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Àlex Boso, Àlvaro Hofflinger, Jaime Garrido & Boris Álvarez

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BREATHING CLEAN AIR OR CHEAPLY HEATING YOUR HOME: AN ENVIRONMENTAL JUSTICE DILEMMA IN CHILEAN PATAGONIA

ÀLEX BOSO, ÀLVARO HOFFLINGER, JAIME GARRIDO and BORIS ÁLVAREZ

ABSTRACT. Cities in southern Chile face serious environmental pollution due to extensive use of firewood for heating and cooking. Lack of access to cleaner energy fuel, low-efficiency building materials, and a cold climate exacerbate the problem, which increases the deforestation of the native forests of Patagonia. While environmental justice research has established clear links between air pollution hazards and vulnerable populations, little is known about how this relationship influences the risk perception and adaptation strategies among all urban residents. This study assesses social vulnerability variables, indoor environments, and air pollution adaptation strategies in households located in the city of Coyhaique by monitoring households' temperatures and conducting semistructured interviews with residents. Focused on interactions between people and their indoor and outdoor environments, this study reveals the microscale hazards and difficulties in overcoming the dilemma between breathing clean air and cheap heating as additional dimensions of environmental injustice. *Keywords: air pollution, air quality perception, Coyhaique, environmental justice, firewood, spatial inequality.*

Coyhaique is the capital of the southern Patagonian Aysén Region (Chile), and in recent decades it has been promoted as the gateway to Patagonia: a pristine nature reserve surrounded by rivers, mountains, grassland, and fresh air. Currently, the air in the city is considered the most polluted in Latin America, above larger cities such as Mexico City, Buenos Aires, Bogotá, or Santiago (WHO 2018). High levels of air pollution are attributed to the widespread use of wood-burning stoves. On certain winter days, when most of its inhabitants turn on their wood-burning stoves, Coyhaique is among the most polluted cities in the world.

If the cities in southern Chile fail to transform their heating system and reduce local air pollution, the consequences could be extremely serious. Long-term exposure to $PM_{2.5}$ and PM_{10} is associated with increased risk of mortality (WHO 2005). According to Richard Burnett and others (2018), approximately 8.9 million people around the world die prematurely due to air pollution every year. Furthermore, air pollution poses great threats to human health in terms of different types of illnesses—ranging from eye irritation or headaches to more severe diseases like chronic bronchitis, heart attacks, or lung cancer—and hospitalization (Cohen 2005; Naeher 2007).

By definition, air pollution has the potential to affect the entire population. However, as Hollifield, Chakraborty, and Walker (2017) pointed out, the impacts

Àlex Boso, Universidad de la Frontera; [alex.boso@ufrontera.cl]. Àlvaro Hofflinger, Universidad de la Frontera; [alvaro.hofflinger@gmail.com]. Jaime Garrido, Universidad de la Frontera; [jaime.garrido.c@ufrontera.cl]. Boris Álvarez, Universidad de la Frontera; [boris.alvarez.e11@gmail.com].

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of environmental problems tend to be unequal; people do not have the same power to contribute to the solutions, nor the information or abilities necessary to be able to perform specific actions. Over the last few decades, environmental geography has documented how socioeconomically disadvantaged and racial minorities are more exposed to environmental threats, such as air or water pollution or proximity to hazardous waste sites (Bullard 1990; Bryant 2003; Buzzelli and Jerret 2007; Walker 2012; Chakraborty, Collins, and Grienski 2016). However, the environmental justice literature still faces some limitations, which we try to address in this article.

First, while the research has quantified different types of environmental inequalities, less work has been able to explain the mechanisms that produce distributional patterns of environmental injustice. The inclusion of microlevel compositional qualitative research has been underutilized in quantitative studies (Hernandez and others 2015). Qualitative data can be useful to identify and recognize the social mechanisms underlying the production of environmental inequalities. Second, in the last 30 years, Latin American cities have been characterized by an explosive growth, high levels of informality, and segregation. This process has generated environmental problems, such as the severe episodes of air pollution in middle-size cities in southern Chile, which have not yet been studied using an environmental justice approach. Third, the indoor environment has not been fully integrated into the environmental justice research (Adamkiewicz and others 2011). Revealing the microscale and place-based drivers of indoor environment quality is a crucial step to informing policies and reducing unjust disparities.

Air Pollution and Environmental Justice

Since the end of the 1990s, air pollution linked to road traffic or industrial activity has been a crucial topic in the environmental justice (EJ) literature (Hollifield, Chakraborty, and Walker 2017). The air pollution problem has stimulated a rich body of literature on the relationship between exposure, socioeconomic status, race, or ethnic origin (Grineski, Collins, and Chakraborty 2013; Huang and others 2017; Prieto-Flores and others 2017; Dons and others 2018). For instance, some studies conducted in the United States show that higher levels of outdoor air pollutants are often found in low-income neighborhoods or areas with high proportions of racial minorities (Brody and others 2004). Most of the research in this area has been focused on assessing the existence of spatial distribution of air pollution inequalities in metropolitan areas using quantitative methods (Walker 2012). Urban EJ research is still recent and underdeveloped in Latin America (Vásquez and others 2018). As far as we know, in Chile, only a few previous studies have studied how different socioeconomic groups are unequally affected by air pollution (Romero and others 2013).

These studies are an important precedent for our research, mainly because they point out patterns of the social distribution of air pollution, which can also be found in urban Patagonia. The relationship between inequality and air quality in southern Chile is complex and demands the comprehension of two relatively underestimated EJ issues: the trade-off between the perceived risks (indoor air pollution) and benefits (heat their homes) of using wood-burning stoves, and disparities in indoor residential environmental quality.

