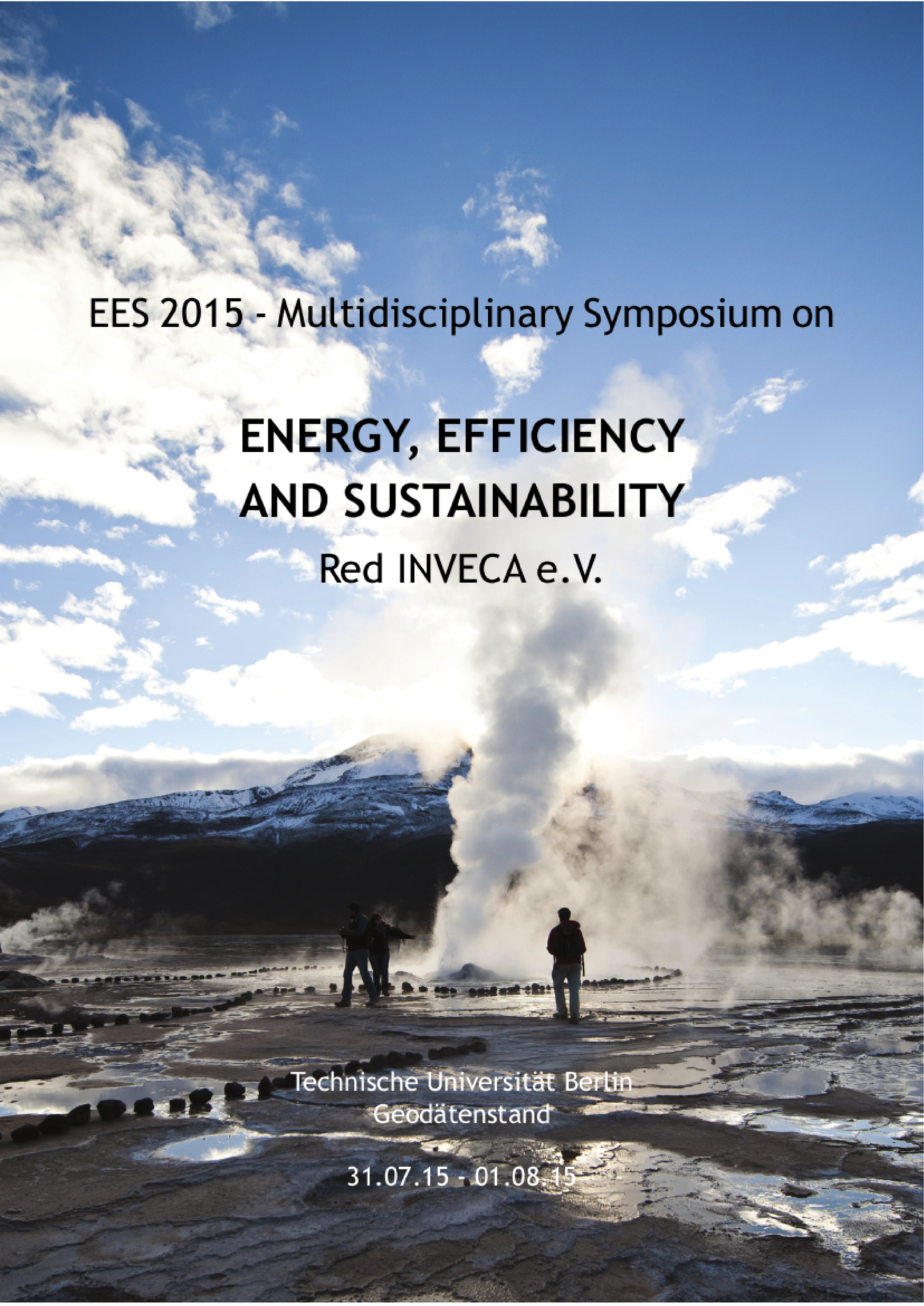

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# The effect of energy efficiency policies on air pollution in south-central Chile

Alejandra Schueftan [1], Alejandro González [2]

