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Localising urban sustainability indicators: The CEDEUS indicator set, and lessons from an expert-driven process

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ABSTRACT

The development and application of urban sustainability indicators has gained momentum in recent years, especially since the generation of specific urban indicators for the Agenda 2030. Urban sustainability is a broad concept involving many dimensions, therefore the generation of a short, but comprehensive list of indicators is a significant challenge. In this paper, we present a set of 29 indicators designed to characterise urban sustainability in Chile, which we also expect to be relevant to other cities, particularly in the Global South where issues of poverty and inequality are prevalent. We first outline the process of selecting the indicators through expert consultation. Then we present selected indicators, and the variables used to measure them. Subsequently the set is applied to six Chilean cities that are diverse in terms of population, socio-economic conditions and geography. We show that some indicators highlight negative nationwide trends that are common to the cities, while other indicators reveal notable differences that can be traced back to their local contexts. The CEDEUS indicators provide a complement to the UN's Sustainable Development Goals (SDGs) for cities; therefore, a comparison is made with the SDGs. The indicator development process is critically examined and policy recommendations are given.

1. Introduction

The term "sustainable development" was popularised by the publication *Our Common Future*, known as the Brundtland Report, in 1987. In general terms, sustainable development is understood as a strategy that aims to promote harmony between humanity and nature, based on inter- and intra-generational considerations (WCED, 1987). This strategy became the basis of the UN development agenda from the Conference on Environment and Development in Rio de Janeiro in 1992. Agenda 21, the action plan for the twenty-first century, was designed to ground this thinking in planning and management at the local level, and this Agenda included a chapter on the importance of indicators for monitoring and assessment (chapter 40). However, the Agenda was promoted in a highly selective manner around the world, with countries such as Germany and Spain enthusiastically mainstreaming it, while the USA and many others effectively ignored it. A particular absence in all applications, however, was the lack of effective indicators at the local level, in spite of the UN national level sustainable development indicator design process led by the Commission for Sustainable Development, with three iterations of the indicator set in 1996, 2001 and 2006. In parallel, the Millennium Development Goals (MDGs) were launched in 2000 to monitor progress on international development to 2015, while we are currently in the implementation phase of the Sustainable Development Goals (SDGs) as part of the Agenda 2030 process (United Nations, 2015) as the follow-up to the MDGs within the context of Agenda 2030, the global sustainable development strategy, 2015–2030. Of the 17 SDGs goals, it is Goal 11 that tackles the challenge of Sustainable Cities and Human Settlements, and which aims to "*make cities and human settlements inclusive, safe, resilient and sustainable*" (United Nations, 2015, p. 14). It is this Goal that will also underpin the aims of the New Urban Agenda (NUA) agreed at Habitat III in October 2016. However, in spite of these advances since Rio '92, the absence of

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local urban indicators remains as critical as it was in the early 1990s. This is the context for the work presented in this article, which highlights the methodological challenges experienced in the creation of an indicator set relevant to the contemporary challenges, and considerable diversity of Chilean cities.

1.1. Urban sustainability indicators

Agenda 21 called on countries to develop indicators for sustainable development, and the 2030 Agenda for Sustainable Development indicates that countries have the responsibility to follow-up and review the progress made in implementing the 17 Sustainable Development Goals (United Nations, 2018a, 2018b) — but if progress at the national level has been slow, at the local, urban scale it has been at best partial, and at worst, absent. As Simon et al. (2016, 60) note: "*If the urban SDG is to prove useful as a tool as intended for encouraging local and national authorities alike to make positive investments in the various components of urban sustainability transitions, then it must be widely relevant, acceptable and practicable.*"

The need to monitor urban sustainable development has been renewed by Agenda 2030, the SDGs and the NUA. In the case of Chile, it is also linked to the approval of a National Urban Development Policy in 2014, that also highlighted the importance of urban metrics to monitor progress. The expert-process associated with the work in this paper has been generated by the Center for Sustainable Urban Development (CEDEUS), a national priority area research and policy initiative with funding from the National Research Council (Conicyt) that includes two universities: the Pontificia Universidad Católica de Chile and the Universidad de Concepción. This paper reports on the process and the results, i.e. an urban sustainability indicator set and its application in 6 Chilean cities. Its objective is to communicate the methodological challenges inherent in the process in order flag-up obstacles and potential responses for similar work undertaken elsewhere. From Agenda 21 to Agenda 2030, the theme of cooperation for sustainable development has been highlighted, and this involves sharing of methods and experiences of planning and implementation. It is this vein that this paper seeks to make a contribution to indicator design and development for more effective and sustainable urban development planning.

Sustainability indicator sets can provide a comprehensive, easy to understand, and reliable picture of the sustainability conditions of a municipal area, a city or a country, with the intention of informing decision-making (Rinne, Lyytimäki, & Kautto, 2013; United Nations, 1992). These indicators reflect different components or dimensions of the complex system that is, in this case, the city (Morrison & Pearce, 2000). When aggregated, indicators can produce indices or other synthetic indicators, such as carbon and ecological footprints, Genuine Progress and material flow analysis, which frequently involve the conversion of measures to common units and the definition of weights to each measure in relation to their importance (see Rogmans & Ghunaim, 2016). Indicators have also been used for certification and rating systems, such as LEED and BREAM, and the ISO 37120 (2014), which define and establish methodologies to measure the performance of services and quality of life, applicable to any city, municipality or local government — independent of its size and location in a comparable and verifiable manner (ISO, 2014). All of these are regarded as positive contributions to assessing the objectivity of sustainability choices in urban projects (Ahvenniemi, Huovila, Pinto-Seppä, & Airaksinen, 2017; Chastenet et al., 2016). There are many assessment tools based on indicators that have been developed to support political decision making, environmental management, advocacy, participation, consensus building, research and analysis (Komeily & Srinivasan, 2016), however, many structural problems remain in terms of their design and use.

Indicators have multiple limitations. Although they can provide information about a particular system, they cannot demonstrate causal links or tell the whole story, because they can only "indicate" and have to rely on available data, which is often of poor quality, in temporal and spatial terms (Morrison & Pearce, 2000). The design of sustainability indicators in particular is a challenge due to the complexity of different types of data, criteria, information gaps, vagueness, ill-definition and uncertainties when combining diverse variables (Komeily & Srinivasan, 2016). Despite this complexity, the optimistic assumption remains that, with better information and a rational planning system, decision-makers will be able to make better decisions. However, this optimism is rarely tested and it is likely that many indicators fall into the third of Rinne et al.'s (2013) categories of indicator use:

1. Instrumental: direct link between indicators and decision outcomes,
2. Conceptual: indicators as tools for new ideas, learning and understanding, and
3. Political: indicators are (ab)used to justify decisions already taken.

The political nature of indicators is also reflected in the work of King (2016), who defines a functional classification based on a discrete framing of outcome values and purposes, which can be characterised as having intrinsic and extrinsic value. The intrinsic value is defined by the internal structure being measured, and the extrinsic value relates to the characteristics of other systems and elements in the environment. The intrinsic functions are those pertaining to leadership and organised stakeholders, while extrinsic functions are those pertaining to citizen involvement and management of the commons. Based on this framing, the author sets up a dichotomy between the "leaders' interests" and the "general public interests" as a "top-down" versus "bottom-up" approach. Despite this divergence and the risk of 'capture' by decision-makers (as in Rinne et al.'s, 2013 third category), sustainability indicators have the potential to (i) measure and improve a government's operational efficiency and accountability (intrinsic), and also to (ii) address public aims and aspirations (extrinsic). It is for these reasons, based on the first and second of the categories, that CEDEUS sought to contribute to national urban indicator development in Chile, and the monitoring of the National Urban Development Policy (2014) in particular.

1.2. Urban sustainability indicators in Latin America, with a focus on Chile

According to Pintér, Hardi, Martinuzzi, and Hall (2012), the starting point of sustainability assessment is to develop a conceptual framework that defines the issues to be measured, followed by the measurement of a baseline and follow-up measures to determine progress. This is useful if the measures are standardised and comparable. A good indicator system can not only support decision-making but also encourage participation of stakeholders and society in developing a shared sense of vision for action.

On the global stage, to encourage participation and develop a shared vision of the city is also the purpose of Goal 11 of the SDGs, with its 15 indicators for monitoring progress on the Goal to, "Make cities and human settlements inclusive, safe, resilient and sustainable". Although Sustainable Development Goal 11 focuses specifically on cities, there are other indicators across the other 16 goals that are pertinent to cities, such as SDG 6 on the provision of water and sanitation, or SDG 13 on climate change (Hardoy, 2017; UN Department of Economic and Social Affairs, 2018). These were taken into consideration by the experts in the development of the indicator set presented here. Despite the definition of global sets of indicators, their use and meaning needs to be adjusted to the context of each country, its problems, its culture, its state of (economic) development and the data publicly available, among other factors. While some argue that standardised indicators are useful for the comparison of data, problems and contexts, i.e. enabling benchmarking, others argue that a single set of common indicators cannot be applied to all cities, because they should reflect the particular cultural, political and institutional contexts (Moreno Pires, Fidélis, & Ramos, 2014). Therefore, whereas the UN is making an effort in creating standardised indicators for countries, there is a continuous growth in the definition of “local” sustainable development indicators (Moreno Pires et al., 2014). Ultimately, they should complement each other and reveal both the intrinsic and extrinsic value of indicator uses for effective decision-making. It is the development of local indicators that is key to this article, but with the additional criterion that these should, and could, provide the basis for other local contexts – in Latin America for example – with appropriate adaptation and selective substitutions.

The Latin America and Caribbean region (LAC) is considered to be the most urbanised in the world, with almost 80% of the region's inhabitants living in cities in 2012 (UN-Habitat, 2012). Although the urban population is growing at a slower pace over recent decades, the urban development of medium-size cities and metropolitan areas has increased the range of environmental, social, and economic challenges (Dobbs et al., 2018; Jordán, Rehner, & Samaniego, 2010); this is the case for Chilean cities. Of particular relevance for Chile are those challenges relating to equity. Urban inequalities have had an impact in terms of access to green spaces, and also public services such as sanitation and transport (Borsdorf & Hidalgo, 2010; Pauchard & Barbosa, 2013). Other aspects that are particularly relevant to LAC cities are their high population density, high building density, the proportion of the urban areas used to build public housing and informal settlements, the low urban vegetation cover, and fragmented green spaces (Dobbs et al., 2018; Isendahl & Smith, 2013; Roberts, 2005). Socioeconomic status is the predominant factor that determines access to green — regardless of climate (Celemin, Marcos, & Velázquez, 2013; Dobbs et al., 2018; Scopelliti et al., 2016). At the same time construction of – often informal – settlements can eliminate vegetation and expose vulnerable populations to disaster risks if settlements are founded on slopes and in riverbeds (Benitez, Perez-Vasquez, Nava-Tablada, Equihua, & Lavarez-Palacios, 2012; Dobbs et al., 2018). LAC cities have also been defined by neoliberal development models, with Chile leading in this dimension, that have impacted state-led urban planning, with real estate-oriented instruments to the fore (Dobbs et al., 2018; Roberts, 2005).

In response to the particular socio-economic, socio-ecological and political contexts that predominate in the region, there have been several attempts to ground the global sustainable development agenda in a more regionally-appropriate strategy (Burgess, 2003), e.g. the Summit of the Americas on Sustainable Development in Santa Cruz de la Sierra, Bolivia, in 1996 and 2006 (OEA, 1996a, 1996b), the LAC Initiative for Sustainable Development (ILAC), and the Sustainability Assessment in LAC (ESALC). While the ILAC was adopted in 2002 by LAC governments during the World Summit on Environment and Sustainable Development in Johannesburg, South Africa (UNEP, 2008), ESALC was led by the Division of Sustainable Development of ECLAC (CEPAL) in 2004 with the objective of using a combination of environmental, social and economic indicators in a systemic framework (Quiroga Martínez, 2007). ESALC was rolled out in Argentina, Brazil, Nicaragua, Panama, Peru and the Dominican Republic (Quiroga Martínez, 2007). Private companies have also become increasingly involved, as in the Latin American Green City Index – in the vein of Smart City promotion – developed by The Economist group and sponsored by Siemens (Economist Intelligence Unit, 2010).