Despite a large body of evidence generated by EJ literature about the relationship between risk of exposure to air pollution and social vulnerability, few studies have examined how concerns and subjective evaluations of air quality intervene in this relationship (Chakraborty and others 2017). Air quality reports reveal that risk perception tends to vary according to the sociodemographic and cultural characteristics of the population and certain contextual factors. Throughout the last decades, various studies have shown that air quality perceptions might be associated with diverse factors, such as residents' satisfaction and neighborhood attachment (Bickerstaff and Walker 2001; Brody, Peck and Highfield 2004); age (Howel and others 2003); socioeconomic status and educational level (Deguen and others 2017); gender or belonging to a minority group (Johnson 2002); information and exposure to messages about risk and air quality (Oltra and others 2017; Mirabelli and others 2018); or political identification (Brody, Peck, and Highfield 2004). The discrepancy between the public's perceptions and the actual levels of air pollution has been a concern among policymakers or administrators in local governments. An inappropriate understanding of the air quality problem can prevent individuals from protecting themselves or developing mitigation behaviors.

Even though the impact of air pollution on health is recognized by experts and public organizations, a variety of circumstances can limit the individual's ability to correctly understand its effects (Johnson 2002; Chakraborty and others 2017). Thus, the perceptions of severity and health risks due to poor air quality tend to vary within the population (Bickerstaff and Walker 2001). For example, most of available evidence indicates that, although on occasion individuals recognize the seriousness of health problems derived from air pollution, they tend to deny the potential effects on themselves (Bickerstaff and Walker 2001; Reeve and others 2013; Boso and others 2017). This fact is particularly interesting in cities highly polluted due to wood smoke, where diverse psychosocial mechanisms like the affect heuristic, (Bhullar and others 2014; Boso and others 2018) or the halo effect (Hofflinger and others 2019) that hinder a transition to a more sustainable scenario have been studied. Some qualitative studies have shown how narratives of citizens' resistance to technological change often hide health risks, either through economic considerations or through the elaboration of cultural or identity-focused discourse (Reeve and others 2013; Jalas and Rinkinen 2016; Boso and others 2018; Boso and others 2020). In sum, the psychology-based risk-perception perspective could be revealing that, in the decision-making process of coping and mitigation behaviors, residents are influenced by the trade-off between the perceived risks and benefits of using wood-burning stoves in southern Chile.

People tend to underestimate hazards in environments where associated benefits are perceived greater than the costs (Siegrist and Cvetkovich 2000). In Chilean Patagonia, energy poverty could be linked to this problem. In regional cities such as Coyhaique, Osorno, Temuco, or Padre Las Casas, energy poverty can be defined as the lack of access to quality energy sources due to low income, high cost of alternative heating systems, and the low level of energy efficiency of houses (Urquiza, 2019; Boso and others 2020). Despite the high level of air pollution, it is estimated that approximately 85 percent of the households still use wood or derivative products to heat and/or cook (Casen 2017). Based on the previous research, it is plausible to hypothesize that Patagonians could accept higher levels of hazard exposure in exchange for greater thermal comfort. But can we assume the same level of agency for the entire population? Do the most socially disadvantaged groups have the ability to anticipate, cope with, and recover from the double impact of air pollution and cold winters in Chilean Patagonia?

There is an important body of literature in geography that analyzes the social distribution of air quality in developed countries. However, while it is known that levels of ambient air pollution can be far more severe in cities of middle- and low-income countries, there is a paucity of literature that addresses this problem, in particular studies that focus on patterns of environmental injustice (Walker 2012). Indoor issues associated with poor-quality housing or energy poverty could increase the damage linked to environmental pollution. Nevertheless, it is hard to establish a clear relationship because the research in this area is still incipient. To fill this gap in the literature, this article combines different datasets to conduct microscale mixed methods research, intending to uncover situational and subjective factors that influence everyday experiences of injustice, from a small sample of households located in an extremely poor air quality environment.

Research Design: Study Area, Data, and Method

STUDY AREA

This study is focused on Coyhaique (S 45° 34′30.9”, W 72° 3′58.3”), situated in Aysén, the third-largest territorial region of Chile (Figure 1). This region is in between the regions of Los Lagos and Magallanes, known as Chilean Patagonia, and has similar weather requirements and solutions for energy needs (INE 2010). The economy is mainly based on the forest industry, ranching, fishing, and tourist activities.

The population of Coyhaique is 57,818 inhabitants (INE 2017). The city occupies 7290 km^2 and is about 130 meters above sea level. The average annual temperature is 7.1° C (45°F), and the weather is cold and rainy most of the year, especially from April to August, with a mean annual rainfall of 900 mm, approximately. The cold season spans from May to October, with frequent snowfall. The average winter temperature is 3.2°C (38°F), frequently reaching temperatures below zero degrees Celsius (INE, 2016). The combination of unfavorable weather conditions and

Fig. 1—Study area.

inefficiently insulated houses generates a high-energy demand for heating, which is primarily covered by firewood.

