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Engaging Communities in Energy Transitions: A Study on Attitudes Towards Sustainable Heating Technologies and the Role of Peer Effects in Southern Chile

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Abstract: This study investigates the role of peer effects in shaping the adoption of sustainable heating systems in two highly polluted communes in Southern Chile. Despite policies promoting cleaner alternatives, wood-burning stoves, a major source of particulate matter emissions, remain widespread. This research work addresses a critical gap in the literature by examining how peer influence—typically studied in relation to visible technologies like solar panels or electric vehicles—affects the adoption of less visible but essential sustainable heating technologies. The main objective of this study is to understand how peer networks can influence the attitudes of residents towards sustainable heating technologies in highly polluted urban environments. Employing a non-experimental, cross-sectional design with a sample of 244 participants, this study reveals that peer effects and health risk perception are significant predictors of positive attitudes towards sustainable heating systems. These findings contribute valuable insights for policymakers seeking to accelerate energy transitions in polluted regions.

Keywords: air pollution; peer effect; sustainable energy; wood-burning stoves; risk perception; pollution perception

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1. Introduction

Understanding the conditions under which people choose to adopt sustainable technologies is key to transforming our energy systems [1–3]. At the household level, the uptake of low-carbon energy technologies is not only positive for technological development but can also be critical for health and for addressing the challenges of climate change. New technologies entail changes in consumption patterns, which in some cases can lead to apathy and resistance, slowing down or even jeopardizing energy transitions, and in others to relatively easy acceptance. Technology diffusion is a particularly important element in energy transitions [4,5]. Programs to replace inefficient domestic heating systems often introduce new technological developments in geographically defined local communities [6,7]. They are undoubtedly a crucial step in the development of environmental transitions and the consolidation of more efficient energy systems. However, these programs often present specific challenges for citizen involvement that are not easily observed or understood by policymakers [8]. This study investigates social dynamics through the lens of social influence, peer influence, and technology adoption.

To frame our analysis, we propose a conceptual structure that links three key elements: social influence, peer influence, and technology adoption. Social influence refers to the ways in which individuals' attitudes, behaviors, and decisions are shaped by the actions,

opinions, and behaviors of others within their social networks. This influence can manifest through direct interactions or through observing the behaviors of others in their community. Within this broader concept, peer influence plays a particularly critical role, as individuals tend to be more strongly affected by the behaviors and opinions of those they consider their equals or peers, whether they are family members, friends, or members of the same social group [9–11]. Lastly, technology adoption is the outcome of these influences, where the decision to adopt new technologies is influenced not only by their technical advantages but also by the social pressures and norms established within one's peer group.

Understanding the mechanisms that explain the effect of social influence on technological adoption processes is often underestimated in the design of intervention programs [12,13]. Environmental sociology has shown that social influence is a fundamental factor in both energy-saving behavior and the adoption of new energy technologies such as solar panels or electric vehicles [14,15]. However, the role of social influence in the adoption of other emerging domestic energy technologies has been much less widely studied. This study investigates the role of social influence, specifically peer effects, in shaping attitudes toward the adoption of sustainable heating systems in southern Chile. The objective of this research is to explore how peer networks affect residents' decisions to transition from traditional wood-burning stoves to more sustainable alternatives. Our research aims to address the following hypothesis: residents who are positively influenced by peers regarding sustainable heating technologies will exhibit more favorable attitudes toward adopting these systems. By testing this hypothesis, we aim to provide insights that could inform policy interventions for promoting cleaner energy technologies in highly polluted regions. At the same time, we will try to identify the main attitudinal determinants that lead to the adoption of energy-efficient technologies in order to guide air pollution control measures.

The adoption of sustainable technologies is a critical factor in promoting energy transitions, particularly in regions facing environmental crises. However, existing studies have primarily focused on the diffusion of highly visible technologies, such as solar panels or electric vehicles, with limited attention given to the social dynamics influencing the adoption of other critical systems, such as sustainable heating technologies. In southern Chile, where wood-burning stoves are a major source of pollution, understanding the role of social influence—particularly peer networks—in the adoption of cleaner heating alternatives is crucial. While previous research has shown that geographic proximity to and the visibility of sustainable technologies can significantly impact adoption rates, there is a gap in understanding how informal peer interactions, particularly in non-visual contexts, influence decision-making. This study addresses this gap by investigating the influence of peer effects on sustainable heating technologies in a region where environmental and public health challenges make this transition particularly urgent.

This study is structured as follows. The following subsections define the peer effect and present the case study. The characteristics of the methodological design used in this study are then described. Subsequently, the results of the analyses and statistical models used to address the study objectives are presented. Finally, the implications of the findings and their relationship with the literature are discussed.

1.1. Acceptance of Sustainable Technologies and Peer Effect: Previous Studies

In most countries, households account for a significant proportion of national energy consumption and contribute to greenhouse gas emissions [16]. The social sciences have sought to understand how people make decisions about energy consumption and to identify the most effective intervention strategies to promote behavioral change [17,18]. The contribution of environmental sociology to this body of literature has been particularly valuable in highlighting social influence as a fundamental element of study. From this perspective, when we analyze energy-related behaviors, we find that both individual and collective decisions are influenced by other members of the group. The Diffusion of Innovation theory proposed by Rogers [19] was one of the first to suggest that social interactions play a relevant role in individual decisions to adopt of new technologies. Since

then, it has been found that the introduction of a heating system in a household can change the decisions of other socially close people in a short period of time [20].

