UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA

Advancing knowledge on Environmental Health in urban settings. From evidence to designing a tool to improve environmental health monitorization in Lisbon.

Marta Alexandra Mendes Salgado

Orientador(es): Prof. Doutora Mónica Duarte Oliveira

Prof. Doutor Paulo Jorge da Silva Nogueira

Engª Anália Torres (enterprise tutor)

Tese especialmente elaborada para a obtenção do grau de Doutor em Tecnologias da Saúde – Especialidade em Saúde Ambiental

2022

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ABSTRACT

Environmental health (EH) is influenced by complex interactions between health and the built and natural environments, there being little research on its specificities in urban settings. The accelerated urbanization and industrialization have created EH problems that threaten sustainable environment development and affect our health. The monitorization of these interactions to improve EH became a priority to local authorities and industries. Nevertheless, there is a gap in knowledge about which environmental indicators are suitable for monitoring EH in urban settings. This deficit hinders national and local interventions from improving EH. With the overall objective of advancing knowledge towards the monitorization of EH in Lisbon as a case study, three different studies were performed:

Study 1) Aimed to systematically review key environmental determinants and respective dimensions and indicators, evaluate population health in urban settings, and understand their potential implications into policies. A literature search published between 2008 and 2018 was conducted, resulting in 94 studies of varied methodological approaches. The review identified positive associations between the socioeconomic, built environment, natural environment, healthcare, behaviors determinants, and health outcomes - overall mortality and morbidity, in urban settings. Improvements in income, education, air quality, occupation status, mobility, and smoking habits indicators impact overall mortality and chronic diseases' morbidity indicators.

Study 2) Aimed at selecting the indicators suitable to monitor and assess EH in Lisbon city. This study was informed by evidence derived from a systematic review of literature and data from Lisbon and Portuguese databases. 12 Portuguese experts analyzed the data in individual semi-structured interviews to identify the relevant indicators and emerging issues in the Lisbon urban setting. The outputs from the interviews were validated by a two-round Web-Delphi process with a panel of 22 experts from different areas of expertise. Seventeen indicators were validated in the Web-Delphi process. The results from the adopted participatory approach point out gaps in the collection of noise and mobility indicators data and raise emerging issues on housing indicators that require further research.

Study 3) Aimed at defining requirements for a dashboard to inform decision-makers analysing and visualizing EH information using the context of Lisbon city as an example. A user-centred approach was employed to engage end-users and to collect their visualisation preferences. Three online semi-structured group interviews with eleven potential end-users from different organisations were conducted using design cards with visualisation options regarding 17 indicators of built and natural environment determinants. The feedback obtained from the semi-structured interviews was synthesised into a framework with eleven requirements to design a dashboard to monitor EH in Lisbon.

In conclusion, the work in this dissertation identified the key indicators to monitor EH in the Lisbon urban context and set a framework to inform the design of a monitorization dashboard. The combined methodology described in this work can be used to inform the design of decision-aid tools to monitor EH in urban settings. It could serve as a reference for other researchers for other contexts.

The improvement of EH could help alleviate the healthcare burden and have multiple co-benefits in economic development, improvement of industry-related processes, and climate change mitigation. This work demonstrates that only integrating theory and tools that incorporate scientific, institutional, and community stakeholders will devise interventions to allow substantial gains in EH.

Keywords: Environmental health, environmental indicators, urban settings, monitorization tools.

RESUMO

A saúde ambiental é influenciada por interações complexas indicadores de saúde e indicadores do ambiente natural e construído. Contudo, existe pouca investigação sobre as especificidades dessas relações nas populações que residem em contexto urbano. A crescente urbanização e a industrialização que se tem observado têm criado vários problemas de saúde ambiental e ameaçam não só o desenvolvimento sustentável do ambiente, como afetam a nossa saúde a médio e longo prazo. Melhorar a saúde ambiental e monitorizar as relações entre ambiente natural e construído com a saúde da população tem sido o mote de várias medidas legislativas globais e tornou-se também uma prioridade para as autoridades locais e indústrias. No entanto, é incontestável que existe uma lacuna no conhecimento atual sobre quias os indicadores ambientais adequados para uma monitorização efetiva da saúde ambiental em ambientes urbanos. Esta lacuna dificulta a tomada de decisão por parte dos decisores políticos e indústrias relativamente a intervenções nacionais e locais com vista à melhoria da saúde ambiental. Com o objetivo de contribuir para o aumento do conhecimento sobre a monitorização adequada da saúde ambiental em Lisboa foram realizados três estudos diferentes envolvendo evidência científica e opiniões de especialistas e *stakeholders* de diferentes áreas de conhecimento.

Estudo 1) Este estudo teve como objetivo principal fazer uma revisão sistemática da literatura para identificar os principais determinantes e indicadores ambientais com evidência de estarem associados a impactos na saúde da população, em contextos urbanos. Esta revisão sistemática da literatura permitiu também compreender as potenciais implicações destas interações nas políticas de saúde. Para isso, foi realizada uma pesquisa de literatura publicada nas bases de dados PubMed, Web of Science, Scopus e SciELO Portugal entre 2008 e 2018. Esta pesquisa resultou em 94 estudos em que foram identificadas as associações entre determinantes ambientais e resultados em saúde de populações residentes em ambientes urbanos. Este trabalho permitiu identificar associações positivas entre indicadores socioeconómicos, do ambiente natural, ambiente construídos, serviços de saúde e comportamentais com indicadores de saúde, entre eles mortalidade e morbilidade. Os resultados desta análise permitem inferir que melhorias no rendimento, no nível escolar, na qualidade do ar, no tipo de ocupação laboral, na mobilidade e nos hábitos tabágicos têm um impacto positivo nos indicadores gerais de mortalidade e de morbilidade por doenças crónicas.

Estudo 2) Este estudo permitiu selecionar os indicadores adequados para a monitorização e avaliação da saúde ambiental na cidade de Lisboa. Partindo da evidência recolhida no estudo anterior e focando em indicadores de ambiente natural e construído foi realizada uma pesquisa nas bases de dados nacionais e da cidade de Lisboa para complementar a evidência recolhida. Tendo sido identificado um grande número de indicadores, optou-se por fazer uma avaliação prévia da informação através da realização de 12 entrevistas individuais e semiestruturadas com especialistas portugueses. Nestas entrevistas foi pedido a cada um dos especialistas que analisasse a informação recolhida e identificasse quais os indicadores necessários para monitorizar de forma adequada a saúde ambiental em Lisboa. Para validar os resultados das entrevistas foi realizado um processo de Web-Delphi com duas rondas, que envolveu um conjunto alargado de especialistas de diferentes áreas de conhecimento (22 especialistas). Neste processo de Web-Delphi foram validados 17 indicadores, 6 indicadores de ambiente construído e 11 indicadores de ambiente natural. Os resultados deste método participativo apontam para lacunas na recolha dos dados dos indicadores de ruido e mobilidade e levantam questões emergentes relativas a indicadores de habitação que requerem mais investigação.

