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# A Study on the Commonly Adopted Energy Sources and Production Systems for Domestic Hot Water in the Calabria Region (Italy)

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**Abstract:** Worldwide, there are many options to ensure domestic hot water (DHW) provision in dwellings. This study aimed to depict the distribution of energy sources and DHW production systems in the Calabria region. The research was focused on understanding which variables, among contextual variables and building characteristics, may influence the adoption of a particular energy source or production system. Descriptive statistics and chi-square test of independence have been developed. Significant relationships were found between the climatic zone and the energy source used as well as between the climatic zone and the production system installed in both households with a separated and a combined DHW production system. Furthermore, the population of the municipality and the dwelling type resulted to be significant variables for the preference of an energy source or the diffusion of a combined production system.

**Keywords:** DHW energy sources; DHW production systems; Survey; Chi-square test

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## 1 Introduction

Nowadays, the provision of domestic hot water (DHW) is assured in the majority of houses of developed countries. Many studies give an overview of aspects related to DHW consumption in households and energy-related issues, and they usually consider a single production system. Fuentes at al.[1] collected comprehensively different investigations, reporting aspects related to: a) information on the current approaches based on international standards that are of potential use in research studies on DHW consumption, b) assessment of the existing methodologies for estimating the mains water temperature and hot delivered water in DHW systems, c) characteristics of DHW consumption profiles, inclusive of timing and duration of water usage events in various types of building, d) analysis of the main technical and socio-economical factors affecting the shape of DHW consumption profiles of households, and e) evaluation of the most adopted modelling techniques existing in the literature to estimate DHW consumption profiles in buildings. In the same review, proposals and research lines to improve the state of the art on the research field of DHW consumption in buildings are also highlighted and consist of: a) providing information on DHW demand, hot water usage profiles, and the influence of socio-economic factors for other than residential building types; b) identifying factors that influence DHW demand (e.g., number of draws, draw length, volumes, flow rates and starting times of events for different buildings, users, and climatic conditions); c) providing relationships between socio-economic factors and detailed usage of DHW in buildings; d) deriving suitable models that are valid for different climatic conditions and distribution systems to constrain the relationship between these variables; e) analyzing the influence of seasonality on the shape of the daily tapping profiles and how their variation can affect the design of energy management strategies;

f) assessing the representativeness of profiles in standards as compared with real DHW patterns.

Furthermore, it's common to find studies on the energy source used for cooking, especially in developing countries such as Tanzania [2], Ethiopia [3], Nigeria [4], and India [5], and investigations reporting the variety of production systems for space heating or the household preference on space heating [6–11]. On the other hand, just a few studies on the DHW production systems have been found. In particular, Goto et al. [12] analyzed how consumers select ecologically efficient water heaters in Japan in relation to retail energy prices, government financial support, marketing activities, consumers' housing attributes (floor space and age of the buildings). Moreover, Pomianowski et al. [13] reported recent studies connected to improvements in the energy performance of DHW systems, in phases of DHW production, distribution, and circulation, wastewater heat recovery, and control strategies, for diverse types of energy sources and systems currently used for the production of domestic hot water in residential buildings in different countries.

The aim of this study is to help to bridge the gaps in literature concerning the types of DHW production systems and the used energy sources in Mediterranean regions. Furthermore, this investigation considered contextual variables belonging to diverse categories such as climate, population of the municipalities, buildings' characteristics. The analysis was performed using collected data by survey that were processed by statistical approaches.

The contents of this paper can be summarized as follows: section 1 is comprised of a brief literature review and the research proposals, section 2 describes the methodology of data collection and the description of the analyzed sample, section 3 discusses the obtained results illustrating the distribution of the DHW production systems and of the energy sources in relation to the contextual variables, and giving an overview of the used renewable technologies. Also, the results of the Chi-square test of independence test were reported to verify the significance of the selected variables. Section 4 is dedicated to conclusions and future works.

## 2 Data collection and sample

This section introduces the structure of the survey adopted for data collection along with a description of the distribution methods. Details about the final sample are also reported.2.1 Survey description

Aiming to describe the commonly used energy sources and production systems for DHW production in the Mediterranean zone, a questionnaire survey was distributed to the families located in the Calabria region (Southern Italy). The questionnaire was drafted by the Environmental Applied Physics research group of the Department of Environmental Engineering of the University of Calabria and distributed from 2017 to 2020. Specifically, two delivery methods were used: online and face-to-face. In total, 237 households were involved and 67 municipalities were reached. As a result of data cleaning, 193 questionnaires were accepted as valid for the analyses.