## ABSTRACT

We have investigated technical, economical and policy aspects in the use of fuel wood in households of south-central Chile. Low efficiency in buildings' envelopes was found, which leads to very high consumption of firewood and hence to high emissions of particulate matter (PM). In addition, user practices that systematically choke the air inlet of fuel wood stoves were found to further increase PM emissions. Around 95% of households in Valdivia use firewood for heating and 80% of households were found to spend more than 10% of their income in residential energy. Present policies promote energy efficiency through subsidies for retrofitting and to replace old stoves and their effects on emissions reductions, comfort standards and energy poverty were studied. Different techniques and materials to retrofit existing houses and the replacement of old stoves for newer technologies were studied for a sample of 2025 households in Valdivia. It was found that retrofits have high potential to lower fuel consumption and thus reduce air pollution and energy costs; while replacing stoves could have a limited effect on lowering emissions but would not alleviate energy poverty. In the economic analysis we have calculated the total cost for private and public sector. From private households' point of view, the options with retrofit led to much lower cost as the savings in fuel wood are significant, and subsidies reduce the cost of retrofits. For the public sector, the savings are in healthcare services and the main investment is in the subsidies, thus the option replacing only stoves has lowest cost for the public sector. However, this option is not sustainable due to persisting high consumption of firewood and vulnerability to air choking practices.

**Keywords**: Air pollution, fuel wood, house thermal efficiency.

## I. INTRODUCTION

Major cities in south-central Chile face a serious problem of air pollution, which has worsened the last ten years. Particulate matter (PM) in air has been increasing steadily in the last decade, and measurements and chemical analysis found that the main contribution is combustion of wood fuel in household stoves. For instance, data was clear in attributing major air pollution to wood stove emissions in the city of Temuco, where 93% of the $PM_{2.5}$ fraction originated from firewood burning [1].

Firewood is extensively used for heating due to its low price compared to other fuels and the cold climate in the region, which extends the need for heating between six to eight months in the year. When making a comparative analysis of fuel prices for consumers for the year 2013, the cost for obtaining 1 GigaJoule relative to firewood price is, 3.6 for diesel, 5.2 for gas and 6.6 for electricity. According to these price ratios, the only accessible fuel for medium and low income households is wood fuel (INFOR, 2012).

Despite the lower price of firewood, in a study conducted in the winter of 2007 and summer of 2008 for the determination of baseline energy consumption for heating and indoor temperature in households it was found that the average heating time per day for households varies between 7 and 14 hours in the cities of south-central Chile. As for indoor temperature in households, the average air temperature was between 14.3°C and 16.5°C [2]. Hence, it can be seen that the temperature conditions of households are under comfort levels most of the time in winter days, what is probably more critical in the low-income population. Comfort temperature is assumed between 18°C and 19°C [3].

At present, two government programs promote thermal efficiency to control contamination: 1) subsidies for replacing old stoves with new models; and 2) subsidies for thermal refurbishment of dwellings for low-income sectors. In 1) a program for replacing old stoves and steel cook stoves used as heaters intended to incorporate new models which improve combustion due to secondary burners. In 2), thermal improvement of houses for the lowest income sector intends to refurbish dwellings to achieve a minimum thermal efficiency as stated in the Chilean Norm from 2007. In previous works, a very large potential for reducing firewood consumption through improved dwellings' efficiency was found [4-5].

The aim of the present work is to identify major causes of air pollution and discuss possible reasons explaining the failure of current policies to reduce hazardous emissions. Once identified and their potential for improvement assessed quantitatively, the cost of the measures to reduce air pollution will be used to perform a cost-benefit analysis including their health consequences. Based on the observation of households' mechanisms to ensure the satisfaction of heating demands, and given the current low thermal efficiency, we argue that the current programs

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have very limited potential for reducing air pollution. With this information, policy makers can focus on measures that could have greater impact for reducing wood fuel consumption and thereby toxic emissions.

