

Social impact of decarbonization objectives through smart homes: Survey and analysis

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ABSTRACT

The technological development and economic growth of renewable energy are the key solution for almost full decarbonization of the energy systems. The sustainability and energy efficiency, artificial intelligence and connectivity will be the determining elements towards reaching this ambitious goal. Household appliances and tools for controlling energy consumption, temperature, lighting, etc. In the smart home will play a key role to increase awareness of families' energy consumption. IoT (Internet of Things) devices for the smart home allow us to monitor consumption and pay attention to efficiently energy use. However, savings are not the only important element of the smart home. Together with the digital control of the home these are elements that include a fundamental dimension: decarbonization, which is the cornerstone of the energy transition, which must involve an epochal change of mentality to our society where digitalization and people's well-being meet. The paper deals with social analysis of large cities population perception on integrating renewable energy sources and necessary devices to transform existing houses in smart homes towards economic wellbeing and decarbonization of the energy sector. Different classes of respondents were interviewed – owned and rented home, rural and urban inhabitants, different segments of age, various number of inhabitants in urban areas and the capital, women and men, high-income and low-income, different levels of education – to support or disregard smart home technological development and reveal the different perception towards further usage of smart devices for daily benefits.

1. Introduction

The interest of European citizens in renewable energy, sustainability and digitalization is always growing. There are some countries which are behind, compared to other more developed European countries, in using renewable energy, electric and sustainable mobility, energy saving and smart home applications for smart home management [1,2]. Experience has shown that, in time, technological developments are constantly changing. In the same time, the tendency to have a personal property home and environmental awareness will remain an objective for the majority of the population [3]. This element is synonymous with a guarantee for the various manufacturing companies to continue to evolve and propose increasingly intelligent and innovative devices, which can support green energy management in homes, to improve the quality of life [4].

However, it is necessary to consider and integrate the social and psychological factors that can modify and delay the evolution of these devices, for example.

- lack of cognitive elements: due to the growing age of the population, it is often difficult to be able to interact with the different internet of things (IoT) devices and how these devices can help carry out even daily actions;
- complexity and difficulty of interaction: only some devices appear to be simple to use, while the complex ones sometimes require information technology (IT) skills and familiarity, which is not a common ability, especially for the elderly, who may already have limitations in using a smartphone.

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- privacy and cybersecurity: a very controversial key element, as despite the efforts to guarantee security and ethics in this sector, they are often a deterrent to insert such devices into the home [5].

In addition, there are also technical limits like.

- connectivity and interoperability, when the devices do not belong to the same companies or cannot have the same communication protocol. If the connectivity standards were still different, it would be necessary to modify and implement a unified system to avoid having compatibility and therefore interaction problems. Finally, if you use devices from different brands, the network interfaces could also be difficult to integrate, while it is the key element for the end user, who aspires to use user friendly smart appliances. So instead of helping the development of the smart home, it could slow it down.
- the reliability of the Internet is the key challenge: in fact, in the absence of a connection to the network and therefore to the clouds that offer services, these intelligent devices would not be able to carry out their functions.

Currently, it is unlikely that the internet network will be slow or non-existent, especially in developed countries, however, this deficit can occur, in the event of a blackout for example, or in countries where the fifth generation (5G) network has not yet been implemented. The redesign of domestic environments and the reconfiguration of their use have led to the greater use and purchase of intelligent appliances and digital tools [6]. The integration of technological innovations into families is stimulating the growth of businesses. Manufacturers are constantly inventing and improving smart home devices to meet the needs of tech-savvy consumers. Additionally, manufacturers are working on intelligent automation and high-tech features for smart homes [7].

On the other hand, high expenses associated with technical advancements, which could lead to an increase in total product costs, could have a negative influence on the growth of the industry. However, growing consumer preference for smart appliances in emerging countries such as China and India, as well as greater consumer spending power, will be important drivers of demand. Furthermore, the more connected objects also entail a greater risk of attack by hackers, intent on exploiting the weak points of the network and connected devices, for improper uses and thus the risks to privacy can grow exponentially.

Smartphones already record a large part of our online activity: our preferences, habits, and our movements, cars do and will increasingly do the same thing, at least at home it is best to take maximum precautions. That is, there is a need to ensure that the information collected does not leave the domestic perimeter or, worse still, is used for other purposes. The greater interest in smart home therefore goes well beyond the need to make their homes more automated and functional, and takes on a broader and deeper importance in terms of reducing the environmental and energy impact of our habitat [1,8,9].

Like any new idea, there may be unshared consensus, and it will lead to doubts and criticism. At the same time, those who are already enthusiastically testing Smart Homes can be a further driving force [10]. Interventions within the home, even the less invasive ones, such as the installation of home automation systems, are always characterized by a certain degree of inertia [11]. These years, however, our homes, at least as regards their usual use, have undergone major upheavals. The changing needs, dictated by the limitations imposed by the health protection, have asked domestic environments to demonstrate a degree of adaptability never seen before. Home spaces have in fact gradually had to be converted into flexible, multifunctional and digital environments capable of meeting the changing and disparate needs of the different members of the family unit in the different time slots of a weekday or holiday: from distance learning to work remotely, from exercise to home cinema, from shopping to condominium meetings.

The conducted survey will show that despite these problems, users

appreciate the convenience that smart homes will bring them in the future. This is an encouraging vote of confidence for smart home technology moving forward, and it is born to improve our lives, our cities, the environment for future generations too [1].

In terms of reasons that push people not to purchase smart objects, the following are instead found.

- a perception of products that are still too futuristic;
- failure to understand the benefits deriving from the devices;
- the price still considered too high;
- the absence of a real need.

From the analysis carried out in Romania it therefore clearly emerges that in many cases the consumer is still not able to fully understand the value of Smart solutions.

2. Integrating smart home technology

The Smart Home is any home that is equipped with one or more interconnected home automation or entertainment devices that are connected to the web and can be controlled remotely, which different components (actuators, sensors, webcams, thermostats, locks, entertainment systems, switches, smartphones, tablets, laptop, etc) [1]. In the world, the Smart Home market is worth around €68 billion in 2020, to reach around €110 billion in 2023, thanks to an average annual increase of almost 17 %. The USA and China are the main world markets and grew by 20 and 40 % respectively during 2019, while for 2020, a substantial freeze in growth is expected. As far as European countries are concerned, Italy and Spain are at the rear with a market value of around €600 million each, but with excellent growth prospects.

Thanks to the widespread diffusion of smartphones, the implementation of smart appliances has also grown and the availability of wireless solutions is one of the determining factors for the growth of the smart appliance market. Features such as convenience, cost reduction and energy saving are now essential decisive elements for the end user [12]. Furthermore, the increasing trends of home improvement projects and the rapid growth of wireless communications and IT sectors are influencing the Smart Home market.

The needs underlying the purchase of a Smart Home vary from the search for greater control over housing costs and therefore energy saving, to automation and remote control to save time, domestic settings for greater well-being and entertainment, greater security with cameras and sensors both in terms of anti-intrusion and in terms of domestic accidents [13]. A survey analysis on acceptability of smart buildings by property valuers, estate developers, and service users as a future built environment was carried on in Nigeria [14]. The analysis revealed the importance of reducing energy costs as first perceived driver of smart buildings, beside the measures to provide higher security.

