Impact of Geographic Location on Energy and Fossil Fuel Demand as well as Climate Change in the Life Cycle of Tourist Accommodation Establishments in Chile

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Abstract: Tourism is a rapid-growth industry on a global scale that includes transportation, excursions and tourist accommodation establishments. In turn, these activities have an impact on energy demand, to achieve thermal comfort, in addition to environmental impacts such as climate change and fossil fuel demand. These impacts vary depending on energy sources, water and solid waste treatment, and availability of resources, among other factors. The objective of this study was to evaluate the influence of geographic location on energy demand to attain thermal comfort and to assess the environmental impacts of tourist accommodation establishments in Chile. DesignBuilder software was used to evaluate energy demand for thermal comfort in the establishments, by measuring thermal transmittance through roofing, walls, flooring, doors and windows of the establishments, following the MINVU (NTM 11) technical standard. Moreover, different building materials were modelled for each establishment, depending on their geographic location. Climate change and fossil fuel demand were analysed using a life cycle assessment in accordance with ISO 14044, using a functional unit of 1 guest night. Inventory and impact assessment data were modelled using SimaPro software, thereby obtaining different energy demands based on the establishment’s geographic location. Northern establishments were shown to have greater impact on climate change and fossil fuel demand with coal being most relied upon in this respect and CO₂ the substance chiefly emitted in environmental impact on climate change (a carbon footprint of 15.68 kg CO₂ equals one guest night). This study determines that geographic location impacts energy demand, climate change and fossil fuel demand.

1. Introduction

Tourism is one of the most important [1] and rapidly growing industries in the world [2], currently considered a key activity for development due mainly to its direct social, cultural, educational and economic effects on a population [3].

The World Travel and Tourism Council [4], reports that tourism accounts for 9.8% of GDP and 284 million jobs globally. In addition to economic development, tourism consumes between 200 and 300 L of water [5] per tourist day and generates from 1 to 12 kg of solid waste [1] per tourist day. This consumption and generation, among other issues such as energy consumption and wastewater generation [6], lead tourism emissions to be considered significant, due to their negative environmental impact. Among the most substantial environmental impacts are noise, air and water pollution, climate change [7], soil pollution [1] and loss of biodiversity [8].

With respect to climate change, greenhouse gas (GHG) emissions caused by tourism contribute approximately 5% to global carbon dioxide (CO₂) emissions [6]. According to [8], tourism GHG are mainly generated by air travel (40%) and tourist accommodation establishments (21%). Given the
environmental consequences of the tourism industry, more priority must be given to mitigating its environmental impact.

In 2016, visiting Chile 5,640,700 foreign tourists [9], representing a 21% increase over those of the previous year while there are a total of 867,196 tourist accommodation establishments [10] to accommodate these tourists.

According to [11], many tourists focus on environmental wellbeing, favouring establishments with minimal environmental impact. The environmental impact of tourist establishments varies depending on size, type of lodging, type of building, heating, ventilation and air conditioning (HVAC) technology, electrical systems and occupation rate ([12], [13], [3], [1]). These elements affect fuel, electricity and water consumption, wastewater and solid waste generation, environmental emissions and other green considerations that can have diverse environmental impacts.

The technologies of various services and supplies required by tourist accommodation establishments in Chile differ with respect to their geographic location. Among these are electricity supply, sanitation services, food availability, solid waste treatment and energy resources, for which climate also impacts the energy required to achieve thermal comfort in the establishments, due to climate diversity in Chile from north to south [14]. Thus, tourist accommodation dynamics are affected and therefore its supply. Depending on [15], geographic location is a key element in the environmental impact of tourist accommodation establishments.

A methodology used to assess the environmental impact of activities, products and services, such as those of tourist accommodation establishments, is to consider Life Cycle Assessment (LCA) [16]. As in [3], quantifying the environmental impact of tourism through the application of LCA has gained acceptance within the scientific community. Thus, LCAs have been applied to tourism packages, hotel construction and to calculate global warming, among other options. In Chile, the LCA methodology has been used for several authors ([17], [18], [19]), therefore there is useful base information to carry out LCA models in Chile.

For the above-mentioned reasons vis-a-vis tourism, its accommodation, their impact and factors influencing their impact, the object of this study was to assess the effect of geographic location on energy demand for thermal comfort and to analyse the environmental impact of tourist accommodation establishments in Chile.