The Chilean National Commission for the Environment (CONAMA, now a Ministry of Environment since 2010) worked on the development of a system of indicators to monitor sustainable development in the 1990s at a regional level, but there was no implementation process (Blanco, Wautiez, Llavero, & Riveros, 2001; Quiroga Martínez, 2001). There have also been pilot exercises in Santiago de Chile, from the analysis of its ecological footprint by Wackernagel (1994) and others, to the indicator set developed by an expert-led process (as part of the Risk Habitat Megacity project, 2007–11) including the Regional Government, Ministry of Environment, and researchers from the Pontifical Catholic University of Chile, the University of Chile and the Germany Helmholtz Association (Barton & Kopfmüller, 2017; Kopfmüller, Barton, & Salas, 2012). However, in the framework of the National Urban Development Policy of 2014, an extensive indicator set for cities has recently been generated, called SIEDU, and it is currently in the hands of the National Statistical Office to oversee its implementation (UNDP, 2017). In parallel with the generation of this SIEDU indicator set, the Chilean Centre for Sustainable Urban Development (CEDEUS) created a Working Group in 2014 with researchers from different disciplines to develop a more synthetic set of indicators — in the knowledge that the former government driven exercise was designed to create a larger database of urban indicators rather than a more limited set with greater potential for influencing local authorities and civil society participation. In this paper, we report on the methods and results of CEDEUS' expert-led initiative, involving the participation of academic experts in eight disciplines, including public health, urban geography, transport engineering, urban sociology, architecture, environmental engineering, environmental science and urban planning. The research question that the group sought to answer was: *Is it possible to find a small but comprehensive set of sustainability indicators to characterise and monitor urban development of Chilean cities considering their differences in size, climate and economic conditions?* Based on this question, four main research objectives were developed:

- To define a manageable set of indicators that characterise urban sustainability with a focus on Chilean cities;
- To operationalise the indicators through the selection of variables;
- To apply the indicators to selected cities of different sizes and climatic zone in order to (3a) assess whether the set was able to reveal differences among cities, and (3b) reveal the sustainability condition of each; and
- To define sustainability standards for each indicator.

In the following section, we outline factors that were taken into account in the iterative indicator selection and development process of the Working Group, including issues of definition and criteria. This is followed by a section on how the set of urban indicators was developed and the selection of variables. The 29 indicators and an analysis of the results in six cities follow. Finally, we discuss this applied process, the indicators, indicator and variable criteria, and compare the set to the UN SDGs. The article closes with reflections on the replicability of these indicators across the Global South.

2. The construction of urban sustainability indicators

The construction of urban sustainability indicators has been influenced by the development of indicators in different fields, such as environmental and natural resource development, health sciences, economic development, and social development (Waas et al., 2014). As stated earlier, indicator use may serve different purposes that can be instrumental, conceptual and political, consequently different indicators are useful for different types of decisions. Sometimes the very same indicators can serve different purposes, while in other situations separate sets of indicators may be needed. Generally speaking, urban sustainability indicators should be limited in number, should be well founded, should use official data, and should have a broad coverage of urban development conditions, as clearly outlined from Agenda 21 (chapter 7, 1992), through the Melbourne Principles on Sustainable Cities (2002) to the New Urban Agenda of 2016 (Munier, 2011; UN, 2017). Indicators should also be assessed by criteria of transparency, scientific value, sensitivity, robustness, their capacity to be ‘linkable’, for their relevance to a particular issue, to promote and measure changes in policy and practice, and generate impact in the intended audience (Peterson, 1997).

Criteria applicable to an indicator will not necessarily be applicable to a set of indicators, because each situation has its own priorities for data collection and analysis (von Schirnding & WHO, 2002). For example, if indicators are intended to inform the general public, the criteria for selection should include factors such as simplicity, ease of interpretation and appeal to the interested parties (von Schirnding & WHO, 2002). The formulation of clear definitions early in the indicator development process should guide work on the indicator set, including questions such as "Who will be responsible for the final selection and publication of the indicators?", "How will stakeholders be involved?", "Who will be in the expert group?", "Will public consultation be undertaken?", etc. (Brown, 2009).

In relation to the process, there are two main approaches to indicator development: (i) the top-down (expert-led) approach considering international or national standards and strategies, and (ii) the "bottom-up" (citizen-led) approach which draws on local expertise and involves the public (Lützkendorf & Balouktsi, 2017). The tensions between these two models have led to a combination of the two approaches in order to effectively obtain indicators that are representative of both sides (Lützkendorf & Balouktsi, 2017; Turcu, 2013). In this Chilean experience, the approach has been explicitly 'expert-led' since the generation of wider participation without a mandate for final application by national or local authorities could have led to false expectations (based on the prior experience of the Risk Habitat Megacity project).

The definition of a conceptual framework can offer a guide for developing an indicator set, enabling a structured approach, with clear variables and measurement units by theme and sub-theme. However, data availability often constrains this process, hence the need to work simultaneously with concepts and data sources (Brown, 2009; von Schirnding and WHO, 2002). Finally, the presentation of the indicators can influence decision making, and bridge the gap between measurement and governance (von Schirnding and WHO, 2002), hence the need for indicators to be legible for different audiences.

A large number of urban sustainability indicator sets have been developed around the world since the early 1990s (Adelle & Pallemaerts, 2009; European Commission DG Environment, 2018; Munier, 2011) and this facilitated the first steps of the Working Group: an in-depth literature search and a series of meetings with ministerial experts in which existing sets of environmental and social indicators were reviewed and discussed. The initial selection was based on 7 indicator sets: (1) Global City Indicators (Global Cities Institute -University of Toronto, 2010), (2) Environmental Performance Index (Emerson et al., 2010), (3) CASBEE for Cities (Japan Sustainable Building Consortium, 2012), (4) ISO 37120 — 2014 (ISO, 2014), (5) Urban indicators for managing cities (Westfall & De Villa, 2001), (6) International Urban Sustainability Indicators List (Shen, Ochoa, Shah, & Zhang, 2011), and (7) UNICEF KID Index of Urban Child Development. In the following section we describe in detail the process of how the CEDEUS indicator set was derived from these 7 alternatives, how it was tested, refined and applied, and who was involved in this process.

3. Methods

Given our four objectives of defining, testing and applying a manageable set of urban sustainability indicators, a general work plan and workflow chart for the initiative was outlined. This work plan is shown in Fig. 1, and contains 5 general phases: In Phase 1 a set of indicators was elaborated; in Phase 2, variables were defined, usually one for each indicator, allowing the measurement of an indicator's status and progress; in Phase 3, the variables were applied to a number of cities to assess the sustainability condition of these cities; in Phase 4, the usefulness of the variables were evaluated and the sustainability characteristics of the cities were compared; and in the final Phase, standards of sustainability were defined for each indicator, with the objective of enabling specific city-based assessment beyond multiple city comparisons. In the following sections we will discuss the methods and results for Phases 1 to 4. The evaluation of indicators and the sustainability of cities, i.e. Phase 4, is covered by the later discussion section. Development of the sustainability standards is still an ongoing process, involving the Working Group, and results will be reported at a later stage.

3.1. Phase 1: selection of indicators

The set of indicators was developed by a Working Group of university researchers, all associated with CEDEUS. Researchers participated voluntarily in the Working Group's monthly meetings — 7–15 people at each. A workflow outlining the indicator selection process is shown in Fig. 2. The meetings were designed to discuss progress, review indicator proposals, evaluate calculation results, and distribute tasks. The first meetings were focused on introducing the work objectives and finding a common language. This included the discussion of sustainability terms, the review of sustainability frameworks, such as Daly's Triangle (Meadows, 1998), the 10 Melbourne Principles for Sustainable Cities (UNEP, 2002), and the Happy Planet Index (Abdallah, Thompson, Michaelson, Marks, & Steuer, 2009), and the definition of the Working Group goals. As a result of these meetings, a definition for "sustainable development" was generated: "*sustainable development is a process whereby communities flourish harmoniously in both present and future generations.*"

With respect to the indicator initiative goals, the Group agreed that the set of indicators should be manageable and comprehensible, e.g. by elaborating a set that ideally contained less than 20 indicators. Criteria that indicators should fulfil were also discussed, however, the set of criteria was never formally established by the Group. The only criterion that was applied explicitly from the outset was that of "implementability", i.e. the availability of data.

A further goal that was agreed on was to present the indicators and results for each city on a webpage. While there are similar web pages in Chile that present data and indicators (e.g. by the Observatory of Cities UC: www.ocuc.cl, and by the Ministry of Housing and Urbanism: www.observatoriourbano.cl), these are intended for independent consultation and do not have an explicit sustainability orientation. In our case the webpage was devised as a tool for future discussion in meetings and workshops with civil society and local authorities to support the development of local sustainable city planning agendas. With respect to the publication of results, the Group agreed that a ranking of cities was not a goal, in order to avoid stigmatisation. Nevertheless, a comparison of two cities for selected indicators, was regarded as a useful tool for workshops.

The initial meetings followed an in-depth literature search and a

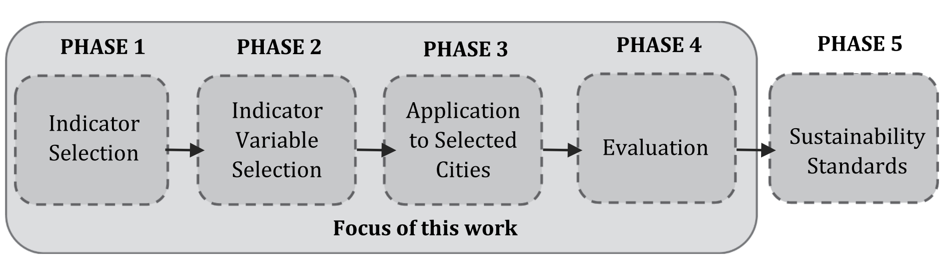

Fig. 1. The process for developing a set of urban sustainability indicators. Source: Authors.

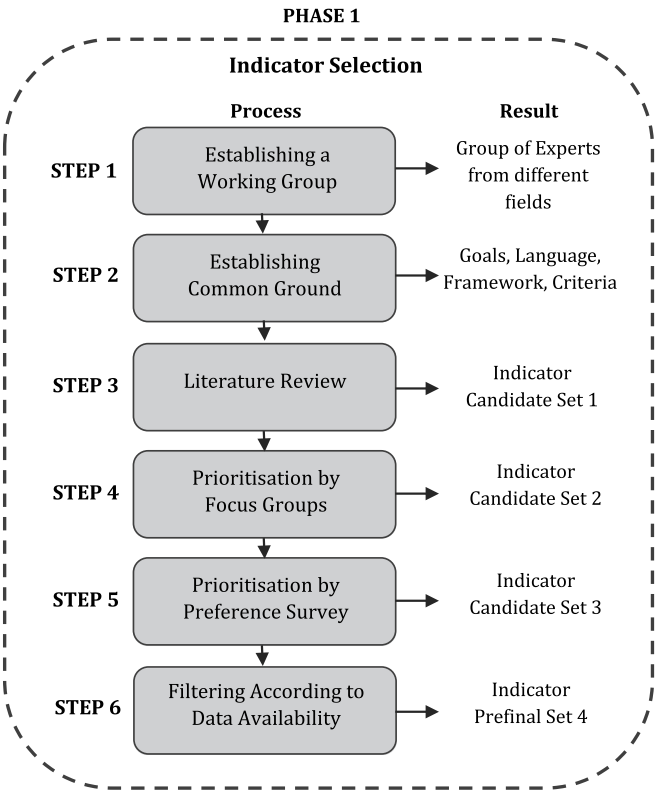

Fig. 2. Detailed steps of Phase 1 of the process in order to obtain a list of indicators that characterise urban sustainability. Source: Authors.

round of meetings in which existing sets of environmental, economic, and social indicators were reviewed and discussed, focusing on different geographical scales (i.e. regional, country and city scale) and covering urban contexts, in preference to rural or natural contexts. A set of five broad sustainability dimensions was established based on the 7 sets noted above, and other literature: (i) environment, (ii) economy, (iii) government, (iv) (city) profile, and (v) social aspects — with the latter dimension also including indicators on transport, housing, health, education. This work phase resulted in a first set of 574 indicators, which we will refer to as candidate set 1. These indicators were established from the literature and by members of the Working Group.