Estudo 3) Este trabalho derivou da necessidade de implementar ferramentas para monitorização da saúde ambiental identificada nos estudos anteriores. Para definir os requisitos para construção de um dashboard para monitorizar a saúde ambiental para a cidade de Lisboa foi implementada uma abordagem centrada no utilizador. Esta abordagem envolveu potenciais utilizadores de instituições locais na identificação e discussão das preferências de visualização dos indicadores de ambiente natural e construído. Foram realizadas três entrevistas de grupo online, com onze potenciais utilizadores. Nessas entrevistas foram utilizados cartões que continham diferentes opções de visualização para cada um dos indicadores validados. O feedback obtido nestas entrevistas foi analisado e utilizado para construir um framework com onze requisitos de design para construir um dashboard de monitorização da saúde ambiental em Lisboa. O framework que resultou deste processo permitirá construir uma ferramenta eficaz e flexível para ser utilizada por decisores políticos, indústrias e organizações locais.

Em suma, este trabalho permitiu identificar os indicadores essenciais para monitorizar a saúde ambiental no contexto urbano de Lisboa além de ter permitido identificar uma serie de requisitos para a construção de um dashboard. A combinação de métodos participativos descritos ao longo deste projeto pode ser utilizada para quer para validar informação quer

para ajudar a estruturar a construção de ferramentas para apoio à decisão. Podem também servir como referência para outros trabalhos de investigação em outros contextos.

Este trabalho demonstra que a melhoria da saúde ambiental pode aliviar a sobrecarga sentida pelos sistemas de saúde e contribuir para melhorias em outros sectores como o desenvolvimento económico, melhoria de processos industriais e mitigação das alterações climáticas. Contudo, deixa também claro que intervenções que visem melhorar a saúde ambiental têm de ter por base a integração de evidência e de ferramentas que incluam os contributos da comunidade científica e institucional.

Palavras-chave: saúde ambiental, indicadores ambientais, contexto urbano, ferramentas de monitorização.

THESIS OUTLINE

This thesis is composed of five chapters. Chapter 1 corresponds to a general introduction about the scope of EH. This first chapter provides a brief overview of the historical evolution of EH, explores the concepts of sustainable EH development and the complexity in assessing EH. Some key definitions of EH concepts are presented in this chapter along with a review of EH monitoring and evaluation.

Chapters 2, 3, and 4 are composed of the full text of the publications produced during the PhD project. A brief rationale is provided at the beginning of the respective chapter. All references are jointly presented at the end of this thesis.

The second chapter provides a systematic review of literature on the environmental determinants of population health in urban settings. This review focuses on environmental determinants – socioeconomic, built environment, natural environment, healthcare, behaviours – and respective dimensions and indicators with evidence of impacting health outcomes – overall mortality and morbidity, in urban settings. An overview of their potential implications for policies is also presented. The results showed that initiatives to improve population health in which policymakers can be more evidence-informed include the socioeconomic, natural environment, and built environment determinants.

The third chapter was dedicated to the selection of suitable indicators to monitor and assess EH in Lisbon. To reach this objective a participatory approach combining semi-structured interviews and Web-Delphi was implemented to gather the views of a heterogeneous group of experts. The results pointed out some gaps in data collection and suggested the need for monitorization tools and local interventions to improve EH in Lisbon.

Chapter 4 is composed of one submitted publication in which is described a user-centred approach to define a set of requirements for a dashboard to monitor EH in Lisbon. The results presented in this chapter provide guidance to inform the design of a dashboard to monitor EH, which can be used by different institutions and could serve as a reference for other dashboards or monitorisation tools for other contexts.

Chapter 5 encloses an integrated discussion of all the work with concluding remarks and future perspectives.

The facsimiles of all publications are presented at the end of the thesis in annexes.

This thesis is based on the following published or submitted manuscripts:

- Salgado, M., Madureira, J., Mendes, A.S. et al. Environmental determinants of population health in urban settings. A systematic review. BMC Public Health 20, 853 (2020). https://doi.org/10.1186/s12889-020-08905-0
- Salgado, M.; Vieira, A.C.L.; Torres, A.; Oliveira, M.D. Selecting Indicators to Monitor and Assess Environmental Health in a Portuguese Urban Setting: A Participatory Approach. Int. J. Environ. Res. Public Health 2020, 17, 8597. https://doi.org/10.3390/ijerph17228597
- Salgado, M.; Nogueira, P.J.; Torres, A.; Oliveira, M.D. Setting requirements for a dashboard to inform Portuguese decision-makers about Environmental Health in an urban setting. Int. J. Environ. Res. Public Health 2021 *(under submission)*

LIST OF ABBREVIATIONS

EH	Environmental Health
IDC	International disease classification
PH	Population Health
SDG	Sustainable development goals
RCT	Randomized clinical trial

Chapter 1

General Introduction

1. Introduction

The origin of environmental health (EH) began with the need to balance the relationships between humans and the environment (Berridge and Gorsky 2012). Historically, EH is linked to industrialization and urbanization. It considers the changes they cause in the environment and how they relate to human health (WHO 2010b).

This chapter provides: an overview of the fundamentals and relevance of EH; defines a set of EH concepts that will be used along with this thesis; explores the challenges within the context of EH monitorisation in urban settings. To conclude this chapter, the thesis objective, and research questions are presented.

1.1. A brief history of EH

Since the 70s of the last century, the European Union countries have been developing programmes that have set a series of legislative proposals and goals to improve EH sustainability (Halmaghi 2016). In 1989, the World Health Organization (WHO)/Europe coordinated the first Environment and Health process. Environment and health decision-makers met in these events to discuss and shape European policies and interventions on environment and health.

The Environment and Health processes were the starting point of various plans and programs like the Sixth Community Environment Action Program (2002 to 2012) and the European Environment and Health Action Plan (2004-2010) (Halmaghi 2016). In Portugal, the government developed a National Environment and Health Action Plan (2008-2013), which involved an intersectoral collaboration, strengthening and integrating national policies in the field of environment and health (Moreira et al. 2010).

On a global scale, the United Nations defined, in 2015, the 17 Sustainable Development Goals (SDGs). The SDGs aim at creating an agenda for poverty eradication and global economic, social, and environmental development by 2030, known as 2030 for Sustainable Development Agenda (United Nations 2015a). One year later, the WHO still reported that 24% of global deaths were due to environmental dimensions, and that percentage increased to 28% of deaths among children under five (WHO 2016). The last important commitment was signed in 2017 with the Ostrava Declaration, which focused on “Better Health. Better Environment. Sustainable Choices”. The Member states from the WHO European region committed to developing national portfolios that should address the importance of improve EH and address the environment-related health targets of the Agenda 2030 (WHO 2017).

To deliver on the challenges raised by the Agenda 2030 it is critical to understand which environmental factors are critical for the monitorization of EH. This knowledge can provide an insight into the EH status and help informing policymaking and strategies to improve EH.

2. The Environmental Health field

According to the WHO, health refers to "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO 1946). This definition was based on an absence of pathology, and it was supposed to provide a vision of "health for all" (Lancet 2009). However, understanding disease at molecular, individual, societal, and environmental levels has changed health's vision. Assessing health certainly has to encompass these complex factors of illness (Brussow 2013).

Environmental health is the science that addresses the health outcomes affected by factors in the natural and human-made environments (Kotchian 1997).