Figure 2 illustrates the fine particulate matter concentration ($PM_{2.5}$) in Coyhaique between September 2013 and April 2019. The graph shows the level of $PM_{2.5}$ concentration is far above both national and international standards. This includes the World Health Organization (WHO), which recommends that the daily concentration of $PM_{2.5}$ should not exceed 25 μg/m^3 (WHO 2005), the U.S. Environmental Protection Agency (EPA) limit of 35 μg/m^3 (EPA 2016) as well as the Chilean norm, which allows a maximum of 50 μg/m^3 per day. Also, the air pollution pattern demonstrates that high concentrations occur seasonally, especially during winter months (June to September),

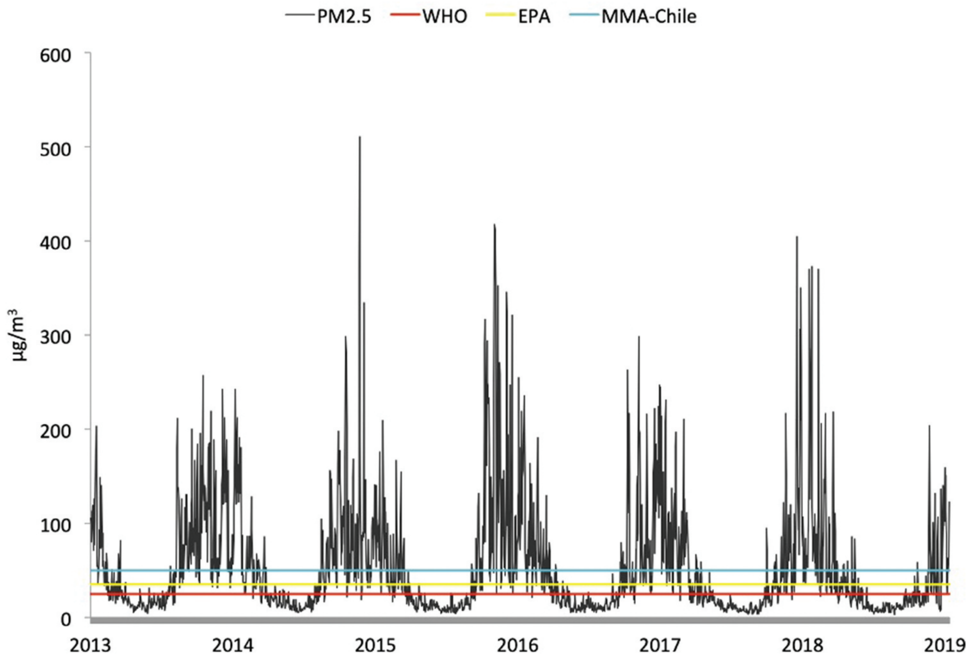

FIG. 2—Fine particulate matter concentrations ($PM_{2.5}$) in Coyhaique between 2013 and 2019 (24 hours average).

where the conditions for smoke accumulation are most favorable due to low temperatures, thermal inversion, and a lack of wind (MMA 2016).

DATA

To study how households from several socio-environmental positions attempt to balance high levels of air pollution with the need for thermal comfort in cold Patagonian winters, this study used mixed methods with three different data sources.

The first dataset comes from the Chilean Population and Housing Census of 2017. The census data is aggregated at the block level, and in the case of Coyhaique provides full information on 736 blocks. The census data is divided into three main categories: location of household (blocks); household characteristics (blocks): type of house, quality of the house, type of building materials, for example; and population characteristics (blocks): age, gender, ethnicity, nationality, and the like. In total, there are 36 variables available in these three categories. Blocks with fewer than 20 inhabitants are excluded from the analysis, which represents 47 blocks in the urban area of Coyhaique. We used census data to create a social vulnerability index linked to air pollution, and then we divided the city into blocks with low, medium, and high levels of social vulnerability (see Figure 3).

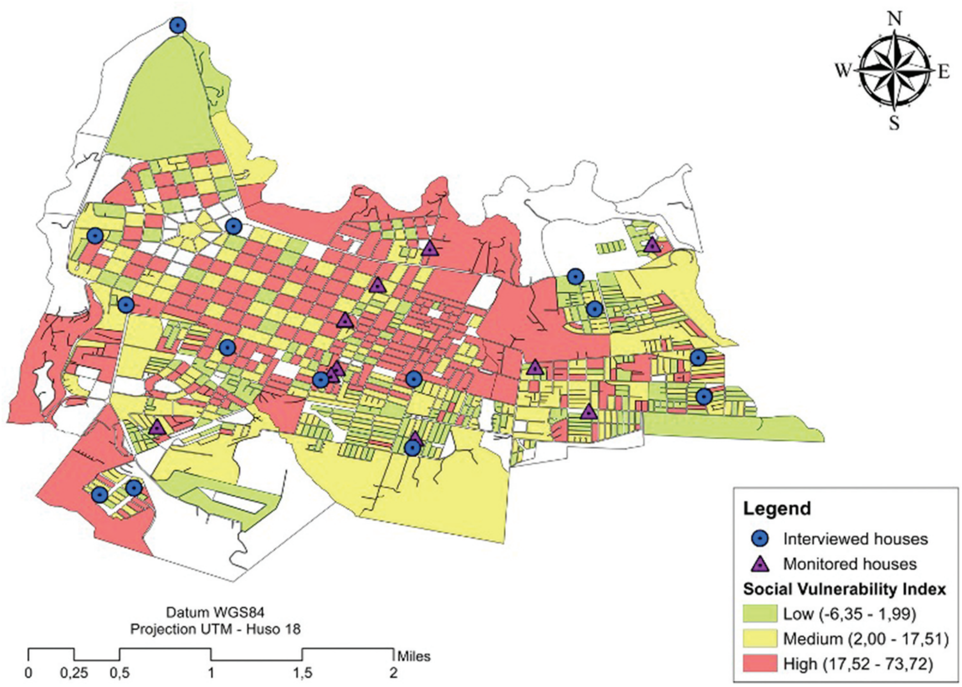

FIG. 3—Social vulnerability level of Coyhaique.