To obtain a manageable set of 10 to 30 indicators a further round of meetings was set-up to review and prioritise them. There were two key events in this phase: First, a focus group among CEDEUS researchers – around 50 people – who were assigned to five multi-disciplinary groups and tasked to prioritise subsets of the indicator candidate set 1. This reduction method resulted in a set of 79 indicators (candidate set 2). Second, given the lack of consensus in how to further reduce the set of 79 indicators, a new method was introduced that aimed at bringing sustainability down to a human scale with respect to quality of life. The members of the Working Group were given the task to "*Choose five aspects* (*or indicators*) *with respect to* (*your*) *quality of life that you would wish to minimize, and five that you wish to be maximized.*" The answers were evaluated with the Driver-Pressure-State-Impact-Response framework (DPSIR by Hammond, Adriaanse, Rodenburg, Bryant, & Woodward, 1995, Bossel, 1999) to obtain a priority ranking. This ranking was discussed and modified in a further five meetings, resulting in a set of 26 indicators (candidate set 3). For this third candidate set a pre-screening of data availability was performed, which led to the elimination of five indicators and a provisional set of 21 indicators. This set remained provisional (or pre-final), since the indicator operationalisation based on variables and further discussion rounds led to adjustments and, finally, an increase in the number of indicators.

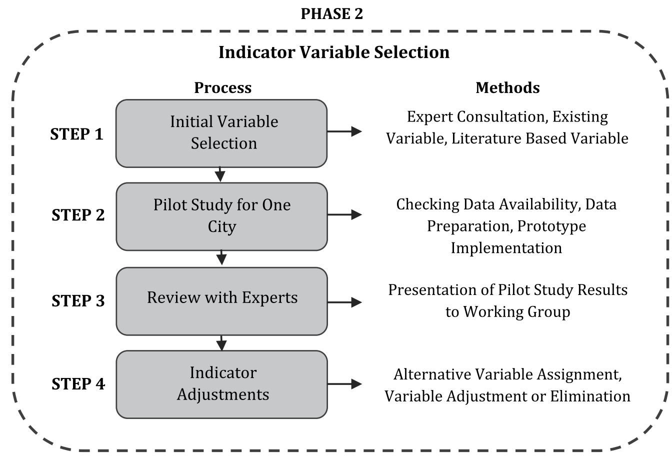

Fig. 3. Detailed steps of Phase 2 of the Indicator project to obtain variables for the indicators set. Source: Authors.

3.2. Phase 2: indicator variable selection, piloting and variable adjustments

In Phase 2, the set of 21 sustainability indicators was operationalised, i.e. finding or developing appropriate variables that would enable an indicator's status to be assessed over time. This phase was carried out by a small pilot team and can be broken down into four Steps as shown in Fig. 3: (i) initial variable selection, (ii) pilot study, (iii) review of pilot study results, and (iv) adjustments to indicators and variables. Although this process description (Fig. 3) may suggest that finding and selecting variables is a linear process, in reality the development was more cyclical and iterative.

To obtain a variable for a particular indicator, different approaches were utilised. First, if possible we elaborated the variable based on the advice of one of the experts in the field. Second, based on the recommendation of one of the experts we directly adopted an indicator from other – often governmental – sources. Third, a variable was developed based on the literature. For example, an indicator variable generated by an expert is "Access to high quality education"; an indicator suggested by an expert and taken from an external source is "child health" measured through obesity; and an indicator based on the literature is "Fire Department Emergency Coverage".

A pilot study was then undertaken with the aim of calculating all variables (Step 2 of Phase 2). For that study we chose a mid-sized city (150,000 inhabitants) in the south of Chile, the city of Valdivia. Part of the pilot study was the detailed evaluation of data sources, which included assessing the temporal and spatial availability of required datasets. Temporal evaluation aspects included an assessment of the last publication or survey date and the frequency of updates (daily, quarterly, yearly, every 10 years, etc.). This involved the criterion that data should not be more than 5 years old, and ideally have a yearly update cycle. Given that the Chilean census is applied every 10 years, the maximum acceptable update cycle was also specified as 10 years. Variables that used datasets that have been surveyed only once were replaced by others. Spatial evaluation aspects included an assessment of geographical coverage and survey scale, e.g. data at household, block or municipal level. Requirements were that a dataset should be available for several cities — pointing to governmental/ministerial data sources, and that data needed to be available at least at municipal level, but ideally at street block level. Additionally, metadata of the survey datasets were evaluated for information on statistical representativeness. Based on the data assessment some variables were replaced by others.

Following these steps, the data were prepared for the calculations and calculation models were developed according to the literature or expert advice. The results of those calculations for the pilot city of Valdivia, in most cases a single value per variable, were presented to the Working Group for discussion (Step 3 in Fig. 3). Each variable was

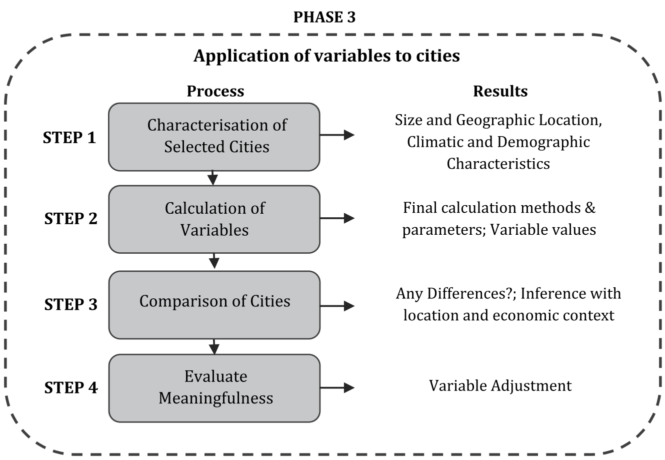

Fig. 4. Detailed steps of Phase 3 which applies the indicators to selected cities. Source: Authors.

evaluated with respect to methodological and data problems. The follow-up discussions led to changes for about half of the indicators, ranging from simple changes of calculation parameters to replacements of variables since assessment objectives for an indicator were not met.

We note here that the expert consultation and evaluation of a variable resulted in some cases to the suggestion of using more than one variable for a particular indicator. In these cases, we calculated values for all suggested variables to let the Working Group decide which variable should be kept or if this variable should become a new indicator. The outcome of this review of the pilot study results was that the set of indicators increased from 21 to the final 29 indicators.

3.3. Phase 3: application in six cities

Given the set of 29 indicators and their associated variables, the next phase was to apply these to a selection of Chilean cities (Fig. 4). The purpose of this task was threefold: (i) to characterise each city, (ii) to compare them against each other, and (iii) to evaluate the meaningfulness, or utility, of the indicator variables a second time, following the initial pilot study.

For that experiment, we selected a further five cities with a view to engaging with differences of city size, major economic sectors and climate. In Table 1 we outline the main characteristics of the six cities, while Fig. 5 shows their geographical locations. Two of the cities are metropolitan areas: Santiago with 7.5 million inhabitants and Concepcion with 1.1 million inhabitants. Three are coastal cities, while the other three are inland; these factors influence rainfall and temperature, and subsequently variable values such as energy consumption and air pollution.

The calculation process for each indicator variable was in most cases as follows: (i) data gathering or creation of data, (ii) data cleaning and pre-processing, (iii) development of calculation scripts that implement the particular calculation model or, in some cases, only read and manipulate the data from an existing database, (iv) data output in the form of tables, and (v) (geo)graphical visualisation when needed or appropriate (Fig. 6). For some indicators, geographic data needed to be created or digitalised using Geographic Information Systems, such as QGIS and ArcGIS. Implementation of scripts, i.e. data pre-processing routines and calculation models, was done with the software R (R Core Team, 2017). Developing the routines in R allowed for a high level of automatisation in the calculations. This in turn is beneficial if parameters need to be adjusted and indicators are to be calculated for different cities. The output of the calculation followed in the form of a simple table, since we obtained only one value per indicator for almost all indicators.

Table 1
Characteristics of case study cities - ordered from north to south. Sources: (i) population data: Chilean National Institute of Statistics (INE) *Demográficas y Vitales* 2017 (http://www.ine.cl/estadisticas/demograficas-y-vitales), (ii) the built-up area was calculated from a *Pre-Censo 2016* zones dataset, (iii) climate zones from (Sarricolea et al., 2017) , (iv) economic activities: adapted from (Fuentes et al., 2017).

City	Number of municipalities	Population 2015 (projection)	Built-up area in km^2 (pre-census 2016)	Climate (Köppen-Geiger)	Main economic activities
Copiapó	1	172,000	34	BWk(s) — Cold Desert	Mining
Coquimbo–La Serena Conurbation	2	323,000	107	BSk(s) — Cold Semi-Arid with Oceanic Influence	Services, mining, tourism
Santiago Metropolitan Area	34	7,460,000	782	Csc — Mediterranean	Industry and services
Concepcion Metropolitan Area	9	1,015,000	248	Csb' — Mediterranean with Oceanic Influence	Industry, forestry, fishing
Temuco–Padre Las Casas Conurbation	2	374,000	61	Csb — Mediterranean	Forestry
Valdivia	1	167,000	45	Cfb'(s) — Marine west coast climate with Oceanic Influence	Forestry, tourism

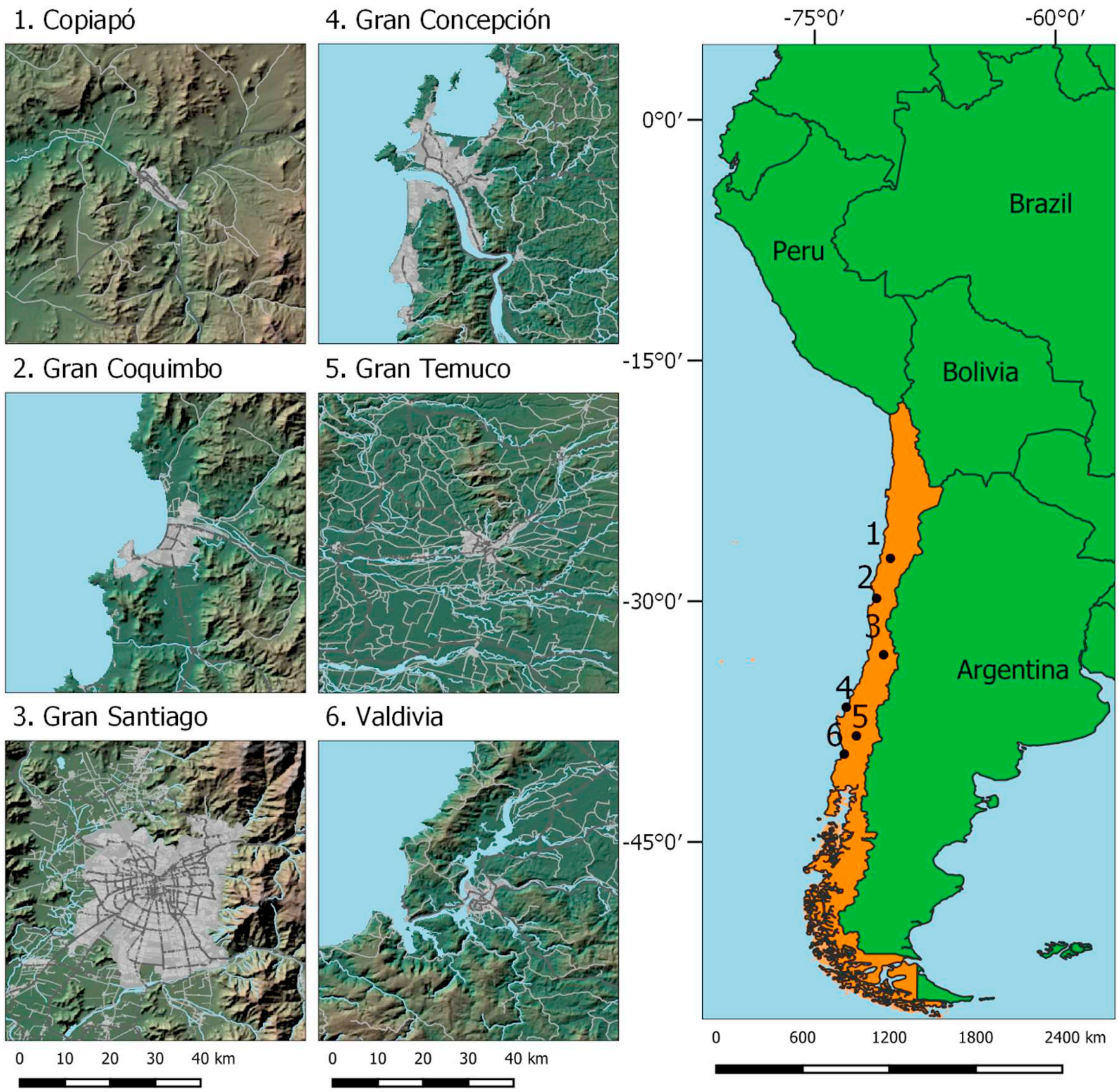

Fig. 5. The six cities to which the indicator set was applied, ordered from north (left) to south (right). Urban areas are shown in grey together with mayor roads in dark grey. Source: Authors.