The peer effect is a concept that is generally used when the attitudes, values, or behavior of an individual or collective are influenced by the behavior of a group of peers [21–23]. The study of this phenomenon is particularly relevant to environmental sociology, as the change in behavior of a given pioneering individual (or group of individuals) can have a contagion effect so that the pro-environmental actions of that individual influence more people, increasing the chances of success of a given ecological transition [23].

The peer effect has been studied to analyze adoption decisions for clean technologies, especially solar panels [11,21,22] and hybrid [24] or electric vehicles [25,26]. Early studies on the diffusion of solar panels documented how geographic proximity can act as a catalyst for the peer effect [9,11,27]. This effect was clearly observed in a tendency to adopt a new solar system in households located around a house that had just installed the system. That is, the visibility of the installation of the new system in energy generation system seems to motivate neighbors to purchase this technology [11,14,27]. There is thus an aggregate effect whereby the probability of an additional new installation is higher in geographical regions where there are more solar panels [10], or even when the installations are closer in time, better connected by road or other transport route [9]. There is also evidence of a geographic proximity effect on the adoption of electric cars [15,28,29], although some studies suggest that their visibility in people's daily commutes may accelerate the decision to purchase a new vehicle [30].

While studies on solar panels and electric vehicles have demonstrated the influence of peer effects, these findings may not be directly applicable to heating systems. Factors such as installation costs, visibility, and the nature of interactions between households may differ across these technologies. Studies on peer effects on the adoption of alternative technologies to wood stoves or cookstoves are relatively scarce. In Rwanda, Seguin et al. [31] found a significant peer effect on adoption decisions to upgrade to pellet or wood stoves. Specifically, they observed that when peers highlighted the positive aspects of the improved stoves, such as cleanliness, low cost, and efficiency, the likelihood of adopting the new technology increased. In contrast, when peers made negative comments (high initial investment costs, damage to pots), the effect was discouraging. In Uganda, Beltramo et al. [32] found that positive comments from neighbors increased the likelihood of adopting an efficient cookstove by 17–22 percent. However, they found no evidence that peer opinion influenced the likelihood of purchase. In Bangladesh, Miller and Mobarak [33] showed that while peer influence is important, it can also have a negative effect—that is, if new technologies are not adapted to local needs, the negative opinions of neighbors induce resistance to technological change.

While this manuscript primarily focuses on active measures for emission reduction, such as stove replacement and cleaner fuels, passive approaches to energy mitigation are also crucial for a comprehensive strategy. For instance, recent developments in advanced thermal management materials, like ultrathin aerogel-structured micro/nanofiber metafabrics, offer promising solutions for passive radiative heating. These materials provide exceptional thermal insulation and heat retention properties while maintaining high breathability and mechanical strength. By incorporating these passive technologies, such as self-sustainable heating fabrics and air filtration materials, the overall energy demand for heating can be significantly reduced, offering a complementary approach to active mitigation measures [34].

Beyond the studies on the adoption of solar panels and electric or hybrid vehicles, there is little research on other energy technology contexts, as we see in the case of efficient stoves or cookstoves. The evidence of geographical proximity—that is, the observation that new installations of solar panels or purchases of electric vehicles are more frequent when the neighbor has already adopted such technologies—suggests that observational learning may be a relevant mechanism. Classical theories of social learning suggest that individuals learn from new behaviors and model their attitudes towards these actions

through active observation and imitation [35]. However, it is known that individuals can also be influenced by the opinions and experiences of those who have adopted a new technology and who are not necessarily their neighbors. In the study of energy, "peers" are usually defined in terms of spatial proximity. In other fields of study, however, sociology defines "peers" less narrowly. A peer group can also be based on membership of a group, such as employees of a particular company, students in the same class, or members of a charity. But even a group can consist of individuals who share a digital identity, based on connections in social networks such as WhatsApp groups. Individuals may not even know each other personally but feel a group affinity and be influenced in their energy-related behaviors. In this study, we consider those people that the subject perceives as such because of their closeness or connection to that person, including family, friends, or acquaintances.

Despite the growing interest in sustainable heating solutions, there is a lack of comprehensive research on the role of peer effects in their adoption. The peer effect, defined as the influence of social networks on individual or collective decision-making, has been widely studied in the context of renewable energy adoption, particularly in the case of visible technologies like solar panels and electric vehicles. Research has shown that the geographic proximity of such technologies often triggers adoption through observational learning. However, the adoption of non-visual technologies, such as sustainable heating systems, may follow different social mechanisms, particularly in environments where social conversations and trust networks play a greater role. While studies from regions like Rwanda and Bangladesh have highlighted the role of peer influence in stove adoption, these studies often focus on the physical visibility of the technologies. In contrast, our research delves into the conversational dynamics of peer influence, particularly in the context of southern Chile, where environmental policies have yet to fully capitalize on the social dimensions of energy transitions. By focusing on peer influence in a non-visual, trust-based context, this study offers novel insights into how social networks contribute to the adoption of sustainable heating technologies, filling an important gap in the existing literature.

1.2. Case Study

In Chile, the issue of air pollution caused by fine particulate matter ($PM_{2.5}$) has become a critical public health concern, with more than 10 million people exposed to annual average concentrations above the national standard of 20 $\mu g/m^3$ set by the Ministry of the Environment [36]. The cities of Temuco and Padre Las Casas, located in the Araucanía region, serve as a significant example of this issue due to their severe air pollution levels, which are among the highest in the country and Latin America. This case study focuses on these two cities to illustrate the challenges and complexities of transitioning to more sustainable heating practices in regions heavily dependent on wood-burning stoves. Understanding this context is essential to highlight the socio-environmental impact of energy poverty and the difficulties of implementing cleaner technologies in communities with constrained economic resources.

