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Local Air Quality Issues and Research Priorities Through the Lenses of Chilean Experts: An Ontological Analysis

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ABSTRACT

Air pollution problems can be large, complex, and ill-structured. They can vary from location to location and combine many complex components: urban expansion, increasing vehicles and industrial emissions, biomass burning, geographic and meteorological conditions, cultural aspects, and economic effects. However, the existing research, accumulated knowledge, and local research priorities are spread over many disciplines and lack a systematic mapping to help manage and develop new strategies for researchers and policy makers. Ontological analysis can be used as a tool to capture this complexity through simple natural-language descriptions and a structured terminology. We describe the development of an ontological framework for "Air Quality Management in Chile" and its application to evaluate the current state of the research. The process was based on focus groups and validated by a panel of multidisciplinary experts. We used the developed framework to highlight the topics that have been heavily emphasized, lightly emphasized, or overlooked in the Chilean research. The framework developed can help researchers, practitioners, and policy makers systematically navigate the domain and provide the opportunity to correct blind spots by enabling more informed hypotheses that deal with air quality issues at a national level. We believe that applying this same process to different countries will yield different results (due to differences in local knowledge and experience). The framework presented could be used to evaluate other important stakeholders (government, media, NGOs, etc.), which will provide a complete picture of how local societies deal with air quality issues at different levels. Additionally, local government institutions will benefit from this analysis by improving funding allocation and opening new research opportunities to improve the distribution of the local body of knowledge. *Integr Environ Assess Manag* 2020;00:1–9. © 2020 SETAC

Keywords: Air quality Chile Management Ontology PM

INTRODUCTION

Indoor and outdoor air pollution is responsible for an estimated 4.3 million deaths per year worldwide (Shiraiwa et al. 2017). It is among the 7 largest health risk factors, together with high blood pressure, tobacco smoking, diabetes, childhood undernutrition, high body mass index, and high cholesterol, and it is significantly associated with all-cause mortality, cardiopulmonary, and lung cancer mortality as well as with effects on the immune system (Shiraiwa et al. 2017; Glencross et al. 2020; Pope et al. 2020). Air pollution can have both anthropogenic and natural sources and may include a huge variety of chemical compounds, free allergens, and plant, animal, and human pathogens (Prendez et al. 2013; Underhill et al. 2015; Zuo et al. 2020). This variability is strongly related to local sources or local meteorological conditions. Air quality problems are therefore wicked problems: large, complex and ill-structured, which combine many complex components and often require iterative approaches to cover all of the potential combinations of related topics (Ramaprasad and Syn 2014a).

Urban air quality management aims to establish an effective and sound basis for maintaining acceptable levels of air pollution in a specific area to ensure that the impact on human health remains minimal (Sivertsen and Bartonova 2012; Gulia et al. 2015). Additionally, managing air quality is a crucial issue to prevent climate change from deepening (Sullivan et al. 2018). According to previous research, the most important aspects of a successful urban air quality management strategy are setting the right objectives, having a good monitoring action plan (i.e., source characterization and apportionment), forecasting and reporting systems, and control strategies (Gulia et al. 2015; Miranda et al. 2015; Represa et al. 2020). However, these strategies can vary from

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country to country and are based on the local priorities that are agreed upon to maintain an acceptable ambient air quality (Gulia et al. 2015). In this context, local air quality management plans are thought to be a representation of the distribution of power at the community level and require strong communication and cooperation between stakeholders (Longhurst et al. 1996). Local air quality management frameworks have been developed in North America and Europe through international actions and based on comprehensive research programs within a specified temporal horizon (Sivertsen and Bartonova 2012; Miranda et al. 2015). However, this has been complicated in developing countries due to the lack of good quality data, government commitment, and stakeholder participation, as well as weak policies, standards, and regulations (Gulia et al. 2015).

Urban centers in Chile have shown deteriorating air quality due to urban expansion, increasing emissions from vehicles, industrial activities, and biomass burning (Molina et al. 2017). Additionally, geographic and meteorological conditions (i.e., low temperatures and recurring inversion layers) increase the vulnerability of some areas of the country (Molina et al. 2017). However, environmental impacts are not the only side of the story, there is also a cultural side (e.g., firewood burning is associated with the warmth of homes), an economic side (e.g., firewood is the cheapest fuel available) (Reyes et al. 2015; Perez-Fargallo et al. 2018; Reyes et al. 2019; Lu 2020), and a psychological side (Lu 2020). The Chilean government has designed and implemented a large monitoring effort, which includes monitoring stations in several cities throughout the country and decontamination plans (of which 15 are active in 2020), in order to reduce the concentration of pollutants and comply with air quality regulations. However, recent studies concluded that these programs have had limited effectiveness in reducing particulate matter (PM) concentrations (Molina et al. 2017; Mardones and Cornejo 2020). Additionally, government-run monitoring stations are often situated in locations that may not reflect the representative concentrations of pollutants experienced by the general population, while focusing on a limited number of contaminants. Chilean academia has played an important role in the advancement of local knowledge in the last decade and has explored new dimensions of local air quality issues, including the evaluation of local government networks (Toro et al. 2014, 2015; Molina et al. 2017), personal monitoring (Manzano et al. 2019), biogenic compounds (Prendez et al. 2013), and their social and economic implications (Boso et al. 2018; Perez-Fargallo et al. 2018; Reyes et al. 2019). However, except for a couple of recent scientific reviews (Molina et al. 2015; Gallardo et al. 2018), there is a lack of systematization of the information produced by the stakeholders, which complicates the management and development of new strategies and research plans (Represa et al. 2020). It is well known that an integrated assessment could address the environmental, health, and economic impacts of air quality issues and their mitigation measures (Miranda et al. 2015).