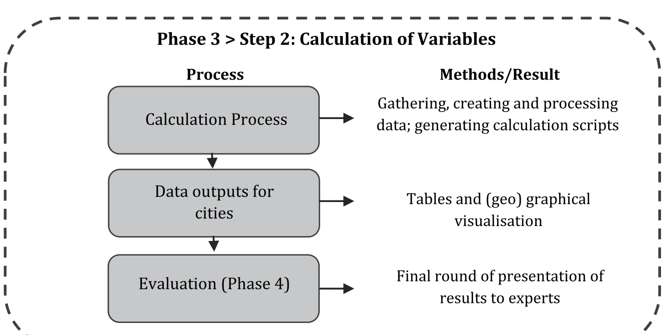

Fig. 6. Detailed steps of variable application, i.e. calculation of values for cities. Source: Authors.

In some cases, and in particular for the metropolitan areas of Santiago and Concepcion, simple maps were created to validate the results and to explore the spatial variation visually. A visual validation was possible due to the metropolitan area of Santiago being characterised by particularly strong socio-spatial segregation (Sabatini, 2005; Sabatini & Wormald, 2013), hence a clear spatial pattern for several of the indicator variables.

Besides R and GIS software, the software OpenTripPlanner was used for calculations of accessibility variables. For instance, OpenTripPlanner was used to calculate 10 min walking areas for access to green spaces/parks, and 30 min access areas, using public transit, to access leisure and culture amenities. Data were obtained from different sources, but in most cases were provided by government agencies. In some cases, data was acquired via requests for information, i.e. through the Chilean freedom of information act.

http://www.ine.cl/estadisticas/demograficas-y-vitales

4. Results

4.1. A set of 29 urban sustainability indicators

Five sustainability categories were established: Access and Mobility (AMC), Environment and Sanitation (ESC), Governance (GC), Health (HC) and Social Equity (SEC). These categories emerged from the practical needs of the pilot team to manage the indicators when we got to the stage of calculating the indicator values for all six cities. They were formed by grouping the indicators by either assigning them to an existing category or by establishing a new one. While this grouping was

Table 2
Indicators grouped by sustainability category and their associated variables. For more detailed information on each indicator please see Appendix A and http://indicadores.cedeus.cl. Source: Authors.

Category	Indicator	Variable(s)
Access and Mobility (AMC)	Access to sports facilities	Percentage of urban population close to sports facilities (10 min walk).
	Access to cultural facilities	Percentage of urban population close to cultural facilities (30 min bus ride).
	Mode share	Percentage of travel by foot, bike, public transit, private car, and other.
	Travel time	Percentage of urban population that spends more than one hour per day travelling, considering all trip purposes.
	Accessibility to green spaces	Percentage of population living close to green spaces (5 min walk to green areas larger than 0.5 ha, or 10 min walk to areas larger than 2.0 ha).
Environment and Sanitation (EC)	Drinking water service quality	Index of drinking water service: standard compliance, service coverage, and service continuity.
	Wastewater treatment service quality	Index of wastewater treatment service: standard compliance, service coverage, treatment technology, and service continuity.
	Provision of green spaces	Total green space area per capita. These areas need to have a minimum size, may have vegetation and can be equipped, e.g. provide seating. "Green" also includes none or sparse, native vegetation of desert climates.
	Drinking water consumption	Annual average of daily water consumption per capita.
	Air quality	Annual average of daily PM2.5 concentration over the last 3 years.
	Energy consumption	Annual average of monthly energy consumption by household.
	Domestic solid waste	Annual domestic solid waste per capita in kg.
Governance (GC)	Participation in elections	Percentage of voting population that participated in the last municipal elections.
	Government response to request for information	Percentage of formal answers to freedom of information requests.
	Municipal budget dependence	Percentage of the municipal budget that comes from the inter-municipal transfer fund.
	Police emergency coverage	Percentage of urban population reachable within 5 min by car from a police station.
	Medical emergency coverage	Percentage of urban population reachable within 5 min by car from a medical emergency centre.
	Fire department emergency coverage	Percentage of urban population reachable within 10 min by car from a fire department.
Health (HC)	Effectivity of health services	Avoidable Mortality - i.e. percentage of deaths caused by failures in health prevention or care of insufficient quality.
	Adult health	Years of Potentially Life Lost (YPLL) - Sum of years lost for 100.000 people considering the OECD reference life expectancy of 70 years.
	Child health	Percentage of children (3–18 years old) considered obese or overweight.
	Access to farmers market	Percentage of population living within a 10 min walk to farmers market.
Social Equity (SEC)	Child poverty	Percentage of children living in poverty.
	Access to (online) information	Percentage of population with access to cable internet.
	Access to high quality education	Percentage of children receiving high quality education, with zero or low inscription fees (less than 20 USD per month) and within walking distance to their home (10 min walk).
	Women employment	Percentage of working woman, aged between 15 and 60 years old.
	Gender equity in employment	Percentage of women working in relation to the population of men working.
	Household overcrowding	Percentage of the population living in an overcrowded household.
	Informal settlements	Number of families that live in informal settlements.

applied for practical aspects, the Working Group also took steps to develop a set of general sustainability dimensions by analysing several existing sustainability frameworks, such as Daly's Triangle (Meadows, 1998) and the prism of sustainability (Valentin & Spangenberg, 2000), the dimensions of Chilean National Urban Development Policy (Spanish abbrev.: PNDU) published in 2015, or by employing the Driver-Pressure-State-Impact-Response framework of Hammond et al. (1995). However, none of these groupings of dimensions reflected well the local relevance of specific topics and indicators as identified during the focus group meetings.

Of the 29 indicators only 13 were listed in the original base set of 574 indicators; more than half, i.e. 16 indicators, were developed in response to the rounds of discussion among the experts. A further consideration is that several indicators can be assigned to more than one sustainability dimension. To favour such multi-faceted variables was a decision taken during the discussion rounds in order to provide a more comprehensive perspective of urban sustainability in a small indicator set. The final assigned category, as presented in Table 2, is the result of the grouping exercise. Appendix C outlines compliance of indicators to criteria established by several of the authors mentioned in Section 2 of this paper; revealing the challenges in terms of the final selection.

4.2. Characterisation of urban sustainability for the six cities

Results for each indicator and city are provided in Appendix A together with information about data sources, unit of measurement, and value range. Below we summarize the variable values using a spider diagram (Fig. 7) and graphs (Fig. 8) so that one can assess differences and similarities among cities and indicators. We note that for Fig. 7, variable values were transformed to provide a unique direction for sustainability with 100 (%) being positive, and 0 (%) indicating a sustainability or equity challenge (a deficit or negative). Details on the transformed variables can be found in Appendix B. Some of the variable values can also be compared to indicator values published by the OECD (Organisation for Economic Collaboration and Development). From this comparison, positive or negative performance regarding a sustainability aspect can be established. Looking at multi-city-averages and comparing these to OECD statistics improves the overall evaluation of national trends.

Fig. 7 reveals that the six Chilean cities perform well with respect to access to sports facilities and cultural facilities (AMC), effectivity of health services, i.e. avoidable deaths, (HC), geographical coverage of fire departments and responses by the government to information requests by citizen (GC), prevalence of low levels of household overcrowding (SEC), and good drinking water service quality (EC). Poorer performances are observed, for example, in geographical coverage of medical emergency services (GC), access to cable Internet (i.e. online information), access to high quality education, and female employment (SEC). Other indicators do not show a uniform performance across all six cities. These indicators with higher variability may rather express local differences of a geographic or economic nature.

Indicators that show high variability among cities are: accessibility to green spaces (AMC), which varies between 22% (Coquimbo) and 63% (Valdivia), and access to cultural facilities, with values between 24% (Valdivia) and 84% (Santiago). In the Government (GC) category

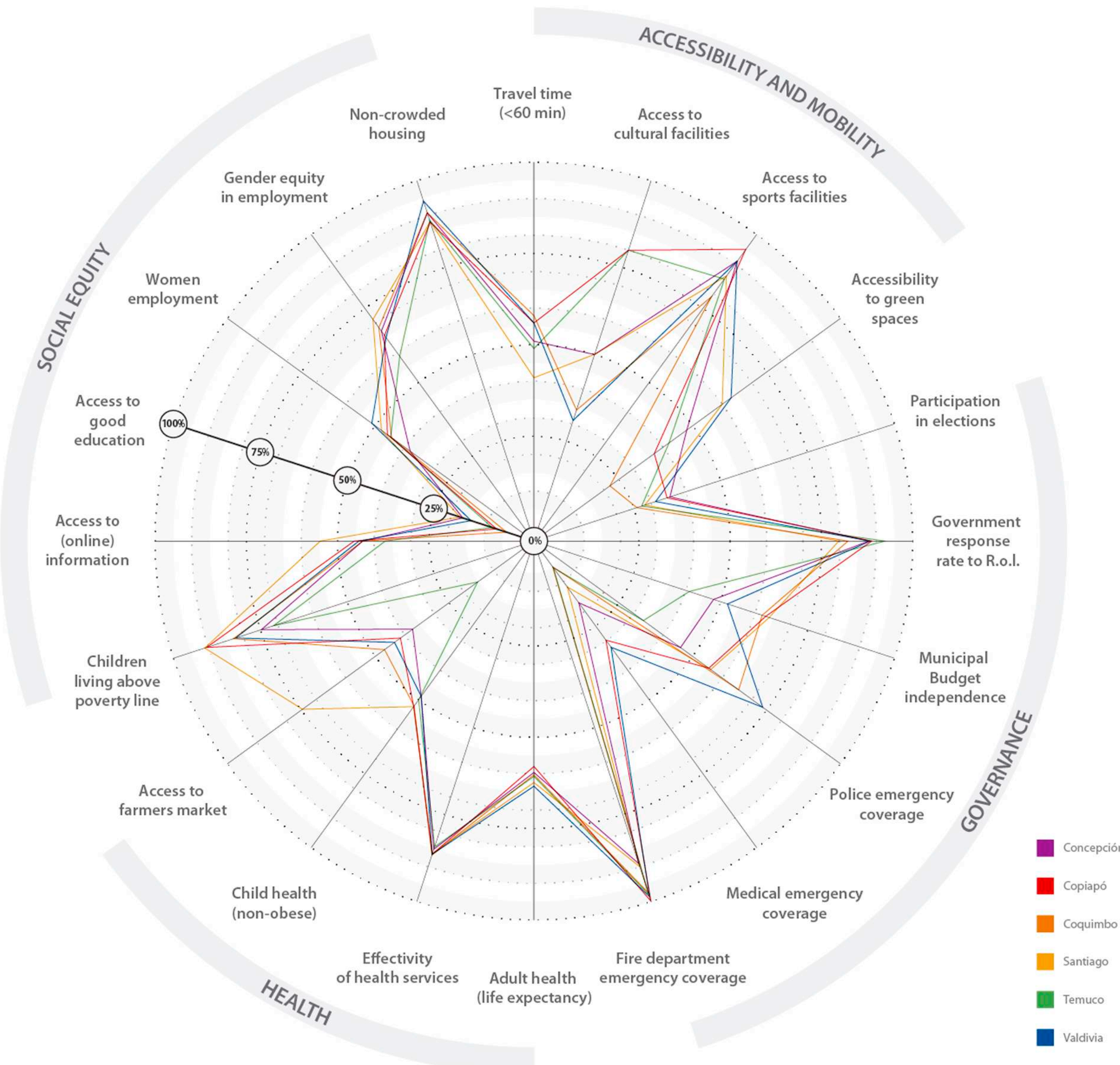

Fig. 7. Results for 20 of the 29 sustainability indicators for the six cities. We only present the 20 indicators where a value of 100% can be formulated as a sustainability goal. To achieve this, scales for some variables were transformed, e.g. inverted — see Appendix B for details. Source: Authors. (For interpretation of grey scales, i.e. colours, in this figure, the reader is referred to the web version of this article.)

