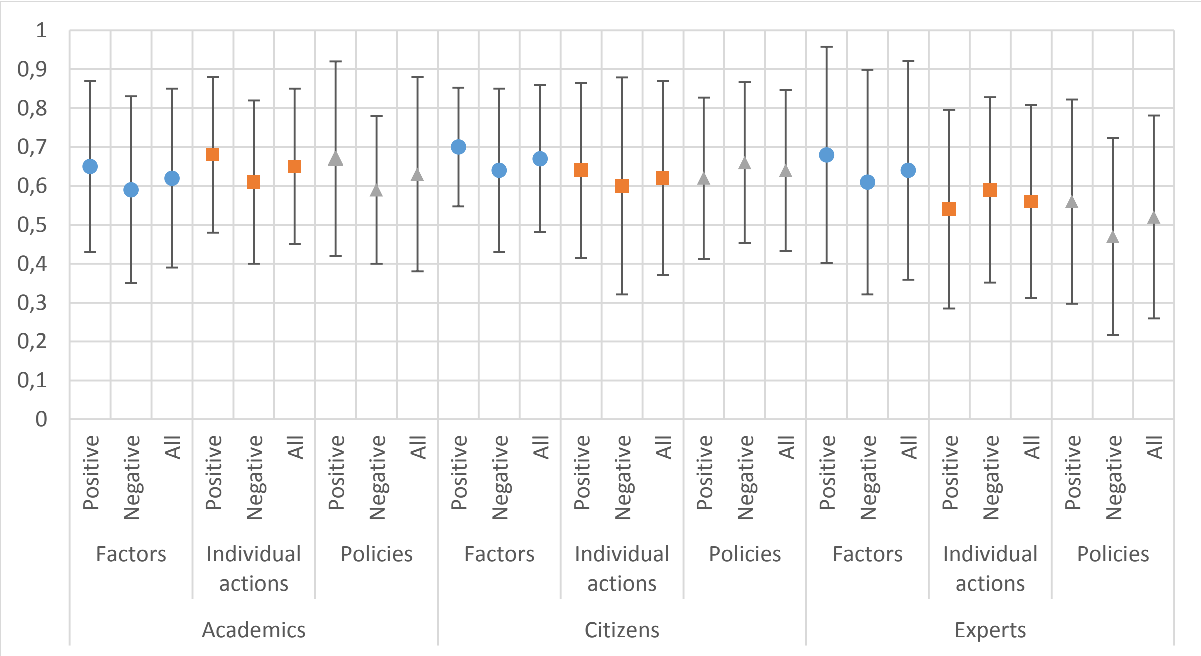

Fig. 4. Mean of connections with standard deviation

The complexity of the maps, reflected here in the number of concepts and connections, can vary with occupational background [98]. Our study seems to confirm this (Table 2). Academics and energy experts provide more concepts and connections than citizens. Citizens' maps are denser[7]: 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 C) 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

[7] "Density" is defined in Appendix B.

income and regulatory interventions. Appendix C provides information on the importance of other concepts for each FG.

Table 2

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. [98]. 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 [113–117]. 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).

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.

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Appendix A: Supporting material for focus groups

Table A.1: 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 B: 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 [55].

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

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 [118] 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).

$$C_{ti} = O_i + I_i \quad (2)$$

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 [55]. It is calculated as per equation (3) by adding up the absolute weights, w_{ik} of all outgoing connections of a particular concept.

$$O_i = \sum_{k=1}^{k} w_{ik} \quad (3)$$

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.

$$I_i = \sum_{k=1}^{k} w_{ki} \quad (4)$$

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" [50].

Appendix C: 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 D: Descriptive statistics

Table D.1: 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

Table D.2: 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

Table D.3: 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