The main cause of the high levels of pollution, common to almost all urban areas in the southern region of the country, is energy scarcity. It is estimated that around 96% of annual particulate matter emissions are due to the widespread use of wood-burning stoves [37] (Figure 1). These systems are characterized by low energy efficiency and high pollutant emissions. In addition, the operation and use of these heating systems is sometimes deficient, involving poor maintenance and cleaning. However, firewood remains the most accessible and economical fuel for heating compared to most alternatives available on the market in the region. In both formal and informal markets, cheap firewood is readily available, but it is often of low quality and a high moisture content, causing even more pollution [38]. Furthermore, many houses have poor or no thermal insulation, either because they are located in lower-socioeconomic-status neighborhoods or due to inadequate regulations when they were built, leading to increased energy demand [39,40].



Figure 1. Chimneys in Temuco emitting smoke from wood-burning stoves (source: own picture).

This situation makes the transition to a more sustainable scenario urgent. In response, Temuco and Padre Las Casas were declared saturated zones for PM_{10} and $PM_{2.5}$ in 2005 and 2013, respectively. Consequently, since 2015, the Atmospheric Decontamination Plan (ADP) has been implemented, which considers four lines of mitigation strategies: (i) improving the thermal conditioning of homes; (ii) replacing wood stoves with cleaner heating systems (e.g., pellet, electricity, natural gas, liquefied gas, kerosene); (iii) improving the quality of fuels offered by the market; and (iv) promoting environmental education campaigns [41].

One of the flagship measures of the ADP is the wood stove replacement program. The government offers free replacement of old wood stoves with systems that have higher energy efficiency and lower emissions of $PM_{2.5}$ for households that apply to the program and meet specific requirements. Globally, stove replacement has proven to be one of the most effective measures for improving air quality [42–44], with significant reductions in pollution levels and $PM_{2.5}$ and CO emissions in various countries [45–47]. The Chilean Ministry of the Environment defines sustainable heating as a set of measures that allow homes to be heated in a more environmentally friendly way, using more efficient heaters and cleaner fuels. In its various replacement programs, it offers sustainable alternatives to traditional wood stoves, such as split air conditioning, oil-electric/thermo-fan, natural gas, liquefied gas, kerosene, and wood pellets.

The ADP for Temuco and Padre Las Casas initially aimed to replace a total of 27,000 wood stoves with more sustainable alternative heating systems over a five-year period from 2015 to 2020. However, according to the 2022 evaluation report of the wood stove replacement program, only 13,794 stoves were replaced between 2015 and 2021, achieving just 51.1% of the target [48]. Some studies suggest that potential barriers might hinder the stove replacement process [49–51]. However, there is currently no research that specifically analyzes the peer effect on the adoption of sustainable heating technologies in southern Chile, and studies in other geographical contexts are also very limited.

2. Materials and Methods

2.1. Design and Participants

The design of this research was quantitative, non-experimental, cross-sectional, and correlational–comparative in scope. The study sample was obtained through a non-probabilistic convenience sampling during the months of June to September 2020. This sampling technique was chosen because of practical constraints, including limited time

and resources, and the difficulty in accessing a more probabilistic sample as a result of the COVID-19 pandemic, which restricted in-person interactions. The inclusion criteria were as follows: (i) being over 18 years old; (ii) living in the communes of Temuco, Padre Las Casas, or the surrounding areas; and (iii) being or having been a user of wood stoves.

The final sample consisted of 244 participants aged between 18 and 73 years (M = 34.4; SD = 13.7). Of these, 144 were current users of wood stoves, while 100 were former users who currently used another heating system. Other sociodemographic characteristics of the sample are shown in Table 1.

Table 1. Sociodemographic characteristics of the sample.

Variables		n (%)
City	Temuco	141 (57.8)
	Padre Las Casas	52 (21.3)
	Surrounding sectors	51 (20.9)
Sex	Man	83 (34.0)
	Woman	159 (65.2)
Respiratory disease	Yes	50 (20.5)
	No	194 (79.5)
Indigenous people	Yes	42 (17.2)
	No	202 (82.8)
Socioeconomic level	Low	180 (73.8)
	Medium-High	62 (26.2)
Main current heating system	Wood stove	144 (59.0)
	Other (pellet, kerosene, gas, electricity)	100 (41.0)

Source: Own elaboration.

2.2. Collection Instruments and Techniques

The instrument for this study was developed based on the experience of previous studies [52,53], which measured variables of interest for this research such as attitudes towards sustainable and non-sustainable heating systems, risk perception, and air quality perception.

The first section of this questionnaire consisted of sociodemographic questions such as age, sex, place of residence, indigenous affiliation, and the presence of respiratory diseases in the household. In addition, the socioeconomic level was measured using the Association of Market Researchers (AIM) Socioeconomic Group Classification (GSE) questionnaire. This measure makes it possible to classify people into socioeconomic groups according to their level of well-being by combining three variables: (i) the equivalent per capita income bracket (total household income divided by the number of members), (ii) the educational level of the household's main breadwinner, and (iii) the occupational level of the household's main breadwinner. The different groupings were E, D, C3, C2, C1b, C1a and AB, with group E having the lowest economic well-being and group AB having the highest [54]. Participants were also asked about the main heating system they used, whether it was firewood, kerosene, natural gas, liquefied gas, an electric stove, pellets, air conditioning, or a fan heater.