## II. Methods

Data from a survey of 2025 households in Valdivia were used for the study. The survey was performed during 2011 by Certificación e Investigación de la Vivienda Austral (CIVA), Universidad Austral de Chile. Dwellings in the urban area built before the enactment of the 2007 building codes were considered. In a first stage of the project the most typical typologies were identified [6], and in the second stage a random selection of one-family dwellings of the most common typologies located throughout the city were surveyed [7]. The survey included 42 questions, of which 12 were considered for the present work, related to: house value; information on fuels used for heating and amount yearly consumed; types of stoves and age; air-mode of operation of combustion stoves; period in which firewood is acquired; whether certified or informal commercialized firewood is preferred, and amount; house thermal quality; and level of consumer awareness on topics like wood moisture and subsidy options. Since income levels were not included in the survey, we assumed here that the house value is an indication of income, whenever needed for the analysis. Due to the house-value range criteria, the sample is associated with low to middle income sectors.

Income levels were identified as C2, C3, D and E and represent the typical socio-economical classification according to income, place of residence and consumer habits. C2 corresponds to the highest income group and E to the lowest. There are also higher income groups (ABC1) that were not included in the analysis because they are not represented in the survey, and account for only 6% of the population in Valdivia.

Levels of energy poverty for Valdivia were studied, which in this case is directly related to the high consumption of firewood by households. The definition of energy poverty first appeared in England at the beginning of the 1990s as the inability of a household to obtain an adequate amount of energy services with 10% of their income. When energy for heating or cooling is included, the amount of energy to maintain an indoor temperature between 18ºC and 21ºC must be considered, with heating being available for 9 h on weekdays and 16 h at weekends. Households in fuel poverty do not meet this thermal standard and it has been found to be associated with excess winter mortality and morbidity [8].

Fuel poverty due to high levels of energy consumption was studied for the 5 income groups. Energy expenditure was Official data for income levels, gas and electricity consumption were used, and the consumption of firewood assess from the survey of 2025 households in Valdivia, adjusted to ensure an indoor temperature of 18ºC to provide minimum comfort level.

The costs and emissions reduction of thermal improvements for dwellings were studied for four different levels of efficiency: (1) the base house as it is but replacing existing fuel wood stoves by low-emissions fuel wood new models; (2) house retrofit complying with the 2007 Norm (NT2007); (3) the 2007 norm improved with double-glazed windows, sealing of doors and active ventilation systems (NT2007 I); and (4) an energy efficient option complying with European standards (EE). Options 2, 3 and 4 also include the replacement of the heating devices and cooking stoves for new models. A retrofit cost per $m^2$ was obtained for the different levels of efficiency and different typologies of walls and roofs.

Technical aspects and costs for different retrofit proposals where studied and technical solutions where developed with construction materials regularly found in the market, and requiring simple labor. All the retrofit proposals where designed to be performed in inhabited dwellings and the utility for the construction firms that perform retrofits was calculated assuming a large-scale intervention.

We have calculated the net present value (NPV) for private (household) spending on refurbish dwellings, stoves, firewood and healthcare. Different income levels were considered as explained before, and the sample of houses surveyed in Valdivia analyzed. NPV is defined as the sum of the net cash flow for each year divided by the discount factor for the period of years considered (http://www.financeformulas.net/Net_Present_Value.html ). In the present case the value at time zero is negative as it represents the spending in improvements. The interest rate used was 5.18%, which is the past-10-year average for no-risk savings published by the Central Bank of Chile. The four options of efficiency improvements were considered as defined in previous sections. Private cash out-flows include spending in retrofit, and cash in-flows are savings in healthcare and in purchase of fuel wood.

The modelling of the energy demand for the different retrofit levels was performed according to ASHRAE methodology with degree-days method for the heating requirements. Official climatic data from Dirección Metereológica de Chile [9] averaged over the period 1971-2000 was used. Since the official station is in Pichoy Airport, 30 km north from Valdivia, we adjusted average temperatures by using available official data for Valdivia from 1994 to 2002 [9]. Our calculations where performed for an indoor temperature of 18ºC, as internationally recommended [3].

To calculate de emissions reduction for the stove replacement the current stove was considered with emissions of 13gPM/kg of firewood burnt and an efficient new stove with 6.5 gPM/kg firewood. The values for the emissions were obtained from experimental studies done in New Zealand with similar fuel wood stoves [10-11] and were explained in a recent article [5].