The second data source comes from the National Monitoring System (Sistema Nacional de Monitoreo, RENAM), which is part of the Ministry of Housing and Urban Planning (MINVU). RENAM collects both indoor and outdoor information nationwide about households' temperature, noise, and humidity, as well as indoor air quality (CO). In Coyhaique, RENAM collects information on ten houses. To perform a comparative analysis, we selected three of these households from three different social vulnerability levels using the following criteria: (1) each household comes from a block with low, medium, or high social vulnerability index (SVI), and the SVI was created using the Chilean Population and Housing Census, 2017; (2) we selected households with complete information from April 1 to September 30, 2018; (3) we chose households that, at microscale, best represent each of the three vulnerability levels. To confirm that the level of social vulnerability of each block was correctly described by the household selected, we checked in the dataset that each household has different characteristics linked with social vulnerability such as monthly income, household members, and house ownership, among others.

Finally, the third source of information comes from semistructured interviews conducted with residents of 14 households in Coyhaique. These participants were recruited through nonprobabilistic sampling. Based on the social vulnerability index created in this study, we selected households from blocks with low, medium, and high levels of social vulnerability (Figure 3). To compare different experiences and perceptions of the residents to heat their houses. We double-checked the levels of social vulnerability of each household through socio-demographic information as well. Of the total sample, 28.6 percent are men, and 71.4 percent are women, with ages ranging from 18 to 65 years old. Table 1 describes the main characteristics of the participants in this study.

Interviews were conducted between June and July 2019. With the prior consent of the participants, interviews were digitally recorded. They lasted an average of 40 minutes and were open-ended. We explored different topics, such as perception, awareness, and feelings about air quality; policy acceptance; intention to change their current domestic heating system; self-efficacy; and protection measures. All interviews were immediately transcribed and checked for accuracy. Each transcript was analyzed using the NVivo 11 software, followed by additional memo writing (Tracy 2013). Codes were reviewed, organized into categories, and reapplied to the data in another round of transcript review, with additional iterative code development and refinement (Creswell 2013). We identified emerging themes in participants' interviews, and then we discussed and refined these with the research team.

VULNERABILITY INDEX

We constructed a social vulnerability index at the block level using the Chilean Population and Housing Census of 2017, which allowed us to classify residents of the city of Coyhaique in three levels of social vulnerability: low, medium, and high. The literature identified several variables that increase the population's vulnerability to air pollution. For example, age influences the level of vulnerability, as children and the elderly are more vulnerable to developing diseases linked to air pollution (Romero-Lankao, Qin, and Borbor-Cordova 2013; Moreno-Jimenez and others 2016). Furthermore, certain groups such as immigrants (Lalloué and others 2013), indigenous peoples (Prieto-Flores and others2017), and those living in poor-quality houses (Reyes and others 2019) are more likely to be affected by air pollution. However, the use of indexes to quantify social vulnerability has been criticized, mainly because of the use of a limited number of variables and the lack of interrelation among them (Hofflinger and others 2019b). To address this problem, we used a principal components analysis (PCA) to construct a social vulnerability index following the methodology developed by Cutter and others (2003). A PCA can extract information from a set of variables and represent them in a new set of variables called principal components (Abdi and Williams 2010). The use of this technique makes it possible to obtain a robust and consistent estimation of social vulnerability (Cutter, Boruff, and Shirley 2003).

We selected those variables present in the census and previously identified in the literature as theoretically linking social vulnerability and air pollution. To construct the social vulnerability index, we followed Cutter and others (2003)

TABLE 1—MAIN CHARACTERISTICS OF THE PARTICIPANTS

CASE	INTERVIEWEE	OTHERS HOUSEHOLD MEMBERS	HOUSEHOLD TOTAL INCOME PER MONTH (US DOLLARS)	OTHERS CHARACTERISTICS
1	Female, Pastry-making	1 child (3-5years), 1 adult (30-64years)	434—722	Rented house, built in 2000, 50m², mostly wood and concrete
2	Male, Waiter	1 adult (30-64years)	434—722	Own house, built in 1998, 45m², mostly wood
3	Female, Coffee shop assistant	1 young adult (18-29years), 1 adult (30-64years)	434—722	Own house, built in 2014, 40m²
4	Male, Professional cyclist	1 toddler (< 3years), 1 young adult (18-29years)	1444—3608	Rented house, built in 2016, 68m², mostly zinc
5	Female, Lawyer	1 young adult (18-29years), 1 adult (30-64years)	>3608	Own house, built in 2003, 283m²
6	Female, Coffee shop supervisor	1 adult (30-64years)	434—722	Rented house, built in 1970, 35m², mostly concrete
7	Female, Primary school teacher	1 child (6-11years), 1 young adult (18-29years)	723—1443	Rented house, built in 2000, 90m², mostly wood
8	Male, Engineer in workplace hazard prevention	1 adult (30-64years)	723—1443	Rented house, built in 2002, 30m², mostly wood
9	Female, Coffee shop assistant	1 adolescent (12-17years), 1 young adult (18-29years), 1 adult (30-64years)	434—722	Own house, built in 1996, 48m²
10	Female, Waitress	1 toddler (< 3years), 1 child (6-11years), 1 young adult (18-29years),	434—722	Own house, built in 2008, 40m²
11	Male, Public servant	1 young adult (18-29years),	1444—3608	Rented house, built in 1950, 105m², mostly wood
12	Female, Teacher	1 adult (30-64years)	1444—3608	Own apartment, built in 1980, 100m²
13	Female, Speech-therapist	1 young adult (18-29years)	723—1443	Own house, built in 2008, 107m²
14	Female, Secretary	1 adult (30-64years)	1444—3608	Own house, built in 1990, 80m²

and Schmidtlein and others (2008), who listed seven steps to calculate the index. As with Cutter and others (2003), we assumed that all components make the same contribution to the index. Then, and using the social vulnerability index, we divided Coyhaique into three levels: blocks with low, medium, and high social vulnerability to air pollution.