Ontological analysis can be used as a tool to capture this complexity and encapsulate the logic of the analysis using natural-language descriptions and a structured terminology (Ramaprasad and Papagari 2009). Ontologies are used in information systems to standardized terminologies, map requirements, and organize them systematically (Gruber 1995; Ramaprasad and Papagari 2009). In science and technology studies, ontological approaches are expected to help researchers understand the multiplicity and degrees of alterity of relevant topics, explore their compositions and multiple solutions, and address information gaps by facilitating data centralization and integration (Mattingly et al. 2012; Woolgar and Lezaun 2013). An ontological framework is a type of cognitive map (a graphical representation of a set of ideas derived from individuals, institutions, or groups), as it is based on the analysis of the relationships between concepts rather than the concepts themselves (Axelrod 1976; Golledge 2005). It presents a complex problem (i.e., the domain) in its different parts (i.e., its dimensions), which are constructed using discrete categories developed from the statement of the problem, previous knowledge, and local context (Ramaprasad and Papagari 2009; Ramaprasad and Syn 2014a). The set of all combinations across all categories is thought to represent a complex concept. Ontological frameworks can be used to map the state-of-the-need, the state-of-the-research, and the state-of-the-policy, if the right elements are mapped into the developed framework. Assessing the gaps between these states can help public health planners, policymakers, and regulators design strategies to bridge the gaps through research and implementation. These frameworks have been used to study knowledge sharing in project management (Ramaprasad and Prakash 2009; Syn and Ramaprasad 2019), cultural heritage (Yaco and Ramaprasad 2019), health behavior (Win et al. 2019), key performance indicators for emergency departments (Nunez et al. 2018), e-health applications (Cameron et al. 2017), national health programs (Ramaprasad et al. 2016), and e-commerce applications (La Paz et al. 2015).

The objectives of this study are 1) to develop an ontological framework for air quality management and research priorities in Chile based on the experience and knowledge of local experts, and 2) to evaluate the current state of the local research using this developed framework. The built framework was based on focus groups (a scientific panel), validated by a panel of multidisciplinary experts (an expert panel), and applied to evaluate the role of academia and highlight the topics that have been heavily emphasized, lightly emphasized, or overlooked (Ramaprasad and Syn 2014b). The process to build ontological frameworks presented in this manuscript may be replicated in other countries, regions, or scientific areas with different scientific and expert panels.

METHODS

Creating and validating an ontological framework

The ontological framework was constructed following the methodology originally developed by Ramaprasad and

Mitroff (1984), Ramaprasad (1987), and Ramaprasad and Syn (2014a), as well as previous work in exposure ontology by Mattingly et al. (2012). An initial problem was defined: "Air Quality Management in Chile" (i.e., our domain). Relevant local information about the domain was then abstracted from focus groups and semistructured interviews with 5 experts from the Faculty of Science of the University of Chile (Santiago, Chile) who have or have had relevant experience teaching or doing research on air quality issues (the scientific panel). The main topic was set up by our team using related questions that guided the discussion: 1) what strategies should be followed to manage air quality issues in Chile?; 2) who should be interested in dealing with air quality issues?; 3) what are the potential impacts of air quality issues?; 4) what contaminants should we pay more attention to?; 5) how should we evaluate them?; and 6) where should we measure them? The informal interviews were conducted at lunch time (once per week for approximately 3 months, for a total of 11 interviews).

The results were organized in a first framework (i.e., including general dimensions divided in categories) that was later validated through the Delphi technique. This technique uses a series of questionnaires to develop a consensus within a group in an independent and individual way until a consensus is reached based on collective agreement. However, selecting a group of "experts" was not trivial, particularly due to the difficulties of defining what an Air Quality expert really means. Previous studies have selected a panel of experts based on personal nominations, citation, or publication metrics and other academic criteria (Cisternas et al. 2014). However, given the multidisciplinary nature of the problem, we chose to select our group of experts using a broader approach and recruiting them from different backgrounds; our selections were based on their professional interests, scientific productivity (i.e., publications in the last 10 years), and previous participation in national conferences related to air quality, so that the problem could be analyzed from different perspectives. A total of 100 national experts were initially invited to participate in the study, including junior and senior scientists from the Chilean Society of Environmental Chemistry, medical doctors that authored scientific papers on the domain, civil engineers with known interests on environmental topics, social scientists, members of the Ministry of the Environment, and environmental consultants (the expert panel). Participation in this study was anonymous, voluntary, and no economic or material compensation was offered. The panel of experts was contacted via e-mail (with a total of 3 reminders), in which the general objectives of the study were presented, along with informed consent forms, confidentiality agreements, and general instructions. After acceptance, they were presented with a series of questions in which they ranked all dimensions and categories in a scale from 1 (low relevance) to 5 (high relevance). Additionally, they had the opportunity to suggest the addition or removal of any of the categories or subcategories presented. Later, a second round of questions were focused on evaluating the updated framework using Yes or No answers. An inclusion or exclusion criterion of 70% acceptance rate (rankings 4 and 5: mid-high + high relevance, or 70% positive answers for round 1 and 2 of Delphi, respectively) was used throughout the study. The iterative process was anonymous and oriented toward getting a representative opinion of the group and reaching consensus (Figure 1).