The second section of this survey included a total of 27 Likert-type response items, which aimed to explore social factors relevant to this study. These included the following: (1) peer effect, understood as the influence of nearby experience with sustainable heating systems on participants' attitudes towards these systems (3 items); (2) perception of air quality (3 items); (3) perception of pollution's risk to their health (5 items); (4) attitude towards wood heating systems (8 items); and (5) attitude towards sustainable heating technologies (7 items). The attitudinal variables toward heating systems assessed aspects

such as ease of use, type of heat, economic cost, comfort, pollution, and other aspects. Detailed information about the items used to construct each factor is provided in Table 2. Response options ranged from 1 = very bad to 5 = very good for the perception of air quality items and from 1 = strongly disagree to 5 = strongly agree for the remaining variables in this section.

Table 2. Survey items used to construct each factor in the present study.

Dimension	Items
Peer effect	1. My friends, family members, and/or neighbors have recommended that I switch to a sustainable heating system: 2. My friends, family members, and/or neighbors have had positive experiences with sustainable heating systems: 3. My friends, family members, and/or neighbors prefer the use of sustainable heating stoves over other types:
Perception of air quality	1. I consider the air quality in my city to be: 2. I consider the air quality in my neighborhood to be: 3. I consider the air quality inside my home to be:
Perception of pollution risk to their health	1. I believe poor air quality affects my health: 2. I believe poor air quality affects the health of my family and friends: 3. I believe poor air quality affects the health of vulnerable groups (children, pregnant women, the elderly, others): 4. I believe poor air quality can cause me respiratory and/or cardiovascular diseases: 5. I think I should protect myself from air pollution:
Attitude towards wood heating systems	1. They make me feel positive emotions (calmness, satisfaction, others): 2. They are better than other heating systems: 3. They produce more heat than other heating systems: 4. They are more useful than other heating systems: 5. They are more economical than other heating systems: 6. They are more comfortable than other heating systems: 7. They are safer than other heating systems: 8. They are more reliable than other heating systems in emergencies (e.g., power outages):
Attitude towards sustainable heating technologies	1. If I could, I would opt for a sustainable heating system: 2. I like sustainable heating technologies: 3. They are less polluting than other heating systems: 4. They are more efficient than other heating systems: 5. They are more expensive than other heating systems: 6. They are more difficult to use than other heating systems: 7. They are cleaner than other heating systems:

Source: Own elaboration.

To ensure the proper functioning of the aforementioned factors, their psychometric properties were evaluated. First, an exploratory factor analysis (EFA) was conducted to assess the underlying structure of the proposed items. This analysis was based on a polychoric correlation matrix, considering the ordinal nature of the variables. The extraction method was ordinary least squares with oblique rotation to obtain a more realistic view of the associations between variables. The number of factors was determined using parallel analysis [55]. For an adequate fit, a Kaiser–Meyer–Olkin (KMO) value > 0.05 and a significant Bartlett's test of sphericity ($p < 0.05$) were considered [56,57].

In the case of the peer effect, the items were found to be factorable with a KMO = 0.668 and a significant Bartlett's test of sphericity ($p < 0.001$). The resulting dimension explained

53.5% of the variance. On the other hand, for the perception of air quality, a KMO = 0.597 and a significant Bartlett's test of sphericity ($p < 0.001$) were obtained. These items formed a single factor which explained 60.6% of the variance. For the perception of pollution risk to health, adequate factor indices were obtained with a KMO = 0.783 and a significant Bartlett's test of sphericity ($p < 0.001$). With a unidimensional solution, 62.3% of the variance was explained. For the attitude towards wood-burning stoves, a KMO = 0.873 and a significant Bartlett's test of sphericity ($p < 0.001$) were observed. With 52.9% of the variance explained, a single-factor solution was suggested ($p < 0.001$). Finally, the items related to attitudes towards sustainable heating systems showed a KMO = 0.770 and a significant Bartlett's test of sphericity ($p < 0.001$), yielding a single-factor solution that explained 48.7% of the variance.

In terms of reliability, McDonald's Omega index was used, which is suitable for ordinal variables. Adequate levels of internal consistency were observed for the different scales used in this study, including peer influence ($\omega = 0.682$), air quality perception ($\omega = 0.771$), risk perception ($\omega = 0.906$), attitude toward wood-burning stoves ($\omega = 0.873$), and attitude towards sustainable heating technologies ($\omega = 0.720$). Regarding the latter, we decided to eliminate two items in favor of parsimony and to increase the internal consistency ($\omega = 0.804$). On a separate note, it is worth noting that prior to data collection, the instrument was pilot-tested with a group of 20 participants who qualitatively assessed the relevance and wording of the items and instructions [58].

2.3. Procedure

Several data collection techniques were applied to ensure sample diversity. Firstly, the survey was disseminated through different social networks (e.g., Facebook, WhatsApp and Instagram). In addition, the collaboration of the Psychology Department of the Catholic University of Temuco was requested in order to disseminate the survey among the different members of the Faculty of Health. Telephone calls were also made to various contacts of the researchers in order to ensure the participation of people outside the university, of different ages, or with limited access to the Internet. Each participant was given detailed information about the aims of the research, the criteria for participation, and an informed consent form, which included ethical safeguards such as voluntary participation, anonymity, and confidentiality of the information provided [58].