The questionnaire is composed by 64 questions grouped into 3 main categories: information on building and installed systems, family composition and energy consumption, and energy-related occupants' behavior. 2.2 Sample description

Information on the average household's age, number of components, gender prevalence, income, and electric energy consumption were compared with the ISTAT data [14] to verify the representativeness of the sample. Furthermore, the distribution of the sample in different climatic zones was compared to the distribution of the entire region analyzed, according to the Italian law [15], that divides Italy in six climatic zones. Those zones differ for the heating degree days (HDD) and are defined as: zone A - <600 HDD, zone B - 600-900 HDD, zone C - 901-1400 HDD, zone D – 1401-2100 HDD, zone E - 2101-3000 HDD, and zone F - >3000 HDD. The result of this verification showed that the sample satisfactorily represents the regional context. Coherently with the aim of the paper, a certain number of variables were considered. Those consist of contextual variables and building characteristics. The formers refer to the climatic zone and the number of inhabitants in the municipality where the household lives. The latter refer to dwelling type (apartment or detached house), house ownership status, the year of construction, and the floor area. The sample characteristics are reported in Table 1.

**Table 1.** Sample characteristics

| Contextual variables | Climatic zone | Zone B: 2% |
|---|---|---|
| | | Zone C: 38% |
| | | Zone D: 41% |
| | | Zone E: 19% |
| | Municipality population | Up to 3000: 30% |
| | | 3001-10000: 38% |
| | | 10001-60000: 15% |
| | | More than 60000: 18% |
| Building characteristics | Dwelling type | Apartment: 40% |
| | | Detached house: 60% |
| | House ownership | Rented house: 12% |
| | | Owned house: 88% |
| | Year of construction | Historical building (before 1950): 5% |
| | | 1951 – 1973: 19% |
| | | 1974 – 1991: 45% |
| | | 1992 – 2005: 15% |
| | | 2006 – 2015: 12% |
| | | From 2016: 1% |
| | | I don't know: 3% |
| | Dwelling floor area ($m^2$) | Up to 80: 15% |
| | | 81-100: 24% |
| | | 101-160: 44% |
| | | 161-200: 11% |
| | | More than 200: 6% |
| | | I don't know:1% |

The sample is mainly constituted of houses located in areas with a mild climate (38% in climatic zone C and 41% in climatic zone D), and in municipalities with less than 10000 inhabitants. The households live mostly in detached houses (60%) and in houses they own (88%), most of them built in the years 1974-1991, with a surface area of 101-160 m2.

# 3 Results

In this section, the distribution of energy sources and production systems for DHW production in relation to the selected variables were investigated. The results of the statistical analyses are presented separately for households with a different heat generator system for space heating and DHW and dwellings with a combined production system of thermal energy. The results section continues with an analysis of the production systems that apply renewable energy sources. Finally, the Chi-square test of independence was used to establish the factors that significantly influence the choice of the DHW energy source and production system.

## 3.1 Energy source for DHW production

Figure 1 shows the distribution of the energy sources used in buildings with a separate DHW production system as a function of contextual variables. This subset represents the 47% of the entire sample.