Mapping the current state-of-the-research

We used our developed framework to evaluate the distribution of scientific articles published between 1987 and 2018 regarding our domain. A general search for articles published between 1987 and 2018 was performed on 17 December 2018, in Web of Science (WoS: 264 articles), PubMed (PM: 260 articles), and Scielo (SC: 31 articles) using the string "Air Quality in Chile." A total of 555 combined articles were obtained. Review articles, duplicates and those not related to our domain were excluded from further analysis, leaving us with a total of 247 unique articles (see Supplemental Data Table S1) to be coded onto the validated ontological framework. The state-of-the-research (i.e., the existing literature on the domain) was coded onto our validated ontological framework in an Excel-based tool (Microsoft Corporation) that was developed in house. The coding was performed by at least 3 reviewers and was individual and binary (i.e., whether the category of the validated ontological framework was present in the abstract or not: 1 or 0), and the frequency of the occurrence of an element was not counted (see Supplemental Data Figure S1). Although automated tools may be available, we believe expert judgement is still needed as the keywords may not be easy to find within the context of each paper (Ramaprasad and Syn 2014a, 2015). A comparison matrix to highlight the similarities and differences in their coding was generated, and the differences were reconciled by the same reviewers based on discussions of the abstracts, titles, and keywords to ensure the reliability of coding (Aravindkumar et al. 2018). Further data analysis was conducted in SPSS Statistics for Windows, version 17.0 (SPSS Inc., Chicago, IL, USA) based on the Single Linkage (or nearest neighbor) between the clusters to provide a direct visualization and identify closely related categories without forcing associations. The distribution of published articles in each category and dimension was analyzed, as well as their most common combinations.

RESULTS

According to previous research, the ontological framework should encapsulate the logic of the system, and the potential errors of omission (i.e., exclusion of items that should be included) and errors of commission (i.e., inclusion of items that should be excluded) should be controlled (Ramaprasad and Syn 2014a). The process of ontological analysis has been shown to be iterative, in which an initial framework is formulated, evaluated, reabstracted, and reorganized if necessary (Ramaprasad and Syn 2014a). In this study, a first description of our domain was built based on