Assisted living scenarios are emerging, in which sensors and the use of automation are connected to the remote control of fragile but still self-sufficient people, such as the elderly, and come to mix with e-health solutions in prevention and remote monitoring [15]. A home automation can be very practical, for example through vocal devices that can be controlled with the voice, while we are busy with other things or simply because a command can be carried out without any switch or remote control. A house characterized by technological and intelligent components certainly undergoes a reevaluation of its value. New technologies are the key tool for enhancing domestic environments and condominiums [16]. Talking about home automation or smart home simply means understanding what transformation we want to carry out in our homes, to determine what we want comfort to be, but also to be able to choose the IoT tools, which are best suited to the individual needs and capabilities of each person. Citizen.

Another important interpretation is the possibility of implementing the different steps over time, having the possibility of investing over time, a sort of installment plan for the home automation system. Only

about ten years ago it would have been unthinkable to have such technological homes, something today made possible not only by the development of information technology, but also by new technologies, especially in the cloud, which allow the internal systems to be managed as "services" of a house.

Through voice control or a simple touch from a smartphone it is possible to manage the hot/cold air conditioning system, start the washing machine, open the windows, prepare coffee, change the luminous flux of the lights, while sitting comfortably anywhere in the world, at advantage of economic, environmental and safety savings sustainability of the planet.

A sociological survey was carried out in Romania in there grouped regions (Transilvania + Banat, south + Dobrogea, and Moldova), for different types of cities (function of population size) by means of a telephone survey, on a representative sample of 1600 subjects of the population. Data were collected using computer assisted telephone interviewing (CATI - Computer Assisted Telephone Interviewing). The maximum admissible error was set to 2.5 %. By definition, the questionnaires not completely filled out (partially applied) or not following

the instructions sent at the beginning of data collection were considered incorrectly applied questionnaires.

The sampling of the population was done considering.

- gender;
- age;
- education level;
- home ownership;
- type of housing.

The first fundamental step was to understand if the term "Smart Home" was known and understood by the interested parties in the surveys. As shown in Fig. 1, the first values obtained have an average value higher than 70 %, which appears decidedly high, if compared with the values obtained subsequently and which will be examined. In the meantime, it can be understood that the topic has stimulated considerable interest and curiosity, leading users to learn more and more about a current, useful but at the same time apparently complex topic.

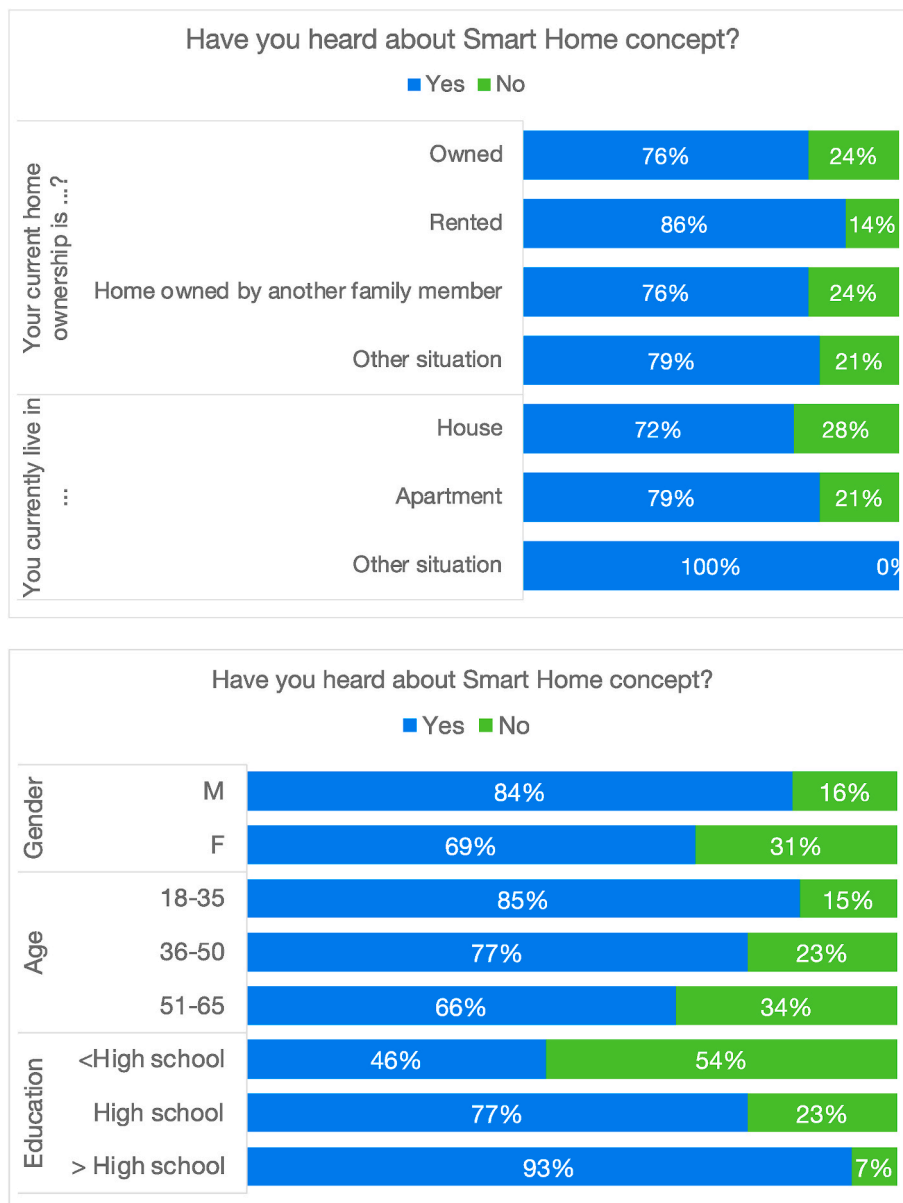


Fig. 1. Smart Home concept survey.

3. Smart home vision

The transition from home automation to smart home is closely linked to the concept of IoT. The latter, which has various applications even outside the domestic sphere, refers to physical objects, devices, capable of connecting to the internet, directly or indirectly.

Therefore, a smart home is connected and made up of devices (appliances, switches, light bulbs, thermostats, sockets, cameras, etc.) capable of sending and receiving data thanks to a wireless communication protocol (and not wired as happens in home automation).

The user can bring together different devices or objects in a real interconnected network, thanks to the use of a hub/gateway which, sharing the same communication standard, allows them to interact with each other. Some devices can directly integrate a WiFi module, while others use the hub as a bridge to access the internet connection.

The elements that constitute the smart world vision for homes, can be identified in the following macro-areas, which are not exhaustive, as they are constantly evolving are summarized below.