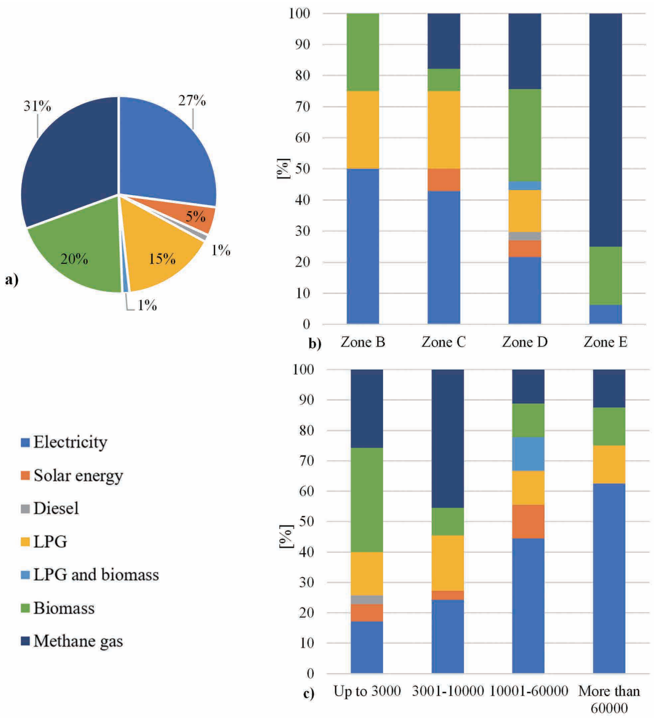


**Figure 1.** Energy source and contextual variables for dwellings with a separate production system. Distribution for a) the entire sample, b) climatic zone, and c) population in the municipality.

As shown in Fig. 1a, methane gas, electricity, and biomass were the most common energy source, with a percentage equal to 31%, 27%, and 20%, respectively. The use of electricity and LPG decreased from a warmer climatic zone to a colder one, while the use of methane gas increased as the climatic zone became colder, as displayed in Fig. 1b. Regarding the population in the municipality, households preferred the use of electricity especially if they live in larger municipalities. On the contrary, biomass was largely diffuse in the smallest municipalities (see Fig. 1c).

Figure 2 presents the distribution of the energy sources used in buildings with a separate production system in relation to the building characteristics.

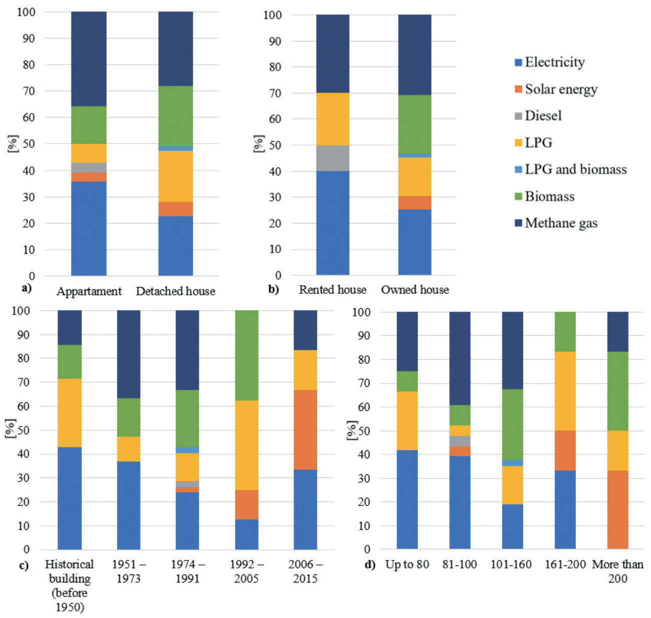


**Figure 2.** Energy source and building characteristics for cases with a separate production system. Distribution for a) dwelling type, b) home ownership, c) year of construction, and d) dwelling surface (m$^2$).

In apartments, the choice was mainly limited to electricity (36%) and methane gas (36%), while in detached houses more options were found: electricity (23%), LPG (19%), biomass (23%), and methane gas (28%), as shown in Fig. 2a. The same trend was observable in Fig. 2b, for households in a rented house than owners. The use of biomass increased from historical houses to those built by 2005. Solar energy was used in houses built from 1974, with an increase from 2.4% to 33.3% for houses built by 2015. Solar energy was more used in houses with surface larger than 160 m2, while methane gas was more utilized in houses with surface lower than 160 m2 (Fig. 2d).

The analysis of the energy sources adopted in dwellings with a combined production system for heating and DHW is shown in Figure 3.