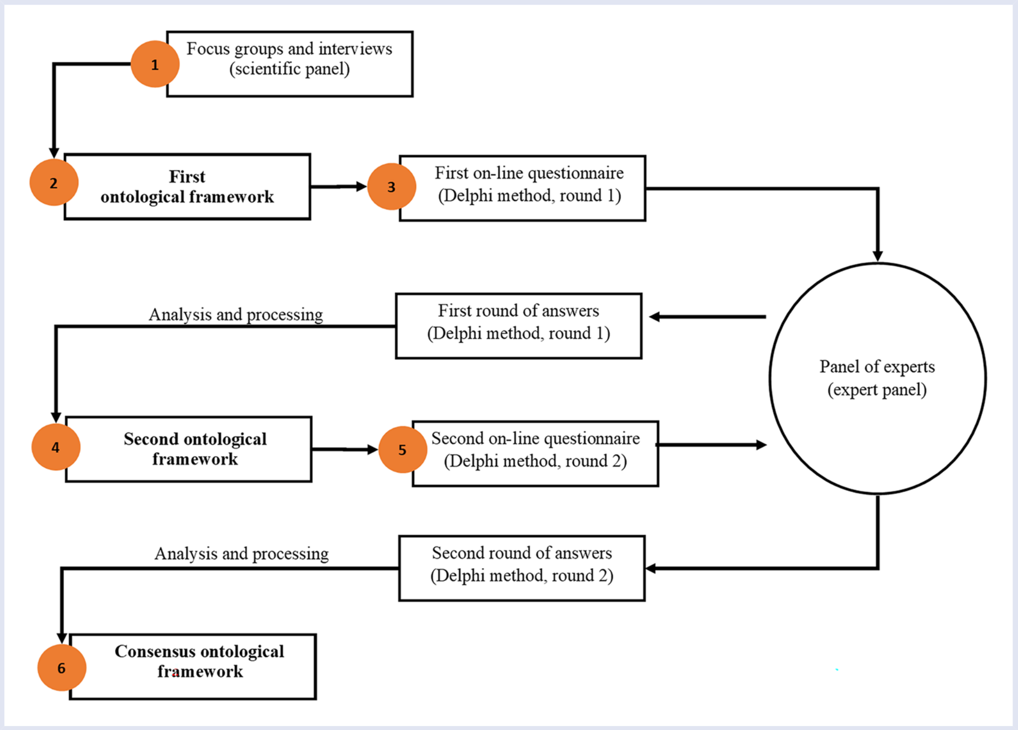


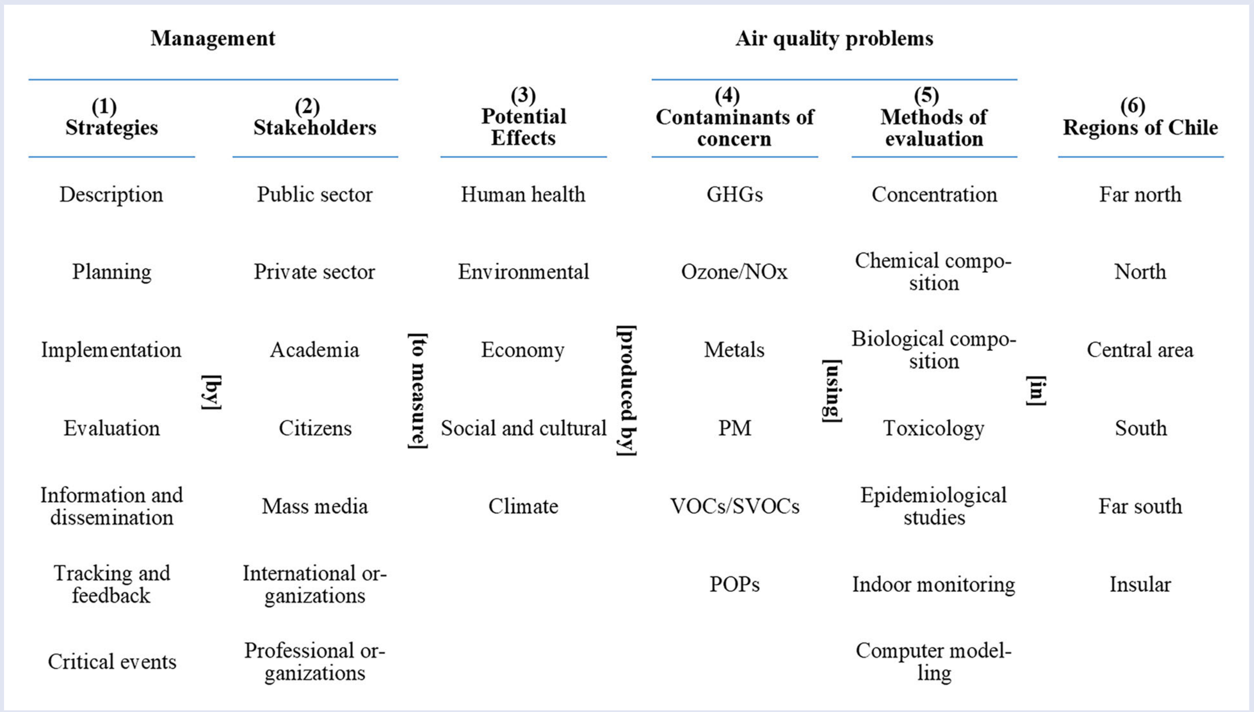
Figure 1. Workflow used in the generation of a validated ontological framework for Air Quality Issues in Chile. Focus groups (1), ontological framework drafts (2, 4), Delphi iterations (3, 5), and the resulting ontological framework (6) are shown.

the results obtained from the scientific panel. However, some answers were not trivial or unique and represented a series of complex steps to be followed. We tried to capture all points-of-view expressed and developed an initial ontological framework, in which the categories for each dimension were organized based on increasing levels of complexity (see Supplemental Data Figure S2). The information obtained from the scientific panel was summarized into 6 general dimensions that represented the answers to the 6 questions originally asked, and the top hierarchical level for our first developed ontological framework, which was organized to produce natural-language sentences: 1) management strategies, 2) stakeholders, 3) potential effects, 4) contaminants of concern, 5) methods of evaluation, and 6) regions of Chile (see Supplemental Data Figure S2). The next step was to extract the logic underlying these dimensions (i.e., define relevant categories for each dimension) to provide a complete and closed description of the problem (Ramaprasad and Syn 2014a). It is well known that the dimensions and categories of the ontological framework must be parsimonious yet comprehensive; too many dimensions will exponentially increase the design complexity, while too few dimensions may partially or incorrectly specify the problem (Ramaprasad and Syn 2014a). The categories for our initial domain were extracted from the answers obtained in the scientific panel and included the description, planning, implementation, evaluation, and communication of the strategies; public and private sector, academia, citizens, and nongovernment organizations (NGOs) as relevant stakeholders; and PM, greenhouse gases (GHGs), O_3 as contaminants of concern, among others (see Supplemental Data Figure S2).