We analyzed the data from RENAM using descriptive statistics. We compared the indoor and outdoor temperature data of households located on blocks with low, medium, and high social vulnerability, and whether or not the indoor temperature was above or below the World Health Organization's threshold (21°C). Finally, the semistructured interviews were analyzed using thematic analysis with MAXQDA software. The thematic analysis allowed the inductive and deductive generation of codes, and the identification of extracts pertaining to each thematic category. We generated two large groups of thematic codes. The first group was made up of codes referring to the perception of indoor air quality levels. Aspects such as the awareness and understanding of the problem of air pollution as well as the beliefs of severity and susceptibility were analyzed. The second group was made up of issues related to the individuals' behavioral intentions regarding air pollution and heating practices.

Figure 3 shows the level of social vulnerability in Coyhaique identified by PCA using census data from 2017, as well as where the households measured by RENAM are located (indoor and outdoor temperature) and where the interviews were conducted. The most vulnerable blocks are those with a higher percentage of renters, immigrants, families with children (less than five years old), and indigenous people. Instead, the less-vulnerable blocks are localized in the suburbs, outside of the traditional downtown area, and most of the houses in this zone have been built after 2007.

The Relationship between Air Pollution, Indoor Temperatures, and Social Vulnerability

Do Indoor Temperatures Vary with Social Vulnerability?

Figure 4 shows indoor and outdoor temperatures between April 1 and September 30 (2018) of all monitored houses (*N*:10) by RENAM in Coyhaique. During this period, the average temperature in Coyhaique was 4.2°C (39°F), fluctuating between 1° and 8°C and reaching its lowest point on July with -11°C (22°F) and the highest on April with 20°C (68°F). By contrast, the average temperature of the monitored houses was 17.2°C (63°F) in this period, which is lower than the 21°C (70°F) proposed by the WHO as a thermal comfort standard (1987). This means the heating system and house conditions are not efficient enough to generate and hold the energy needed to maintain a comfortable indoor temperature. Furthermore, it is important to note that there was a high variability on the temperature trends among households located in blocks with low, medium, and high vulnerability.

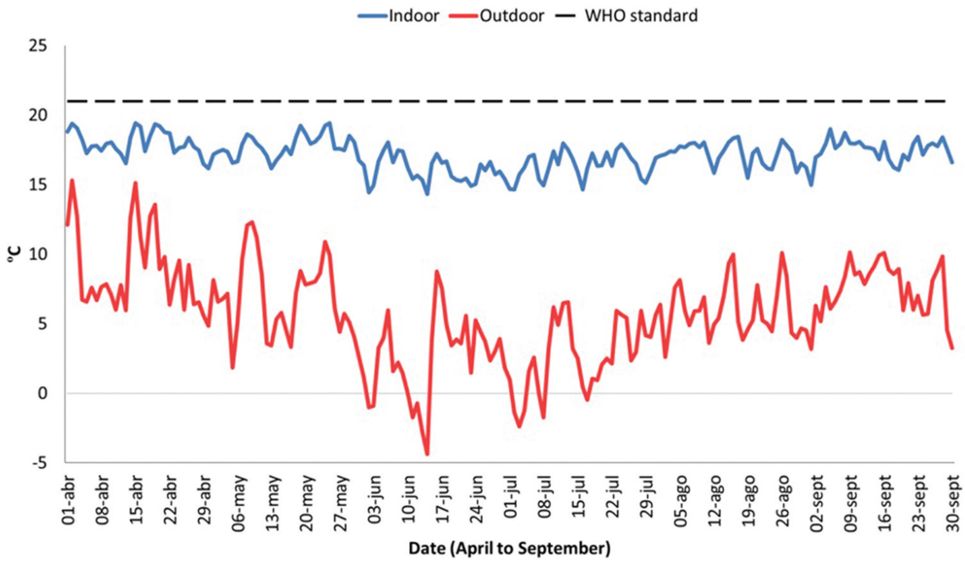

FIG. 4—Indoor (10-house average) and outdoor temperatures from April to September 2018. The reference line shows the WHO's thermal comfort standard, which is 21 °C in the living room (WHO, 1987).

When we analyze specific cases of indoor temperature in houses that use wood-burning stoves as their primary heating system, we observe that there were distinguishable temperature trends depending on the characteristics and period when the homes were built (Figure 5). For instance, we can see that the house in Figure 5a (located in a block with high social vulnerability) has the lowest temperature trend, going up and down constantly and hardly ever reaching the thermal comfort temperature defined by the WHO (1987). In part, this can be explained by the building characteristics of the house, especially in terms of thermal insulation. The house has 106-140m^2 divided into two floors and was built before 2000, when there were no insulation standards for house construction in Chile. Also, the house has single-pane windows. Three individuals live there (one of them older than 65 years old), and they use a wood-burning stove as their primary heating system.

The house from a block with medium social vulnerability index (Figure 5b) was built after 2007 according to insulation standards and shows a trend with higher temperatures, but with higher fluctuation of indoor temperatures, with peaks above the comfort standards, but not being able to hold those temperatures steady over time. This house has one floor of 36-70m^2, with single-pane windows. The house is inhabited by two people, older than 65 years, who complement their wood-burning stove heating system with an oil stove as well as an electrical heater.