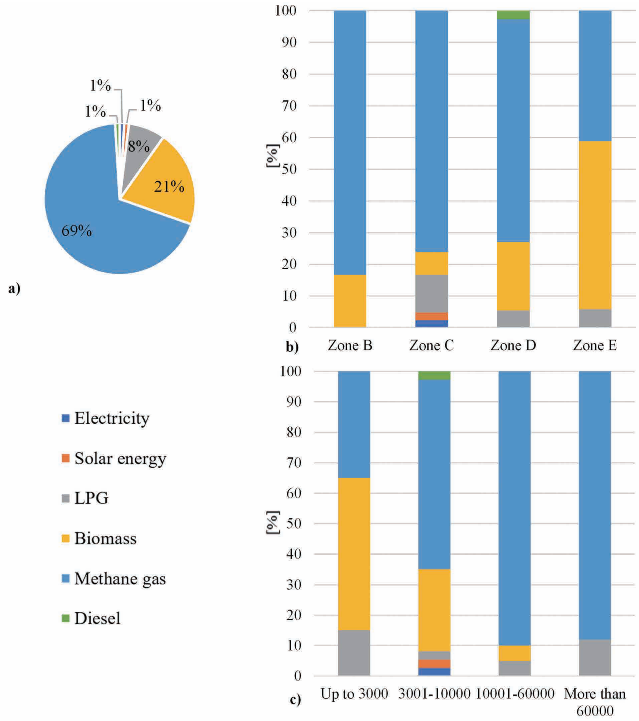


**Figure 3.** Energy source and contextual variables for cases with a combined production system. Distribution for a) the entire sample, b) climatic zone, and c) population in the municipality.

From Fig. 3a, it can be inferred that methane gas was the preferred choice followed by biomass with a percentage of 69% and 21%, respectively. The use of methane gas decreased from a warmer climatic zone to a colder one (Fig. 3b), and it strongly increased in houses located in larger municipalities (see Fig. 3c). Furthermore, the use of biomass decreased as the population in the municipality increased.

The distribution of the energy sources for dwellings with a combined production system is presented in Figure 4 as a function of the building characteristics.

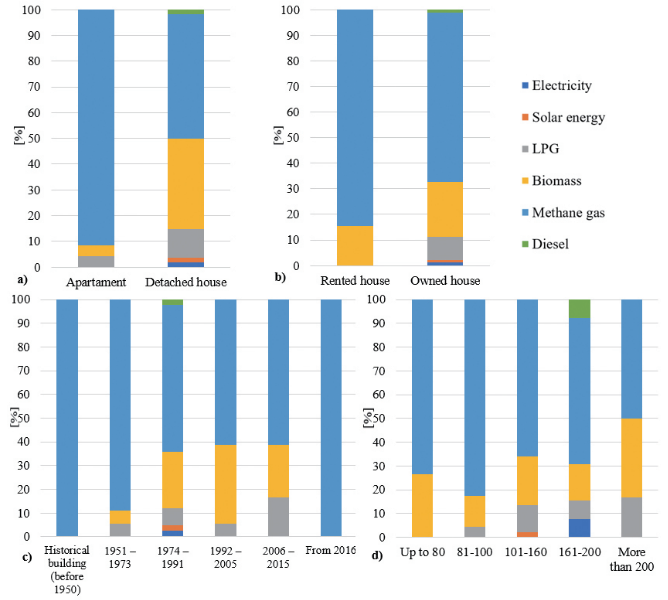


**Figure 4.** Energy source and building characteristics for cases with a combined production system. Distribution for a) dwelling type, b) home ownership, c) year of construction, and d) dwelling surface ($m^2$).

In dwellings with a combined production system, methane gas was the preferred choice both in apartments (92%) and in detached houses (48%). In the last ones, also biomass was used by 35% of families. Independently of the house ownership (Fig. 4b), methane gas usage covered at least 65% of the sample, followed by biomass for rented houses, and other options for the owned houses with very low percentages. As shown in Fig.4 c, the use of methane gas stands out regardless of the year of construction; the use of biomass was more common in houses built from 1951 to 2015. Moreover, methane gas and biomass were the most predominant energy sources, independently from the house's surface (Fig.4 d).

## 3.2 DHW system production

The production systems adopted in the houses that use a separate system are shown in Figure 5.