- a. Smart appliances
 - ❖ Smart household appliances such as washing machines, refrigerators, dryers, ovens
 - ❖ Small household appliances such as robots, vacuum cleaners, microwave ovens
- b. Energy Management
 - ❖ Products and services for controlling and reducing consumption
 - ❖ Timers, radiator valves, temperature sensors, photocells, actuators
- c. Safety
 - ❖ Cameras, digital peepholes and systems to prevent theft and intrusions
 - ❖ Motion sensors, door locks, smoke/fire sensors
- d. Lighting and comfort
 - ❖ Sensors and actuators to improve home comfort
 - ❖ Smart lamps
 - ❖ Door and window sensors, gate and shutter controls
- e. Controls and connectivity

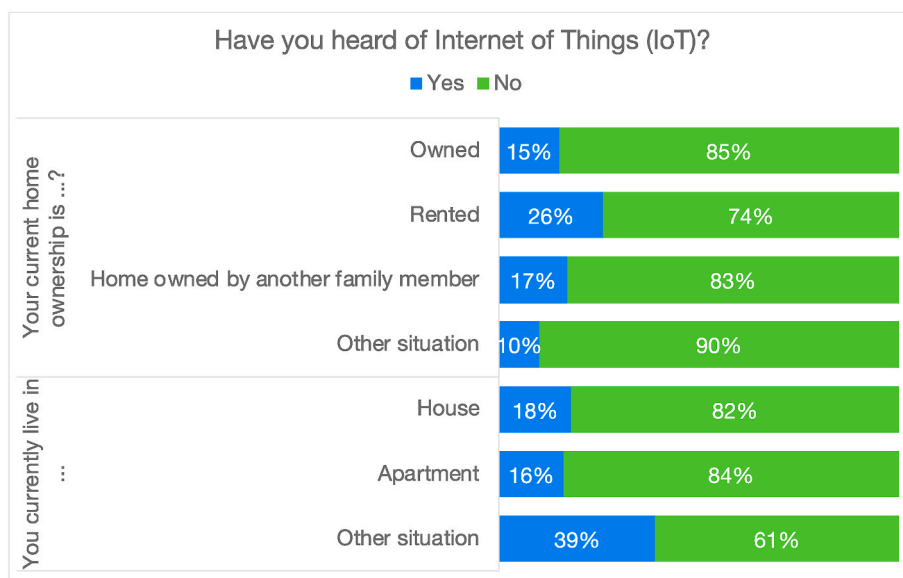
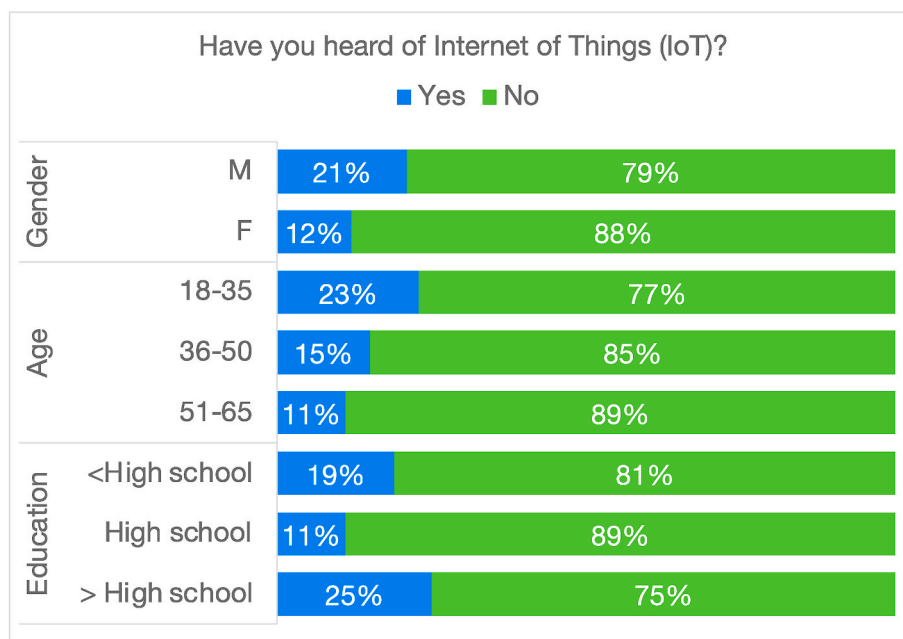


Fig. 2. IoT knowledge survey.

- ❖ Gateway and Hub for device control
- ❖ Smart sockets, programmable buttons, actuators
- f. Home Entertainment
 - ❖ Systems and services for home entertainment
 - ❖ Multiroom audio
 - ❖ Streaming systems

Among IoT devices, those based on artificial intelligence (AI), stand out and, in particular, among these we find home assistants, but also systems that we do not see and that regulate the functioning of networks, devices and applications.

As for artificial intelligence, there are various types of technologies that take this name, but at the moment the ones that attract the most attention are machine learning systems and large language models (LLMs).

Despite the widespread diffusion of connected objects, when interviewees are asked what their knowledge of the IoT is, and then go into detail about the technologies that make smartening the home possible, the percentage of knowledge drops significantly.

In fact, from Fig. 2 we obtain that 21 % of male respondents heard about IoT, while 25 % of respondents with higher education have knowledge about IoT. In fact, also the youngest people below 35 years and at high school have heard about IoT, which means the in early education and youngest people are more interested in smart home devices and how these can help to reach decarbonization, energy savings and well-being.

Fig. 3 illustrates that cyber security and privacy are a concern for more that 50 % of respondents. Despite the advantages, the risk associated with them, such as the management of personal data, can be a strong deterrent, this coming against the desire to have smart devices in one’s home.

4. Green smart home

Renewable energy must be produced, but it must also be managed: in fact, obtaining efficiency and savings thanks to home automation systems must be among the primary objectives of the ecological transition. In smart homes, energy supply can take place via a photovoltaic or wind system directly interconnected with the other components of the system, all managed through a device that carries out energy analysis, as it is equipped with artificial intelligence. The self-produced energy can be directed according to the energy expenditure of each appliance, or collected via a storage device to be used at a later time, for example during the night.

Romania is currently integrating in the power system more and more energy generation from renewable sources, in particular wind and photovoltaic power plants. Yet, the survey results gave unexpected

results, as shown in Fig. 4. As could be expected, photovoltaic is preferred by more than 60 % of the inhabitants in cities, slightly less by the inhabitants in rural areas, probably linked to the fact that the land they could no longer be used for agriculture. In addition, the necessary investments for private owners in the urban and rural areas in renewable energy generation are determining the respondents to be reticent in installing these units and using their energy production. The situation is reversed with wind power where the majority of those interviewed would not use it as a source of energy, especially in rural areas.

The interviewees themselves function of age, as shown in Fig. 5, highlight how the youngest and oldest are the most hostile to the use of such sources. This is probably linked to the fact that the intermediate age groups are those who get the most information, or in the case of younger people they are less interested in saving on their bills.

Today people are called to rediscover a direct relationship with energy, where the demand and production of energy are concentrated in the same place, the direct contact of people with the energy itself is, in part, at the basis of sustainable behavior in city.

The terms of green economy and smart city as perspectives which, through highly technological solutions, aim for greater attention to the natural, economic and social environment, become inseparable. In many ways the green economy is presented as a trend that cuts across all economic sectors and areas of production, consumption and living, which includes various ongoing trends and transformations, including those that concern the urban environment. With the new objective of the smart city.