The WHO defines EH as "aspects of human health, including quality of life, that are determined by physical, chemical, biological, social, and psychosocial factors in the environment". It also refers to the theory and practice of assessing, correcting, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations" (WHO and UN Habitat 2016). Noteworthy in this definition is the mention of the quality of life, a subjective term. Thus, given the broader environmental context of the definition, quality of life could include the adverse mental outcomes of living near a highway with exposure to high noise and air pollutants (Johnson and Lichtveld 2017).

It is also important to highlight the consideration of the future generations in the scope of EH, which is associated with the need to adopt a sustainable development with a long-term perspective (Fullman 2017). Sustainable development is affected by the complexity of EH (Racioppi et al. 2020). This multifactorial problem has been a global concern that has become a goal present in policymaking (Vidal et al. 2019).

2.1. Sustainable EH development

The concept of sustainable EH development emerged with the shift from short-time and reduced environmental awareness to long-term and sustainable development about EH issues (Maia et al. 2020). Sustainable development is defined as a "development that meets the needs of present generations without compromising the ability of future generations to meet their owns" (Lafferty 2004).

Within the last decades, sustainable EH development relied on evidence from an increasing number of studies with broader appraisals which have promoted a better understanding of the complexity and multidimensionality of EH (Lauriola et al. 2020; Dahl 2016). Interventions to promote a sustainable EH development have been implemented at the individual, local, and national levels by interventions that aim to: (1) improve environmental quality for the populations with the greatest burden of diseases (WHO and UN Habitat 2016); (2) identify environmental issues that can benefit health by, for example, creating conditions that encourage biking for transportation which increases physical activity and consequently reducing pollutants emissions (Bircher and Kuruvilla 2014).

The evolution of the progress towards the goals of sustainable EH development must be monitored to collect information that allows to clarify the complexity of EH, inform the design of monitorisation tools, and the implementation of EH interventions suitable to the context (Monteiro 2020).

2.2. The complexity of EH

Most environment and health experts would possibly agree that the field of EH is a perfect example of complexity (Keune 2012). EH challenges are complex and interlinked, not only in themselves but also with economic and social goals (Doğan, Saboori, and Can 2019). The interaction between environmental dimensions like pollutants, living context, and health outcomes, as well as a range of variables such as lifestyle or economic benefits, have shown the increasing difficulty in characterizing this complex interplay, let alone fully measure, describe, and monitor all the factors (Senanayake and King 2017).

Traditionally, EH problems have been addressed by controlling a single environmental or health factor. However, the interconnected and interacting EH problems require holistic approaches addressing their multifactorial effects and their monitorisation (Lauriola et al. 2020; Keune 2012). Such monitorisation is essential to provide knowledge and detection of any change in key factors of the environment with impacts on health (Nunes, Lee, and O'Riordan 2016).

To monitor EH would be important to define: 1) which factors need to be monitor and measured; 2) how to measure environmental factors and health outcomes; 3) which areas need intervention; and 4) how to monitor where advances have been achieved (Kirschke, Borchardt, and Newig 2017; Fullman 2017; Racioppi et al. 2020). The scale of information required for the continuous monitoring of EH is considerable (Monteiro 2020). However, the goal of monitoring EH would always be to improve the quality of sustainable EH development decisions that have been implemented at the local and national level (Vidal et al. 2019).

3. Key EH definitions

To understand the complexities of monitoring EH, a common vocabulary is essential to guarantee the understanding among experts, researchers, practitioners, and policymakers (Eyles and Furgal 2002a). With this approach in mind, the definitions for key concepts that will be used along this thesis are proposed hereinafter.

3.1. Determinants of health

Determinants of health represent the “contextual factors which help people stay healthy, rather than the services that help people when they are ill” (National Academy of Sciences 2003). A health model should assume that health is affected by interactions between multiple determinants such as behavioural, built environment, genetics and natural environment determinants. These complex interactions take place over the life course, and their identification is critical to understanding and improving health and health policies (WHO 2010a; Goldberg 2017).

Over the past two decades, the attention toward climate change effects has been growing and it poses new and unique challenges that threaten the environment and the human health (Doherty, Klima, and Hellmann 2016; McMichael 2020). Climate change is a global problem and has evidence of impact on all the determinants of health (McMichael 2020). Although, having present the inherent complexity of addressing EH, the present work will focus on enhancing the understanding on the impact on health of the built and natural environment determinants.

3.1.1. Health dimension

The determinants are divided into dimensions. These dimensions represent different axes of concern. Each dimension can be made operational through a combination of indicators (Hoskins and Mascherini 2009). Air quality, water quality, housing conditions, and green spaces are examples of dimensions.

3.1.2. Health indicator

"Every health indicator is an estimate (a measurement with some degree of imprecision) of a given health dimension in a target population" (WHO and PAHO 2018). It is usually used to measure the current condition of a system, predict future outcomes, and monitor the results of a program or policy over time (Bana e Costa 2005). Examples of indicators include the "concentration of $PM_{2.5}$", "area of parks and green area", "mortality rate", and "cancer incidence, by type of cancer".

3.2. Environment

The environment is "all that which is external to the individual human host. Can be divided into physical, natural, social, etc." (Porta 2008).

The environment is closely related to health both directly and indirectly by representing all the surroundings of humans from the built and natural environment to the socioeconomic environment. Another important feature of the impact of the environment is the longitudinal assessment. It is irrefutable that the environment impacts health from conception to death (Kim and Hong 2017). The simultaneous, overlapping, and/or sequential exposure to multiple environmental determinants contributes to health inequalities (Morello-Frosch et al. 2011).

Our "environment" includes both physical and social environments. Understanding the concept of the built, natural and socioeconomic environment, and the differences in the extent, regularity, or timing of exposure to each one of those environments will help to understand the relationships between them and the impact on EH (Sexton and Hattis 2007; Solomon et al. 2016).

3.2.1. Built environment

Built environment refers to the physical elements and structures created or modified by humans and all the spaces in which people live and work. It includes the design of buildings, road networks, green spaces, streets, and parks (Marmot and Bell 2012).

The relation between the built environment and health can be measured at two geographic scales: local to regional. At the local scale, the analysis is made at individual homes up to neighbourhoods. The regional scale represents an analysis of an area higher than 10km2 like cities (Rao et al. 2007).

The study of the influence of built environments on health has brought together fields like architecture, engineering, and public health with a common concern: the living conditions of the population and their decreasing quality of life (Lopez 2012). However, many aspects of the built environment can resist rapid change. From a policy perspective, the built environment is a key factor, as it is one that policymakers can change to be more health-supportive (Bird et al. 2018). Although the built environment has an indirect impact on health, policies that make cycling networks denser and improve the quality of green spaces could help increase physical activity. The resulting outcomes would be a decrease in respiratory diseases, better mental health, and, therefore, the quality of life (Renalds, Smith, and Hale 2010; Moore et al. 2018).

3.2.2. Natural environment

The natural environment encompasses the natural and physical surroundings that occur outside and independently of human behaviour (Lauesen 2013). It includes dimensions like air, noise, soil, and water quality.