2.4. Data Analysis

Data analysis was conducted using the statistical program SPSS version 26.0.0, while the graphs and other complementary analyses were performed using RStudio version 2023.09.1 Build 494. First, descriptive statistics of central tendency and variability were performed for the different areas of study. The normality assumption of these variables was then tested using the Kolmogorov–Smirnov test. As no variable met the normality assumption ($p < 0.05$), non-parametric tests were used.

In the case of correlations, Spearman's rho (Rs) was used for Likert-type categorical ordinal variables. For the comparison of independent groups, the Mann–Whitney U test was appropriate. However, its parametric equivalent, Student's *t*-test, was also applied, yielding the same results. Consequently, the *t*-test values were reported, as they are easier to interpret when working with means, unlike the Mann–Whitney U, which is based on medians. Finally, the multiple linear regression test was applied to construct a predictive model for the dependent variable, attitudes towards sustainable heating technologies. The peer effect was included as the main independent variable of the model, while other relevant factors identified in the literature were incorporated to control for their influence on the relationship between the peer effect and attitudes toward sustainable heating systems. These factors included psychosocial variables such as air quality perception, risk perception, and attitudes toward wood-burning stoves, as well as sociodemographic factors like belonging to an indigenous group (no/yes), the presence of respiratory diseases (no/yes), age, and socioeconomic level. By incorporating multiple independent variables into the model, the

impact of each variable on the dependent variable can be isolated while accounting for the influence of others. This is achieved by holding the effects of the remaining variables constant when estimating the impact of each independent variable, thus removing their confounding influence from the equation. The assumptions of homoscedasticity, linearity, non-collinearity, independence of errors, and normal distribution of residuals were checked to verify the validity of the analysis.

To provide a clearer understanding of the research process, a visual representation of the study's layout is presented in Figure 2.

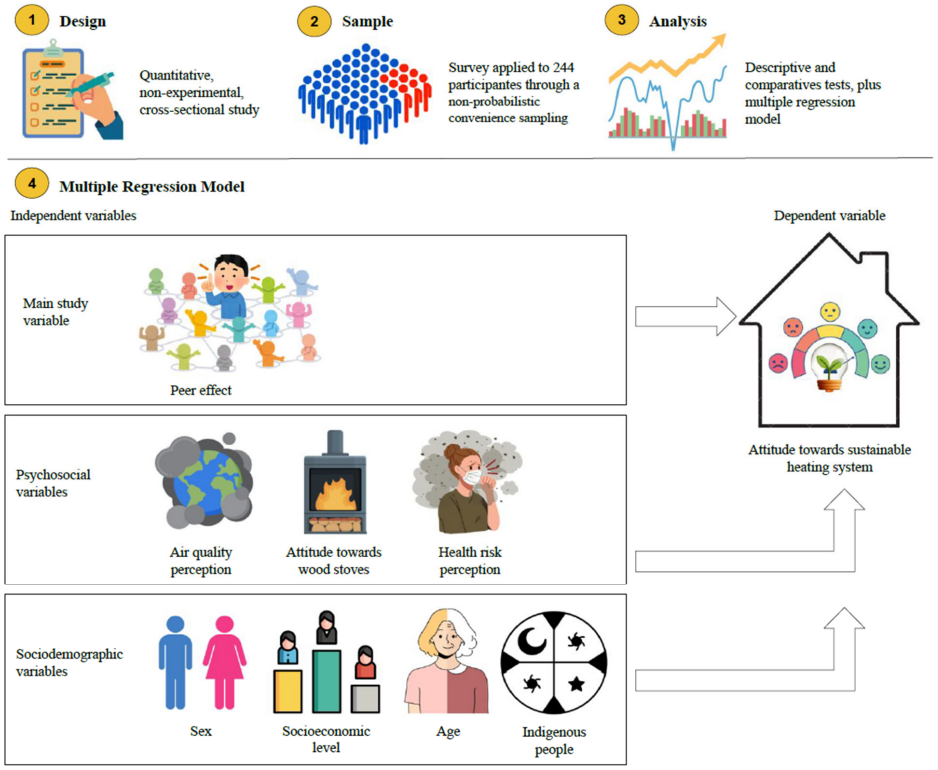


Figure 2. This study's layout (source: own elaboration).

3. Results

First of all, the survey analyses show that the participants have a medium–high value for peer influence on the adoption of sustainable heating systems (M = 3.57; SD = 1.03). This means that participants believe that their relatives or friends have had positive experiences with this type of system and have recommended it to them. Furthermore, it is observed that the participants have a more positive attitude towards sustainable heating systems (M = 4.28; SD = 0.72) compared to other heating systems such as firewood (M = 3.55; SD = 0.87). Similarly, participants on average have a poor perception of air quality (M = 2.53; SD = 0.86) and a high perception of health risk due to pollution (M = 4.74; SD = 0.52).

With regard to attitudes towards sustainable heating technologies, it can be seen that this is significantly and positively correlated with the peer effect ($r = 0.276$; $p < 0.01$), such that those who are positively influenced by their peers towards sustainable systems have a more positive attitude towards these technologies. Similarly, attitudes towards sustainable heating systems show a significant positive correlation with risk perception ($r = 0.269$, $p < 0.01$) and a negative correlation with air quality perception ($r = -0.128$, $p < 0.05$). This means that users who perceive higher health risks from pollution tend to have more favorable attitudes toward sustainable heating technologies, while those with poorer perceptions of air quality also exhibit more positive attitudes toward these technologies. On the other hand, they also have a significant and negative correlation with

wood heating systems (r = −0.318; $p < 0.01$), where the better the attitude towards wood stoves, the worse the attitude towards sustainable systems.