In fact, this combination is amply demonstrated by the results shown in f.

Fig. 6, where more than 70 % of those interviewed believe that green energy is a key element that constitutes the smart city and vice versa.

Finally, as shown Fig. 7, green energy as an element that identifies the smart city is considered regardless of age, gender and economic conditions. A difference can only be seen in relation to the level of education, which shows that where there is a higher level of education, 80 % of those interviewed give importance to the issue of green energy, compared to 66 % of those interviewed with a higher level of education. Lower.

5. Spread of smart home systems

In the world, the smart home businesses it is prospected to generate an income of more than US\$100bn in year 2024 [17]. The Smart Home market has faced challenges due to compatibility between devices. Different communication protocols and the lack of a universal standard limit consumers’ options and cause installation difficulties. The spread of 5G globally could also impact the use and properties of smart home devices. In fact, 5G will reach speeds 10 to 50 times faster than the

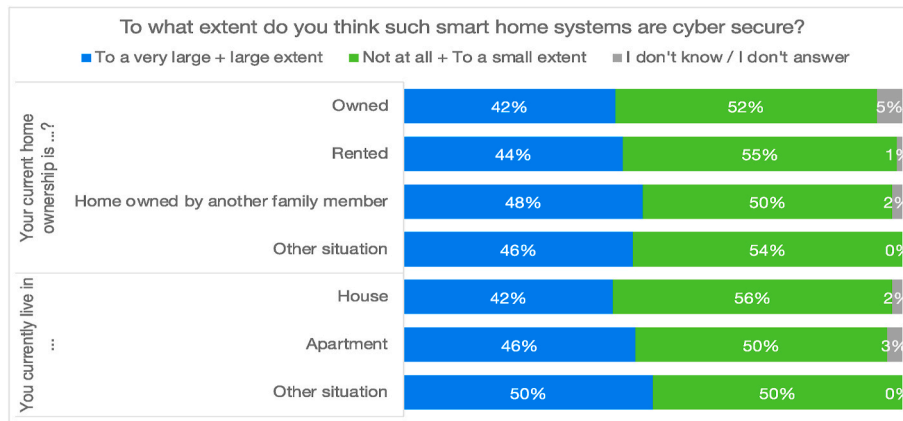


Fig. 3. Privacy and Cybersecurity survey.

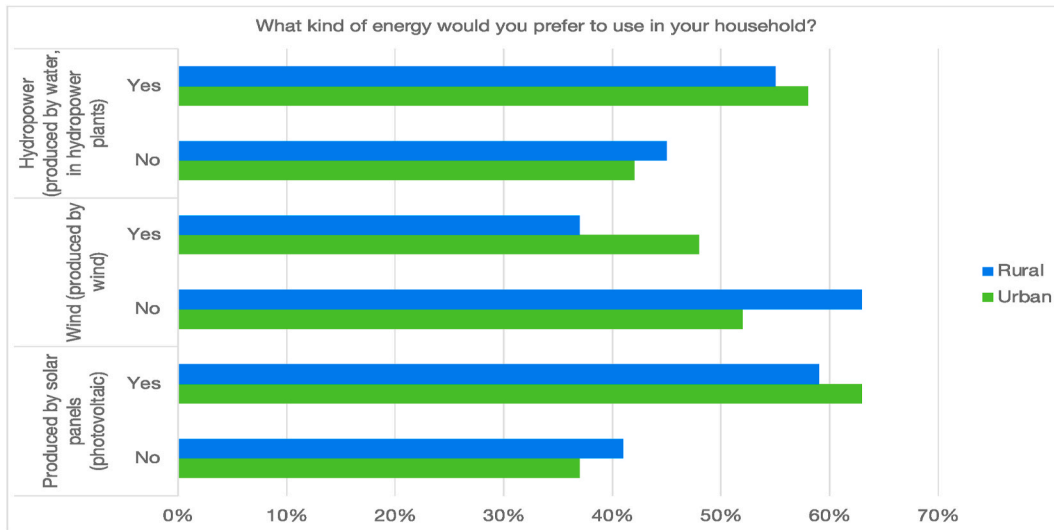


Fig. 4. Integrating green energy into smart homes - urban versus rural areas - survey results.

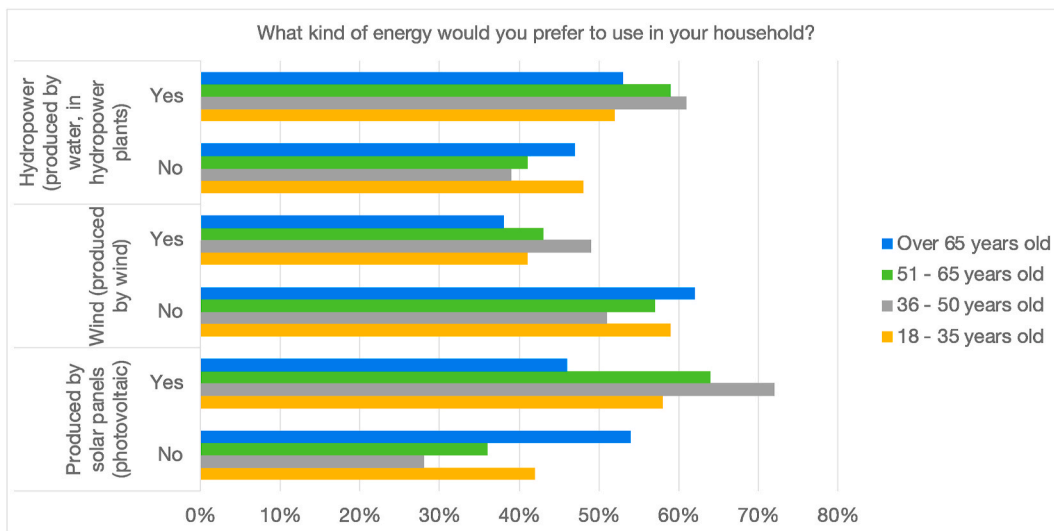


Fig. 5. Integrating green energy into smart homes – various segments of age - survey results.

fourth generation (4G) network. Through the 5G network it will be possible to share more data between smart home devices and will be able to connect with smart city technologies and self-driving cars.

Currently the average values of those who own Smart systems at home are still low and are less than 20 %, despite this the figure of those who, despite not having any device, would like to have one is important (around 40 %), as shown Fig. 8. For this reason, the percentage of people who rely on smart solutions will increase. The awareness of all inhabitants highlights that the technological home is no longer a luxury, but a necessity.

In the last five years, the technological development led to the installation of certain systems that increase the energy class of the entire property, while other solutions, such as video surveillance systems, however, increase the sense of security and comfort of buyers. The future is “smart”, but the period to convert existing homes into smart homes appears long. In fact, from the interviews with results shown in Fig. 9, when asked “how long do you think it will take for your home to become a smart home?”, over 60 % of those interviewed foresee this change in at least 4–5 years.

To speed up the process of energy transition process, which entails further economic advantages, an element that can trigger a virtuous

process is certainly the possibility of being able to manage devices (which are now already present on the market) that can train and inform the consumer in real time on behavior and energy consumption, to change the ways of use, making them virtuous and guaranteeing lower energy expenditure [18].