The natural environment directly impacts health beyond the control of the population and requires action by regional, national, and even international authorities. Exposure to air pollution affects health through its direct impact on exacerbations of respiratory outcomes like asthma (Bhatnagar 2017). The quality of water has been reported to influence the prevalence of cancer (Ward et al. 2018). Noise, in turn, can act as a general stressor disturbing the body homeostasis through the “stress syndrome” and increase the prevalence of cardiovascular diseases (Montes-González et al. 2018). The impact of soil on health is directly linked with the reactions with the air and water, which has been associated with respiratory and gastrointestinal outcomes (Morrison, Fordyce, and Scott 2014).

3.2.3. Socioeconomic environment

The socioeconomic environment influences how individuals can gain the resources needed to meet their basic needs. It indirectly impacts health, and it usually includes education, social status, income, and occupation (Darin-Mattsson, Fors, and Kareholt 2017).

The socioeconomic environment is constantly measured at different geographic levels (for example, census tract or municipalities) by governments to access health inequalities (Lian, Struthers, and Liu 2016).

The socioeconomic environment has a differential impact according to the life stage and the social stratification. Evidence has been showing that disadvantage socioeconomic environments in childhood appeared to have a stronger influence on cardiovascular diseases and cancer later in adulthood (Hu et al. 2016). If the socioeconomic environment showed influence predominantly during adulthood, it would impact mainly the wellbeing and the prevalence of chronic diseases. The constant influence of the socioeconomic environment during childhood until adulthood would impact other diseases like respiratory outcomes and mortality (d'Errico et al. 2017).

4. Environmental Health monitoring and evaluation challenges

There is a clear demand to incorporate the monitorisation of EH in the decision-making process to improve sustainable EH development (Fullman 2017). Monitoring EH should be informed by robust knowledge regarding EH's complexity and the identification of the key factors impacting EH and the challenges faced in the monitorisation and evaluation of EH.

4.1. Challenge 1: Broad perspectives

EH is a challenging research issue for many reasons. The link between environment and health has been mainly considered from a narrow perspective (Dhesi and Lynch 2016).

The traditional “source-exposure-receptor” model has been used to understand the relationships between environmental determinants and health. However, there is still a need for a paradigm shift in EH involving the abandonment of the traditional model to develop broader perspectives (Guidotti 2018a). Focusing on a limited set of environmental determinants has been considered insufficient to capture the multitude of environmental dimensions and indicators with impact on health (Rodriguez-Villamizar et al. 2015).

Achieving the complex aim of building broader and holistic frameworks requires collaborations across communities, industries, researchers, and policy. The consequences of EH interventions may well spread over and are hardly constrained within research boundaries or political silos (Johnson and Lichtveld 2017). For example, toxicity research has shown the impact of air pollutants emissions on health outcomes, like asthma and other respiratory diseases. This evidence was used to inform political interventions targeted at reducing emissions of air pollutants from a specific sector such as vehicles and industries, which impact both human and ecosystem receptors as well as economic development (Heal, Kumar, and Harrison 2012; Croft et al. 2019). Ultimately, it is important to remember that EH is both a precondition for and a product of policymaking (Furie and Balbus 2012).

Nevertheless, the continuous evolution of conceptual frameworks and their application in research and policymaking is still taking place mainly within established boundaries. Lately, the DPSIR (Driver-Pressure-State-Impact-Response) framework has been the option used to illustrate the multiple relationships between environmental context and policy in EH assessment (Figure 1) (Reis et al. 2012).

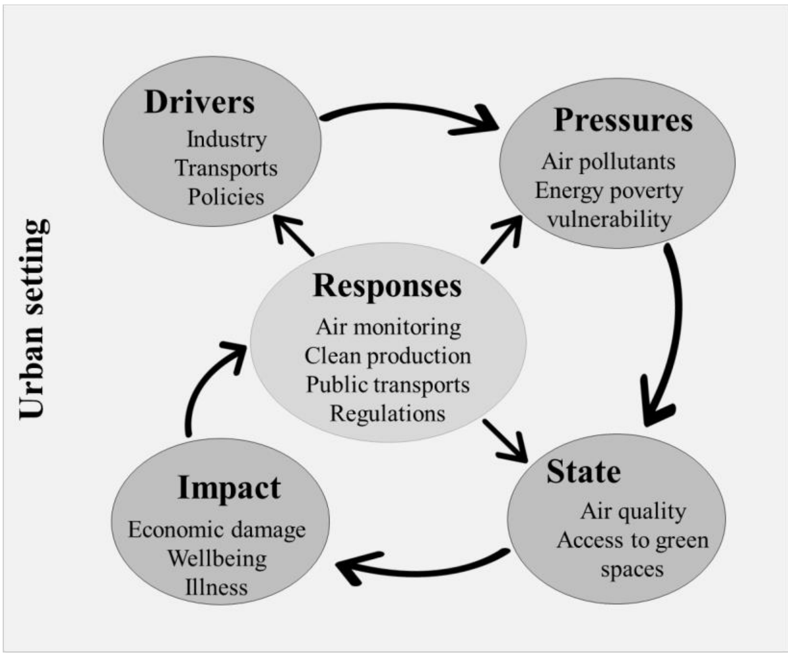

Figure 1. DPSIR framework addressing the context of urban settings, environmental dimensions, and policies. *Adapted from European Environment Agency (EEA 1997).*

The central model for assessment and monitorization of EH requires contextualization. More efficient and effective solutions to the challenges posed by, for example the climate change, would be designed by starting to consider individual disciplines as components of a complex and highly interconnected whole. An EH framework must integrate and address disciplines like biomonitoring, urban development, natural resources management as well as evidence from environmental studies identifying the appropriate indicators and quantifying the impact of the indicators (Guidotti 2018b).

4.2. Challenge 2: Selecting the relevant indicators

The second challenge is related to the complexity to select the appropriate indicators to analyse, monitor and/or evaluate EH (Maia et al. 2020).

The technological advancements have boosted data collection, and currently, researchers have an unprecedented volume of environmental data. The challenge is selecting the relevant and suitable information to answer the research questions (Tisch et al. 2014). Along with the wide range of indicators comes the availability issues. Data from indicators such as air quality, water quality, road network, or percentage of green spaces are publicly available. However, extracting that information to incorporate in EH assessment and monitorization tools is not always easy and may require specialized expertise. Also, from a technological standpoint, it is challenging to work with a high amount of data (Dash et al. 2019).

4.3. Challenge 3: Taking into account the EH context

Processes of rapid regional and global change as well as the need to adapt to a changing climate are transforming living contexts, lifestyles, and demography with consequences on EH. Analysing these differences at distinct geographic scales, including local, regional and national, will help policymaking contributing to effective interventions for the concrete needs in the daily life of specific populations (UN and World Health 2020).

Currently, 55% of the European population live in cities, and it is projected to reach 68% of the population in 2050 (EUROSTAT 2016). Thus, urbanization is of central importance when assessing EH. Health problems may differ in urban, as opposed to rural, environments and the disparities urban/rural need to be accounted for in the approaches to assess and monitor EH (Boone and Fragkias 2013; WHO 2002).