2. Methodology
The LCA methodology established by the ISO 14040 (2006a) and ISO 14044 (2006b) standards was used to analyse the environmental impact of tourist accommodation in various geographic locations in Chile. The LCA consisted of four stages (Figure 1): goal definition and scoping, inventory analysis, impact assessment and interpretation ([20], [21]).

![Figure 1. Life cycle assessment stage [20]](image)
2.1. Goal and scope
The goal of this study was to evaluate the influence of geographic location on energy demand required for thermal comfort as well as to analyse the environmental impact of tourist accommodation establishments in Chile, for which four establishments located in Arica, Olmué, Coyhaique and Punta Arenas were assessed.

Given that the purpose of the establishments is to provide a guest with tourist accommodation, the functional unit (FU) used in this study was one guest night in each establishment. This unit is compatible with the functional units presented by other authors in LCA studies of tourist lodging ([3], [22], [23]).

The product system is shown in Figure 2. For all the establishments, electricity, water treatment, fuels, solid waste and wastewater management subsystems were considered from cradle to grave. The last of these subsystems implied an analysis from the extraction of primary materials associated with the product system to its disposal as waste. The infrastructure of the establishments and food were not included in the scoping given that they were not considered integral to the study. Additionally, regarding food, information needed could not be sourced to complete the inventory due to the fact that food varies by area and the index required for this in Chile is non-existent.

![Figure 2. System boundaries for LCA of tourist accommodation establishments](image)

2.2. Life cycle inventory
Inventory data was obtained from scientific articles, a LCA database, technical standards and the tourist accommodation establishment located in Olmué, used as the baseline for the other establishments.

The study setting was Chile (Figure 3), a country located between 17° 30’ and 56° 32’ latitude south and between 66° 30’ and 75° 40’ longitude west [24], on the southwestern coast of South America [25].

The geographic locations throughout Chile of the four tourist accommodation establishments employed in this study are indicated in Figure 3.
Figure 3. Map of Chile that presents the geographical locations of the tourist accommodation establishments used in this study.

Each of these establishments demonstrated different variables relative to its geographic location, such as climate, temperature, precipitation, heating type, ventilation and thermal area. The last of these was in accordance with the MINVU 11/2 (NTM 11/2) [26] technical standard on “Accreditation requirements and mechanisms for environmental conditioning in buildings. Part 2: hygrothermal behaviour.” The guideline divides Chile into nine areas depending on its climate characteristics, to acclimatize the establishments to its corresponding area. Table 1 displays these parameters with temperatures and precipitation from 2016.

Table 1. Climatic characteristics of tourist accommodation establishments

| Parameters               | Arica                          | Olmué                          | Coyhaique                      | Punta Arenas                   |
|--------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Weather                  | Warm desert with abundant clouds | Warm with Winter rains          | Tundra due to height / Mild rainy cold without dry season | Mild rainy cold without dry season |
| Maximum temperature      | 27.3°C                         | 23.7°C                         | 23.3°C                         | 15.7°C                         |
| Minimum temperature      | 15.3°C                         | 6.7°C                          | 0.1°C                          | -0.4°C                         |
| Average annual rainfall  | 0.3 mm                         | 392.3 mm                       | 527.9 mm                       | 221.6 mm                       |
| Heating                  | It is not required              | Electric / Firewood            | Firewood                       | Gas                            |
| Cooling                  | Electric                        | Natural                        | Natural                        | Natural                        |
| Thermal zone             | A                               | D                              | I                              | I                              |

The model for these four establishments was a surface area of 39 m² with capacity for four guests per night, as shown in the standard floor plan in Figure 4. Specific characteristics for each establishment were taken into account with respect to their geographic location.
With regard to electricity, the electric supply in each area was considered for 2016. The systems taken into account were North Grande Interconnected System (SING) for the establishment in Arica, Central Interconnected System (SIC) for Olmué, Medium Systems of Aysén for Coyhaique and Medium Systems of Magallanes for Punta Arenas. The different energy sources used in the electricity supply for each system are shown in Table 2. International (Ecoinvent) databases were adapted to Chilean reality using SimaPro software based on the different energy mixes.