the indicator that assesses geographical coverage of police service is the one with strongest differences, varying from 33% (Temuco) to 74% (Valdivia) population coverage. In the Health category (HC) access to farmers' markets, a source of fresh and economic food, varies from 15% (Temuco) to 75% (Santiago). In Environment and Sanitation (ESC) all indicators show very different results for each city, for example, annual daily average of concentrations of particulate matter PM2.5 varies from 14 $\mu g/m^3$ (Coquimbo) to 37 $\mu g/m^3$ (Temuco); and wastewater treatment service quality (a composed index with a 0–1 value range) varies from 0.27/0.29 in Coquimbo, Temuco and Valdivia, to 0.58/0.59 in Copiapó and Santiago. In the Social Equity Category (SEC) the quantity of families living in informal settlements varies from 0 (Temuco) to 5420 families (Concepcion).

The results do not indicate that a particular city can be considered much more sustainable or less sustainable than any other city. Each city exhibits at least one indicator with good performance, i.e. where it performs better than any other city. The same holds for poor performances, i.e. each of the six cities is performing worst in at least one variable. However, counting the number of best performances and worst performances for a city and analysing the ratio among both, enables the identification of more sustainable and less sustainable cities across the full range of indicators. If we assume that each indicator is of the same importance (i.e. all have the same weight), then the cities of Copiapó and Valdivia show the best sustainability ratios of 7:3 and 7:5 respectively; that is for 7 variables Copiapó shows the most sustainable values (i.e. ranks first), and shows worst values for 3 variables (i.e. ranks last) among the 6 cities. That both cities fare equally is remarkable, since they are characterised by different climatic zones: Copiapó is an inland desert city, while Valdivia is a green coastal city with an abundance of rain (see Table 1).

Fig. 8 shows differences among variable values that emerge from a city's geographic context (North-to-South, Coastal vs. Inland). For instance, air quality deteriorates from north to south as the climate cools and humidity increases in the winter months. Household water

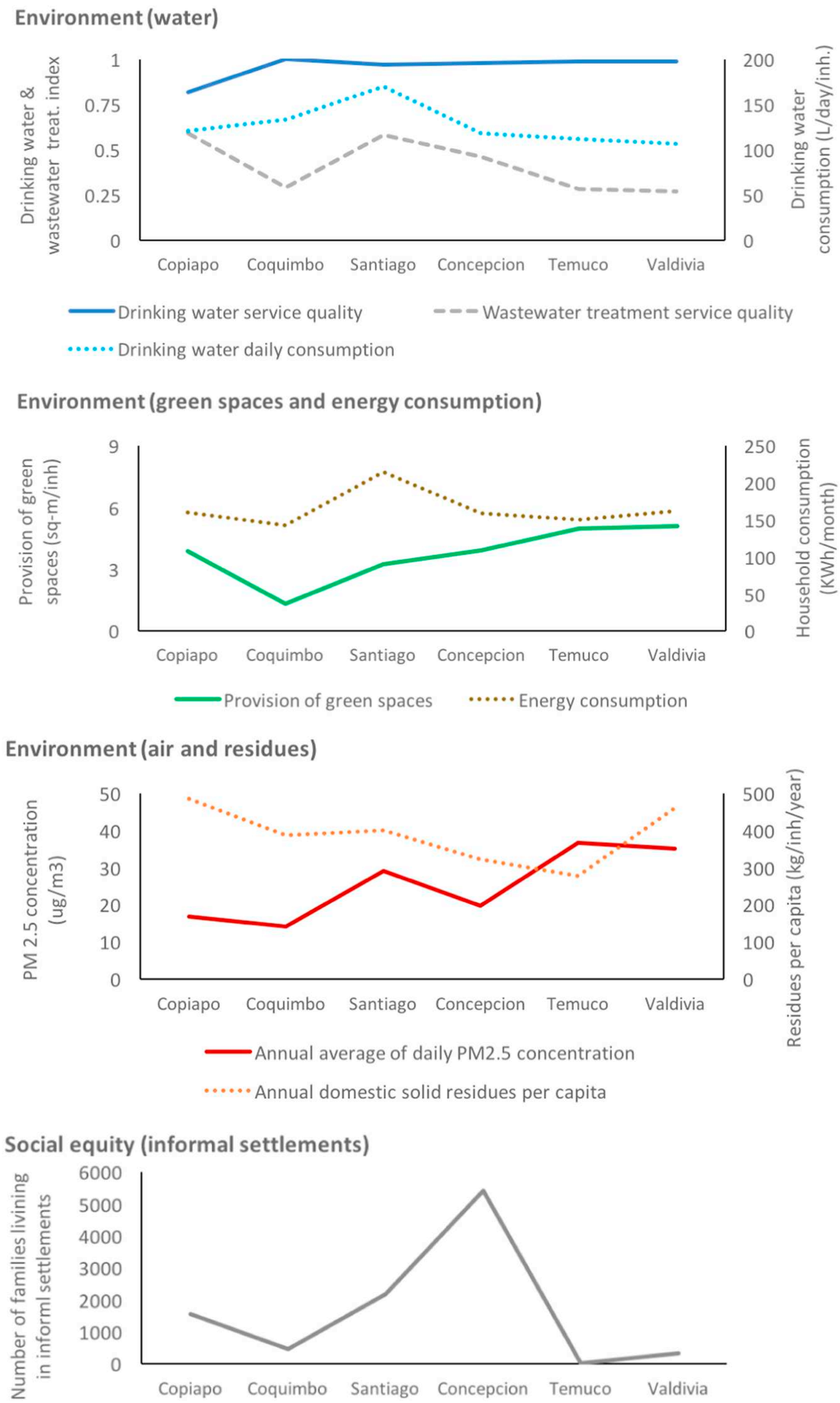

Fig. 8. Visualisation of Environment and Sanitation (ESC) indicators and the variable "Families living in Informal Settlements" for the six cities with a North (left) to South (right) perspective. Source: Authors.

consumption is also lowest in the three cities south of Santiago with more rainfall and less demand for green space irrigation. The strength of the local economy is visible when values for Municipal Budget Independence are compared: the cities in the north, with their mining activities, and Santiago, as the national service centre, are less dependent on funds from the inter-municipal transfer fund than the other three cities to the south.

The results table of Appendix A presents variable values at the city scale, but these can vary strongly within cities too, especially for the two metropolitan areas that are comprised of several municipalities (i.e. Santiago and Concepcion, see Table 1). Figs. 9 to 13 provide a more detailed picture for access to green space (AMC) as well as access to high quality education (SEC) using data at block scale, with child obesity (HC) and budget dependence (GC) at the municipal level.

The five maps show that there are strong geographical differences within a city (Figs. 9–13). For example, values given for an entire city for the indicator "Accessibility to Green Spaces" (AMC) and the indicator "Provision of Green Space" (in Figs. 7 and 8) are not able to convey that those living in peripheries or specific areas of Santiago and Concepcion actually lack access to green space — something that the

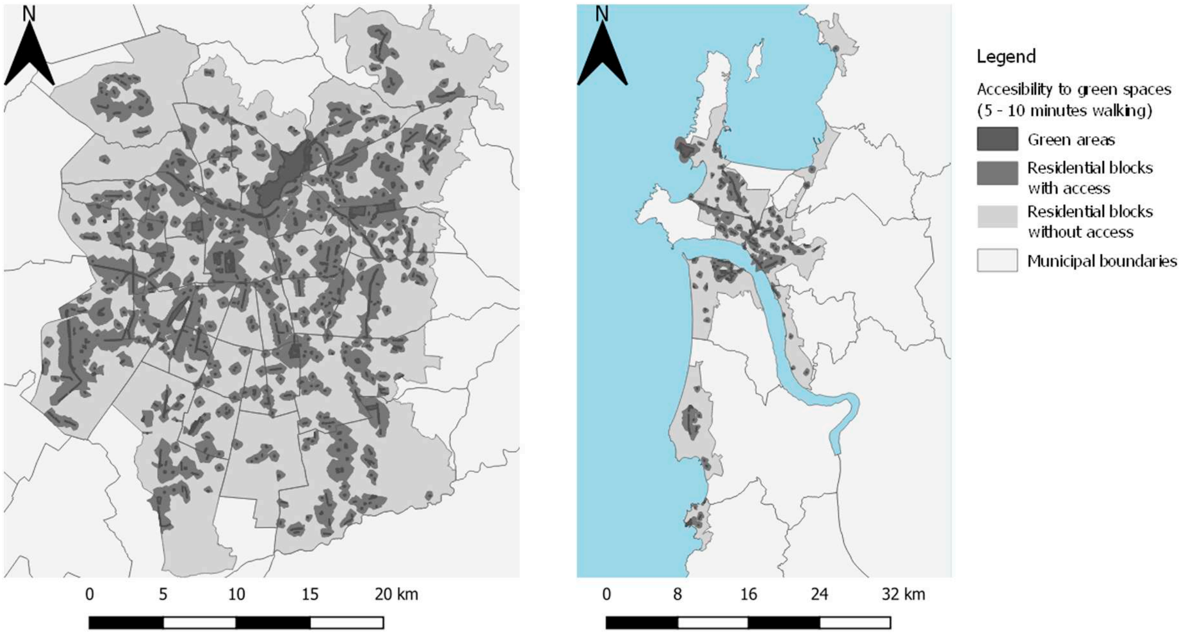

Fig. 9. Accessibility (10 min walk) to green spaces for Santiago (left) and Concepcion (right) calculated at street block scale. Source: Authors.