4.3.1. Rural settings

Rural settings are intrinsically important and fundamentally different from urban settings and thus require different interventions and policies to improve EH (EUROSTAT 2021). A combination of criteria characterises rural settings as population size and density, the presence of agriculture, remoteness from urban areas and lack of infrastructure and/or basic services (Ramírez, Estrada, and Ruiz 2017).

The rural setting plays an important role in the health and quality of life of the population. Still, it is often overlooked in national health planning, particularly in mental health, ageing and chronic diseases prevention (Roberts 2019). The differences between the services offered in urban and rural settings and the health inequalities have been considered the main reason for the migration of the population to urban settings (Apostolopoulos et al. 2020).

4.3.2. Urban settings

With massive urbanization occurring on a global scale, the concern has increasingly centred on the state of the environment and health in cities. Urban settings have unique climate and environmental risks and they been seen as having a distinct role in the climate agenda in terms of both mitigation and adaptation (Kühner, da Silva Pinto, and Naves David Amorim 2021). According to the United Nations, improving EH in cities, reducing their ecological footprint, and adapting them to climate change are three challenges that need to be addressed (UN Habitat III 2017).

Urban settings are already affected by climate change and extreme weather events which are projected to become more intense and frequent. Therefore, cities present an unprecedented opportunity to understand the inter-linkages between built and natural environment indicators and health and implement solutions following an intersectoral approach (Balogun et al. 2020). As the climate change progresses, cities need to adapt in order to remain functional and prosperous for human health as well as to develop in a sustainable way. Consequently, one of the greatest challenges for the next decades to respond to this adaption process has been the development of environmental policies towards health to ensure sustainable urban development (Felappi et al. 2020).Well-planned and sustainable changes in housing, green areas, urban transport, renewable energies, and cleaner productions have the potential to mitigate climate change impacts by improving air, water, and noise quality in urban settings, providing better health (Vardoulakis et al. 2020).

A deeper knowledge of the relations and associations in the way cities are designed, built, and governed and how these aspects affect EH has evolved significantly in recent years. Two global milestones had driven the concept that local decision-making actions that recognize environmental and urban policies are, in fact, key public health interventions (Ramirez-Rubio et al. 2019). The first was the approval of the 2030 Sustainable Development Agenda. This agenda has a global geographical scope and comprises an operational framework that calls for the need to account for urbanization in the assessment of health (United Nations 2015a). The second milestone was the New Urban Agenda at Habitat III, the United Nations Conference on Housing and Sustainable development, approved in 2016. These milestones mark the first time EH appeared as a central component of urban planning and government (UN Habitat III 2017).

4.4. Challenge 4: Aligning EH promotion with global programs and policies

The 2030 Sustainable Development Agenda represents a challenge for all countries. The 17 SDGs adopted have focused the interest of researchers, specialists, and policymakers on interventions that can provide multiple co-benefits for health, the environment, and the economy, particularly in urban settings by 2050 (Figure 2) (United Nations 2015a). The motto of this agenda is to achieve justice and equity in the world by 2030, leaving no one behind.

Figure 2 The 17 Sustainable Development Goals available on (United Nations 2015a).

The SDGs include a strong focus on EH by integrating health into a broad agenda with economic, social, and environmental dimensions. Implicit in the SDGs logic is the presence of different synergies and trade-offs between goals and targets, with progress on some indicators being necessary to achieve or advancing on others (Nilsson, Griggs, and Visbeck 2016). For instance, achieving affordable and clean energy (SDG7) may be closely related to the industry, innovation, and infrastructure (SDG 9), which in turn can be related to sustainable cities and communities (SDG11) that can have an impact on good health and well-being (SDG3). All of these goals can be achieved by partnerships (SDG 17).

Adopting an integrated approach would be particularly difficult at the national level since governments and organizations are not structured to integrate partnerships across ministries, departments, and outside organizations. A new culture of consultation and collaboration needs to be created to overcome the silos in which policymaking usually operates (Dahl 2016). This culture could be especially important for developing SDGs at the national level, in the design of national and local goals and indicators, and the monitoring process.

National indicators for the monitoring process require a strict selection methodology and a high amount of data to be collected and analysed. Although, there is still data that are not available for many indicators (Joas et al. 2018). A robust methodology needs to be undertaken in this particular situation before starting to collect the necessary indicator data.

The prior collecting of the requirements would allow overcoming issues regarding the key interlinkages across goals and indicators that should be part of the monitoring process, and which data need to be disaggregated. How to operationalize data disaggregation in implementing the local indicator set for monitorization tools should be useful to improve the understanding of EH determinants and identify vulnerable populations and areas.

The EH challenges in urban settings are different within the country and would require differentiated responses. The emergent task has been to complement the global indicators with indicators at the local level to be developed by each country. Monitoring tools are being developed and requested to refine the targets, strengthen the scientific evidence, and a complete set of appropriate indicators. Many refinements will be needed in the years ahead (Dahl 2016).

5. PhD objective

This PhD thesis aims at advancing knowledge towards the monitorisation and measurement of EH in urban settings.

5.1. Specific aims

The following questions were answered with this PhD thesis:

1) Which are the environmental determinants with evidence of impacting health in urban settings?
   a) Which dimensions and indicators can be used to operationalise the environmental determinants?
   b) How these factors interrelate, and how they may be tackled in policymaking?
2) How to involve a large number of experts in the process of selecting the key dimensions and indicators relevant to monitor EH in Lisbon?
3) How to gather the data requirements, use the evidence and data visualization principles, and inform a dashboard design to monitor EH in Lisbon?

The studies described in this PhD thesis derive from the evidence found in the literature to inform a participatory approach to select the dimensions and indicators from built and natural environment determinants relevant to monitor EH in urban settings, with application to Lisbon. Based on the evidence and stakeholder's views, the requirements for a dashboard to monitor EH and to inform decision-makers were also defined.

Chapter 2

Systematic review of literature

Rationale

A systematic review of literature provides sound data and information, as well as transparency to the process of collecting and synthesising scientific evidence on specific EH questions. For instance, it helps to understand the breadth and depth of the existing body of work and identify gaps in the literature. More, the results of a systematic review can be used to inform decisions, reach conclusions, or identify needs to support future research (Johnson et al. 2014; Rooney et al. 2014).

The starting point of this chapter was the need to understand the environmental determinants and respective dimensions and indicators, with evidence of impacting EH in urban settings. According to Tisch et al. (2014), the evidence regarding the impact of the built and natural environment indicators on health remains an issue in assessing EH. In fact, the preliminary search on EH determinants in urban settings revealed a high number of studies addressing EH within fields such as toxicology, ecology, and epigenetics to explain the pathways of disease. However, this chapter aimed to rethink the classical view of EH beyond the source-exposure-receptor model to place it inside a contextual framework, including the role of natural and man-made environments. In sharp contrast with the lack of evidence about EH determinants, many studies have already investigated the use of environmental dimensions and indicators to improve population health (Etches et al. 2006; Kindig DA and G 2014; Santana 2017). For this purpose, a state-of-the-art search was conducted to understand which environmental determinants had been used to evaluate population health in urban settings.