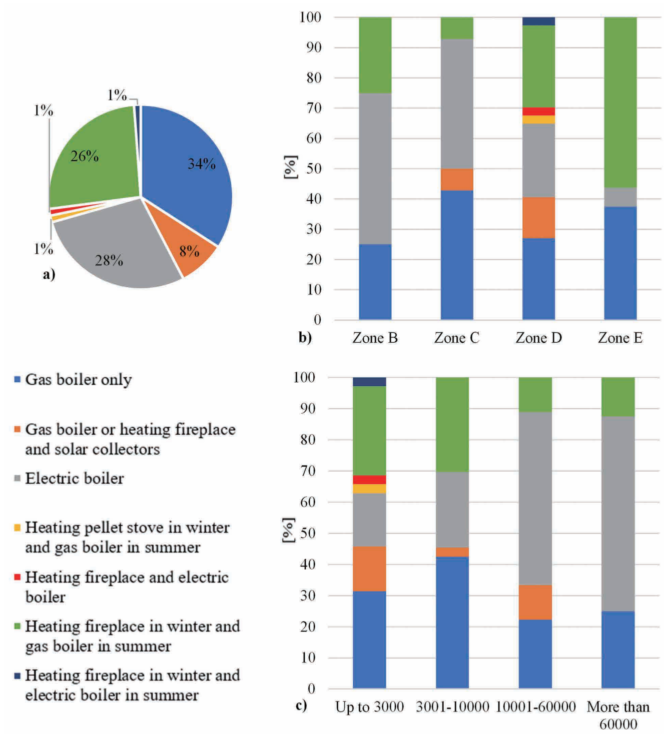


**Figure 5.** Production system and contextual variables for cases with a separate production system. Distribution for a) the entire sample, b) climatic zone, and c) population in the municipality.

Gas boiler, electric boiler, and the heating fireplace in winter and gas boiler in summer were the most adopted production systems with a percentage equal to 34%, 28%, and 26%, respectively. The heating fireplace in winter and gas boiler in summer increased from a warmer climatic zone to a colder one (Fig. 5b) and decreased in the most populated municipalities (Fig. 5c). Opposite trend was observed for the electric boiler. Solar collectors were installed in climatic zones C and D and combined with other systems (gas boiler or heating fireplace). Moreover, an ample variety of production systems were installed in the smallest municipalities, as reported in Fig. 5c.

As a function of the building characteristics, Figure 6 illustrates the analysis of the production systems in the houses with a separate facility.

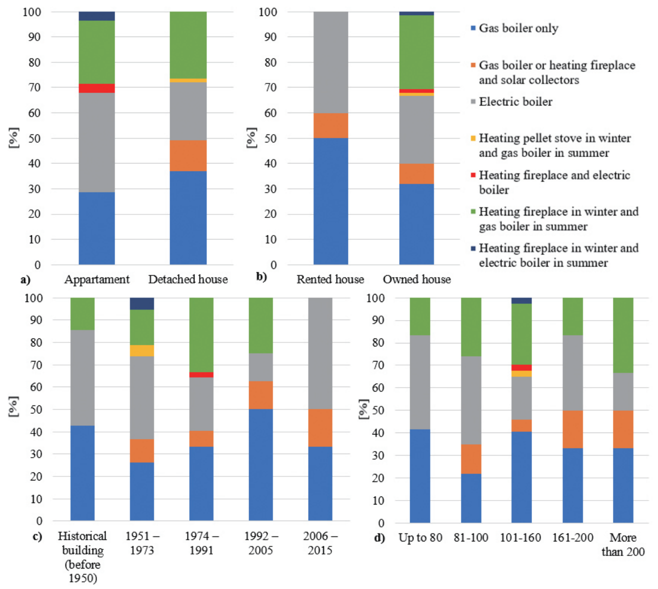


**Figure 6.** System production and building characteristics for cases with a separate production system. Distribution for a) dwelling type, b) home ownership, c) year of construction, and d) dwelling surface ($m^2$).

In apartments, electric and gas boilers were more common with a percentage of 39% and 29%, respectively. The same production systems were chosen in detached houses but in different percentages (23% for electric boilers and 37% for gas boilers), as illustrated in Fig. 6a. In rented houses, the choice was limited to gas and electric boilers, with a small percentage (10%) of solar collectors coupled with gas boilers or heating fireplaces. In contrast, more options were considered from the owners. Regardless of the year of construction, electric and gas boilers were rated as the most utilized. More typologies of production systems were used in houses built from 1951 to 1991. A trend in production systems and house surfaces was not highlighted (Fig. 6d).

Figure 7 presents the system adopted in the houses with a combined production facility.