In fact, as shown in Fig. 10, almost 80 % of interviewed are in favor of adopting such devices to obtain data on energy consumption, in order to reduce the energy bill, but a further important factor, as can be seen from Fig. 11, that thanks to these systems energy consumption can be reduced/shifted during midday, concomitant with usage of economic renewable energy sources for supporting industry sector.

It is widely believed that Smart systems can help reduce the energy consumption of families, thanks to tools linked to energy monitoring, so it is possible.

- greater awareness of one’s consumption;
- control the switching on and off of the device in real time
- connected systems, avoiding consumption peaks;
- spontaneous mechanism of greater caution in energy management.

Currently, wired systems also provide a connection with the outside

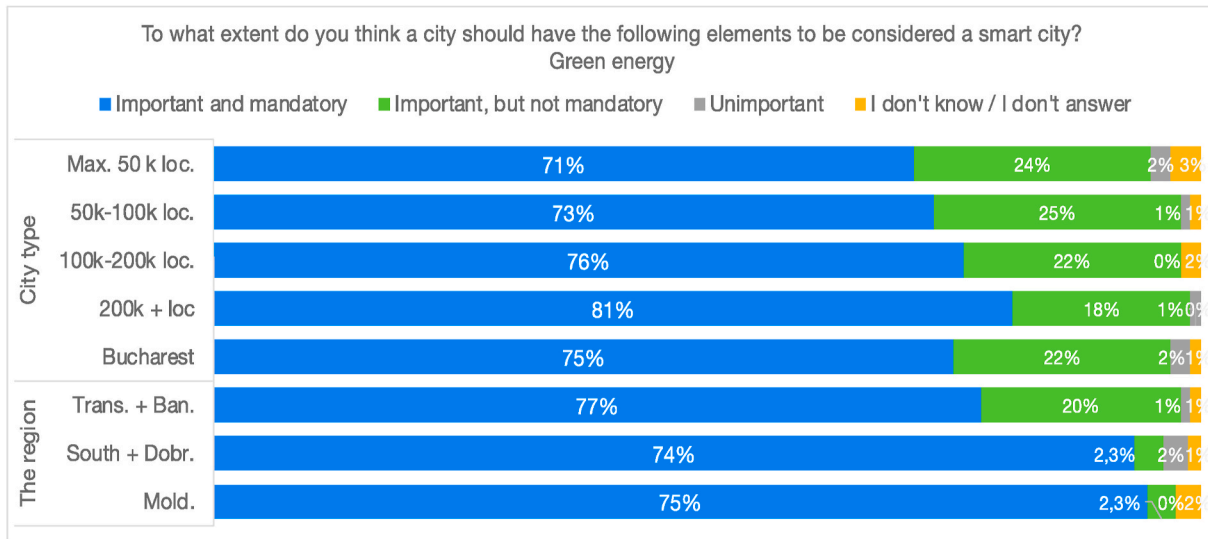


Fig. 6. Integration of green energy in smart cities survey results function of population size.

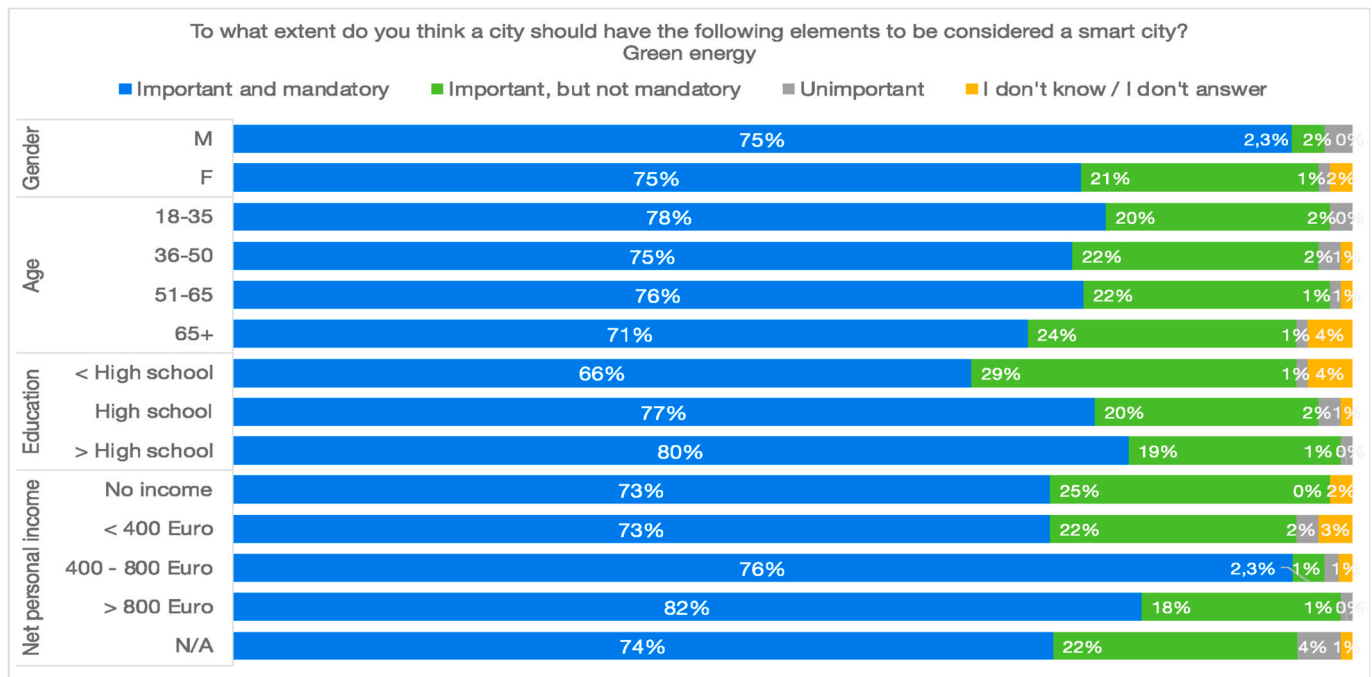


Fig. 7. Integration of green energy in smart cities survey results function of education, age, gender and income.

so that you can manage the home remotely and also use additional services such as video surveillance. In recent years they have been joined by wireless systems. The evolution of traditional home automation towards the "smart home" model was possible thanks to the introduction of devices, systems, actuators, connected wirelessly, which allow the creation of systems with lower costs and above all in a simple and fast way. , without necessarily having to intervene in the renovation of the house.

In fact, a very interesting fact can be deduced from Fig. 12: it was asked which type of system is preferable between wired and non-wired, and as expected around 90 % prefer Wireless systems.

Installing Smart systems for the home is cheapest, since the cost of the home automation system is mainly limited to the purchase of the devices themselves and the Wi-Fi system does not require major building works. Furthermore, since most devices are controlled and displayed via

user-friendly Apps, the transition to a Smart Home would become easier and more intuitive.

A question was proposed, namely the possibility of carrying out multiple actions at the same time, which is actually a peculiarity of home automation and smart houses, i.e. the "Scenarios". For example, the "Good morning" scenario with the alarm clock can at the same time raise the shutters, heat the bathroom, turn on the lights moderately, start the radio and the coffee maker; or the "Leave home" scenario will simultaneously turn off the lights, close the windows, arm the burglar alarm and alarms, and adjust the air conditioning to the preset value.