Grounded on the dimensions and indicators retrieved from this study and focusing on built and natural environment determinants, the evidence will be used to inform the participatory approach to select the key indicators to assess and monitor EH in Lisbon.

The following study was performed by **Marta Salgado** (MS), Joana Madureira (JM), Ana Sofia Mendes (AM), Anália Torres (AT), João Paulo Teixeira (JPT) and Mónica Oliveira (MO).

MS, JM, AM and MO are the principal investigators responsible for the conception of the review's aim. MS, JM and AM carried out the initial literature review. All authors participated in the discussion of the analysis, the editing of the drafts and read and agreed on the final version of this manuscript. All authors participated, read, and approved the final manuscript.

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Environmental determinants of population health in urban settings. A systematic review

Abstract

Background: Population health is influenced by interactions between environmental determinants, which are captured by dimensions and indicators. This study aims to systematically review key environmental determinants and respective dimensions and indicators, relevant to evaluate population health in urban settings, and to understand their potential implications into policies Methods: A search of literature published between 2008 and 2018 was conducted in PubMed, Web of Science, Scopus and SciELO Portugal databases, on studies with evidence on association between an environmental determinant and a health outcome in urban contexts. Health determinants, dimensions and indicators researched in the selected studies were synthetized, and associations analyzed. An independent assessment of quality of the studies was performed. Key conclusions and policy recommendations were extracted to build a framework to analyze environment related population health and policies in urban settings.

Results: 94 studies of varied methodological approaches and quality met the inclusion criteria. The review identified positive associations between all environmental determinants -socioeconomic, built environment, natural environment, healthcare, behaviors, and health outcomes - overall mortality and morbidity, in urban settings. Improvements in income, education, air quality, occupation status, mobility and smoking habits indicators have positive impact in overall mortality and chronic diseases morbidity indicators. Initiatives to improve population health in which policymakers can be more evidence-informed include socioeconomic, natural environment and built environment determinants.

Conclusions: There is scope and need to further explore which environmental determinants and dimensions most contribute to population health to create a series of robust evidence-based measures to better inform urban planning policies.

Keywords: Population health, urban settings, environmental determinants, systematic review

1. Background

Assuring the health of the public goes beyond focusing on the health status of individuals; it requires a population health approach. Population health refers to “health outcomes and their distribution in a population. These outcomes are achieved by patterns of health determinants” (Kindig 2007). Recent studies and socio-ecological models have been demonstrating that population health is influenced by economic factors, employment, education status, access to green spaces, walkability, water and air quality and individual behavior (Eibich et al. 2016; Franca et al. 2017; Franca, Barbosa, and D'Orsi 2016; Huang, Leung, and Schooling 2017; Luo et al. 2017; Morisco et al. 2017). This wide range of factors can be considered as environment because formally, everything other than the genome is or can be connoted as part of the environment (Bradley 1992). Taking this broad perspective of environment and perceiving it as relevant to population health (Guidotti 2018a), environmental determinants include the physical, chemical and biological factors external to the individual, as well as all the other factors impacting behaviors in order to prevent diseases and create healthy environments (Bircher and Kuruvilla 2014). Thus, including socioeconomic dimensions- education, employment, income, racial segregation, healthcare dimensions- access to hospital care, health insurance, and behavior dimensions- alcohol consumption, nutrition, physical activity, and smoking habits. The complex and dynamic interaction between environmental determinants and health outcomes are known to affect the development of good livelihood, the building of a sustainable workforce and resilient communities (United Nations 2015b; "World employment and social outlook 2015: The changing nature of jobs" ; Hankey and Marshall 2017; York, Rosa, and Dietz 2003).

The impact of urban settings on population health has been increasing as more people live in cities and towns than in rural areas (World Health Organization 2010; Moore et al. 2018). As reported by the United Nations (2018), in 2018 about half of the world’s population lived in urban areas but, by 2030, the numbers are expected to increase to two-thirds. Hartley (2004) has documented a difference between urban and rural health frequently expressed in terms of determinants as medical care, built environment, natural environment, and socioeconomic status. Urban settings offer a high variety of opportunities, jobs and services, but the diversity, urban segregation and heterogeneous socioeconomic characteristics contribute to inequalities in health (Pons-Vigues et al. 2014). Population health has changed as the cities become bigger leading to changes in population heterogeneity, environment and society with impact on health and have for long been a serious health policy concern in many countries because there is no consensus on what can be routinely done to overcome intra-urban inequalities in health, their distributions within the country and with other countries (Shawky 2018). Population health equity is also often dependent on political decision-making (Mackenbach and McKee 2015). The increasing concern about the influence of context on health (Moore et al. 2018) requests for the integration of population health into urban planning as an essential goal to improve related-policymaking decisions, to foster healthier lifestyles and to avoid major health risks (World Health Organization 2016; Vardoulakis, Dear, and Wilkinson 2016).

An integrated and holistic overview is necessary to facilitate a systematic examination of population health and its multiple environmental determinants in urban contexts, so that it is possible to track new evidence (Pettibone et al. 2018; Konkel 2018) and to foster adapted research and policy development into sustainability (European Environment Agency 2019b).

Therefore, we conducted a systematic review of literature to identify which key environmental determinants (socioeconomic, built environment, natural environment, health behaviors and healthcare) and respective dimensions and indicators (used to operationalize the measurement of determinants) are associated with human health outcomes, entailing overall mortality and morbidity, in urban settings. The review enables an informed discussion about relevant environmental health determinants, dimensions, and indicators for urban settings and how these factors interrelate and how they may be tackled through policies defined for the urban context.

2. Methods

This review was conducted according to the recommendations from the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher et al. 2015). A systematic search of PubMed, Web of Science, Scopus and SciELO Portugal database was conducted. Bibliographies of included articles were also searched for possible relevant articles (using the article title). Articles were eligible if they reported a relationship between at least one indicator operationalizing a dimension relevant for an environmental determinant (with socioeconomic, built environment, natural environment, health behaviors and/or healthcare determinants being considered) and at least one indicator operationalizing an health outcome (entailing all causes mortality and/or morbidity) in urban settings, areas with high density of population and build-up area (United Nations 2015b). In the adopted nomenclature, determinant – e.g., natural environment - is divided into dimensions like air quality and noise, which are then operationalized through indicators, such as, concentration of particulate matter (PM) or day-evening-night level (L_{den}). A representation of the environmental determinants and dimensions relevant to evaluate population health in urban settings is depicted in Figure 3.

