Energy for Sustainable Development 33 (2016) 26–35

Contents lists available at ScienceDirect

Energy for Sustainable Development

Firewood demand and energy policy in south-central Chile

Alejandra Schueftan [a,*], Jorge Sommerhoff [b], Alejandro D. González [c]

[a] Escuela de Graduados, Facultad de Ciencias Forestales y Recursos Naturales, Universidad Austral de Chile, Valdivia, Chile
[b] Certificación e Investigación de la Vivienda Austral (CIVA), Universidad Austral de Chile, Valdivia, Chile
[c] INIBIOMA, CONICET CCT-Patagonia Norte and Universidad Nacional del Comahue, Bariloche, Argentina

ARTICLE INFO

Article history:
Received 9 September 2015
Revised 23 April 2016
Accepted 23 April 2016
Available online xxxx

Keywords:
Firewood
Space heating
Air pollution
Energy poverty
Energy efficiency

ABSTRACT

Firewood is the major fuel for household heating in south-central Chile and combustion of wood is the major source of air pollution by particulate matter (PM) emissions in this region. This paper discusses various strategies for lowering emissions from household wood combustion and their effectiveness in reducing air contamination. A survey of 2025 households and previous analysis performed with these data showed large consumption of wood fuel for heating in dwellings in Valdivia. The main variable identified is the low thermal efficiency of household envelope. Low efficiency of household envelope, low comfort, and a large share of income dedicated to energy, determines a high level of energy poverty. We have modeled the thermal retrofitting of dwellings under three efficiency scenarios, including stoves' and house's envelope improvements. Retrofitting houses led to energy poverty alleviation; in contrast, improvement of heating appliances alone does not alleviate energy poverty nor improve indoor comfort.

Introduction

Residential energy use varies widely across countries and even among regions within the same country. In Chile, the national production of energy depends on biomass, hydroelectric energy, and gas, accounting for 34% of the total energy available, with biomass representing 72% of the nationally produced energy resource. The major resources of oil, gas and coal are imported (66% of total) (IEA, 2016). This makes the country highly vulnerable to energy imports, while biomass is the cheapest energy resource. For instance, 95% of households in south-central regions use wood fuel for heating and partially for cooking (INFOR, 2012).

As wood fuel is the cheapest energy source in this region, not only the residential sector, but also the large public buildings like hospitals and schools depend on firewood for heating. Currently firewood is 4, 5 and 6 times cheaper than diesel, gas or electricity, respectively (Schueftan and González, 2013). Although human beings have been burning wood for heating purposes for over 500,000 years, doing so in a densely populated city such as those in south–central Chile is novel, and leads to serious environmental, economic and social consequences (Cereceda-Balic et al., 2012).

Our aim is to identify the major causes of air pollution and discuss the possible reasons that could account for the failure of current policies to reduce hazardous emissions and fuel poverty in south-central Chile. Once identified and their potential for improvement assessed quantitatively, the cost of the measures to reduce air pollution and a cost–benefit analysis was studied. Based on the observation of household mechanisms to ensure the satisfaction of heating demands, and given the current low thermal efficiency in building envelopes, we argue that the current programs have very limited potential for reducing air pollution. We seek to provide information that could be useful to policy-makers, so that they may shift their attention to those measures that could have a significant impact for reducing wood-fuel consumption and thereby reduce toxic emissions and improve indoor comfort in dwellings.

An outline of the paper is as follows. In the "Environmental issues" and "Economic and social issues" sections of the Introduction we present a literature review to understand the context of the problems related to the use of firewood, and in the "Current government subsidy programs" section we summarize the current programs to reduce air pollution that have been active for the last years. The "Methodology" section requires an extensive explanation ("Retrofit proposals and costs for households," "Emissions reduction," and "Energy expenditure in households"), as the effects of wood fuel use are related to current buildings' quality, climate, social status, and different levels of improvements related to government subsidies for refurbishments. In the "Results and discussion" section we present the results and discussions on retrofitting proposals and their costs for households, emissions reductions, the current energy poverty indicators and the decreases in firewood consumption obtained with energy efficiency improvements.