Validation

We recognize the limitations of the first developed framework, particularly because it came from a small group of experts from the same background and academic institution (the scientific panel). Therefore, validating it became a critical step in our research. The validation of the first ontological framework was conducted through an independent panel of experts (the expert panel). The first Delphi iteration had a 63% return rate (63 responded out of 100 initially contacted) and showed a general agreement with the highest hierarchical level of our initial ontology (i.e., the 6 relevant questions obtained from the focus groups). The total acceptance rates were above 70% for all dimensions (see Supplemental Data Figure S3). With “define potential effects” as the most relevant (i.e., 84%), and “define spatial scale” (Regions of Chile) as the least relevant (i.e., 73%). No extra suggestion for the first hierarchical level was proposed. The second hierarchical level (i.e., categories in each dimension) was also validated during the first round of Delphi and required several modifications. The planning stage was the highest rated step during the development of strategies (86%), while “community engagement” was the lowest (76%) (see Supplemental Data Figure S4). At this point, the panel of experts suggested the inclusion and removal of some categories from this dimension: management of critical events and tracking and feedback were included, communication of results was replaced with information and dissemination, and community engagement, policy, and long-term monitoring were eliminated because they can be described by combining other elements in the ontological framework. Similarly, the academia was rated as the most relevant stakeholder in dealing with air quality issues in Chile (90%), while the NGOs were the least relevant (67%) (see Supplemental Data Figure S4). Mass media, international organizations, and professional associations were included in the list of relevant stakeholders, while NGOs were removed from the list. Although we acknowledge their relevant role in increasing trust and helping during critical times, we chose to rely on only our panel's opinion. Potential human health impacts of air pollution were ranked as the most relevant effects of air quality issues (97%), while psychological impacts were ranked as the least relevant (68%). Climate impacts and cultural impacts were included (the latter as part of the same category as social impacts), while ecosystem impacts were replaced with environmental impacts and psychological impacts were removed (they could be included in the social and cultural effects category). Atmospheric PM was considered the most relevant contaminant of concern (89%), while emerging contaminants were ranked as lower relevance (75%). Metals, cigarette derivatives, and biogenic compounds were added to the list of contaminants of concern, while emerging contaminants were eliminated. Measurements based on contaminant concentrations and toxicological parameters were ranked as highly relevant (90% and 86%, respectively), while citizen's perception was ranked the lowest (63%). Indoor monitoring and computer modelling were added to the methods of evaluation, while citizen's perception was removed. This first round of Delphi provided us with a second ontological framework (see Supplemental Data Figure S5) that was further validated in a second round of Delphi.

This time, the panel of experts (only those that participated in the first round of Delphi were contacted, with a response rate of 47%) was asked to approve or disapprove (Yes or No answer) with the new proposed categories (see Supplemental Data Figure S6). Most of the categories were evaluated above our 70% threshold, except for biogenic compounds and cigarette derivatives, which were removed from the consensus framework shown in Figure 2. We believe that this consensus ontological framework approximates the local point of view on the domain, but it is not the only possible approximation (please refer to the limitations section at the end of the manuscript). By using it, relevant topics regarding the air quality management in Chile could be conceptualized by combining management strategies and the right stakeholder to measure the potential effects of a certain group of contaminants of local interest, which were measured following different approaches in specific regions of the country. All of the potential components of our domain can be articulated by concatenating taxonomies from all dimensions to form natural-language sentences. For example: The evaluation (fourth category in dimension 1) by the academia (third category in dimension 2) of the potential



Management						Air quality problems				
(1) Strategies		(2) Stakeholders		(3) Potential Effects		(4) Contaminants of concern		(5) Methods of evaluation		(6) Regions of Chile
Description		Public sector		Human health		GHGs		Concentration		Far north
Planning		Private sector		Environmental		Ozone/NOx		Chemical composition		North
Implementation		Academia		Economy		Metals		Biological composition		Central area
Evaluation	[by]	Citizens	[to measure]	Social and cultural	[produced by]	PM	[using]	Toxicology	[in]	South
Information and dissemination		Mass media		Climate		VOCs/SVOCs		Epidemiological studies		Far south
Tracking and feedback		International organizations				POPs		Indoor monitoring		Insular
Critical events		Professional organizations						Computer modelling		

Figure 2. Consensus ontological framework developed based on the results obtained from the focus groups and after validation using Delphi and a panel of experts. The 6 original relevant questions are represented by the top hierarchical level, which is composed of categories validated by the panel of experts. The combination of terms from each dimension produces a sentence in natural language that describes a relevant component of the air quality management in Chile. A total of 61 740 combinations can be obtained from the framework.

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economic effects (third category in dimension 3) produced by greenhouse gases (first category in dimension 4) measured using their concentration (first category in dimension 5) in the far south of Chile (fifth category in dimension 6). Since the ontology itself is a complete, closed description of the local domain, it can serve as a structured brainstorming tool for practitioners, researchers, and local authorities interested in air quality issues to consider and think through the exclusion or inclusion of all the potential components synoptically and sequentially. It has the potential to reduce both errors of omission and commission. The granularity of the categories can be refined by adding subcategories and coarsened by aggregating categories. Currently, there are over 61 740 potential combinations in our domain. However, not all combinations will be feasible and expert judgement is required to interpret them.