Operation with air inlet choked is a frequently used mode (68% according to survey Ref. 7). Emissions in choking mode vary according to users´ behavior and there is no precise data about the air inlet or testing for this option. As a reference of the magnitude in variations we have the study of Jordan and Seen [12] in Australia that compared very low emissions for a modern stove with older equipment. These authors found that the modern stove have indeed low emissions (2.6 gPM/kg) when the air inlet is open, but produces 35 gPM/kg with air inlet closed, which are even larger emissions than older stoves in the same choking mode (33 gPM/kg), while these older models with air inlet open showed emissions of 13.5 gPM/kg. This large increase of emissions with air inlet closed was also measured in Chilean-made stoves tested in Switzerland [13]. It is relevant to note that when operating with the air inlet choked, modern and older stoves arise to similar emissions, blurring the advantages that new modern equipment could certainly introduce. This is due to low temperature in the combustion chamber when lacking proper air inlet, and thus secondary combustion, which is the advantage in the design of modern stoves, does not work properly. Choking air inlet is a practice done by the large majority in Chile to let fuel burnt slowly and last longer; however, the practice dramatically increases emissions.

In order to include possible (and very likely in the present case study) rebound effect, we have estimated income-dependent current indoor temperatures. According to previous works, indoor winter temperatures in social housing average 14.5ºC [2]. Based on house typologies, we have assumed 15ºC as for present housing in incomes E and 18ºC present indoor temperatures for incomes C2, the highest considered here, which is reasonable due to housing quality and fuel wood consumed. For intermediate incomes, D and C3, we have assumed 16ºC and 17ºC winter average. The difference in firewood consumption by rebound effect was thus obtained by comparing the heating degree-days (from meteorological data averaged over 30 years) needed with the present winter temperatures and with a desirable level of 18ºC for all income groups.

As mentioned, we have considered three levels of efficiency improvements; however, for each there are also options of two different stove emissions (the present ones and the best low emissions possible). Rebound effect was considered for all cases. To assess the lowering of firewood consumed due to better new stoves, we have used data from the Ministry of New Zealand that experimentally studied "real-life" efficiency of commercial stoves [14]. The average efficiency for current stove is 61.4%, 51% for cooking stoves and 66.7% for new ones. It is important to note that, due to different proportion of older heating stoves and fuel wood cooking stoves, the various income groups experience different efficiency improvements when replacing stoves. The range is between 8% and 20% reductions, from C2 to E, respectively.

To study the increase in emissions by air choking, even allowed in new stoves, we have analyzed the effectiveness in PM-saved emissions for the sample in Valdivia assuming different scenarios of choking. PM saved per cost unit and the effectiveness were compared between retrofitted houses at levels NT2007, NT2007 improved and EE provided with new and old stoves, and for houses without retrofit but new stoves having choking in their operation achieving one-half and one-quarter the reduction in emissions when changing stoves.

To assess the relationship between the costs of thermal improvements and stove replacement and the reduction in PM emissions we have defined effectiveness, as the cost in Chilean pesos ($cl) per kg of PM saved annually.

## III. RESULTS AND ANALYSIS

### A. Fuel poverty

In Valdivia, 95% of households use fuel wood for heating [6-7], so this option was considered in all cases. Income groups D and E spend in energy were 15% and 31% of their total household income, respectively; and thus they are classified as fuel poor. These two groups account for 52% of households. Group C3, accounting for 27% of households, spent in energy 9.8% of their income, and then they are at the boundary level of fuel poverty. Incomes higher than C2 were not at risk, being only 21% of households. It is to note that relative to house size and to income, lower income groups have much higher firewood consumption than higher incomes. This is due to lower house quality and lack of thermal insulation. Hence, government programs prioritize lower incomes to access subsidies; however, the number of subsidies per year is small compared to the need.

### B. Cost Analysis

Figure 1 shows the result of the net present value (NPV) for household spending. The graph reflects a play between private spending in retrofits (moderated by subsidies), firewood costs and health insurance. The option that changes only stoves but does not improve the house envelope efficiency has negative slope due to the fact that more firewood than at present is needed to achieve the comfort condition of 18ºC [3] (rebound effect). Emissions of PM cause health problems and costs. NPV for private spending is very little sensitive to PM emissions, because most households in the sample rely on public healthcare. However, NPV for private spending is very sensitive to fuel wood consumed, and it demonstrates that option 1) that changes only stoves is not sustainable for households, more so in view of the large fuel poverty percentage discussed in the previous section.