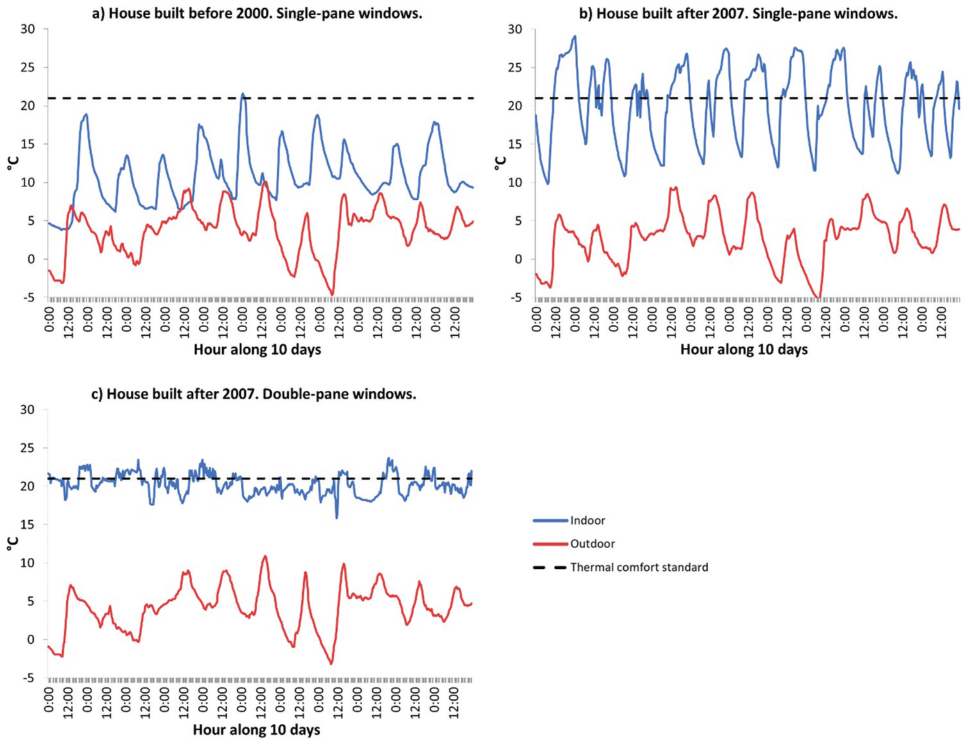

FIG. 5—Cases showing different temperature indoor trends over ten days (July 20th-30th, 2018).

Finally, the house located in a block with low social vulnerability (Figure 5c) has the most stable indoor temperature trend; moreover, it was built after 2007 according to insulation standards, and it also has double-pane windows. The house has two floors of 106-140m^2 and is inhabited by four people (two of them younger than 14 years old), and the family uses wood-burning and oil stoves as the heating system.

HOW DO CITY DWELLERS PERCEIVE OUTDOOR AND INDOOR AIR QUALITY?

All the respondents considered that air quality in Coyhaique is harmful to their health. In the winter months, smoke produced by wood-burning stoves is visible in the whole city, and all participants pointed out that air pollution generates constant discomfort during their daily activities.

For example, one participant, a young professional athlete, explained her experience of the poor air quality when temperatures dropped.

> *P5: "It's super dense, super bad. In fact, I go, and when it's really cold I get out of the car and I really feel that I'm breathing pure crap, nothing but pure chemicals and what the firewood is also spewing out, too. Yes, ultimately I think that long*

term if this problem persists, it will lead to diseases and after there will be catastrophes that can be avoided." (E_05)

Alike, another female participant, who works in a coffee shop and lives a block with high social vulnerability, describes her experience with the air pollution.

P5: "Look, now it's getting gross, after 5 in the afternoon, imagine in the center it's already bad, I've had to walk up by Clotario [a district of Coyhaique] at 6 in the afternoon and in winter you can't see anymore, and you don't know if it's from fog or smoke." (E_09)

Despite the general agreement that air pollution affects the whole population, the most vulnerable groups—identified by the participants—are old adults and children. Furthermore, the participants identified that the primary source of air pollution is linked to the use of wood-burning stoves. However, those who live in blocks with low social vulnerability pointed out that not only the air pollution is associated with the use of firewood, but also the use of wet firewood and the lack of maintenance and cleaning of the wood-burning stoves influence the high air pollution levels.

Likewise, individuals from blocks with medium or low social vulnerability show some levels of awareness about indoor air quality. In general, they believe that their homes will get more polluted if they air them out, especially when there is a high concentration of smoke. However, those living in blocks with high social vulnerability do not show concerns associated with indoor air pollution. It is important to point out that in southern Chile, low-income households often do not have mechanical ventilation, but high levels of air pollution infiltration. This situation is explained by a female participant, who works in a coffee shop and lives in a block with medium social vulnerability

P8: "I think it's so-so because if I open the doors, the windows, there isn't much I can do to change the air because the air that comes in is also contaminated, so how do I circulate the air. I think that I open a door to ventilate, but I'm not decontaminating much." (E_08)

In general, it is observed that there are fewer concerns about indoor air quality than outdoor pollution. Participants believe that particular matter can only enter the home when they ventilate their houses during contamination peaks. However, other sources of indoor pollution, such as having a wood-burning stove, the use of wet firewood, or other types of possible causes of infiltration are not valued. The participants do not report that they change their behavior or daily routines based on the quality of the indoor air

USE AND ATTACHMENT TO FIREWOOD IN URBAN PATAGONIA

When participants describe the advantages of using firewood over other types of fuel, most responses are linked to positive feelings associated narratively with four elements: cultural roots, energy costs, the multifunctionality of the use of wood-burning stoves, and a greater feeling of thermal comfort over other energy systems.