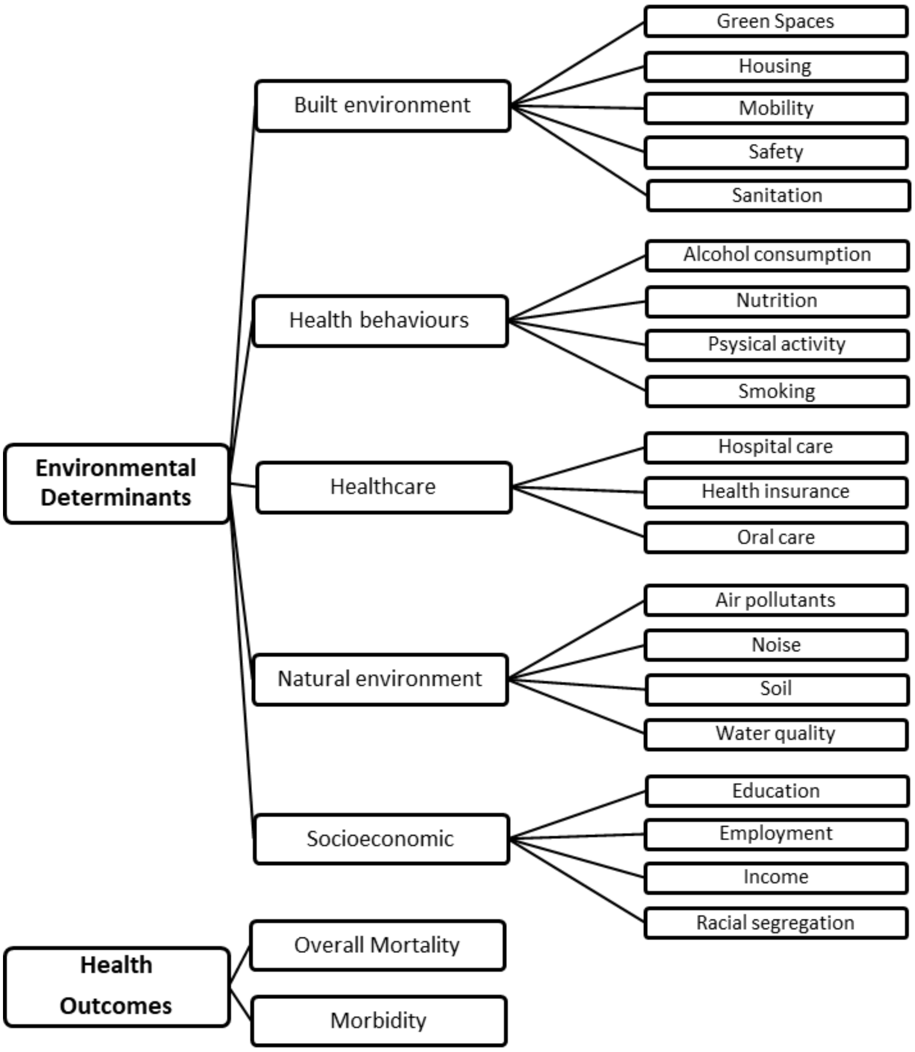

Figure 3 Illustrative representation of environmental determinants to evaluate population health in urban settings, adapted from (Weaver et al. 2014; Santana 2017). *The common dimensions were organized within the considered determinants with differences in: i) education and racial segregation are included in socioeconomic determinants; ii) physical environment is named natural environment, and the dimensions divided in air quality, water quality, noise and soil instead of natural resources; iii) built environment included green spaces and iv) behaviors included physical activity*.

3.1. Search strategy

The period covered in the search was from 2008 to 2018 and the following syntax was used: (#1) ("population health" [All fields]) AND (#2) (city OR cities OR town OR "metropolitan area" OR "urban environment" [Title/Abstract]) AND (#3) (indicators OR determinants [Title/Abstract]).

As inclusion criteria each study had to: (1) be written in English or Portuguese; (2) report a quantitative relationship between at least one environmental determinant, and one health outcome and (3) population health should be analyzed in urban settings at city level, council, or metropolitan area (studies performed in Brazil municipalities must state if the municipality is an urban environment).

The exclusion criteria were: (1) specific populations as migrants or indigenous populations or population living in slums; (2) genetic studies or studies using animal models, as well as studies evaluating the applications of tools or indexes and studies comparing rural and urban environments; (3) qualitative studies, systematic reviews, and meta-analyses and (4) studies that were only published in abstract form. Although, we recognize the value of grey literature, in the current systematic review this form of publication was not considered due to potential risk of bias.

3.2. Study selection and data extraction

Two authors (MS and JM) independently screened all included titles and abstracts of the entire list of studies identified and reviewed full texts of articles that met predetermined inclusion criteria.

All the references identified through the search were uploaded into citation manager software ENDNOTE (X7, Thomson Reuters) and duplicates were removed. Data extracted for each publication was organized by environmental determinant, grouped by category of heath outcome, and included: author and date, aim of the study, study population, study design, association measure, dimension and respective indicators, and type of relation between indicator and health outcome.

The visualization of the relationships between environmental determinants dimensions and health outcomes evidenced in the extracted data was made using Sankey diagram (http://sankeymatic.com/build/). Key conclusions and policy recommendations were extracted to inform the construction of a final framework to analyze environment related population health in urban settings. Discrepancies were solved through a review by a third coauthor (AM).

3.3. Quality Assessment

Acknowledging the relevance of assessing the quality of studies, we evaluated the risk of bias of the sampled studies by means of a checklist previously used in reviews assessing the impact of environmental determinants on health (Rojas-Rueda et al. 2019; van Kempen et al. 2018). For each study, two investigators (MS and JM) independently evaluated the risk of bias associated with exposure assessment, confounding, selection of participants, and health outcome assessment, leading to a risk classification for each bias and globally (low, high, and unclear). The studies that did not obtain the same risk of bias class from the two investigators were discussed with the third author (AM) to reach consensus. The classes set in (Rojas-Rueda et al. 2019) and the respective assessment of the sampled studies are shown in Supplementary Material – Appendix 1.

4. Results

The literature search identified 1369 records. After removing the duplicate records, 1262 studies were screened based on title and abstract and 1019 records were excluded, leaving 243 articles for full-text screening. Ninety-four records met the inclusion criteria and were included in this review while 149 were excluded. Figure 4 provides the flow diagram of articles included and excluded from the review.

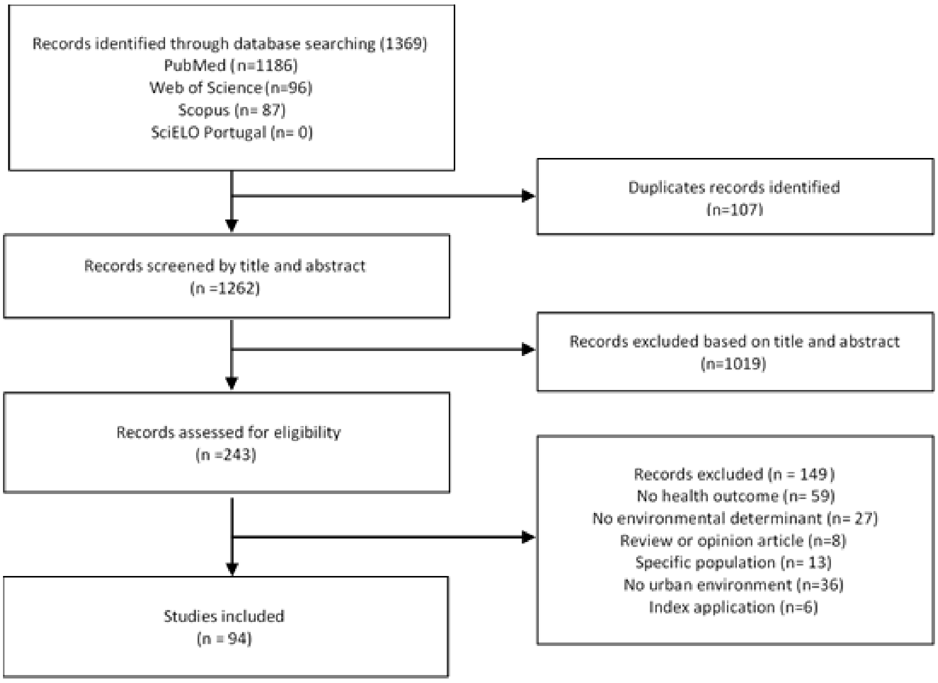

Figure 4 PRISMA flow chart with literature search.