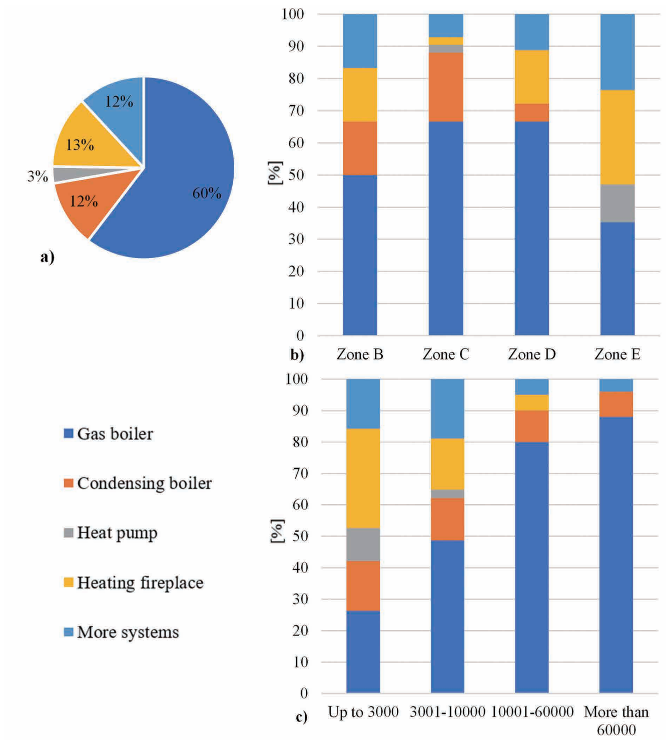


**Figure 7.** Production system and contextual variables for cases with a combined production system. Distribution for a) the entire sample, b) climatic zone, and c) population in the municipality.

Dwellings presented a single or more than one system installed (12%, see Fig. 7a) such as heating fireplace and condensing boiler, heating pellet stove and gas boiler, heat pump and gas boiler, heating fireplace and gas boiler, and heating fireplace and heat pump. The gas boiler was the most adopted production system (60%) in all climatic zones. Fig. 7c shows that the gas boilers increased with the increment of the population in the municipality, as the other systems became less common. The heating fireplaces were more used in climatic zone E and in municipalities up to 30000 inhabitants. Heat pumps were chosen only in climatic zone E (12%) and in zone C (2%). The distribution of the combined production systems as a function of the building characteristics is shown in Figure 8.

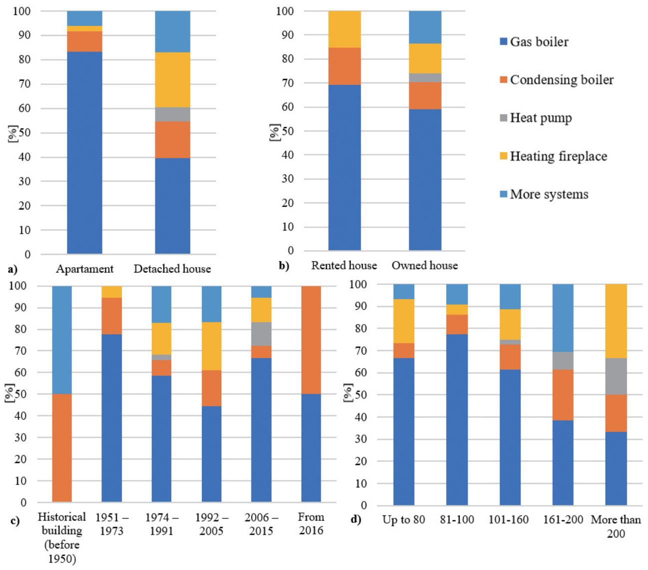


**Figure 8.** System production and building characteristics for cases with a combined production system. Distribution for a) dwelling type, b) home ownership, c) year of construction, and d) dwelling surface ($m^2$).

Heating fireplaces were more diffused in detached houses (23%) and almost absent in apartments (2%), where the gas boiler prevailed over other choices (83%). While in apartments and rented houses the use of gas boiler was predominant with respect to the other facilities, in detached and owned houses more production systems were adopted, see Fig. 8b. Heat pumps were installed only in detached and owned houses, and their number increased in dwellings with the highest surface, as can be seen in Fig. 8d.

