MULTICRITERIA ANALYSIS TO SUPPORT ENVIRONMENTAL MANAGEMENT DECISION: SELECTING AN INDOOR HEATING ALTERNATIVES AT THE SOUTH OF CHILE

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ABSTRACT

Many people around the world uses fossil fuels and other forms of biomass as a source of energy for cooking or heating purposes. These fuels generate high levels of indoor pollutants, which can be extremely deleterious to the health of the exposure persons. This problem is relevant if we consider that people spend about 70-90% indoors spaces, and particularly important to susceptible groups like children, elderly and persons with heart and respiratory diseases and population living in geographic zones with long wintertime. **Objective:** to select the most appropriate energy low emission heating systems considering the balance between social benefits, economic cost, and health and environmental risk. **Method:** Analytic Hierarchy Process (AHP) decision-making method was used. **Results**: This analysis provided a prioritized ranking defining to electricity (oil-electric system) as the most appropriate alternative, which could be explained mainly by the high degree of "safety" that these systems have; being weighted with close to 50% total importance of "social benefits", even though the low environmental risk was also a good criteria and the cost was negative for this heating system. The “gas” and “electricity” options were very similar concerning quality and quantity of social benefits delivered. **Conclusion:** This methodology can support the process of decision-making considering qualitative and quantitative algorithms in an integrated manner, thus specifying the validity of the decisions in environmental management.

Keywords: Indoor heating systems, AHP, Benefits-Costs-Risks analysis

1.- Introduction

According to World Health Organization half of the world’s population uses fossil fuels and other forms of biomass as a source of energy, such as fuelwood, cultivation residues and manure for cooking or heating purposes. These fuels are often used in poorly ventilated areas, generating high levels of indoor pollutants[1]. In the south of Chile households use wood as a primary heating fuel, while other households use wood stoves and fireplaces as supplementary heating sources [2]. Regardless of the benefits and comfort that can deliver a wood stove, keep in mind that wood is a major source of air pollutant emissions, impacting the environment and public health. The choice of an efficient heating system in terms of quality and safety means considering not only the economics factors, but a number of other qualitative elements that have to do with the preference of people, time and place. The present study aims was to use multicriteria analysis to support the decision-making to select and indoor heating alternatives at the south of Chile, considering the most appropriate energy low emission pollutant heating systems by considering the balance between social benefits, economic cost, and health and environmental risk. To assure the consideration of different factors involved in the decision, the Analytic Hierarchy Process (AHP) decision-making method was used. This method allows the organization of data, thoughts, and intuitions in a logical, hierarchical structure. This methodology has been used in different areas where decision-making is necessary [3, 4].

2.- Literature Review

In Chile, indoor air pollution studies in different southern cities have shown high concentrations of air pollutants for PM10 and PM 2.5, PAHs and CO, surpassing frequently Chilean standards for air quality. One of the main sources of indoor emission is the use of biomass fuel (especially wood) {Moriske, 1996 #145;WHO, 2010 #381}. The main pollutant emitted are particulate matter (PM10; PM2.5), ozone (O3), volatile organic compounds (COVS), heavy metals and others (asbestos, radioactive products and polycyclic aromatic hydrocarbons), many of which have been classified as carcinogenic by the [1]. According to World Health Organization half of the world's population uses fossil fuels and other forms of biomass as a source of energy, such as fuelwood, cultivation residues and manure for cooking or heating purposes. These fuels are often used in poorly ventilated areas, generating high levels of indoor pollutants (WHO, 2010). The main pollutant emitted are particulate matter (PM10; PM2.5), ozone (O3), volatile organic compounds (COVS), heavy metals and others (asbestos, radioactive products and polycyclic aromatic hydrocarbons), many of which have been classified as carcinogenic by the (WHO, 2010; Spengler, 1985). The health effects vary, depending the characteristics of exposure: exposition time and dose, exposition route and the type of chemical pollutant. The most studied pollutants producing health effects are: sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC). This problem is relevant if we consider that people spend about 70-90% of their time indoors, and particularly important to susceptible groups like children, elderly and persons with heart and respiratory diseases [5].

3.- Objective

To present a hierarchical plan that considers most of the possible judgment elements, ie, qualitative and quantitative factors such as, social benefits, economic cost and health and environment risk, respectively to support the decision-making to select an appropriate heating system alternative in the south of Chile.