Well, this greatly interested users who would be very satisfied in having this possibility, as shown in Fig. 13, around 80 %, a sign that knowing the opportunities of a Smart Home, they would be even more interested in investing in this sector.

We wanted to conclude this survey with a question that apparently

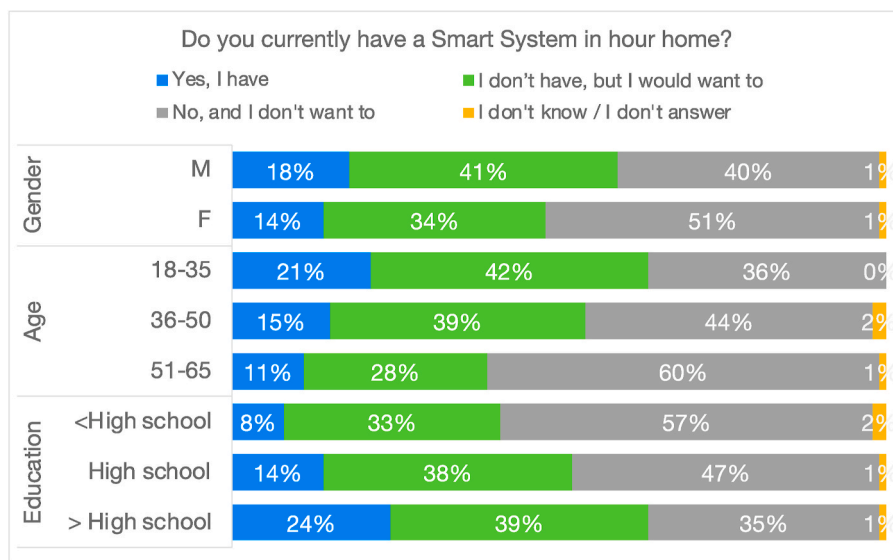
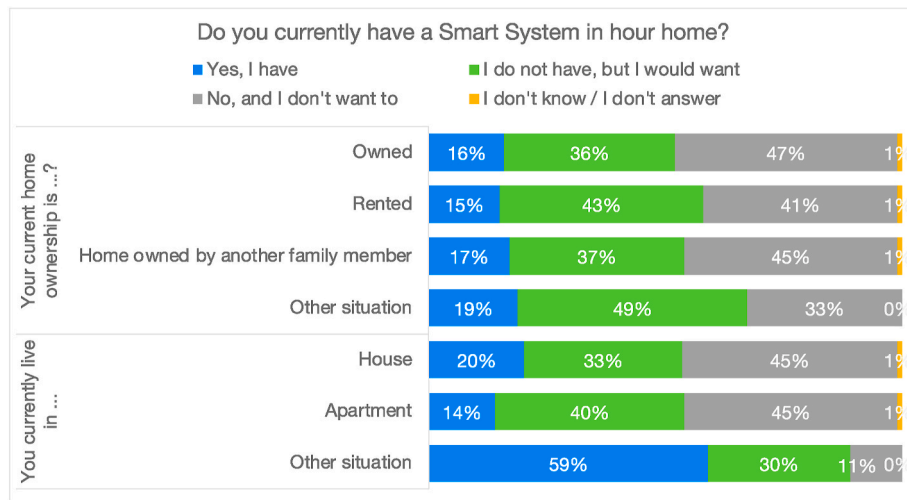


Fig. 8. “Do you have a Smart System in your home?” survey results.

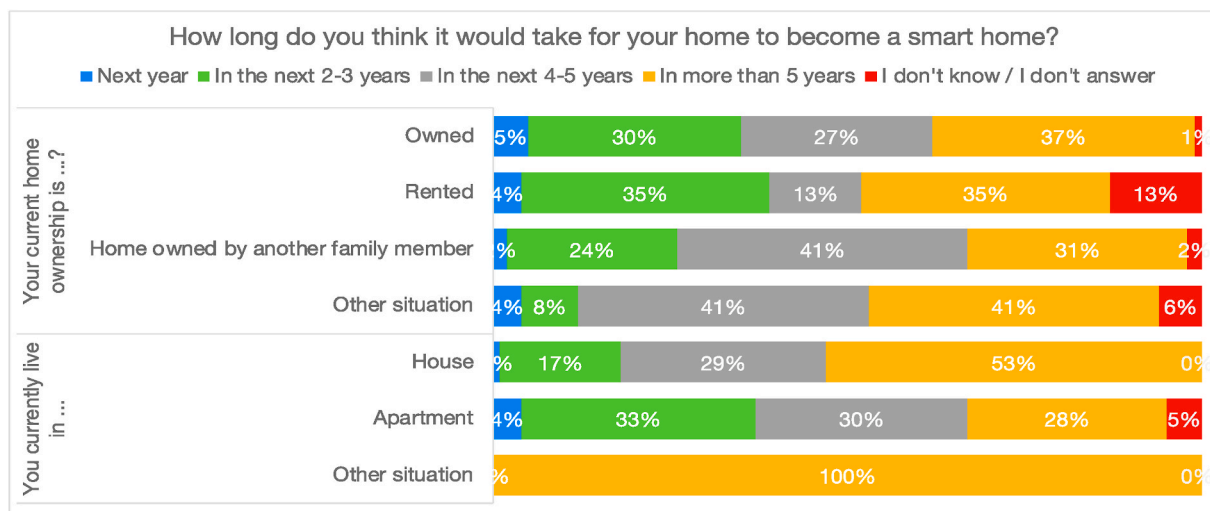


Fig. 9. “How long do you think it would take for your home to become a smart home?” survey results.