**Table 2. Energy mix of Chilean electrical systems**

| Composition               | Unit | Electric system |
|---------------------------|------|-----------------|
|                           |      | SING            | SIC | Aysén | Magallanes |
| Biomass                   | %    | 4,9             | -   | -     | -          |
| Coal                      | %    | 78.5            | 31  | -     | -          |
| Coal + Petcoke            | %    | -               | 0.9 | -     | -          |
| Cogeneration              | %    | 0.7             | -   | -     | -          |
| Wind                      | %    | 1.3             | 3.7 | 5.2   | 4.6        |
| Fuel oil                  | %    | 0.5             | -   | -     | -          |
| Natural gas               | %    | 9.1             | 0.1 | -     | -          |
| Liquefied natural gas     | %    | -               | 18.9| -     | -          |
| Hydraulic reservoir       | %    | -               | 14.7| -     | -          |
| Hydraulic Past            | %    | 0.3             | 21.2| 44.1  | -          |
| Diesel oil                | %    | 5.2             | 1.4 | 50.7  | 3.1        |
| Solar                     | %    | 4.4             | 3.2 | -     | -          |
| Total                     | %    | 100             | 100 | 100   | 100        |

The electricity use of the four establishments was calculated based on a standard consumption of 13.12 kWh per guest night. This standard consumption, as mentioned above, was obtained in situ from the establishment in Olmué, based on the consumption produced by various electrical appliances and electronic devices corresponding to that of one guest over one year [27]. Using the NTM 11/2 standard,
the electricity consumed by the heating and cooling system was calculated based on the thermal comfort required for the geographic location of each establishment.

This thermal conditioning facilitated calculating the energy demands for heating in the Arica and Olmué establishments, modelled using DesignBuilder 3.4 software. This and the coefficients of performance (CoP) shown by [28] were used to calculate electricity consumption to satisfy demand. The amount of electricity for heating, cooling, electrical and electronic devices as well as total consumption are presented in Table 3.

### Table 3. Electric consumption of the tourist accommodation establishments

| Scenarios     | Unit       | Electricity consumption |
|---------------|------------|-------------------------|
|               |            | Cooling | Heating | Electrical and electronic equipment | Total |
| Arica         | kWh guest\(^{-1}\) night\(^{-1}\) | 0,95     | -       | 13,12                                  | 14,07 |
| Olmué         | kWh guest\(^{-1}\) night\(^{-1}\) | -       | 3,16    | 13,12                                  | 16,28 |
| Coyhaique     | kWh guest\(^{-1}\) night\(^{-1}\) | -       | -       | 13,12                                  | 13,12 |
| Punta Arenas  | kWh guest\(^{-1}\) night\(^{-1}\) | -       | -       | 13,12                                  | 13,12 |

The “Heat, central or small-scale” database from Ecoinvent was used for liquefied petroleum gas (LPG) and modified to reflect the reality in Chile. The estimation of LPG consumption was calculated on the basis of gas consumption data and the occupation of the establishment in one year as a baseline. Based on information attained in Olmué, consumption of 10.47 kWh per guest night was established. This figure was taken as the standard for all the tourist accommodation establishments.

Natural gas (NG) was used for heating in Punta Arenas. Ecoinvent’s “Heat, central or small-scale” database was used to model this life cycle inventory. DesignBuilder software was used to estimate the energy demand for heating the establishment, leading to consumption of 16.17 kWh from NG per guest night. This was done based on the thermal acclimatizing in the geographic location of the establishment, using the NTM 11/2 standard. The calculation was made using the same methodological criteria to determine the electricity required for heating and cooling in Arica and Olmué.

Consumption of firewood for heating was established for Olmué and Coyhaique based on the energy demand attained through modelling with DesignBuilder, to thermally acclimatize establishments following the NTM 11/2 standard. Consumption of 2.04 kWh per guest night was established for Olmué, while Coyhaique required 13.36 kWh per guest night.

Water treatment technologies available through local water companies were considered for potable water in each geographic area. In Arica, water treatment is achieved through reverse osmosis, while for Olmué, Coyhaique and Punta Arenas, conventional water treatment is employed. Water consumption was determined on the basis of annual consumption and occupation rates in Olmué for a base year. Average consumption was established at 0.3 m\(^3\) per guest night based on this information. This figure was the standard for all the establishments assessed.

For solid waste analysis, the Ecoinvent “Municipal solid waste” database was used, adapting results to suit Chilean reality, which is that solid waste is disposed of in landfill sites. Solid waste was determined by quantifying those produced in a single day by the establishment in Olmué. Based on this information, 0.4 kg per guest night was fixed as the standard for all of the tourist accommodation establishments.