Environmental issues

Currently, in south-central Chile, the cities of Talca, Chillán, Los Angeles, Temuco, Valdivia, and Osorno, suffer from air pollution with

* Corresponding author. Tel.: +56632271975.
E-mail addresses: aschueftan@a2s.cl (A. Schueftan), jsommerh@uach.cl (J. Sommerhoff), gonzalezad@comahue-conicet.gob.ar (A.D. González).

http://dx.doi.org/10.1016/j.esd.2016.04.004
0973-0826/

concentrations of particulate matter PM_{10} and $PM_{2.5}$ (the subscripts relate to the size of particles present in air, including those smaller than 10 μm and smaller than 2.5 μm, respectively) that surpass both the international and Chilean standards. In Temuco, detailed spectroscopy analysis showed that the main contribution of air pollution is wood burning, to the extent that the city is considered a *monosource* pollution case (Cereceda-Balic et al., 2012), meaning that smoke contributions from wood burning are much greater than traffic or industrial sources. In winter, $PM_{2.5}$ usually accounts for 85% to 90% of the total PM_{10} counting, showing the influence of firewood used for residential heating. A similar PM pattern, with dominant firewood emissions, is shown by daily PM measurements in Valdivia and Osorno (SINCA, 2016). These two cities have been declared saturated of $PM_{2.5}$ in 2014, meaning that they experienced emissions above the Chilean standards for the past 3 years (Schueftan and González, 2015). Temuco has already been in this emergency category since 2013. The official declaration of PM saturation for a particular city is followed by the implementation of a government program intended to find strategies to mitigate air pollution.

A further aggravation of air pollution is the presence in the market of airtight residential wood-burning devices which allow a complete air-inlet choke. This operating mode, which allows for smoldering combustion, is used in most households, at the expense of higher particulate emissions. The measurements of Chilean (CNE, 2009) and Australian stoves' emissions (Jordan and Seen, 2005) demonstrated that choking the air-inlet increases PM emissions in up to a factor of ten, and that this increase occurs equally in new and old stoves. Other Organization for Economic Co-operation and Development (OCDE) countries have stricter regulations on airtight heaters to be sold in cities. For instance, stoves that allow choking are forbidden in New Zealand (Bosca, 2014). This common practice was found in almost all households in Valdivia: 68% respond to surveys that they completely choke their stoves, and 32% reported that they partially choke their stoves. This practice has economic and social consequences as households benefit from using less firewood; but higher emissions take their toll on health, requiring additional spending on public and private health services. Emissions also depend on the quality of the firewood that is used, but 97% is bought in the informal market so there is little control on the moisture content which directly affects the combustion process, as studied in a previous work (Schueftan and González, 2015).

Firewood combustion for heating has also consequences at a global level, contributing to greenhouse gases (GHG). Studies show that the residential heating system of Valdivia annually releases into the atmosphere 94,500 t of CO_2e,[1] when CO_2 in combustion is considered carbon neutral (2.2 t CO_2e/HH/year, meaning CO_2e per household per year), and 285,000 t of CO_2e when it is not considered neutral (7.1 t CO_2e/HH/year) (Reyes et al., 2015). The GHG emissions of firewood depend on the origin of the biomass that is used, being uncertain in the case of Valdivia, where most sources are from informal markets and not from forests managed in a sustainable way in order to be considered carbon neutral (Reyes et al., 2015; Schueftan and González, 2015).

Another negative environmental impact of the massive use of firewood is land reclamation and degradation of native forests. This is a problem that can be seen worldwide and is an increasing trend, as presented by Arabatzis et al. (2012). This aspect has also been studied for the case of Valdivia by Reyes et al. (2015) and it is very relevant, since forests are essential for local economy.