Figure 3 shows that attitudes towards sustainable heating systems vary significantly according to the sociodemographic characteristics of the participants. Firstly, statistically significant differences are observed according to age group ($p < 0.01$), with young people having a more positive attitude towards this technology (M = 4.39; SD = 0.67) than older adults (M = 4.18; SD = 0.76). Secondly, there are significant differences according to indigenous origin ($p < 0.05$), with those who report belonging to an indigenous group having a more positive attitude towards sustainable technologies (M = 4.51; SD = 0.56). Finally, differences were observed according to socioeconomic level ($p < 0.001$), where those with a medium–high socioeconomic level have a more positive attitude towards sustainable heating technologies (M = 4.42; SD = 0.61) compared to those with a low socioeconomic level. No significant differences were found according to sex or the presence of respiratory diseases in the household.

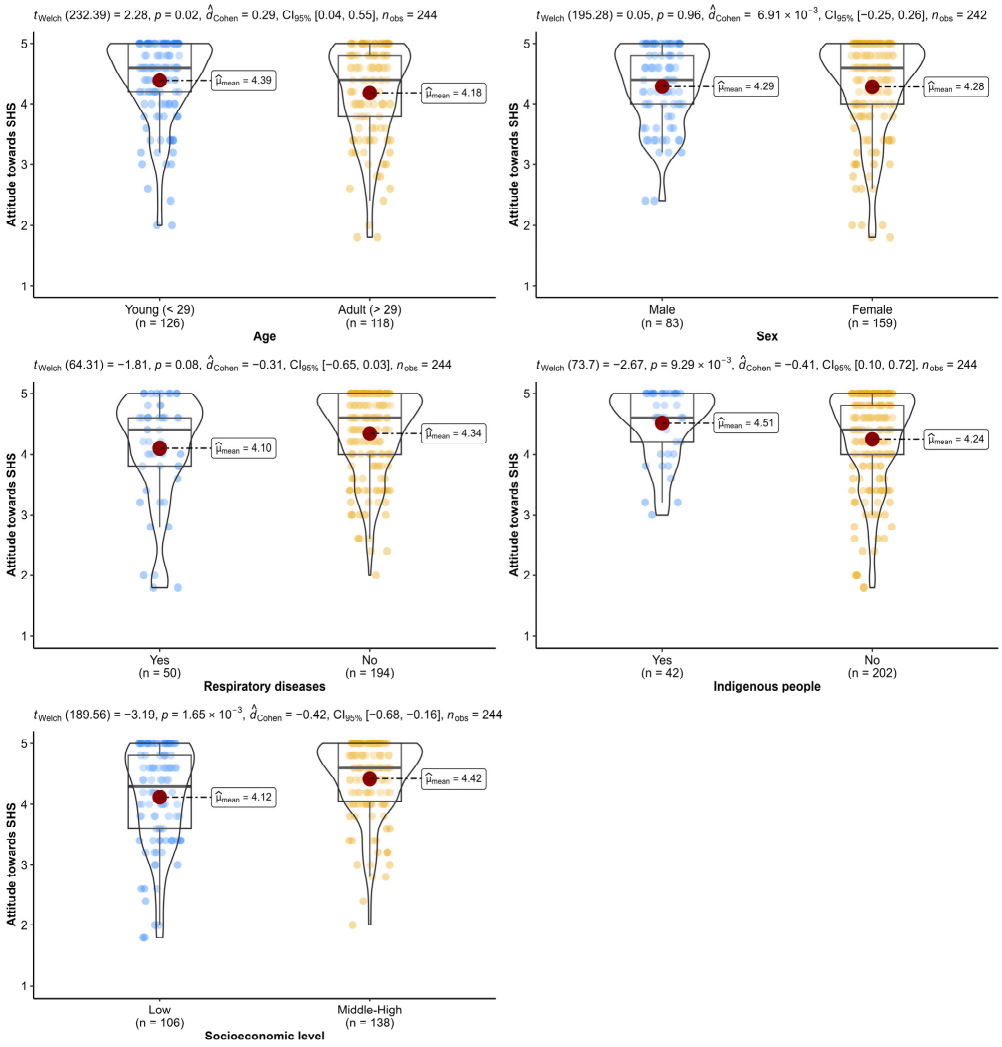


Figure 3. Differences in attitudes towards sustainable heating systems according to sociodemographic variables. Note. SHS = sustainable heating system; t_{Welch} = Welch's *t*-test; $\hat{d}_{Cohen}$ = Cohen's d effect size for *t* tests; $CI_{95\%}$ = confidence interval at 95%; n_{obs} = number of observations (source: own elaboration).

Regarding the multiple linear regression analyses (see Table 3), it can be noted that the model of attitudes towards sustainable heating technologies shows a good goodness of fit (F = 5.741; $p < 0.001$). R^2 value was 0.273, which means that 27.3% of the variance

of the dependent variable is explained by the independent variables considered. This is regarded as an adequate level for social science studies [59]. For this model, the variables peer influence (β = 0.317; $p < 0.001$) and risk perception (β = 0.319; $p < 0.001$) are significant, meaning that that the more positive the peer influence and the higher the risk perception of the participants, the more positive the attitude towards sustainable heating technologies. In contrast, the perception of air quality, attitude towards wood stoves, socioeconomic level, presence of chronic diseases in the home, identification with indigenous communities, and age of the participant do not have a significant effect on the attitude towards sustainable heating technologies. This model satisfies the assumptions of homoscedasticity, non-collinearity, independence of errors, and normal distribution of residuals.