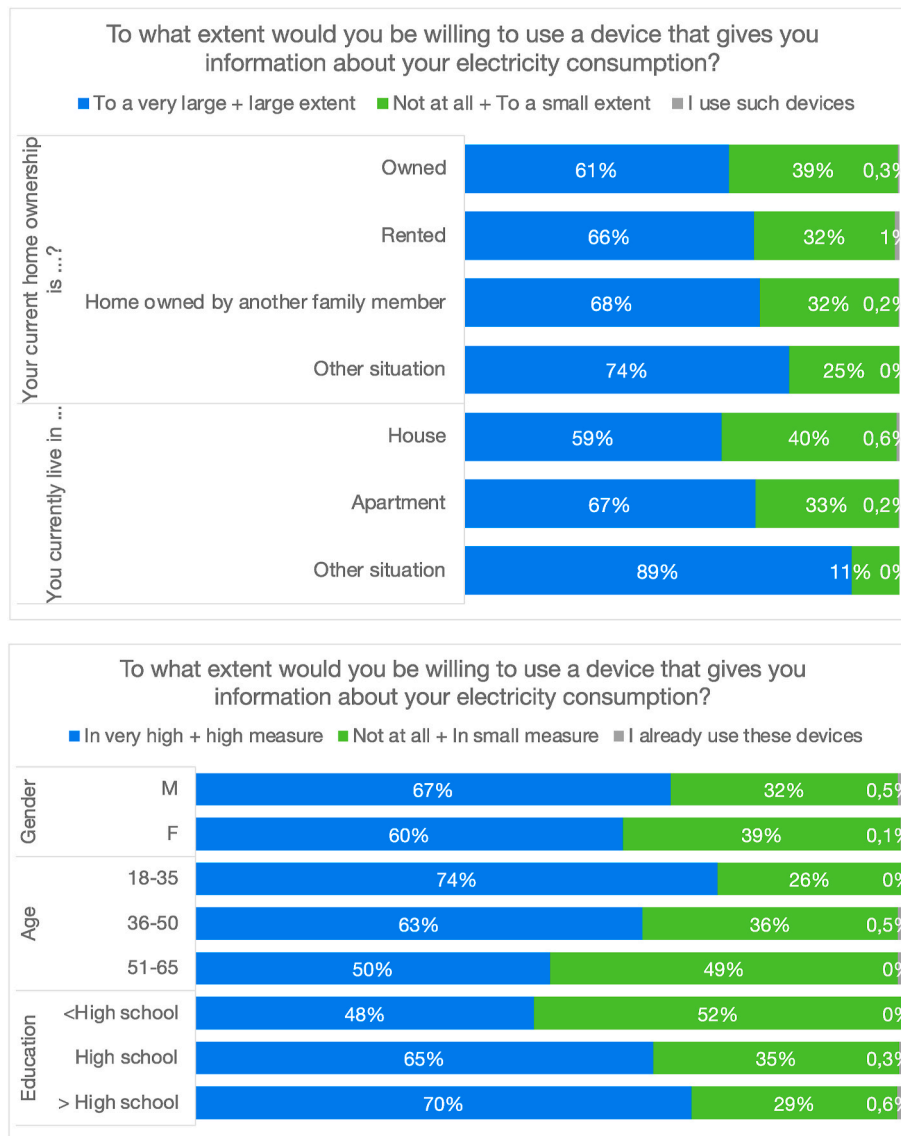


Fig. 10. “To what extent would you be willing to use a device that gives you information about your electricity consumption?” survey results.

might have seemed trivial, that is, whether we were willing to move house for a Smart without paying, for free, from Fig. 14, “only” an average of 55 % would agree. Therefore, despite the economic, sustainable, environmental and improved living advantages, people are very attached to their home, perhaps because they grew up there. This must strongly encourage us to give a push towards rethinking existing houses, rather than building new ones, leaving memories intact, but improved by new technologies.

6. Conclusions

Renewable energy, technology and comfort are some of the main pillars that are changing the way we live at home. The partnership between technological innovation and renewable energy is crucial in an era marked by pollution and climate change: home automation and IoT devices support us in managing the home, between energy efficiency and reduced environmental impact. It is estimated that by 2050, cities and homes will function on the supply of solar, wind, geothermal, biomass and other green energy sources. This change cannot fail to be reflected in the house of the future, where the systems will use less (almost zero) energy compared to traditional houses, with consequent concrete savings on bills in the long term and obviously with different

monitoring and management systems for electrical loads.

The ever-growing interest in smart homes appears linked not only to a significant reduction in energy consumption and help for the ecological transition of our societies. Users are proving to be increasingly autonomous in the use of connected devices, taking advantage of their features and benefits. Interest in new services for the smart home is also increasing, also based on a digital culture which has rediscovered the value of the home. The number of companies offering innovative services is growing, thanks to the use of data collected from devices and the integration of IoT solutions with AI algorithms. The rapid progress of new technologies applied to the home and the desire for a new model of life that is sustainable has led to the new paradigm of homes with intelligent functions, hybrids between home and office, revolutionizing the ancient concept of living in one’s home.

The vision of the “smart home” will include not only smartphones, but also other devices, accessible wherever there is a connection to the WiFi network. The Internet of Things will become a new element of both future and renovated homes, permeated by the digital world, where the domestic environment, with its devices, must adapt to our needs, simplifying our lives, automating processes and providing information in real time, which could not be accessed.

The interviews carried out thus made it possible to outline some key

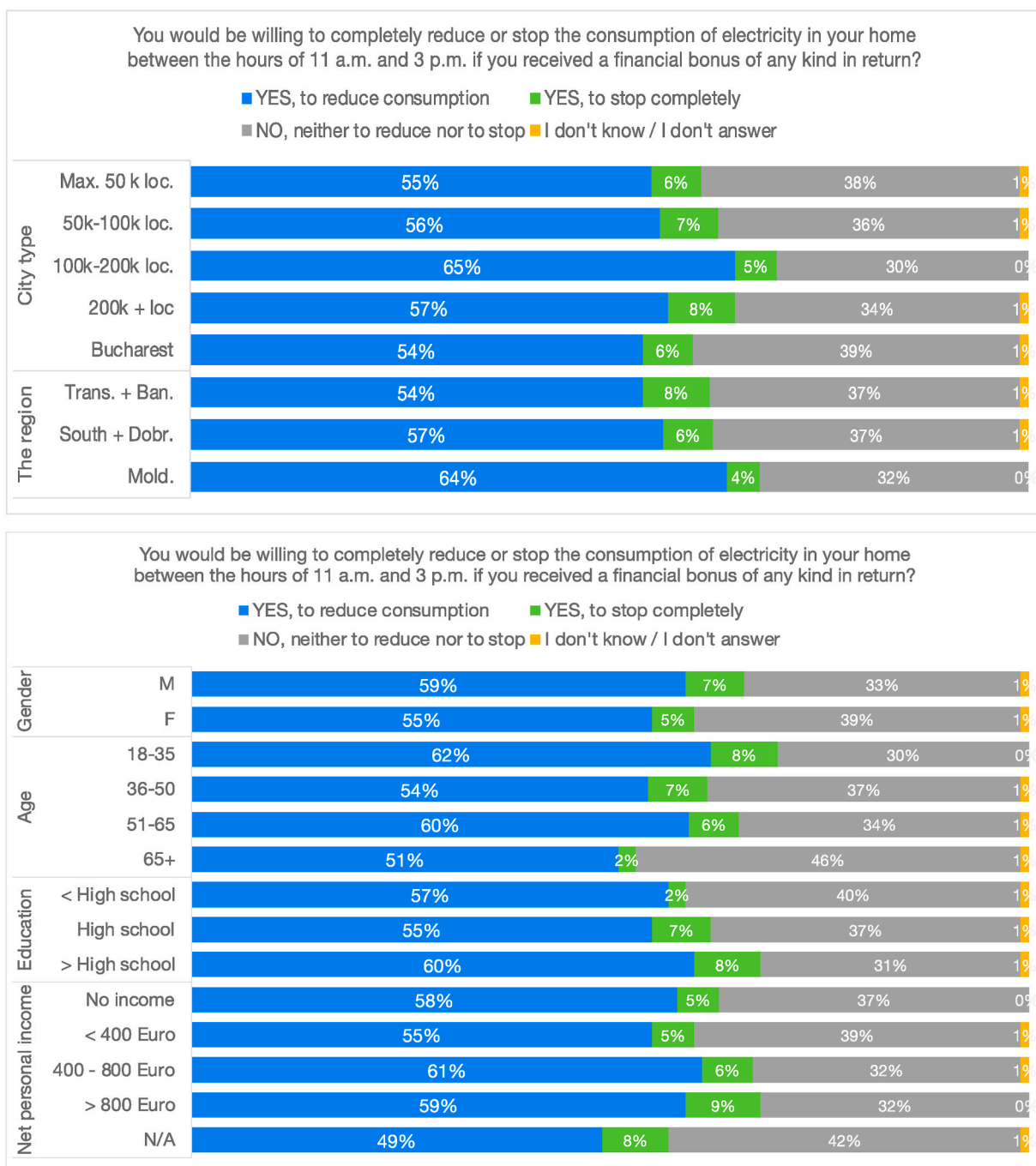


Fig. 11. Smart technologies usage for energy savings survey results.

elements to understand where citizens' interest is concentrated and what they expect from the future in their homes, underlying the deductions obtained with this paper.