### 3.3 Renewable energy sources

Further considerations can be made regarding the production systems that use renewable energy sources such as photovoltaic panels (PV) and solar thermal collectors. Considering the total sample, both solar systems were installed with a limited percentage of 7%. The analysis is shown in Figure 9 for the houses with a combined DHW production system, and in Figure 10 for the cases with a separate production system.

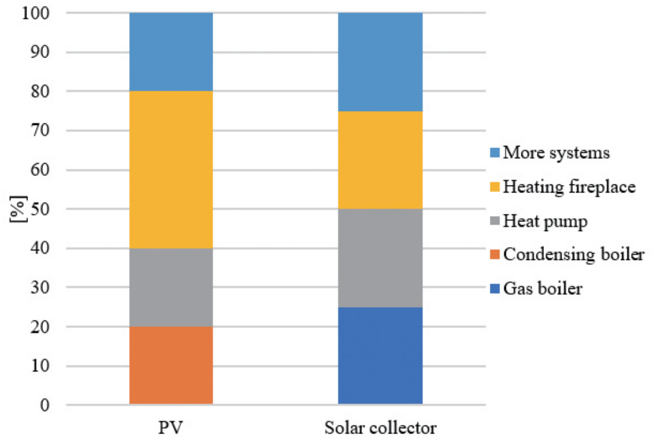


**Figure 9.** Distribution of photovoltaic panels (PV) and solar thermal collectors as a function of the combined production system.

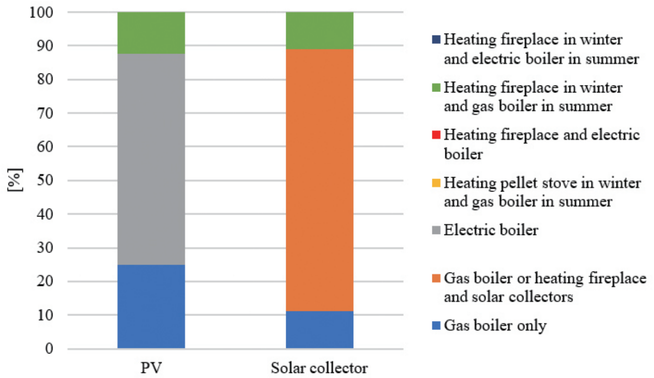


**Figure 10.** Distribution of photovoltaic panels (PV) and solar thermal collectors as a function of the separate production system.

Photovoltaic panels were mainly installed in houses that use the heating fireplace (40%), while solar thermal collectors were equally adopted (Fig. 9). Concerning houses with a separate production system, PVs were preferred in such dwellings that use the electric boiler for DHW production (63%), while solar thermal collectors were installed with a percentage of 78% in combination with gas boilers or heating fireplaces (Fig. 10).

### 3.4 Significance of the investigated variables

The sample was split into two categories: houses with a separate production system and houses with a combined production system for space heating and DHW production. The chi-square test of independence was applied to establish the factors that significantly influence the choice of the energy source and production system for DHW. In order to properly run the analysis, all the categories with percentages lower than 5% were excluded. The results of the chi-square test are reported in Table 2.

**Table 2.** Chi-square test's results

| | Separate production system | | Combined production system | |
|---|---|---|---|---|
| | **Energy source** | **Production system** | **Energy source** | **Production system** |
| Climatic zone | $\chi^2(12, N=83)= 29.17^{**}$ | $\chi^2(9, N=82)= 18.85^{*}$ | $\chi^2(6, N=99)= 16.26^{*}$ | $\chi^2(9, N=98)= 20.13^{*}$ |
| Population in the municipality | $\chi^2(12, N=83)= 18.63$ | $\chi^2(9, N=82)= 13.42$ | $\chi^2(6, N=99)= 25.44^{***}$ | $\chi^2(9, N=98)= 23.48^{**}$ |
| Dwelling type | $\chi^2(4, N=83)= 4.14$ | $\chi^2(3, N=82)= 5.69$ | $\chi^2(2, N=99)= 20.32^{***}$ | $\chi^2(3, N=98)= 19.53^{***}$ |
| Home ownership | $\chi^2(4, N=83)= 3.86$ | $\chi^2(3, N=82)= 4.22$ | $\chi^2(2, N=99)= 1.85$ | $\chi^2(3, N=98)= 2.12$ |
| Year of construction | $\chi^2(16, N=80)= 24.88$ | $\chi^2(12, N=79)= 8.82$ | $\chi^2(10, N=97)= 8.55$ | $\chi^2(15, N=96)= 18.46$ |
| Dwelling surface | $\chi^2(12, N=76)= 19.32$ | $\chi^2(9, N=75)= 7.40$ | $\chi^2(6, N=92)= 3.82$ | $\chi^2(9, N=92)= 12.00$ |