Table 3. Multiple linear regression of attitudes towards sustainable heating technologies.

	B	SE	*β*
(Constant)	2.572	0.661	
Peer influence	0.194	0.053	0.317 ***
Air quality perception	<0.001	0.057	<0.001
Risk perception	0.392	0.100	0.319 ***
Attitude wood stoves	−0.057	0.070	−0.072
Socioeconomic level	<0.001	<0.001	0.047
Respiratory disease	−0.080	0.139	−0.045
Indigenous people	−0.170	0.132	−0.105
Age	−0.003	0.004	−0.062

Note. B = unstandardized beta coefficient; SE = standard error; β = standardized beta coefficient. *** < 0.001 (source: own elaboration).

4. Discussion

The objective of this research was to analyze how social influence affects attitudes towards sustainable heating technologies in highly polluted intermediate cities in the south of Chile. We controlled for the possible effect of other psychosocial and sociodemographic independent variables reported in the literature. In terms of risk perception, the peer effect is the most relevant factor in predicting positive attitudes towards sustainable heating systems. The results also indicate that those who have a positive attitude towards sustainable heating systems are mostly young people, those with an upper-middle income, and those who report belonging to an indigenous community.

In line with other research, this study shows that social influence is a critical factor in shaping attitudes towards sustainable heating systems. Although social science has highlighted the importance of social influence (friends, neighbors, peers) in the acceptance of new energy technologies, most of the available evidence relates to the diffusion of solar panels [60–62] or hybrid and electric vehicles [24–26]. Thus, social networks such as neighbors, friends, and co-workers seem to play a key role in sharing information about sustainable technologies. However, both solar panels and electric cars are highly visible artifacts and allow for the active observation of neighbors. Theoretically, the adoption of other technologies such as pellet stoves could occur through a different social mechanism. The results of our research show that social influence works not only through visibility learning, and it is possible that informal conversations with neighbors, friends, or relatives, or the information they transmit through social networks, have a positive impact on the acceptance of sustainable heating technologies. On the other hand, as other studies have shown, other variables, such as the perceived risk of health effects from pollution, may also play a relevant role in shaping attitudes favorable to technological change [6,63].

Taking into account elements such as the influence of others and perceptions of risk can be a key step in developing strategies for the adoption of sustainable technologies. For example, stove replacement campaigns could seek to make visible and disseminate the

testimonies of users with positive experiences of adopting sustainable heating technologies. This is to promote peer influence, contagion, or snowballing, especially in local settings where the level of closeness or trust of relationships may be higher (i.e., neighborhoods, clubs, neighborhood councils, or groups of friends). Similarly, environmental education campaigns could reinforce the message about the short- and long-term risks of air pollution, considering both indoor and outdoor exposure. In Temuco and Padre Las Casas, despite the progress that the use of ADPs has meant from a purely educational point of view, there is still no regular spatial information on these aspects, since it is mainly focused on (i) informing educational institutions about critical episodes and air quality levels; (ii) declaring and monitoring the suspension of physical activities when there are critical episodes of pollution; and (iii) implementing and following up on the Educa Sostenible Plan-Energy Education Program, which focuses on education on clean technologies [64].

On the other hand, given the sociodemographic differences identified in the results of this research, stove replacement campaigns should be targeted primarily at adults over 29 years of age, those who are non-Mapuche, and those with a low socioeconomic level, as they have a more unfavorable attitude towards these alternative technologies. The environmental education activities of the ADPs focus almost exclusively on educational institutions for people under 18 years of age, with few information facilities for the rest of the population. This is important because those who have the worst attitudes towards sustainable technologies are precisely those people who (in the vast majority of cases) are no longer in the education system. In short, it is necessary to link stove replacement policies more directly and effectively with environmental education campaigns for the population. As various international experiences have shown, strengthening national and local energy transition policies is key to achieving more sustainable scenarios [65,66].

In addition, it is crucial to consider the broader contextual factors that may influence these connections, particularly within the specific context of Temuco and Padre Las Casas in Chile. The cultural norms in this region play a significant role, as wood-burning stoves are not only a traditional method of heating but are also perceived as a cost-effective solution for dealing with the cold climate of southern Chile. This cultural attachment to firewood, deeply embedded in daily life and historical practices, can create resistance to adopting alternative heating technologies, despite their environmental benefits [49].

Economic conditions are another pivotal factor in Temuco and Padre Las Casas, where a significant portion of the population belong to lower-income households. For these families, the economic reality often dictates their energy choices, with firewood remaining the most affordable and accessible heating option [7,38,67]. Even when subsidies or incentives are offered to adopt sustainable heating technologies, the initial investment or perceived long-term costs can be a substantial barrier for these communities. As such, economic constraints play a crucial role in limiting the adoption of cleaner technologies in these areas.

Lastly, the social dynamics within these communities, characterized by close-knit networks and strong family ties, significantly influence decision-making processes. In regions like Temuco and Padre Las Casas, peer influence extends beyond simple observation; it involves active discussions among neighbors, friends, and family members, who often share their experiences and opinions on heating technologies. This social interaction can either accelerate or hinder the adoption of sustainable practices, depending on whether these conversations reinforce positive or negative perceptions of the alternatives to traditional wood stoves [68]. Understanding these contextual elements in the specific socio-economic and cultural landscape of these cities highlights the need for tailored intervention strategies that not only address economic barriers but also engage community leaders and trusted social networks to foster a collective shift toward sustainable heating technologies.