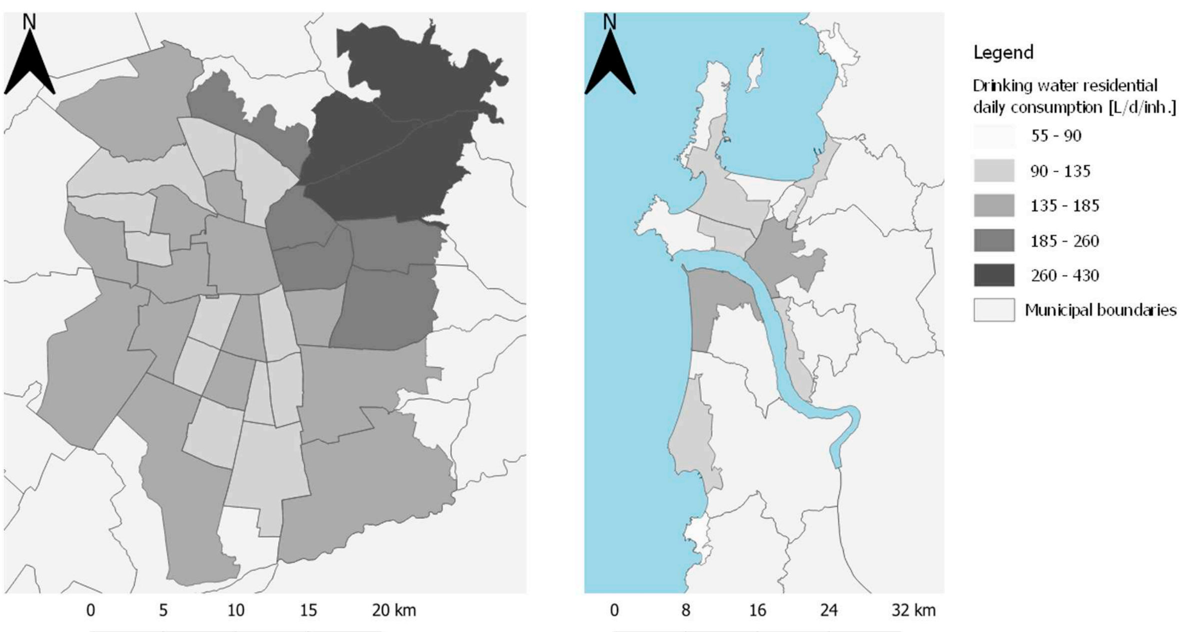

Fig. 10. Drinking water consumption per capita in Santiago (left) and Concepcion (right) at the municipal scale. Source: Authors, based on data from the Superintendencia de Servicios Sanitarios (SISS, 2015).

maps are able to show (Fig. 9). Similarly, we can see from Fig. 10 that water consumption (EC) is much higher in some municipalities of Santiago — in particular those (higher income) municipalities in the north-east that also have more green spaces. The maps in Fig. 11 that visualise budget autonomy (GC) show that peripheral municipalities of both metropolitan areas, except for the municipalities in the north-east of Santiago, are the ones that depend most on inter-municipal fund transfers. This spatial pattern is explained by the tax and licensing system of Chile, since the municipalities with high budget autonomy in the north-east of Santiago host the majority of company headquarters and Santiago's business districts, i.e. work places. Child obesity (HC), mapped in Fig. 12, seems to show a geographic pattern for Santiago with richer (north-east) and poorer (south-west) municipalities revealing lower versus higher obesity values correspondingly (see Fig. 11 for an income comparison). Access to schools that provide good education (quality education indicator, SEC) is imbalanced across large parts of the city, with a few municipalities that do not register one 'good' school within their municipal limits, according to our criteria

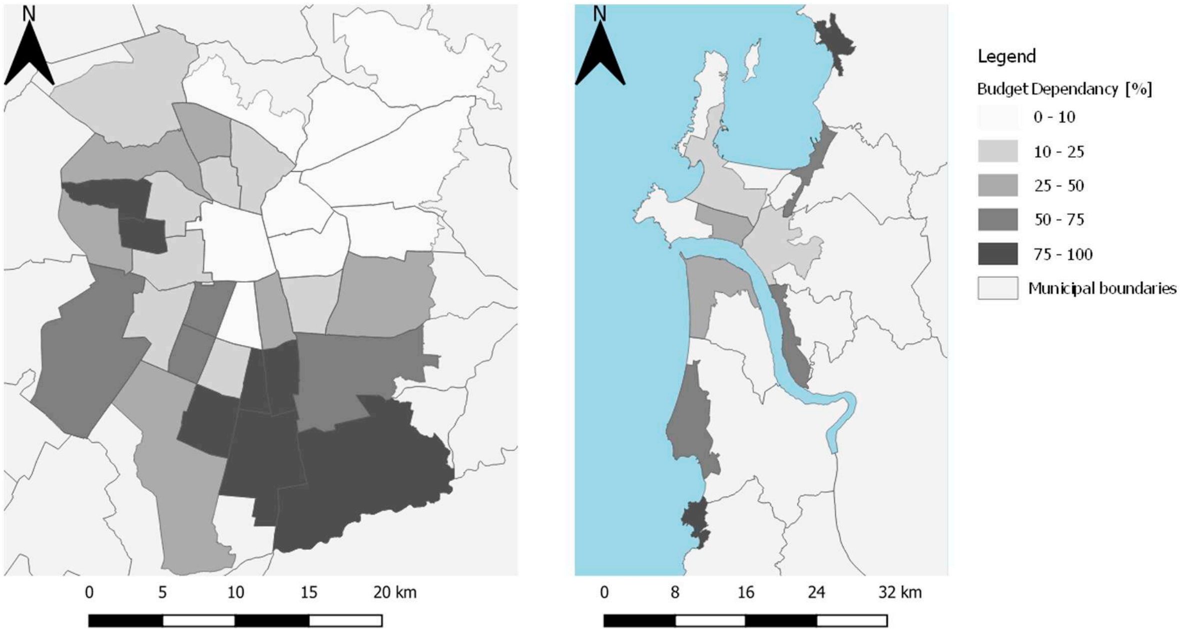

Fig. 11. Municipal budget dependence in the Santiago (left) and Concepcion (right) metropolitan areas. Source: Authors, based on data from the Sistema Nacional de Información Municipal (SINIM, 2016).

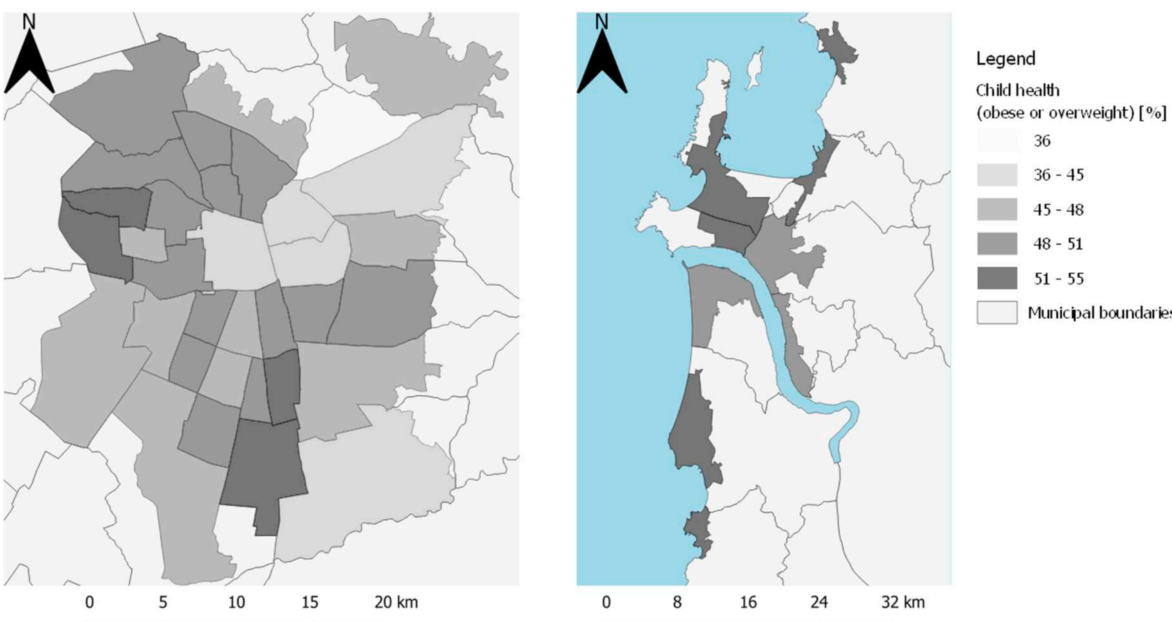

Fig. 12. Child obesity in Santiago (left) and Concepcion (right) at the municipal scale. Source: Authors, based on data from JUNAEB (2016).

that were adopted from the Ministry of Education (Fig. 13).

5. Discussion

5.1. Lessons from an expert-led process

The process of finding a set of indicators for Chilean cities involved a group of experts. Expert-led processes have defined the formulation of sustainability indicators since the early 1990s: 'top-down' and quantitative rather than 'bottom-up' and qualitative (see Bell & Morse, 2008); however, there are experiences of promoting discussion among other stakeholders, while community-level indicators should be encouraged so that they are relevant to the inhabitants and their immediate conditions. In the CEDEUS process, some of the indicators were used in a participatory process to evaluate social justice and equity in transport (Lucas, 2004; Sagaris, Tiznado-Aitken, & Steiniger, 2017), while a more general debate was triggered by press coverage of the release of the data, in particular by the indicators on accessibility, health, and household waste production. The next stage of the process is the discussion of 'meaningfulness' and this will involve municipal planners and community organisations. To date, the meaningfulness lies in their incorporation in the work of the National Council for Urban Development (CNDU) in their pursuit of an official set of indicators in conjunction with the National Statistical Institute (UNDP, 2017).

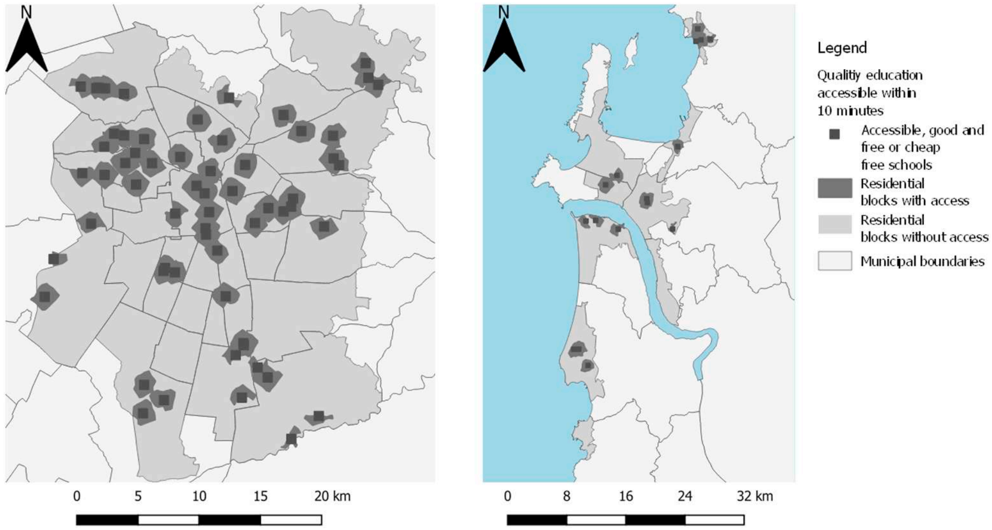

Fig. 13. Access to high quality education in Santiago (left) and Concepcion (right), calculated at street block scale. Source: Authors, based on data from the Ministry of Education (MINEDUC, 2016).

Many difficulties in defining the set of indicators were experienced by the Working Group in the described process, such as a lack of data, information gaps, and uncertainties (see also Appendix C). These issues have been recognised by different authors to be some drawbacks of using indicators later on (Komeily & Srinivasan, 2015; Rinne et al., 2013). This means that indicator sets are rarely as extensive or inclusive as initially planned. In our case, and to address this problem, the indicators and variables were refined following an iterative process including selection, prototyping and discussion phases. However, although the set of indicators can be developed from a rational and abstract conception, reality limits implementation and, consequently, their meaningfulness; it might be argued that the objective of a small indicator set exacerbates all of these factors.

The composition of the expert Working Group also influenced the nature of the process, due to the influence of particular disciplines and research interests. Two apparent weaknesses of the CEDEUS indicator set are, the relative absence of economic indicators and the emissions data. Economic indicators appear in other sets, e.g. CityKeys, ISO 37120, and Casbee for Cities, and are placed in the CEDEUS indicator set in the categories of equity and governance. These are: child poverty, municipal budget dependence, woman employment, and households with cable internet. Indeed, the candidate set of 79 indicators retained an explicit economic category containing 7 indicators. Rather than measuring intermediate economic factors, the objective is to establish economic outcomes within the urban areas, hence these economic impact indicators. In terms of emissions data, and particularly carbon emissions, the decision to not engage with this indicator is a consequence of two related factors, despite the availability of different methodologies, such as in the WRI-WBCSD Greenhouse Gas Protocol, Carney, Green, Wood, and Read (2009) and Kennedy, Steinberger, Gasson, Hansen, et al. (2009). The first relates to data availability to ground these methodologies in Chilean cities, since insufficient public information exists in order to generate a carbon emissions inventory at the urban scale (which limits comparability). The second relates to issues of urban reach, given the role of urban-rural dynamics, and the incorporation or exclusion of extra-urban flows and periphery factors such as landfills and land use change ('border effects'). Currently there is no agreed methodology for measuring urban carbon in Chile. This difficulty is recognised globally since urban carbon emissions per se are not included in the urban SDGs (Chapter 11).