$^{*}P< .05$, $^{**}P < .01$, $^{***}P < .001$

The relation between climatic zone was significant for the energy source used $\chi^2(12, N=83)= 29.17$, $P<0.01$ and production system installed $\chi^2(9, N=82)= 18.85$, $P<0.5$ in households with a separate system. In fact, electricity was the principal energy source in climatic zone C (50%), biomass in climatic zone D (31%), and methane gas in climatic zone E (75%). The electric boiler was the most adopted system in climatic zone B (50%) and C (46%), while the fireplace in winter and the gas boiler in summer was preferred in climatic zone E (56%).

Climatic zones resulted in significant relation also for cases with a combined production system, $\chi^2(6)= 16.26$, $P<0.05$ for the energy source and $\chi^2(9)= 20.13$, $P<0.5$ for the system installed. In particular, methane was used for DHW production in 83% of households in climatic zone B, 80% in climatic zone C, and 72% in climatic zone D. Consequently, the most common production system was the gas boiler in climatic zones B (50%), C (68%), and D (66%). In climatic zone E, gas boiler and heating fireplace were likewise preferred (40% and 33%, respectively). For household with a combined system, the preference of an energy source or the diffusion of a production system significantly differed by the population in the municipality, $\chi^2(6)= 25.44$, $p< 0.001$ and $\chi^2(9)= 23.48$, $P<0.01$, respectively. Elevate significance was also found for the dwelling type $\chi^2(2)= 20.32$, $P<0.001$ and $\chi^2(3)= 19.53$, $P<0.001$. Biomass (50%) and therefore heating fireplaces (35%) were preferred in smaller municipalities. On the contrary, methane was chosen in larger municipalities where was adopted from 90% of households. Consequently, the number of installed gas boilers was higher in municipalities with more than 10000 inhabitants. Methane gas was used widely in apartments (91%), where 83% of households have a gas boiler installed. Moreover, methane was a common choice also in detached houses (51%) followed by biomass (37%).

## 4 Conclusion

A questionnaire survey was delivered in the Calabria region (South Italy) with the aim of investigate the usage of DHW energy source and production systems. The attention was focused on the identification of the most significant variables in the choice of the adopted technology. Due to the climatic diversity and the variety of the building stock, the region offered good opportunities of study. In particular, the investigation allowed to analyze the wide range of energy sources and DHW production systems widespread in the territory. Firstly, the sample was divided into two groups based on the combined or separated DHW production system from the heating facility. Descriptive statistics showed that when a separate system was installed, methane gas, electricity, and biomass were the most common energy sources. Consequently, gas boilers, electric boilers, and heating fireplaces in winter and gas boilers in summer were the preferred production systems. Gas boilers were the preferred production systems in case of combined facilities.

A focus on renewable energy production systems showed how the use of solar energy was limited to a few cases. More resources could be spent by municipalities and regional administrations to encourage the adoption of these systems.

Finally, the chi-square test of independence established the factors that influence the choice of energy source and DHW production system. These factors were divided in contextual and building characteristics.

The Climatic zone was significant for the energy source and production technology in both households with a separated and combined DHW production system. In addition, for dwellings with a combined system (the same system for DHW and heating), the population in the municipality and the dwelling type were significant variables. These findings may be considered as drivers for future investigations addressed to energy policymakers.

In the light of the wide range of production systems and energy sources used in the region of interest, and considering the results obtained from the statistical tests, the authors concluded that contextual variables give an essential contribution to the adoption of a certain technology. Certainly, such outcomes represent a portion of a more considerable study on the topic and encourage for further insights on the influence of other variables and on the collection of larger samples.

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