4.- Methodology

The study of the problem was structured into the following five stages:

Stage 1: Definition of the Problem:

Definition of the problem through the following general objective, criteria and sub-criteria, and definition of alternatives source of energy for heating systems planned to be evaluated.

a) General Objective: Selecting a better energy alternative for indoor heating systems that generates better social benefits while considering cost, environmental and health risks, respectively.
b) Criteria and Sub-criteria of Decision.
    i. Cost (Infrastructure Cost (IC) and Operation Cost (OC).
    ii. Social Benefit
        1. Comfort
        2. Aesthetics
        3. Heat: Surface (m^2) coverage and homogeneity of the heat.
        4. Security: Lower level of accidental injury.

iii. Environmental and Health Risk: include effects on people's health and natural resources.

c) Alternatives.

Gas: natural, catalytic, liquefied. Kerosene. Fuelwood: closed and open systems. Electricity: Oil-electric system. Coal

Stage 2: Definition of Judgments.

Definition of judgments that reflect qualitative and quantitative parameters, such as: the scientific knowledge, social ideas, feelings and emotions, in respect to the outlined problem. This is accomplished through the expert's participation in the different areas that encompass the problems, and where possible, representatives of the community associated with the problem.

The participants make decisions through the review of available data gathered by 1) the authors of this work who represent different areas of expertise regarding the topic (engineering and environmental impact assessment, epidemiology, public health, biochemistry and environmental toxicology), and 2) the people from the community, as users of the studied systems.

Stage 3: Representation of the Judgments (Hierarchy and Ranking).

The representation of judgments was through the analysis and synthesis in an integrated information system to obtain the ranking of alternatives in terms of social benefits, health and environmental risk and monetary cost. The problem was structured into two hierarchies (**Figures 1 and 2**) where the AHP creates a pairwise comparison matrix for each alternative on each criterion and analysis (importance/preference), plus a classic cost analysis model to evaluate the monetary costs of inversion and operation of the different alternatives. This provides a structured approach for determining the scores and weights in a multi-criteria scoring model. This process is repeated to obtain scores for each criterion as well as the criterion weights.

Stage 4: Cost Analysis. The assessment of costs was through the monetary value of the alternatives, as the only economic criterion for measure and ranking the alternatives (**Table 1**).

Stage 5: Integrated Model, obtaining Remaining Scores and Weights. The final ranking is assessing as follows:

$$\textbf{Total Ranking:} \quad \frac{\textbf{Social Benefits}}{\textbf{Economic Costs x Risks*}}$$

* Health and Environmental Risk

Notice: *When assessing the total ranking (i.e. applying the formula above), is important to check the commensurability of the elements in the formula. That is, one unit of social benefits must be as relevant as one unit of Economic Costs and one unit of Risks. ("As relevant", means same order of magnitude).*

5.- Data/Model Analysis

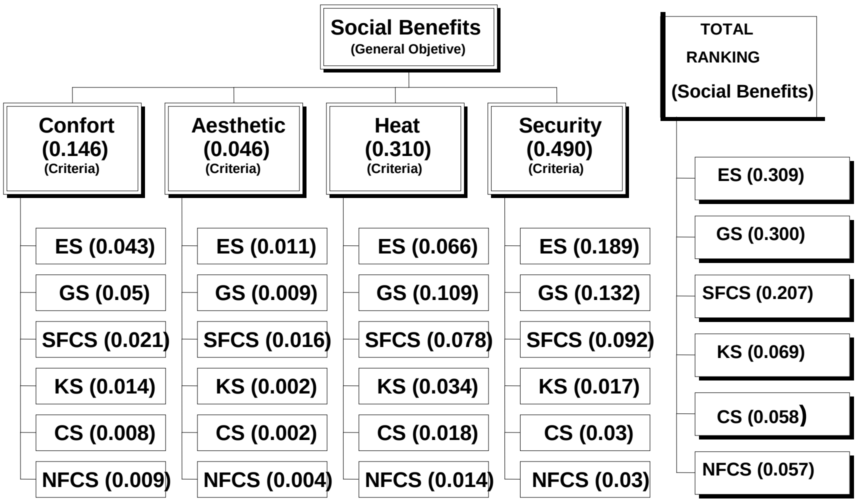
Table 1: Cost analysis: VCNC of the energy alternatives for indoor heating systems *