For the participants from the highly vulnerable households, firewood is the most accessible and cheapest heating fuel. The cost associated with firewood is the central positive aspect reported by the respondents in contrast to the price of other heating fuels such as gas, pellet, or electricity. Hence, they justified the use of firewood despite the negative effect linked to its use. Furthermore, for those households located in blocks with high social vulnerability, the use of firewood has different functions, such as drying clothes, cooking, and obtaining hot water.

An adult female, who works in a restaurant, explains the comparative advantages of the use of wood-burning stoves.

> *PP: "Yes, apart from the comfort, there's the issue of drying. If you don't have heating, you can't dry the clothes here. In this region it's impossible." (E_13)*

Some participants described their positive feelings in terms of the childhood and family memories around the wood-burning stoves. For instance, a woman who lives a block with medium social vulnerability says:

> *P1: "My childhood was around the stove. I still remember the living room in my house where there was a bench where you take a nap, drink hot chocolate, watch mom drinking hot mate warmed up on the same stove, adding water from the teapot . . . and my grandparents were always seated behind on an armchair . . . " (E_08)*

The participants argued that certain cultural conditions define their daily life in Patagonia, where the use of wood-burning stoves is a central element of these social practices. This feature is a crucial difference between firewood and other alternative energy technologies, according to the perception of most of the participants (independent of their social vulnerability level). A female participant, who works in the health sector and lives in a block with low social vulnerability, explains the multifunctionally of wood-burning stoves:

> *P1: "There are a lot of factors that explain why we use firewood so much. To start with, the culture, because the Patagonian is all about wood-burning stoves, mate . . . it's even still used for cooking. There are even stoves that, in fact, are a wood-burning oven that is also used as heating." (E_12)*

Moreover, the participants describe the technical characteristics of wood-burning stoves that appeal to them. In general, they perceive that the heat (radiation) provided by wood-burning stoves is better than the heat emitted by other alternative devices, such as electric heaters or pellet stoves, which work by convection. They argue that the heat produced by wood-burning stoves can cover more substantial spaces and provide higher temperatures than other devices. Several respondents explained that the use of firewood produces a "dry," "direct," "powerful," or "full" heat, and temperature (heat) is also maintained over a more extended period than other technologies. However, this perception does not match the real temperature analyzed in this study (Figure 5), where other factors, such as household thermal insulation, are a crucial factor in explaining thermal efficiency.

The comparative advantages of the use of firewood are summarized by a female worker, who comes from a block with high social vulnerability:

P1: "The truth is that I like the firewood for the warmth it gives, for the square meters it heats, something that doesn't happen with paraffin or other types of heating. The cooling process is also slower, so the house stays warmer longer." (E_09)

Despite the described advantages, the participants from more vulnerable blocks point out that the use of firewood is uncomfortable, dirty and time consuming; in particular, they must spend time in storing, chopping, and drying the firewood; maintaining the stoves; and periodically cleaning the chimney. Individuals from blocks with medium and low social vulnerability do not report the same disadvantages, however. A possible explanation for these differences could be that in households localized in highly vulnerable blocks (measured by the social vulnerability index), residents usually assume all activities and practices related to the use and maintenance of stoves by themselves. On the other hand, participants from less vulnerable blocks explain that with wood-burning stoves, it is more difficult to regulate the indoor temperature. As we observed in the Figure 5, Case B, the use of wood-burning stoves can generate abrupt temperature changes, which may lead to a low level of comfort when residents are at home. This could be a reason to prefer another type of heating system that gives them a more stable temperature. This concern is not expressed by participants from blocks with medium or high social vulnerability.

DO HEALTH-PROTECTION BEHAVIORS VARY WITH SOCIAL VULNERABILITY POSITION?

In terms of actions taken to minimize the impacts of air pollution hazards, participants used four strategies: modify routine activities, modify the home environment and infrastructure, and apply both the wood-stove replacement or thermal retrofitting programs. Despite all groups being aware and developing some protective strategies, hazard-minimization efforts varied with social vulnerability position. Households from less-vulnerable blocks use all four types of action. However, more vulnerable families tend to use only the first category of action (modify routine activities).

In terms of modifying routine activities, participants shared several strategies. The most common was staying at home during "emergency" days (days with high level of $PM_{2.5}$). Some participants mentioned that they have worn a face mask, but its use is in its early stages and concentrated in blocks with low vulnerability. On the other hand, most of the participants pointed out the use of scarves to protect themselves from outdoor air pollution. This action is inefficient as $PM_{2.5}$ can quickly penetrate clothing due to its tiny size.

A male adult from a block with high social vulnerability describes this issue:

P1: "I do not like using a mask ... Generally, I just wear a scarf, but I try not to go out during the hours with the most pollution. I prefer not to go out, just to stay at home. I don't go out much when there is a lot of pollution." (E_03)

Most participants are aware of the need for good thermal insulation in their homes. The difference is that families in blocks with low vulnerability already have better homes (efficient building materials). In contrast, families in medium- and high-vulnerability blocks live in more precarious conditions in terms of insulation and type of building materials. In these households (high and medium income), the use of the wood-burning stove is the primary source of heat during the winter; that is, by not having adequate thermal insulation, the more vulnerable households have a dilemma between replacing the wood stove (lower emissions, but less thermal comfort) or continuing to use firewood as a primary heating fuel (more emissions, but more thermal comfort). Most of the families in more vulnerable households, according to our interviews, choose the second alternative.