Evaluating the state-of-the-research

The distribution of the corpus within the consensus ontological framework was analyzed. The emphasis of the 247 articles was highlighted (Figure 3 and Supplemental Data Table S1). This visualization clearly highlights the areas of emphases, limited emphases, and no-emphasis (i.e., the bright, light, and blind spots) with larger numbers and bars, smaller numbers and bars, or no bars at all (Figure 3). However, there are no objective frequency cut-offs to separate bright, light, or blind spots. Most of the strategies contained in the corpus analyzed focused on the description of air quality issues in Chile (i.e., monitoring efforts to understand the concentration and distribution of contaminants in the local atmosphere: 193 out of 247 articles, 78%), while there were few articles focused on evaluating strategies to reduce their impacts (19%), and no articles were found on implementing those strategies. This was expected, as the traditional way to describe air quality issues is through a set of summary statistics: the arithmetic mean, median, the standard deviation, or the range. A similar result was found in a recent research that looked into 748 articles and concluded that monitoring networks were the most frequent sources of data, with most studies focused on predicting future contaminant concentrations and, in a lesser case, completing information in unmonitored areas (Represa et al. 2020). The academia was the most important stakeholder in the corpus analyzed (94%), which was expected since most of the authors of scientific papers belong to this category; while private institutions contributed very little (6%) and professional organizations were not found. Most of the papers analyzed focused on human health impacts (31%), with very few focusing on climate impacts (1%) or social and cultural impacts (7%). PM was the most studied contaminant of concern (60%), with very little interest shown on persistent organic pollutants (2%). This was similar to other studies that found that PM and O_3 were the most studied contaminants in European plans (Miranda et al. 2015). In the current study, these contaminants were mostly analyzed by their concentrations (75%) or using computer modelling or available data bases (50%), while more complex analyses such as toxicological (2%) or epidemiological models (1%) have been overlooked. The central region of Chile, where most of its population resides,

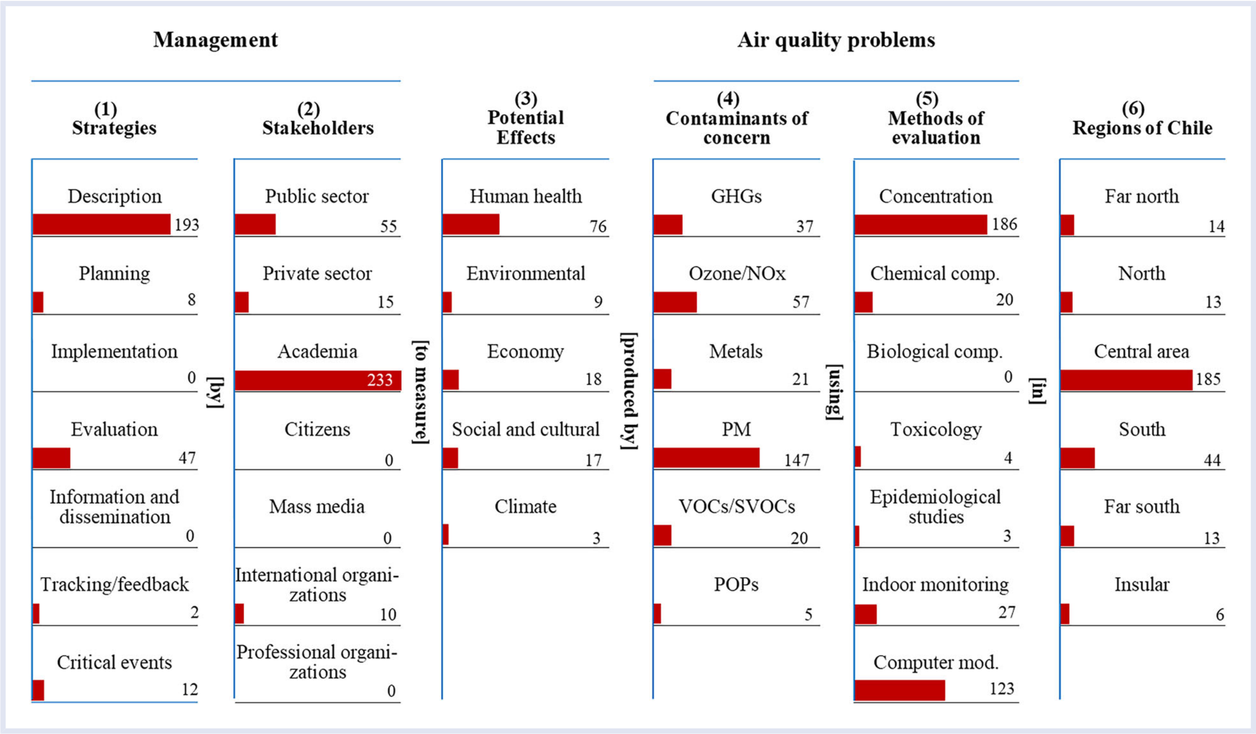

Figure 3. Ontological map of the scientific publications retrieved within the domain "Air Quality Issues in Chile" from 1987 to 2018. The bar below each category is a visual indicator of the frequency of occurrence in the corpus, scaled to the maximum number of occurrences of any one category. The number adjacent to each category indicates the number of times each concept was found.