Alternatives	Cost of heating systems (US$)	Average cost of kind of energy(US$)	Energy cost by hour(US$)	VCNC at third year (US$)
GS	**116.67**	**0.51**	**0.15**	**383.19**
KS	**78.33**	**0.23**	**0.07**	**306.99**
SFCS	**416.67**	**0.13**	**0.17**	**696.29**
NFCS	**200.00**	**0.13**	**0.05**	**654.39**
ES	**101.67**	**0.07**	**0.20**	**490.52**
CS	**8.33**	**0.10**	**0.16**	**270.48**

VCNC: Value Current Net Cost; GS: Gas System; KS: Kerosene System; SFCS: Slow Fuelwood Combustion System; NFCS: Normal Fuelwood Combustion System; ES: Electric System; CS: Coal System.

*This analysis has not considered depreciation and technical revision costs

Figure 1. Analytic Hierarchy Model for the Goal: Social Benefits Assessment
Alternatives: ES = Electric System; GS = Gas System; SFCS = Slow Fuelwood Combustion System; KS = Kerosene System; NFCS = Normal Fuelwood Combustion System; CS = Coal System.



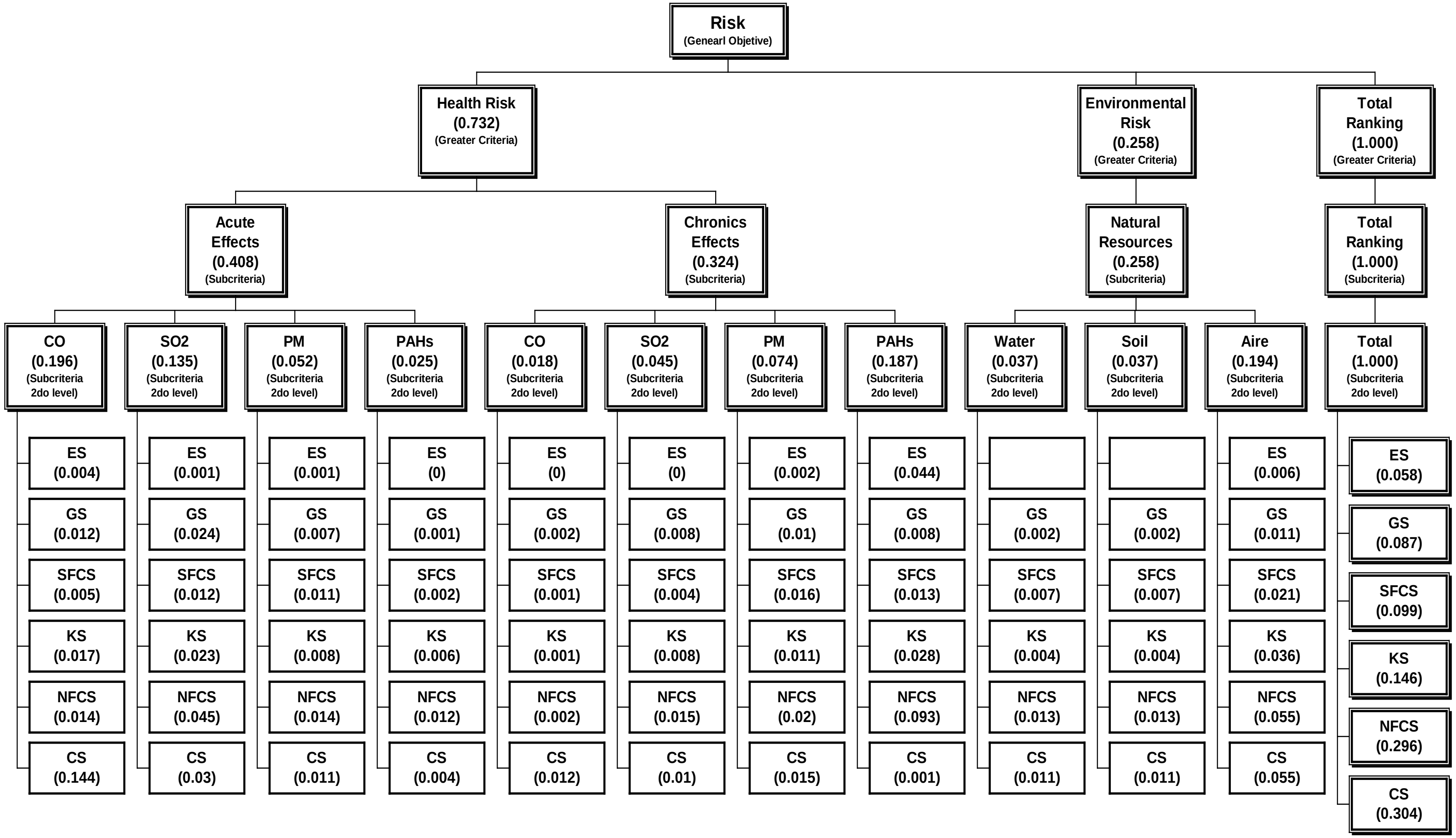


Figure 2: Analytic Hierarchy Model for the Goal: Environment and Health Risk Assessment.

Alternatives: ES = Electric System; GS = Gas System; SFCS = Slow Fuelwood Combustion System; KS = Kerosene System; NFCS = Normal Fuelwood Combustion System; CS = Coal System. CO: Carbon Monoxide; SO_2: Sulfur Dioxide; PM_{10}: Particulate Matter 10 μm Diameter; PAHs: Polycyclic Aromatic Hydrocarbons.

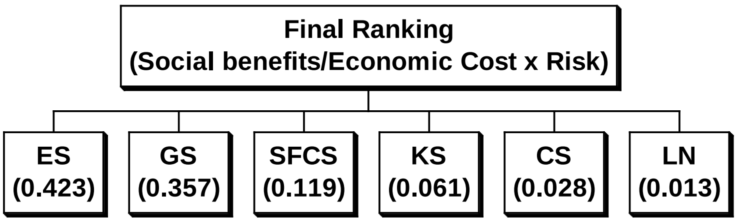


Figure 3: Final weightings for energy alternatives for indoor heating systems according to the decision criteria defined. Alternatives: GS: Gas System; KS: Kerosene System; SFCS: Slow Fuelwood Combustion System; NFCS: Normal Fuelwood Combustion System; ES: Electric System; CS: Coal System

6.- Limitations

Even though this study has been carried out using a rigorous model considered appropriate for this type of analysis, it is also conveniently flexible, allowing inclusion of differing opinions, variation of costs, the state of technology or additional data presented by experts. This information could be incorporated at any time, not to question or rebut the presented analysis, but rather to enrich the problem model. This flexibility comes from the ability of the methodology to allow the incorporation of additional information into the database, automatically reconsidering the weight and scores of the alternatives and the decision criteria.