An Environmental Justice Dilemma in Chilean Patagonia

The emphasis of environmental justice literature has historically been on outdoor pollution sources such as industry or traffic (Walker 2012). Although these sources can influence health disparities, in urban Chilean Patagonia understanding the relation between indoor and outdoor environments is essential. The exploration of the disparities in indoor residential environments remains an underappreciated environmental justice issue (Adamkiewicz and others 2011). Our findings show that the houses' indoor temperatures vary depending upon their social vulnerability levels. For instance, households located in highly vulnerable blocks (measured by the social vulnerability index) have lower indoor temperatures than the thermal comfort standard proposed by WHO. Furthermore, these households present a high variability of temperature trends. Instead, households localized in blocks with a low social vulnerability index have a different pattern. These households have more stable indoor temperatures trends and closer to the WHO's standard. The results of this study suggest that it is urgent to move environmental justice research toward indoor pollution, even though, as previously we have pointed out, it is a challenging agenda.

In winter, most of Coyhaique's inhabitants face a dilemma: try to generate a thermally comfortable environment by using wood-burning stoves, but generating pollution (both indoor and outdoor), or resigning themselves to being cold in winter, abandoning the firewood, and generating low emissions. The most socially advantaged households usually have more adequate insulation, double-paned windows, air filtration machines, economic resources to access alternative heating systems, and are even located in apparently less-polluted neighborhoods.

As the temperature analysis shows (Figure 5), only households located in low-vulnerability blocks manage to maintain a stable and comfortable temperature in the home and escape the dilemma. Households from blocks with medium levels of vulnerability have sufficient purchasing power to buy firewood, but not good thermal insulation. These homes emit a large amount of $PM_{2.5}$ and PM_{10} due to their high energy demand. Also, these families cannot maintain a comfortable and healthy temperature in their homes, as Figure 5b shows.

Wood-burning stoves' characteristics and low energy efficiency building material create an unhealthy indoor environment with cyclic peaks of cold and heat. The situation in the most vulnerable households is even worse. Some of these households, which we observed during the fieldwork, do not even manage to raise the indoor temperature above 21°C (70°F), proposed by the WHO as a thermal comfort standard (see Figure 5a). The temperatures recorded in highly socially vulnerable households provided a point of contrast to the more-advantaged households. They illustrated a critical dimension of the degree of inequality experienced within the same urban area.

On the other hand, this study explored the perception, understanding, and behavior of residents in Coyhaique about air pollution and its associated health risks. The main highlights suggest that families from the three levels of social vulnerability compared in this study perceive that air pollution is harmful to their health and try to adapt their routines to protect themselves. However, the clearest disconnection between knowledge and practice was observed among the most vulnerable households due to their restricted ability to take action to replace their wood-burning stoves, improve their home's thermal insulation, or move to another neighborhood. Regardless of the cultural attachment to firewood rooted in Chilean Patagonia, the multifunctional nature of firewood and wood-burning stoves shows the difficulties for change that the most vulnerable social strata face.

Persons living in more vulnerable households are not only unable to replace functions of wood-burning stoves, such as drying clothes, heating water, or cooking by using other appliances and services, but they are also unable to switch to an alternative heating system as this involves a higher cost they cannot cover. In sum, the more socially vulnerable families do not have the same ability to meet the costs of adapting their homes to the extreme cold and polluted winter environment in urban southern Chile. To some extent, these findings are consistent with those from recent studies conducted in other Chilean cities like Temuco, Padre Las Casas (Boso and others 2020, or Valdivia (Reyes and others 2019).

Our study presents some limitations. First, even though we used a diverse group of households, in terms of their socioeconomic status, it is not possible to generalize our preliminary findings due to the small sample size utilized. Future research could test our results using a larger sample size. Second, we did not collect information (direct observations) about the participants' behavior regarding heating practices or self-protective behaviors against air pollution. The reported behaviors could be less precise and affected by elements, such as social desirability. Thus, conducting studies with direct observations is a pending challenge for future inquiries. After considering these limitations, our key findings remain relevant to the environmental justice literature. Traditional quantitative approaches have contributed little to an understanding of how experiences of injustice in the context of air pollution are influenced by individual perception. The use of qualitative methods, like those applied in this study, at the microlevel paired with an environmental justice approach focused on indoor hazards will guide future research in new geographic contexts.

Conclusions

This article was based on mixed methods research to examine pattern-process linkages in the production of distributional injustice in southern Chilean Patagonia. By clarifying the factors influencing the capacity to cope with indoor and outdoor air pollution and resist low winter temperatures in urban Patagonia, this study aimed to contribute to the existing body of knowledge in the field. Our results suggest the need to apply interventions that take into account the space and social vulnerability of the population. The emphasis that some programs place on behavioral change to reduce air pollution concentrations is unlikely to succeed unless accompanied by a broader understanding of the living conditions of the most vulnerable families. Applying a restrictive measure that prevents the use of wood-burning stoves in urban Patagonia, it would expose the most socially vulnerable households to cooler and better environments. The public policies for replacing a stove with pellet systems (less polluting) not only have a similar effect, but when households do not have good thermal insulation, heating costs rise. Reducing the levels of exposure to particulate matter in exchange for increasing cold and damp housing conditions is the environmental justice dilemma faced by the most socially vulnerable households.

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Orcid

Àlex Boso http://orcid.org/0000-0002-0313-8238

Àlvaro Hofflinger http://orcid.org/0000-0002-1231-9911

Jaime Garrido http://orcid.org/0000-0002-1917-6925

Boris Álvarez http://orcid.org/0000-0002-9725-938X

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