5.2. The CEDEUS indicators and links to the sustainable development goals

When the first round of meetings of the Working Group took place in 2014, proposals for the 17 UN's Sustainable Development Goals and 169 targets were under revision; the SDGs were not ratified until 2015. Consequently, the SDGs were not part of the initial listing of 574 indicators and the process of indicator selection, development, and revision – resulting in a set of 21 indicators by April 2016 – was rather run in parallel with, rather than informed by, the UN process. Now that the 2030 Agenda goals and indicators are published, we are able to compare both sets and analyse our 29 indicators in terms of the potential contributions of the CEDEUS Indicators to the 17 sustainable development goals (Table 4) in urban contexts.

With respect to the first analysis of SDG indicators against the CEDEUS Indicators, we found that 3 indicators are similar or equivalent to SDG indicators. These three indicators are: Air Quality (PM2.5, SDG 11.6.2), Child Health (Overweight and Obesity in Children, SDG 2.2.2), and Poverty (Child Poverty, SDG 1.2.1). We note that the respective SDGs assess the situation in much more detail by either adding complementary indicators, e.g. PM10 for air quality, or by expanding variables to include further age groups and distinguish by sex. A group of 13 indicators can be found to be similar, but not directly equivalent, to SDG indicators. These include water and wastewater service quality (SDG 6.1.1, 6.3.1), domestic solid waste (SDG 11.6.1), avoidable mortality (SDG 3.4.1), and female employment (SDG 8.5.2). Comparing those 'similar' indicators we found that the SDGs do not assess the continuity aspects of water services, or details on urban transport, i.e. urban mode shares. For the remaining 13 indicators, we found few links to the SDGs (see Table 4). This includes, in particular, all five indicators of the accessibility and mobility category, and others such as household overcrowding and green space per capita. From our perspective the SDG indicators fall short by assessing accessibility to different types of basic services (education, health, culture, parks, etc.) only at a general level or, perhaps, not at all, as with green spaces or culture, despite their declared importance for urban dwellers.

Changing the perspective, from SDG indicator level to the 17 principal goals, we are able to assign each of the 29 indicators to a particular SDG. Most of the indicators can be assigned to several SDGs as seen in Table 4, reflecting their multi-dimensionality from a sustainability approach. However, not all of the 17 SDGs are covered. The two

Table 4
Indicators and their relationship to the Agenda 2030 17 sustainable development goals and indicators. Qualification: +: fully compatible, o: somewhat compatible, −: incompatible.

Category	Indicator/variable	Compatibility with SDGs	Possible SDG contribution (goal #)
Environment and Sanitation	Drinking water consumption	o (6.4.1)	6, 12, 13
	Drinking water service quality	o (6.1.1)	6
	Wastewater treatment service quality	o (6.3.1)	6
	Air quality	+ (11.6.2)	3, 10, 11, 12, 13
	Domestic solid waste	o (11.6.1)	11, 12, 13
	Energy consumption	o (7.2.1)	12
	Green spaces	− (11.7)	3, 10, 11, 13, 15
Health	Avoidable mortality (health system)	o (3.4.1)	1, 3
	Years of potential life lost YPLL (adult health)	o (3.4.1)	1, 3
	Child obesity	+ (2.2.2)	3
	Access to farmers market	− (2.1)	2, 3, 10
Social Equity	Household overcrowding	− (11.1.1)	1, 3, 10, 11
	Informal settlements	o (11.1.1)	1, 3, 10, 11
	Child poverty	+ (1.2.1)	1, 2, 3, 4, 10
	Woman employment	o (5.5.2 /8.5.2)	8, 10
	Gender equity in employment	o (5.5.2 /8.5.2)	5, 8, 10
	Access to cable Internet	o (17.6.2)	4, 8, 10, 17
	Access to high quality education	o (4.1)	4, 10
Access and Mobility	Access to green spaces	− (11.7)	3, 10, 11
	Access to sport facilities	− (11.7)	3, 10, 11
	Access to cultural facilities	− (11.4, 8.9)	4, 10, 11
	Transportation mode share	− (9.1.2, 11.2.1)	1, 3, 9, 10, 11, 13
	Travel time	−	3, 10, 11
Governance	Police emergency coverage	− (16.1)	10, 11, 16
	Fire department emergency coverage	−	11, 13
	Medical emergency coverage	− (3.8)	3, 10, 11
	Participation in elections	− (11.3.2, 16.7)	11, 16
	Response to request for information	o (16.6.2, 16.10)	10, 11, 16
	Municipal budget dependence	− (17.1.2)	1, 8, 9, 10, 17

SDGs: 1—No poverty (count: 6), 2—Zero hunger (count: 2), 3—Good health and well-being (count: 14), 4—Quality education (count: 4), 5—Gender equality (count: 1), 6—Clean water and sanitation (count: 3), 7—Affordable and clean energy (count: 0), 8—Decent work and economic growth (count: 4), 9—Industry, innovation and infrastructure (count: 2), 10—Reduced inequalities (count: 16), 11—Sustainable cities and communities (count: 14), 12—Responsible consumption and production (count: 4), 13—Climate action (count: 5), 14—Life below water (count: 0), 15—Life on land (count: 1), 16—Peace, justice and strong institutions (count: 3), 17—Partnerships for the goals (count: 2).

goals that are not covered are Goal 7 — Affordable and Clean Energy, and Goal 14 — Life Below Water (in spite of three of the selected cities being coastal). This is due to the urban focus of the CEDEUS Indicators in the latter case, but also due to the need to arrive at a small indicator set, in comparison with the 232 SDG indicators.

The CEDEUS Indicators contribute the most to Goal 10 of "reduced inequalities", with 16 CEDEUS indicators that are able to measure inequalities at the urban scale. Among these 16 are, for instance, child poverty, the five accessibility indicators (sports, culture, transport, etc.) and access to high quality education. The concentration of indicators that measure inequalities does not seem surprising, considering that Chile has one of the highest Gini co-efficient inequalities in the world, alongside several other Latin American countries, and that the region has one of the highest urbanisation rates, therefore inequality is also, per se, an urban challenge (OECD, 2016).

The second highest contribution is to SDG 3 for "Good Health and Wellbeing" and SGD 11 for "Sustainable Cities and Communities". For each of these two Goals there were 14 contributing indicators. Indicators that measure aspects of health and well-being include not only the 4 indicators of the health category, but also the indicators of accessibility, child poverty, informal settlements, and household overcrowding; UN Habitat estimates that about 24% of the urban population live in informal settlements in Latin America and the Caribbean region (UN-Habitat, 2015). The 14 indicators that support Goal 11 of "Inclusive, safe, resilient and sustainable cities and human settlements" are almost the same indicators as those of Goal 3 of Good Health and Well-being. This is no surprise since one can say that sustainable communities are also healthy communities.

6. Conclusions

Despite a growing interest in measuring and assessing urban sustainability, many countries still lack a relevant indicator set. The complexity and duration of the CEDEUS process reveals why this may have hindered similar exercises elsewhere. For example, to prioritise among the indicators of an initial set of 574 indicators, and to develop the measurement variables for each indicator, we needed to employ different techniques and methods. Another risk is the stigmatisation of cities once they are ranked by results. The intention here was not to rank, but to identify areas of urban development that should be targeted for improvement in relation with other themes and other cities, e.g. the indicator wheel in Fig. 7 shows where a city might improve – by reaching either the value of 100 – i.e. in most cases equal to 100% of the population being covered or – alternatively – by striving to be on a par with similar cities, by size, economic structure or climatic zone.

With respect to comparison and benchmarking the CEDEUS indicators do not only incorporate the attributes of a city in terms of culture, sports, or green space, but also measure the percentage of the population that can actually reach them by using sustainable transport modes in a reasonable amount of time. Including these indicators not only provides a personal (accessibility) perspective for citizens and planners, but it also helps to identify inequalities within cities and across cities. Given the strong disparities of income in Chile, and in other countries in the Global South, these indicators are of particular importance for assessing and monitoring changes in socio-economic segregation. It comes therefore as a surprise that the SDGs do not define indicators that assess accessibility, except to public transport. While there are some overlaps between the SDGs and the CEDEUS Indicators, there are some key differences also. The intention should be to support global indicator processes while, at the same time, promoting locally-relevant indicators that are pertinent to local decision-making processes and concerns (see Simon et al., 2016). The overlaps between both systems provide an opportunity to scale-up and scale-down the monitoring and evaluation processes of urban development in Chile, and across the Global South.

We also identify a lack of SDG indicators that evaluate the temporal continuity of basic services such as water, electricity or gas since, at least in Chile, services may be interrupted at the slightest change of weather conditions over hours or days. However, we have to admit that our indicator set only accounts for service continuity in the case of water services. In other areas of the SDGs where the CEDEUS indicators run in close connection, specific challenges are made explicit, such as gender equity and waste management (once the data deficits in these fields have also been addressed).

Policy makers and planners should be motivated by strategic objectives for targeting investment. In the Chilean case, the CNDU is responsible for implementing the National Urban Development Policy, and it has to do so with the full participation of local authorities and other stakeholders. While it would be idealistic to assume that planning is a rational process without political motivations, and that improved data and indicators will *determine* decision-making processes, the generation of a nationally and locally-relevant indicator set should support more robust governance and a clearer local agenda for urban sustainable development. As a contribution to urban policy and management, the expectation is that this indicator set has sufficient qualities to be adapted to other urban realities, particularly in Latin America and across the Global South.

The set of 29 indicators captures the quality of life and sustainability dimensions of Chilean urban development, based on current data availability. Inconsistencies in data quality, e.g. representativeness, and availability, e.g. long periods between surveys, hinder the use of particular datasets and, for a country undergoing rapid urban and institutional change, these considerations make assessment and monitoring complicated. It is therefore important to reflect on different survey methods that are used by public institutions in particular, for representativeness and frequency. Given the silo-based logic of data collection by public institutions, by ministry or municipality for instance, a role of indicator sets such as this is to stimulate awareness of data gaps and the need for long-term funding on data collection, updating, sharing and integration among public and private institutions. Within market-based urban service delivery models, which predominate in Chile, data on household coverage and consumption remains private data, which poses considerable problems in terms of the potential use of data for integrated planning. Private concessions for public utilities should include data sharing in order for this to take place.

7. Policy recommendations

The final points in this paper relate to the lessons learnt from the development of the methodology for the CEDEUS Indicator Set, and their relevance for understanding the value and limitations of indicators in urban policy and practice. Given the importance of indicators in international development objectives, through the SDGs, and in light of the need to monitor progress against the objectives for urban development outlined in the New Urban Agenda, and the National Urban Development Policy in Chile, the paper presents issues that are relevant not only to the CEDEUS indicators but to others that are being developed for other cities in the Global South.

The lessons that were learnt from the specific CEDEUS methodology were that there are often options of variables for the same indicator. This selection process is complex and is open to interpretation; it is also dependent on data quality. For example, the design of indicator sets without reference to available data, or without a commitment to data collection for these variables based on robust criteria, serves no purpose for urban development. Where data exists, pilot testing is required to assess how robust and sensitive these variables are for assessing different urban and temporal contexts. In the case of the SDGs, and SDG 11 for cities in particular, many are difficult to implement at the scale of cities, given data quality and clarity in territorial boundaries. In order to capture the specificities of the city and manage this scale of indicator construction, indicator sets that are built for this scale are required. This flies in the face of the tradition of national level indicator sets, whether GDP, HDI, IPCC inventories, MDGs or SDGs. The temporal dimension of indicator development is important in contexts where shocks occur, such as earthquakes or tsunamis, that affect the supply of basic services, hence the need to seek ways in which this consideration can be incorporated more effectively.

Cities are in themselves aggregates of neighbourhood diversity and complex urban-rural flows, therefore the development of indicators that can facilitate appropriate policy measures is the proof of the effective indicator set. The target audience has to be the potential users of indicators for policy implementation and for the wider public to assess change through time. Many SDGs lack this local relevance, therefore they need to be complemented with indicators that relate to local contexts and quality of life specificities. In the case of the CEDEUS indicators, results have been communicated through press releases and press coverage in accessible language and with infographics designed to translate complex issues with as much clarity as possible to non-specialists.