has been the most heavily studied region of Chile (75%), while the northern region (mostly industrial) (6%) and southern regions (heavily impacted by wood smoke in wintertime) (18% and 5%) have not received the same level of attention. It is worth mentioning that all categories shown in Figure 3 were classified as having roughly the same relevance according to our panel of experts, which in many cases were the same authors of the publications analyzed as part of the corpus.

The consensus coding was also analyzed using cluster analysis and the simple matching coefficient (SMC) to descriptively summarize the data about the population of articles and identify closely related categories without forcing associations between categories or dimensions (Figure 4 and Supplemental Data Figure S7) (Sokal and Michener 1958). The dominant cluster was found to be the analysis of PM concentrations in the central region of Chile (where the capital city—Santiago—is located): description + by the academia + of the potential effects on human health + produced by PM + measured by its concentration or computer models + in the central region of Chile (Figure 4). A secondary cluster was found to focus on the evaluation of the chemical composition and indoor monitoring of several contaminants in the southern region of Chile, without considering any particular effect: evaluation + by the private sector (i.e., private research centers) + of GHGs/O_3/NOx/Metals/VOCs/SVOCs + measured by their chemical composition or indoor monitoring + in the south region of Chile (Figure 4). The tertiary cluster included all the rest of the categories not considered by the first or second cluster and implied that there is no focus on these combinations of categories in the current research. These included important elements added by our panel of experts, such as the management of critical events, research done and published by the public sector, social and cultural effects of air quality issues, persistent organic pollutants, toxicological studies, and regions in the far north and south of the country (Figure 4).

Although our panel of experts removed some categories such as citizen's perception from the consensus ontological framework, we did find some recent publications showing how sociodemographic variables, emotions, and awareness play an important role in supporting policy actions (Boso et al. 2018). This is aligned with other research that found behavioral changes, such as environmental education, awareness, and car sharing, can reduce the anthropogenic driving forces of air pollution (Miranda et al. 2015). This could indicate the need of expanding the background diversity in our panel of experts, and that the framework developed could undergo constant updates due to the advancement of the area and its multidisciplinary nature. An international validation of frameworks for developing countries is suggested for future work, in which the North American and European experience could be used to develop local air quality frameworks (Sivertsen and Bartonova 2012).

Limitations

The framework presented approximates the local point of view on the problem (air quality) and tries to understand local research priorities. However, it is not the only possible