The results of market surveys which show a significant increase and expansion of the market and customers interested in Smart Home solutions must be read and framed from this perspective. However, the spread of connected devices within homes remains in line with previous years, indicating how the market is driven above all by those who have already approached the Smart Home and are extending the quantity of intelligent objects in their possession.

If we add to the phenomena of adaptation to new behaviors, habits and lifestyles - triggered and accelerated by the pandemic crisis - the considerable incentives that have occurred in different ways in different European countries, it becomes clear that a growing increase in products

in the future is credible and the development of home automation also in Romania as well as in other European countries.

Integrating Smart Home technology into our daily lives offers an effective way to save energy and make our lives and homes more comfortable. As technology advances, so does the possibility that Smart Homes will become the norm, benefiting our savings and the planet.

The study highlighted citizens' knowledge on Smart home issues and energy saving, but above all how new technologies can somehow help users to adopt sustainable behaviours. Investigations of this type certainly help us understand in which field we need to provide citizens with better awareness in order to obtain better results. In fact, it would be advisable to carry them out with time deadlines to support users' decisions on energy consumption.

The limits linked to investigations of this type, which must be carried

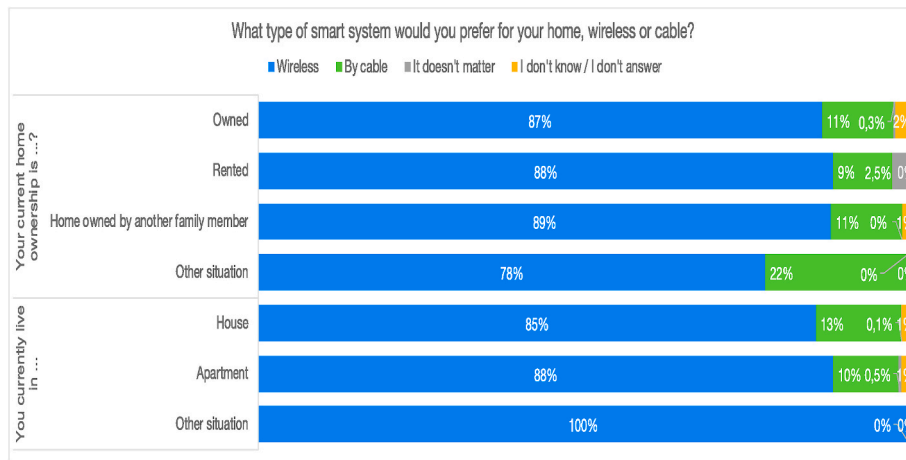


Fig. 12. “What type of smart system would you prefer for your home, wireless or cable?” survey results.

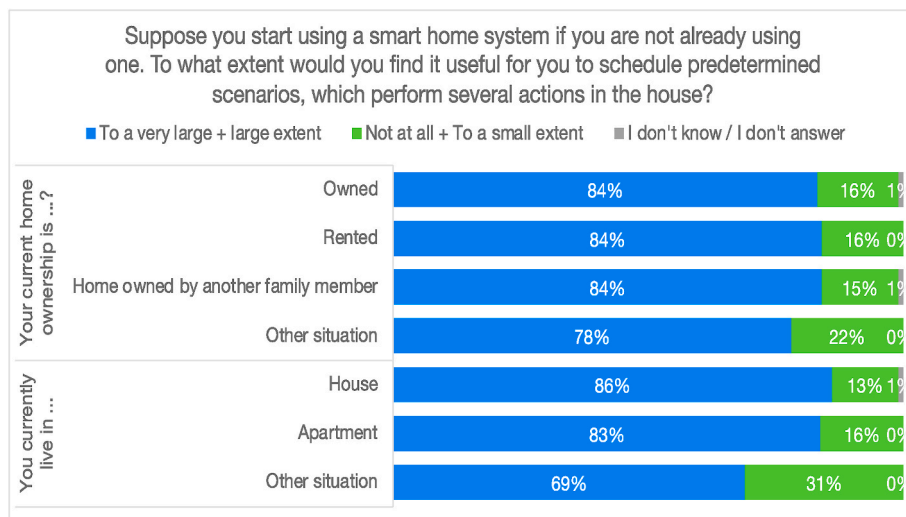


Fig. 13. Scenario predefinition in the smart home survey results.

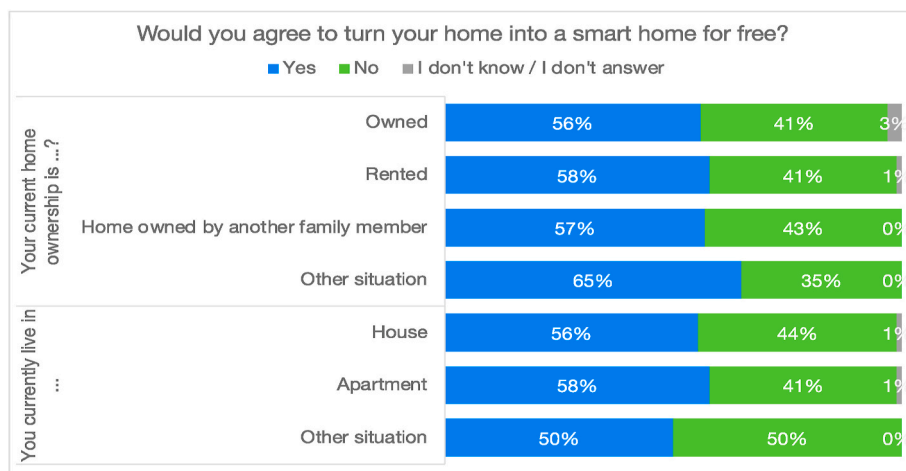


Fig. 14. “Would you agree to turn your home into a smart home for free” survey results.?

out and analyzed, are the timescales. This certainly determines the development of future research, such as, for example, through a specific app, carrying out these interviews in a timely manner and having them analyzed by artificial intelligence, to speed up data analysis times.

CRedit authorship contribution statement

Alexandra Catalina Lazaroiu: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Mariacristina Roscia:** Writing – review & editing, Supervision, Investigation, Data curation. **Vasile Sebastian Dancu:** Writing – review & editing, Supervision, Resources, Methodology. **Georgiana Balaban:** Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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