The complexity of urban development and the multiplicity of potential stakeholders for indicator uses have to be managed with interdisciplinary teams and the involvement of experts for appropriate variable selection. Since the indicator set has to be appropriate, limited and feasible, the role of these experts is also to engage with other disciplines in order to prioritise indicators and understand the relative value of inclusion of others that are covered by other disciplines and areas of specialism, as well as explaining the prioritisation decisions and the value of indicators to non-expert groups. Rather than the abstract creation of an indicator set, the utility of the methodology presented in this paper is that it has undergone a critical assessment following piloting and wider discussion among different stakeholder groups.

For the challenges of urban development highlighted in Agenda 2030, the New Urban Agenda and the Chilean National Urban Development Policy, the prioritisation of effective indicator sets for examining change through time that is highly context specific, will be vital. The CEDEUS Indicator Set offers both a methodological contribution, and a data set, to support this process in Chile.

Access to indicator details and data

The CEDEUS Indicators and further details of the methodology are available in Spanish at: http://indicadores.cedeus.cl. Elaborated indicator calculation scripts in the R language are hosted at the centers GitHub account (https://github.com/CEDEUS/city-indicators-calculation-scripts), and most of the data is made available via CEDEUS' research data infrastructure (http://datos.cedeus.cl).

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Appendix A. Indicators, variables, sources and results for each city. Source: Authors

Category	Indicator	Variable(s)	Variable/data source	Unit	Range (interpretation)	Copiapó	Coquimbo	Santiago	Concepción	Temuco	Valdivia
Access and mobility (AMC)	Access to sports facilities	% of urban population close to sports facilities (10 min walk)	Own elaboration based on MINDEP (2016)	%	0 to 100 (the higher the better)	95%	79%	86%	91%	85%	91%
	Access to cultural facilities	% of urban population close to different types of culture and arts facilities (15 min walk, or 30 min bus ride)	Own elaboration based on CNCA (2015)	%	0 to 100 (the higher the better)	n/a (80% by car)	34%	50%	50%	80%	31%
	Transportation mode share	% of weekly trips done with a particular transport mode	MTT (2010, 2012, 2013)	%	0 to 100						
		Walk				30	31	30	24	22	18
		Bike				1	1	3	n/a	2	2
		Public Transit				33	32	38	40	36	33
		Private/car				35	32	25	31	38	46
		Other				1	2	5	5	2	1
	Travel time	% of population that spends more than 1 h per day travelling considering all trip purposes	Own elaboration based on MTT (2010-2013)	%	100 to 0 (the lower the better)	44%	42%	59%	49	51%	44%
	Accessibility to green spaces	% of population living close to green spaces (5 min walking to green spaces larger than 0.5 ha or 10 min walking from green spaces larger than 2.0 ha)	Own elaboration after Reyes-Päcke and Figueroa Aldunce (2010)	%	0 to 100 (the higher the better)	37%	22%	55%	48%	42%	63%
Environment and Sanitation (ESC)	Drinking water service quality	Composed index of drinking water service: quality standards compliance, service coverage, service continuity	Own elaboration based on SISS (2015)	–	0 to 1 (the higher the better)	0.82	1	0.97	0.98	0.99	0.99
	Wastewater treatment service quality	Composed index of sewage treatment service: quality standards compliance, service coverage, service continuity, treatment technology	Own elaboration based on SISS (2015)	–	0 to 1 (the higher the better)	0.59	0.29	0.58	0.46	0.28	0.27
	Provision of green spaces	Total area of green spaces per capita	Own elaboration based on Reyes et al. (2014)	m^2/inh.	The higher the better	3.9	1.3	3.3	3.9	5.0	5.1
	Drinking water daily consumption	Annual average of daily water consumption per capita	Own elaboration based on SISS (2016)	L/day/inh.	The lower the better	120	133	170	118	111	106
	Air quality	Annual average of daily PM2.5 concentration for the last three years	Own elaboration based on SINCA (2014-2016)	μg/m^3	The lower the better	17	14	29	20	37	35
	Energy consumption	Annual average of monthly energy consumption by household	Own elaboration based on MINERGIA (2015)	KWh/month	The lower the better	160	143	214	159	151	162
	Domestic solid waste	Annual domestic solid waste per capita in kg	GORE Coquimbo (2015), MINSAL (2015)	kg/inh.	The lower the better	485	388	400	321	278	460

Governance (GC)	Participation in elections	% of voter population that participated in the last election	SERVEL (2016)	%	0 to 100 (the higher the better)	35%	26%	28%	35%	27%	31%
	Government response to request for information	% of formal answers to freedom of information requests	Portal Transparencia (2016)	%	0 to 100 (the higher the better)	89%	82%	80%	88%	92%	88%
	Municipal budget dependence	% of municipal budget that comes from the inter-municipal transfer fund	SINIM (2016)	%	100 to 0 (the lower the better)	37%	38%	36%	52%	59%	48%
	Police emergency coverage	% of population reachable within 5 min by car from a police station	Own elaboration based on IDE (2016)	%	0 to 100 (the higher the better)	56%	66%	56%	46%	33%	74%
	Medical emergency coverage	% of population reachable within 5 min by car from a medical emergency center	Own elaboration based on MINSAL (2016)	%	0 to 100 (the higher the better)	30%	5%	12%	17%	5%	32%
	Fire department emergency coverage	% of population reachable within 10 min by car from a fire department	Own elaboration based on Google Maps (2016), Bomberos de Chile (2016)	%	0 to 100 (the higher the better)	100%	97%	80%	89%	98%	99%
Health (HC)	Effectivity of health services	Avoidable mortality — i.e. percentage of deaths caused by failures in health prevention or care of insufficient quality	Own elaboration based on DEIS (2014)	%	100 to 0 (the lower the better)	14%	13%	14%	15%	16%	14%
	Adult health	Years of Potentially Life Lost (YPLL) considering a reference life expectancy of 70 years.	Own elaboration based on DEIS (2016)	years	The lower the better	3293 (w)	3301	3366	3560	3499	3574 (L)
	Child health	% of children (3–18 years old) considered obese or overweight	Own elaboration based on JUNAEB (2016)	%	100 to 0 (the lower the better)	48%	48%	48%	51%	50%	51%
	Access to farmers market	% of population living within a 10 min walk to farmers market	Own elaboration based on ASOF (2017)	%	0 to 100 (the higher the better)	42%	47%	75%	37%	15%	44%
Social equity (SEC)	Child poverty	% of children living in poverty	MDS (2015)	%	100 to 0 (the lower the better)	9%	17%	14%	25%	29%	18%
	Access to (online) information	% of population with access to cable internet	INE (2012)	%	0 to 100 (the higher the better)	53%	51%	56%	53%	51%	57%
	Access to high quality education	% of children having access to high quality education with zero or low inscription fees within a 10 min walk	Own elaboration based on MINEDUC (2016)	%	0 to 100 (the higher the better)	7%	4%	18%	17%	8%	14%
	Women employment	% of women, aged between 15 and 60 years, working	INE (2016)	%	0 to 100 (the higher the better)	46%	45%	48%	38%	45%	51%
	Gender equity in employment	% of women working in relation to the population of men working	INE (2016)	%	0 to 100 (the higher the better)	66%	69%	71%	67%	58%	65%
	Household overcrowding	% of population living in over-crowded households	CASEN (2015)	%	100 to 0 (the lower the better)	12%	9%	12%	9%	11%	6%
	Informal settlements	Number of families that live in informal settlements	TECHO (2016)	–	The lower the better	1562	442	2180	5420	0	328

Appendix B. Indicators and variables with transformed, e.g. inverted percentage scales, for better representation in Fig. 7. Source: Authors

Category	Indicator	Variable(s)	Variable/data source	Unit	Range (interpretation)	Copiapó	Coquimbo	Santiago	Concepción	Temuco	Valdivia
Access and mobility (AMC)	Travel time	% of urban population that spends *less* than 1 h per day travelling	Own elaboration based on MTT (2010 – 2013)	%	0 to 100 (the higher the better)	56%	58%	41%	51%	49%	56%
Governance (GC)	Municipal Budget Independence	% of municipal budget that does not come from inter-municipal funds transfer system	SNIM (2016)	%	0 to 100 (the higher the better)	63%	62%	64%	48%	41%	52%
Health (HC)	Effectivity of health services	% of deaths with natural cause (i.e. non-preventable deaths)	Own elaboration based on DEIS (2014)	%	0 to 100 (the higher the better)	86%	86%	86%	85%	84%	86%
	Adult health	% of population reaching OECD life expectancy (70 years)	Own elaboration based on DEIS (2014)	%	0 to 100 (the higher the better)	58%	60%	62%	60%	61%	63%
	Child health	% of children (3–18 years old) with normal weight conditions	Own elaboration based on JUNAEB (2016)	%	0 to 100 (the higher the better)	52%	52%	52%	49%	50%	49%
Social equity (SEC)	Child poverty	% of child population living above the poverty line	MDS (2015)	%	0 to 100 (the higher the better)	91%	83%	86%	75%	71%	82%
	Non-crowded housing	% of urban population do not live in crowded households	CASEN (2015)	%	0 to 100 (the higher the better)	88%	91%	88%	91%	89%	94%

Appendix C. Indicators and their compliance to (selection & data) criteria. Qualification: +: fully compliant, o: somewhat compliant, −: non-compliant

Indicator/variable	Concept simplicity	Relevance to personal life	Comparability with Standards	Data availability	Contribution to SDGs	Sensitivity (city vs. city)	Geographical coverage	Yearly data update	Data representativeness	Ease of value interpretation (good vs. bad)	Transparency (data + methods)
Drinking water consumption	+	+	+	+	+	+	o	+	o	+	+
Drinking water service quality	−	+	−	+	+	+	o	+	o	o	o
Wastewater treatment	−	o	−	+	+	+	o	+	o	o	o
Air quality	+	+	+	+	+	+	o	+	o	o	+
Domestic solid waste	+	+	+	o	+	+	o	o	o	+	+
Energy consumption	+	+	+	+	+	+	+	+	+	+	+
Green spaces	+	+	+	o	+	+	−	−	o	+	+
Health system (av. mortality)	o	+	+	+	+	o	+	+	+	+	+
Adult health (YPLL)	o	+	+	+	+	+	+	+	+	−	+
Child obesity	+	+	+	+	+	+	o	+	o	+	+
Access to farmers market	+	+	−	+	+	+	o	o	o	+	+
Household overcrowding	+	+	+	o	+	+	+	+	o	+	+
Informal settlements	+	o	−	o	+	+	o	o	+	+	+
Child poverty	+	+	+	+	+	+	+	+	o	+	+
Woman employment	+	+	+	+	+	+	+	+	+	+	+
Gender equity in employment	+	o	+	+	+	+	+	+	+	o	+
Access to cable Internet	+	+	o	+	+	+	+	−	o	+	+
Access to education	+	+	−	+	+	+	+	+	+	+	o
Access to green spaces	+	+	o	o	+	+	−	−	o	+	o
Access to sport facilities	+	+	−	o	+	+	+	o	+	+	o
Access to cultural fac.	+	+	−	o	+	+	+	o	o	+	o

	Simple	Pers. life	Standards	Data avail.	SDG	Sensitivity	Coverage	Yearly data	Represent.	Interpretation	Transparency
Transportation mode share	+	o	+	o	+	+	o	−	o	+	+
Travel time	+	+	+	o	+	+	o	−	o	+	+
Police coverage	+	+	o	+	+	+	+	o	+	+	o
Fire services coverage	+	+	o	+	+	+	+	+	+	+	o
Medical emerg. coverage	+	+	o	o	+	+	o	o	o	+	o
Participation in elections	+	+	+	+	+	+	+	+	+	+	+
Response to req. of info.	+	+	o	+	+	+	+	+	+	+	+
Mun. budget dependence	+	o	o	+	+	+	+	+	+	+	+
Sum score +	25	24	15	19	29	28	16	17	13	24	20
Sum score o	2	5	7	10	–	1	11	7	16	4	9
Sum score −	2	–	7	–	–	–	2	5	–	1	–

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