After two years, all retrofit options showed better NPV than option 1), and after six years, the highest efficiency option EE showed the best NPV results. Not shown in Figure 1, the EE option has also the less sensitive response to air choking practices. This is due to large reductions in space heating needs when dwellings are provided with high efficiency thermal envelopes.

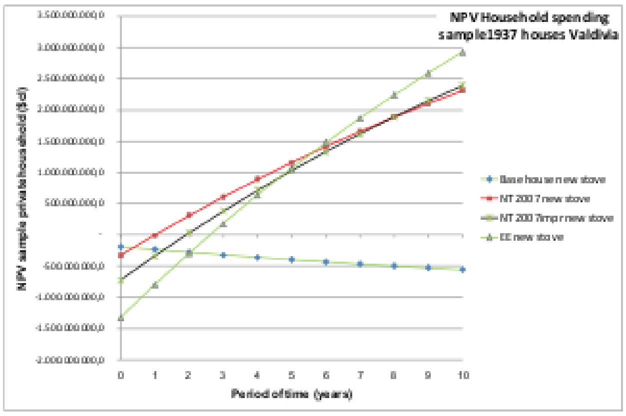


Figure 1. Net present value (NPV) of private household spending to improve 1937 houses in Valdivia

In Figure 2 we have plotted the effectiveness cost per kg of PM saved including the total cost private and public, in which we have included public spending in subsidies for retrofits and stoves and the cost of health care in public hospitals for PM-related diseases. (For simplicity option 3, NT2007I, is not depicted in Figure 2 because the results lay between EE and NT2007).

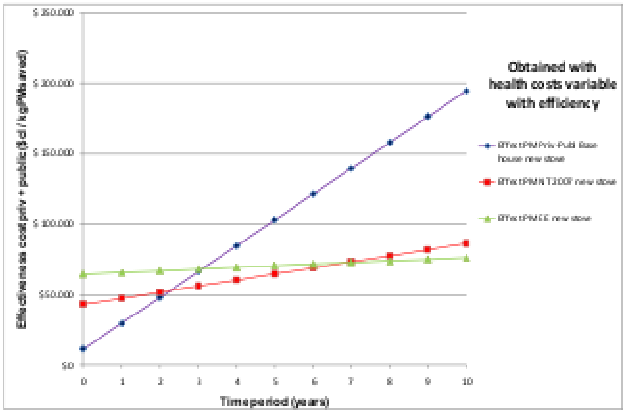


Figure 2. Total private and public effectiveness cost of each kg of PM emissions saved on the sample of 1937 houses studied in Valdivia.

The intersection of the various graphs in Figure 2 is most interesting. Due to higher costs needed for retrofits NT2007 and EE at the starting date, the option for replacing only stoves has lower initial effectiveness cost; however, beyond 2 and 3 years lower fuel wood consumption in retrofitted NT2007 and EE houses leads to lower effectiveness costs, respectively. After 7 years we obtained that the option of EE is most effective, followed by NT 2007.

## IV. POLICY DISCUSSION

House retrofitting, in spite of having by far the highest potential for reducing firewood consumption, improving air quality, improving indoor comfort, and slow forest degradation, is not yet recognized as a priority. According to the study conducted here, the two current main strategies will have limited potential for improving air quality: i) acceptance of certificated firewood is very low; and ii) stove replacement has low impact if wood-heaters with an option of air-choking are still provided. Further acknowledgement on households' realities and further public-private interaction could speed the process needed to combine successfully the three strategies studied.

Given the air pollution emergency that is occurring in all regions of south-central Chile, and the fact that the measures so far could neither reduce air pollution nor create incentives to massively improve thermal quality, we propose here a set of improvements for existing policies based on the above analysis:

**a)** Establish an agenda on priority tasks and involve universities to create national and regional laboratories for research on equipment and techniques, and design a method to measure the real level of moisture in firewood currently in the market. It is urgent to have reliable empirical data on users' practices regarding firewood, equipment, houses, and social receptiveness of proposed changes.