Wastewater treatment technologies were considered for each geographic area of the tourist accommodation establishments. Table 4 shows the different types of technologies for water treatment at the establishments. Wastewater generation was deemed to be 0.3 m\(^3\) per guest night, maintaining a balance with potable water consumption.
Table 4. Wastewater treatment technologies used in the different scenarios

| Scenarios   | Type of technology       |
|-------------|--------------------------|
| Arica       | Submarine emissary       |
| Olmué       | Active sludge            |
| Coyhaique   | Active sludge            |
| Punta Arenas| Submarine emissary       |

2.3. Impact Assessment

The environmental impact assessment was performed using SimaPro 8 software, specifically the ReCiPe Midpoint hierarchical version (H) methodology. The impact category analysed with its corresponding category indicator was climate change (kg CO₂ eq). This was chosen on the basis of a previous study in which the same had been considered as a representative category for tourist accommodation establishments [27]. Cumulative Energy Demand methodology was also evaluated, specifically the category of fossil fuel demand (MJ), as thermal acclimatizing in the establishments was considered. This was done to analyse energy required by the establishment to meet the NTM 11/2 standard.

3. Results and discussion

Based on inventory data, the comparison in Figure 5 demonstrates the extent of impact each establishment has on climate change. According to geographic location, this figure shows that the establishment in Arica generates the greatest environmental impact on climate change, followed by the one in Coyhaique.

![Figure 5. Comparison of the environmental impact on climate change of tourist accommodation establishments](image)

The degree of impact on climate change indicates that the carbon footprint produced by the establishments, with respect to their geographic location, varies from 7.91 kg CO₂ per guest night for Punta Arenas to 15.68 kg CO₂ per guest night for Arica, shown in Figure 5. According to [6], average CO₂ emissions per guest night in a tourist accommodation establishment is 15.9 kg CO₂, taking into account heating and ventilation, indicating that the establishment closest to this average is the one located in Arica. The differences between the kg CO₂ per guest night attained and shown in [6] are due to the differences in geographic location of the study (whereas [6] focused on European countries), climates, types of solid waste and wastewater treatments, water treatment, electricity production and consumption, among other variables.

Next, Figure 6 shows the processes that contribute to climate change generation by the establishments.
The process contributing the greatest degree of climate change is the electricity supply providing the model establishments with their power. Therefore, these systems are considered the most critical factor in the impact of tourist accommodation establishments.

Regarding climate change, the electricity supply (SING) for the establishment in Arica is the factor that makes the largest contribution to climate change with 89% of its impact coming mainly from the carbon dioxide (CO₂) generated by the power grid. This CO₂ is produced as 93.3% of SING output comes from fossil fuels [29], as can be observed in Table 2. These are the fossil fuels that produce GGE, such as CO₂, which in turn fuel climate change. In Olmué, Coyhaique and Punta Arenas, electricity suppliers are the greatest contributors to their impact, with 74%, 75% and 68%, respectively. CO₂ is the substance that drives this impact and the same that mostly influences the Arica electric grid.

This heightened demand in Arica is brought on by the electricity supplier (SING), chiefly due to the coal it consumes to produce electricity, seen in Table 2, representing 78.5% of power grid production, the most common fossil fuel used by SING [29]. Thus, coal demand generates CO₂ emissions, thereby driving climate change, as seen in Figure 5. This demand is due to the fact that the geographic location of Arica requires cooling for relief from its high temperatures (Table 1), fuelling considerable energy consumption, hence higher impact due to the fossil fuels used by the electric grid in that area.

As the Arica scenario obtained the greatest impact on climate change, with 15.68 kg of CO₂ eq per guest night, a sensitivity analysis of the electricity consumption for the tourist establishment was performed (Figure 7). The analysis considered the decrease to the 75%, 50%, 25% and 0% of electricity consumption to reduce, in the latter case, natural ventilation. Figure 7 shows that the decrease in electricity consumption only affects 6% of the decrease in the carbon footprint of the tourist establishment.
Fossil fuel demand is shown in Figure 8, where Arica is seen to have the greatest need per guest night in comparison with the other areas.

The establishment in Olmué had the least fossil fuel consumption per guest night, due mainly to the diesel fuel used by their electricity supply (SIC). For the rest of the establishments, the cumulative energy demand is also a product of their electricity supplies, specifically by diesel fuel consumption in Coyhaique and natural gas consumption in Punta Arenas.

4. Conclusions
As a result of this study, climate change and fossil fuel demand were determined to be impacted by the establishments, varying in degree by their geographic location. Arica was the establishment that caused
the greatest environmental impact in climate change and fossil fuel demand. This is due chiefly to the nature of electricity supply and the energy needs for cooling to achieve thermal comfort.

The most critical factor in terms of the impact of the establishments assessed on climate change was the electricity supply.

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