7.- Conclusions

1. This analysis provided a prioritized ranking of the alternatives in each hierarchy studied, defining electricity (oil-electric system) as the most appropriate alternative, which could be explained mainly by the high degree of "safety" that these systems deliver; being weighted with close to 50% total importance of "social benefits" delivered by the alternatives, even though the low environmental risk was also a good criteria and the cost was negative for this heating system.

2. The “gas” and “electricity” options were very similar concerning quality and quantity of social benefits delivered.

3. Applying sensitive analysis on the Costs model, for any (real) scenario of cost the worst alternatives were coal and fuelwood (with normal combustion).

8.- Key Reference

1. WHO: **Guidelines for indoor air quality: selected pollutants.** . In. Edited by Europe. Rof; 2010.
2. Diaz-Robles LA, Fu JS, Vergara-Fernandez A, Etcharren P, Schiappacasse LN, Reed GD, Silva MP: **Health risks caused by short term exposure to ultrafine particles generated by residential wood combustion: A case study of Temuco, Chile**. *Environ Int* 2014, **66**:174-181.
3. Maruthur NM, Joy S, Dolan J, Segal JB, Shihab HM, Singh S: **Systematic assessment of benefits and risks: study protocol for a multi-criteria decision analysis using the Analytic Hierarchy Process for comparative effectiveness research**. *F1000Res* 2013, **2**:160.
4. Vaidya O, Kumar S: **Analytic hierarchy process: An overview of applications**. *European Journal of Operational Research* 2006, **169**:1-29.
5. Bruce N, Perez-Padilla R, Albalak R: **Indoor air pollution in developing countries: a major environmental and public health challenge**. *Bull World Health Organ* 2000, **78**(9):1078-1092.