**b)** Implement continuing education and assistance programs in every city. The creation of technical offices for every city sector could assist and train neighbors, and coordinate requirements and suggestions. This is a way to encourage social participation in the process of improving energy efficiency and communitarian and associative initiatives in neighborhoods. Social sectors able to afford improvements could be also encouraged by the continuing assistance and education initiative.

**c)** The emphasis on policy should shift from firewood certification and wood-stove quality to thermal refurbishments, which has the largest potential for lowering air pollution by dramatically reducing heating needs. In addition, improving sealing by implementing vapor barriers should be acknowledge as an effective mean to both reduce consumption of wood fuel and to avoid indoors pollution by incoming outdoor smoke.

**d)** It is urgent to investigate the effects of air-choked equipment on PM emissions and work on it together with industry and commerce. This will lower chimney smoke significantly but, given the low thermal efficiency of current households, proper air inlet would increase wood-fuel consumption. Besides, heaters are located in one room of the house, so even with a replacement for a better technology, indoor temperatures and associated health problems will not improve considerably if the house does not have proper thermal insulation. Therefore changes towards better stoves and house retrofits cannot be separate initiatives, along with changing in practices on the use of stoves. A further step would be to ban devices that allow complete air choking.

**e)** The premises and goals of the wood certification program should be critically revisited. Feasible future goals may merge with a more practical and simple starting strategy focusing in moisture and quality of firewood.

**f)** There is no systematic measurement of wood moisture. It is urgent to help both householders and the informal firewood market to regularly monitor moisture and achieve proper moisture content. This will also help households to improve their current practice on firewood purchase.

**g)** The current thermal efficiency subsidy for low incomes should include those that already have been beneficiaries of non-thermal house improvements; and should be extended to all social vulnerable sectors disregarding social housing plans.

**h)** The limitations on income levels to be eligible for the thermal insulation subsidy should be more lenient so as to include assistance of mid-level income social sectors. It is more likely for medium-income sectors to invest in thermal refurbishment, since low-income sectors are not able to afford it and high-income sectors have less incentive to do so.

**i)** Monitoring and verification protocols should be implemented so results can be verified, not only the number of subsidies have to increase, but also their correct execution. Surveys of households after the retrofit show improvements in condensation, mold reduction, and lifetime of materials, but other problems as infiltrations and thermal bridges were not solved with the thermal refurbishment. The same studies show that sometimes the subsidy is used for other improvements in the dwellings that are not related with the thermal performance.

**j)** Prioritize the elements of the envelope to be retrofitted: nowadays it is common to see investments with the subsidy financing double glass in dwellings that do not even have insulation in the roof. Prioritization of items in retrofits could ensure users are receiving an intervention that will be efficient in reducing their energy consumption.

**k)** In social housing the building extensions made by the owners are not considered in the subsidy; thus, only the original social house is retrofitted. If this extension is not thermally insulated, the overall effectiveness decreases considerably, in some cases even invalidating the effect of the retrofit.

**l)** Householders with no income capacity to afford replacement of old cook stoves should be provided with alternative cooking and water heating devices.

## V. CONCLUSIONS

We have investigated technical and economical aspects of the characteristics in the use of fuel wood in households of south-central Chile. High consumption of firewood was found, correlated with low efficiency in the envelope of buildings and very high particulate matter (PM) emissions.

Different techniques and materials to retrofit existing houses to comply with current regulations and to achieve even better standards were studied. It was found that retrofits have high potential to lower fuel consumption and thus reduce air pollution.

There are presently government programs subsidizing retrofits and stove replacement. We have thus studied different options for stoves and considered emissions as measured in real-life operation, which differ from ideal laboratory measurements. In Chile, wood stoves in the market have the possibility to choke the air inlet. This mode is much used because wood can burn for longer time; however this practice increases PM emissions dramatically due to bad combustion.

In the economical analysis we have consider the cost of retrofits and the savings on firewood in the operation of retrofitted houses with new stoves. The percentage of improvements cost that the subsidies cover depends on income level, as houses in higher incomes are larger and require more spending in retrofit. Technical solutions and economical implications are income sensitive and care was taken to consider the differences.