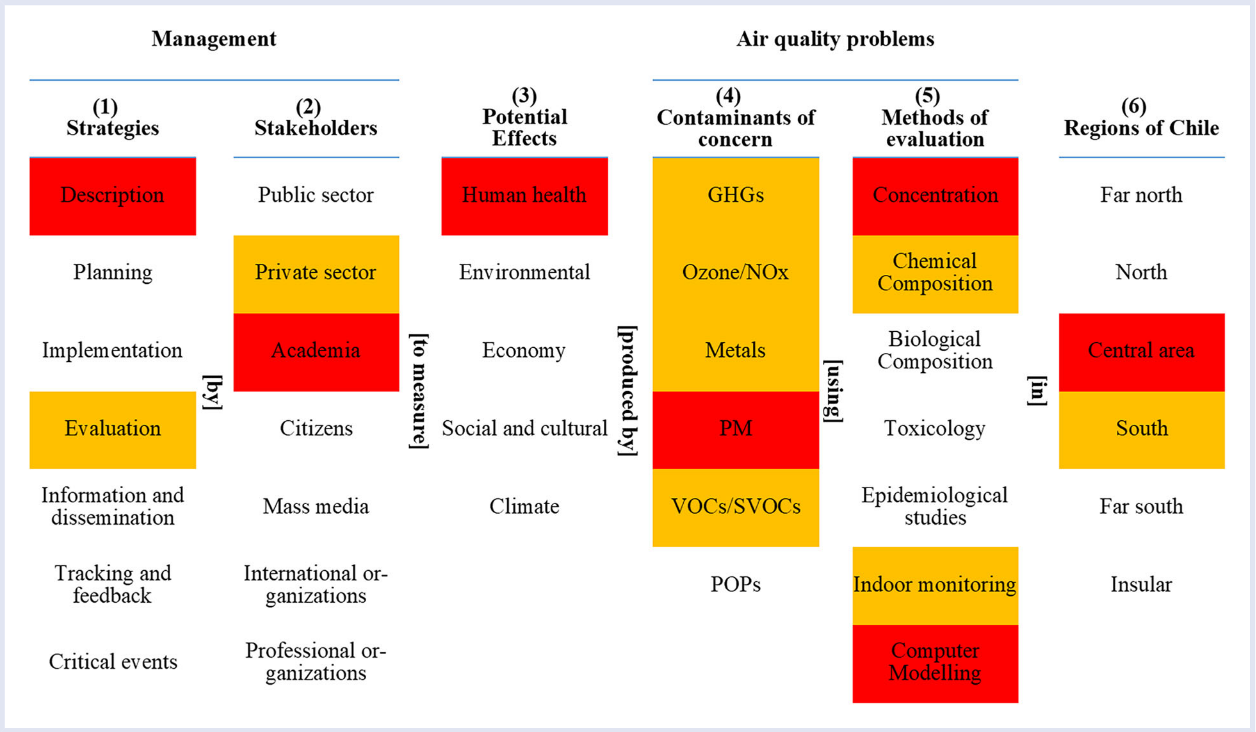

Figure 4. Cluster analysis of the distribution of the corpus analyzed into our consensus ontological framework. The red cluster represents the primary cluster found, the yellow cluster is the secondary cluster found, and the blanks spaces represent the tertiary cluster.

approximation and should be used with caution. Several categories were excluded from the final framework based on a strict cut-off threshold that was arbitrarily set at a 70% acceptance rate (e.g., NGOs, cigarette derivatives, citizen's perception), but this does not mean that they should be left out from other work. Additionally, we used a broad definition of "experts"; therefore, results can vary if only scientific experts are used. We recognize that these frameworks could be influenced by an "echo-chamber effect" if used in isolation; therefore, we propose an additional level of validation in which frameworks from different countries would be compared and discussed in an effort to understand local priorities with respect to a complex problem such as air quality issues.

CONCLUSIONS

Ontological analysis can be used to study the local knowledge and research priorities derived from local experiences dealing with air quality issues. The ontological framework developed helped in the visualization of both the domain and the research priorities derived from it. This framework can help connect scientific findings to the public and policy makers, a weak point for many scientists (Sullivan et al. 2018). It was used to recognize gaps in the body of knowledge according to what was initially considered relevant. It has the potential to help researchers, practitioners, and policy makers systematically navigate the domain, and provides the opportunity to correct blind spots by enabling more informed hypothesis development to correct these distributions. Although the number of categories, dimensions, and overall combinations of terms is relatively high, some categories have been ignored by our group of local experts, such as some criteria contaminants (i.e., SO_2), emerging contaminants, microplastics, and new approaches using low-cost sensors, which are gaining a lot of attention in the last decade. However, this does not necessarily mean that the framework is flawed, but it could indicate that not all countries or regions have the same type of air quality concerns. We believe that this same process applied to different countries or regions will yield different results, according to local knowledge, experience, culture, and methods of approaching problems, which should be analyzed together to understand the basic differences among societies dealing with air quality issues.

The framework could be used to evaluate not only the work done by the academia (the current study), but also other important stakeholders such as the public sector, the existing environmental regulations, and the media coverage, among others. These distributions will provide a complete picture of how local societies deal with air quality issues at different levels.

Additionally, local government institutions should benefit from this analysis to improve funding allocation and open new research opportunities to improve the distribution of the local body of knowledge. We suggest this framework and distribution of articles should be regularly updated to include new published research and new categories as needed.

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Disclaimer—The authors declare no conflicts of interest.

Data Availability Statement—Data and associated metadata and calculation tools are available upon request by contacting the corresponding author Carlos A Manzano (carlos.manzano@uchile.cl).

SUPPLEMENTAL DATA

Figure S1. Example of coding of the corpus (i.e., the scientific articles published from 1987–2018 regarding "Air Quality in Chile") using the validated ontological framework. Title, abstract, and keywords were analyzed and classified using the validated categories, counting the presence or absence of each term.

Figure S2. First developed ontological framework based on the results obtained from the focus groups which were first summarized into 6 relevant questions that were later transformed into the top hierarchical level shown above. Categories under each dimension were derived from the answers to the 6 questions stated originally.

Figure S3. Relevance of the first hierarchical level of our first ontological framework, based on the answers from the first round of Delphi of our panel of experts. The bars represent high to low relevance (i.e., in that order, from left to right), the black bars represent the Total Acceptance level (i.e., defined by high + mid-high relevance) and the red dashed line represents a 70% threshold value.

Figure S4. Relevance of the second hierarchical level (categories) of our first ontological framework, based on the answers from the first round of Delphi of our panel of experts: a) strategies, b) stakeholders, c) effects, d) contaminants, and e) methods. Total Acceptance level is defined as high + mid-high relevance and the red dashed line represents a 70% threshold value.

Figure S5. Second ontological framework developed after the first round of Delphi.

Figure S6. Acceptance (Yes or No answers) of the second hierarchical level (categories) of our second ontological framework, based on the answers from the second round of Delphi of our panel of experts. The red dashed line represents a 70% threshold value.

Figure S7. Simple matching coefficient analysis of categories from the consensus ontological framework.

Table S1. Full list of scientific articles that form our domain "Air Quality in Chile," published between 1987 and 2018.

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