Economic and social issues

A comparative analysis of retail prices for fuel that was carried out in the year 2015 showed the following ratios for 1 GJ of energy, where 1 is firewood: 1:2.6 for diesel; 1:4.2 for gas; and 1:6.3 for electricity (Minenergía, 2015). The economic preference of firewood for heating is thereby obvious, especially in the context of the high energy consumption required by the low thermal efficiency of buildings. It is to note that the price of firewood varies for different species, which also differ in their calorific power. This is an important issue for polices related to the use of firewood, since price determines which species are being mostly harvested and the effect this could have on the forest ecosystem services as carbon storage (Zafeiriou et al., 2011), besides other environmental effects mentioned in the previous section.

Studies for the city of Valdivia found an average consumption of wood fuel near bulk 12 m^3 (ca. 8 m^3solid) per year, corresponding to an energy use of 300 to 540 kWh m^{-2} for heating (MMA, 2010, 2012). This energy demand is very high compared to climate indicators (Schueftan and González, 2013). The ratio of the heating energy used and the number of heating degree-days (HDDs[2]) were used as indicators of energy efficiency. Values around 40 MJ/year HDD were obtained for cities in Argentina and Chile (both countries with similar housing envelope thermal quality), compared to 13 MJ/year HDD obtained in the case of Stockholm, where constructions have better standards of energy efficiency (Schueftan and González, 2013).

In Chile, current building codes that regulate the thermal characteristics of a dwelling envelope (walls, roofs, floors and windows), have soft requirements compared to foreign regulations. The current norm was implemented in 2007, but most constructions were built before this implementation. For example, in the city of Valdivia, 85% of the houses were built before 2007 (Schueftan and González, 2013). Fig. 1 depicts usual house typologies found in the city of Valdivia and in general in south-central Chile, all of which have the same problems of inefficient thermal insulation in the envelope.

In addition to the very high levels of PM emissions, households in south-central regions of Chile are exposed to low indoor temperatures. While the recommended indoor temperatures are between 18 °C and 21 °C, studies have shown that household temperatures in cities from Concepción to Puerto Montt range from 14.3 °C to 16.5 °C during winter (Bustamante et al., 2009), in spite of the high wood-fuel consumption previously mentioned.

Therefore, the three main characteristics that define fuel poverty are found: 1) high prices of energy related to income; 2) inappropriate thermal performance of buildings and high energy consumption; and 3) low comfort standards (Healy and Clinch, 2004; Walker et al., 2012, 2014). An important consequence of fuel poverty is the trade-off that households have to make between keeping warm and paying for other basic needs such as clothing, food and education (Howden-Chapman et al., 2012).

In cities of south-central Chile, partial or total ban to burn firewood is enforced by authorities during air pollution emergencies, with serious consequences to those households which are not able to afford other fuels. During wood burning bans, households in the higher income levels turn to gas or electricity for heating; however, the lower income sectors that use firewood cannot afford the higher cost of gas and electricity, having to cope with the low indoor temperatures of their un-insulated dwellings and the pernicious consequences to health and life quality in general.

Therefore, buildings with low thermal insulation affect health in two simultaneous ways: smoke emissions leading to high PM concentrations, and low indoor air and wall temperatures. The effects on health from breathing air with high concentration of PM, especially $PM_{2.5}$, are well documented (Cereceda-Balic et al., 2012; Allen et al., 2009; Fuenzalida et al., 2013). In Chile, studies of hospital admissions in south-central regions, between the cities of Temuco and Puerto Montt, showed higher than average incidence of chronic bronchitis in the general population, and notable incidence of cardiac diseases during

[1] Tonnes of CO_2e indicates the total amount of the various GHGs emitted in a process, given in equivalent (e) units of CO_2.

[2] Heating degree-days (HDDs) account for the daily differences between actual outdoor temperature and 18.3 °C, considering empirically the outdoor temperature for which heating would not be needed; thus, HDD is an indicator of climate influence on heating needs.