We have calculated the total cost for private and public sectors, which include the initial investment and the yearly spent in fuel wood and healthcare. From private households' point of view, the options with retrofit led to much lower cost as the savings in fuel wood spent are larger, and subsidies reduce the cost of retrofits. From the public sector, the savings are in healthcare services and the main investment is in the subsidies, thus the option replacing only stoves appears as having lowest cost for the public sector. We have calculated the net present value (NPV) of the various efficiency options throughout a 10-year time period. For private households, the option that improves efficiency with new stoves but keeps the house without retrofit led to a decreasing NPV, resulting in more fuel poverty and thus unsustainable. All retrofitting options increase NPV. We have also calculated an effectiveness to save PM emissions (units $cl/kgPM-saved). For the sample in Valdivia, and considering all total private and public cost, between the second and third year the retrofit options have better effectiveness than changing only stoves, and after the sixth year the EE option has the best effectiveness of all, i.e., the cost is smallest for each kg of PM saved.

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**REFERENCES**

[1] Cereceda-Balic, F., Fadic, X., Llanos, A.L., Guevara, J.L., Vidal, V., Díaz-Robles, L.A., Schiappacasse, N., Etcharren, P. Obtaining PAHs Concentration Ratios and Molecular Markers for Residential Wood Combustion: Temuco, a Case Study. Journal of the Air &Waste Management Association vol. 62, 44-51, 2012.

[2] Bustamante, W., Cepeda, R., Martínez, P., Santa María, H. Eficiencia energética en la vivienda social, un desafío posible, en: Camino al Bicentenario, Propuestas para Chile, Santiago, pp. 253-282, 2009.

[3] WHO Air Quality Guidelines. World Health Organization, p. 278-279, 2005

[4] A. Schueftan, A. González, "Reduction of firewood consumption by households in south-central Chile associated with energy efficiency programs". Energy Policy vol. 63, pp. 823-833, 2013.

[5] A. Schueftan, A. González, "Proposals to enhance thermal efficiency programs and air pollution control in south-central Chile". Energy Policy vol. 79, pp. 48-57, 2015.

[6] MMA, 2010. Ministerio de Medio Ambiente. Evaluación de la Demanda de Calefacción y Propuestas de Mejoras en la Envolvente Térmica en Viviendas de la Ciudad de Valdivia. Centro de Investigación de la Vivienda Austral, Universidad Austral de Chile, Valdivia. Accessed June 2014. http://www.combustiblessolidosag.cl/index.php/descarga-documentos

[7] MMA, 2012. Ministerio de Medio Ambiente. Evaluación Técnica y Económica de Viviendas más Incidentes en Demanda Térmica en el Radio Urbano de la Ciudad de Valdivia.

[8] Howden-Chapman, P., Viggers, H., Chapman, R., O´Sullivan, H., Telfar Barnard, L., Lloyd, B. Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts. Energy Policy vol. 49, pp. 134-42, 2012.

[9] Servicio Meteorológico de Chile, www.meteochile.cl

[10] Scott, A.J. Real-life emissions from residential wood burning appliances in New Zealand. Ministry for the Environment New Zealand, 2005 http://ecan.govt.nz/publications/Reports/air-report-emissions-residential-wood-burning-appliances-nz-000805.pdf

[11] Kelly, C., Mues, S., Webley, W. Warm Homes Technical Report.Real Life Emissions Testing of Wood Burners in Tocoroa. Ministry for the Environment, New Zeland, 2007 http://www.mfe.govt.nz/publications/energy/emissions-testing-wood-burners-tokoroa-jun07/emissions-testing-wood-burners-tokoroa-jun07.pdf

[12] JORDAN, T.B.; SEEN A.J. Effect of Airflow Setting on the Organic Composition of Wood heater Emissions. Environmental Science and Technology vol.10, pp.3601-3610, 2005.

[13] CNE, 2009.ComisiónNacional de Energía. Certificación de artefactos a leña.Lic. 610-7-LE09. Informe final, Ambiente Consultores.

[14] National Wood Burner Performance Review, Phase 2. Ministry for Environment, New Zealand Gov. http://202.36.137.86/publications/air/national-wood-burner-performance-review-phase-2

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