There are a number of limitations to this research. Firstly, this study has a small sample, obtained with non-probabilistic sampling, so it is difficult to generalize the results described to other larger groups and the conclusions should be taken with caution. However, given the bias inherent in this type of sampling technique, various outreach

methods were employed across different contexts to promote greater sample diversity. On the other hand, the measurement of attitudes towards sustainable heating technologies in this study was carried out in a general way, without differentiating between different types of heating technologies or systems. It is possible that attitudes towards these technologies are specific to the type of heating, be it pellet, kerosene, or air conditioning. Future studies should explore these nuances by differentiating between specific heating systems and delve deeper into the economic factors that influence decision-making, as they may play an important role in the adoption of these technologies. Furthermore, the sample size should be expanded to include a larger, more representative population. Longitudinal studies could also provide valuable insights into how peer effects and attitudes toward sustainable heating technologies evolve over time, particularly in relation to long-term adoption and adaptation.

5. Conclusions

This study aimed to investigate how peer effects influence the adoption of sustainable heating technologies in southern Chile, an area severely impacted by wood-burning stoves and air pollution. The main research question explored in this study was as follows: how do peer networks shape residents' attitudes towards adopting sustainable heating systems in highly polluted urban areas? By addressing this question, we sought to fill a gap in the existing literature, which has largely focused on peer influence in relation to highly visible technologies like solar panels and electric vehicles, rather than essential but less visible systems like sustainable heating technologies. Our findings indicate that peer influence and perceived health risks significantly affect attitudes towards sustainable heating, suggesting that policy interventions should leverage social networks to promote cleaner energy alternatives.

In this sense, policymakers should design targeted campaigns that encourage current users of sustainable heating technologies to share their positive experiences through community events, social media, and local communication channels. By creating platforms where satisfied users can act as ambassadors, the visibility and acceptance of these technologies can be significantly increased within communities. Also, implementing localized demonstration projects in neighborhoods can help to showcase the benefits of sustainable heating technologies. These projects could be linked with incentives or subsidies for early adopters, which would not only facilitate the transition but also create a ripple effect through word-of-mouth endorsements. Furthermore, given the strong correlation between perceived health risks and positive attitudes toward sustainable technologies, it is crucial to integrate health-focused messages into awareness campaigns. Highlighting the specific health benefits of reducing indoor air pollution and the long-term savings associated with sustainable heating can motivate more households to make the switch.

This study identified variations in attitudes toward sustainable heating technologies based on age, socioeconomic status, and ethnicity. To address these differences, policies should be tailored to target groups that exhibit more resistance to adopting these technologies, such as older adults, lower-income households, and non-indigenous communities. Tailored communication strategies that address the specific concerns and barriers faced by these groups can increase the effectiveness of the interventions. Moreover, collaboration with industry stakeholders to develop more affordable, user-friendly sustainable heating solutions can help overcome the cost barriers that many households face. Promoting innovation in the design of efficient and low-cost heating technologies will not only expand access but also enhance the appeal of these alternatives in the market. Finally, to increase participation in stove replacement initiatives, policymakers could introduce community-level incentives. For example, offering additional subsidies or rewards to communities that collectively reach a certain threshold of sustainable heating adoption could encourage a more unified approach to energy transition.

Implementing policy interventions based on these findings could have several economic implications for the government. On the one hand, promoting sustainable heating

technologies through subsidies and community-level incentives might involve initial costs. These investments would be necessary to lower the barriers to adoption, especially for lower-income households that face financial constraints. However, the long-term economic benefits could outweigh these initial expenditures by reducing healthcare costs associated with air pollution-related illnesses and improving public health outcomes.

Additionally, supporting the development and adoption of more efficient and affordable heating technologies could stimulate innovation and create economic opportunities within the green energy sector. Over time, the reduction in dependence on wood-burning stoves could lead to lower emissions, contributing to Chile's national and international commitments to climate change mitigation.

In summary, while the economic implications for the government might involve upfront investments, these expenditures are likely to be offset by the long-term savings in healthcare costs, economic growth in the green energy sector, and the broader benefits of improved air quality and reduced carbon emissions. The key to successful policy interventions will be to clearly communicate these potential benefits to stakeholders and demonstrate the value of investing in sustainable energy technologies for the future economic and environmental well-being of the country.

Looking ahead, the insights from this study have the potential to transform how communities engage with sustainable energy technologies, setting the groundwork for a broader societal shift towards cleaner energy practices. If the mechanisms of peer influence are effectively harnessed, they could lead to a cascading effect, accelerating the adoption of sustainable technologies not just in southern Chile but also in similar regions worldwide facing comparable challenges. By integrating social dynamics into energy policy design, there is the potential to not only reduce air pollution and improve public health but also to empower communities to become active participants in the global fight against climate change. This research paves the way for future studies to delve deeper into the intersection of social influence and technological adoption, ultimately contributing to the creation of resilient and sustainable energy systems that are driven by both technological innovation and social cohesion.

In short, this research offers novel insights into the mechanisms of social influence in energy transitions and provides practical implications for policymakers aiming to reduce pollution in regions where traditional heating systems remain prevalent. Future studies should continue to explore how informal social interactions shape the adoption of sustainable technologies in other environmental contexts. These insights are crucial for policymakers seeking to improve the effectiveness of stove replacement programs and broader energy transition initiatives. Despite the limitations of this study, including the non-probabilistic sample and the generalized measurement of attitudes towards different heating technologies, the conclusions provide a valuable framework for improving environmental policies and promoting a more sustainable future in regions severely affected by air pollution.

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