Environmental determinants were divided in socioeconomic status, natural environment, built environment, healthcare, and behaviors. Health outcomes were divided into 5 major categories: 1) overall mortality, 2) morbidity related to birth outcomes (low birth weight, preterm, low height and weight for gestational age), 3) morbidity related with overall chronic diseases outcomes (e.g. cancer, cardiovascular, impairment, HIV, oral diseases and respiratory) (WHO 2005), 4) morbidity related with mental illness and 5) morbidity caused by obesity health conditions.

Out of the sample of 94 studies, the largest number of included studies were published between 2012 and 2016. Predominantly the referred studies analyzed the impact of an environmental determinant and/or dimension making use of more than one indicator; and more than half focused on adult populations (18-64-years-old). Most of the studies had a cross-sectional (56%) and cohort (37%) design and the association measures were mainly odds ratio, relative risk, β coefficient and prevalence ratio.

The 94 studies explored 24-paired associations between 45 indicators (within 5 environmental determinants) and the 5 categories of health outcomes. The multilevel mapping Sankey diagram displayed in Figure 5 shows the relationships between environmental determinants and the major categories of health outcomes of the 94 studies. The characteristics of each included study were systematically analyzed and summarized in Tables 1-10 (see Supplementary Material – Appendix 2), in which the relationship between the environmental indicator and health outcome was categorized as follows:

- positive (+), if a desirable improvement in the indicator was associated with an improvement of population health (i.e., a decrease in unemployment is associated with better health), or if a population subgroup is associated with higher population health (i.e., in case White has comparatively higher health than other groups);
- and negative (-), if a desirable improvement in the indicator was associated with a deterioration of population health (i.e., a decrease in unemployment is associated with worse health), or if a population subgroup is associated with worse population health (i.e., in case a Black has comparatively worse health than other groups).

Such cases of positive or negative associations are presented in Tables 1, 3, 5, 7, 9 in Supplementary Material – Appendix 2. If the study reported an association not statistically significant (for the defined statistical level) between an indicator and the health outcome, it was categorized as null (0) (as in Tables 2, 4, 6, 8, 10 in Supplementary Material – Appendix 2).

The published research was conducted in various locations with a high contribution of studies conducted in Europe (35%) followed by Brazil (26%) and USA (16%).

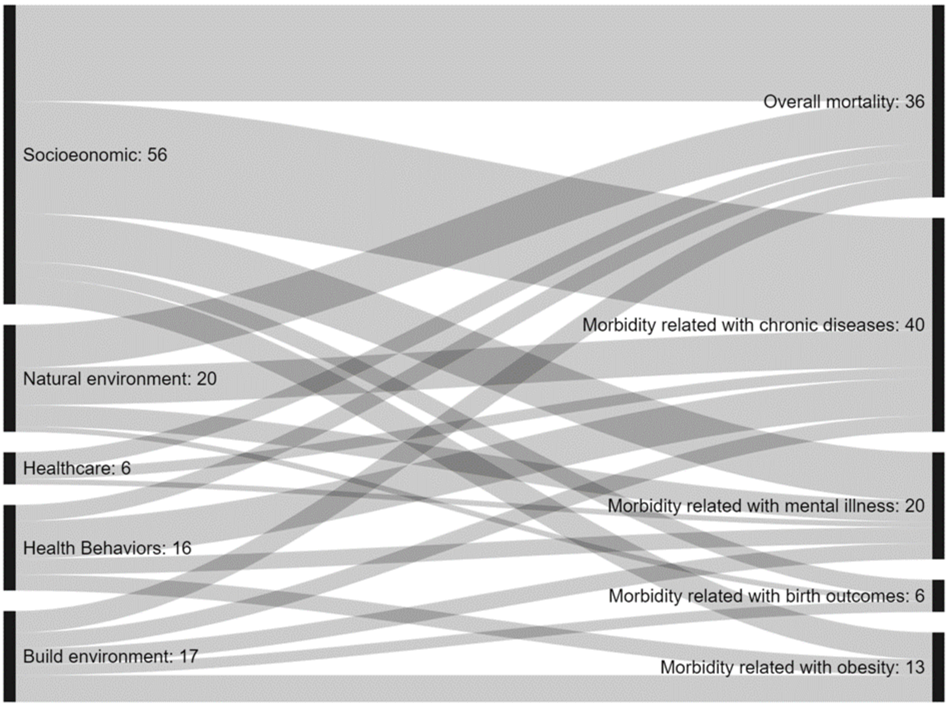

Figure 5 Sankey diagram of studies exploring relationships between environmental determinants and health outcomes (N=94 studies).

Looking into specific environmental health determinants, from the 57 studies evaluating the impact of socioeconomic determinant, 81 indicators showed association with population health. All improvements in socioeconomic determinant indicators were found to positively impact population health.

Of the 36 indicators used to understand the relationship between natural environment and population health, obtained from 18 studies, the evidence showed that increases in the quality of water and decreases in all air pollution and noise indicators are associated with improved on overall mortality, birth outcomes, chronic diseases (cardiovascular, cancer, and respiratory) and mental disorders.

Results from the 18 indicators of built environment show that improvements in mobility and green spaces would improve population health related with overall mortality, birth complications, chronic diseases, mental disorders and obesity, outcomes. Sanitation and safety improvements are associated with improvements in birth outcomes, mental disorders, and obesity outcomes.

Only 5 studies assessed the healthcare determinant showing that increases in hospital supply and infrastructures have positive associations with overall mortality, while dental care use and health infrastructures showed null associations with any health outcome.

Among health behaviors determinant, from the 21 indicators referred in the 14 studies included improvements in human behavior indicators translated into improved population health, but no association was found with birth outcomes and morbidity related with HIV and respiratory diseases.

Contrasting with the initial framework defined for analysis, there was no study assessing the impact of soil indicators, housing indicators and health insurance indicators on mortality and morbidity outcomes. From the reviewed studies, 78% of the studies were found to have overall high risk of bias (see Appendix 1), mostly because of a high bias due to not blinded health outcome assessment.

Lastly, Figure 6 systematizes the determinants and dimensions hierarchy relevant to analyze environmental population health in urban settings, based on findings of this review and on recommendations extracted from the studies included. The urban context and exposure boxes present environmental health dimensions ranked by evidence of association with health as captured by the number of studies providing evidence of association (dimensions without evidence of association were excluded). The health outcomes box displays the main outcomes dimensions relevant to measure environmental population health in urban settings. The straight arrows show generic impact associations.

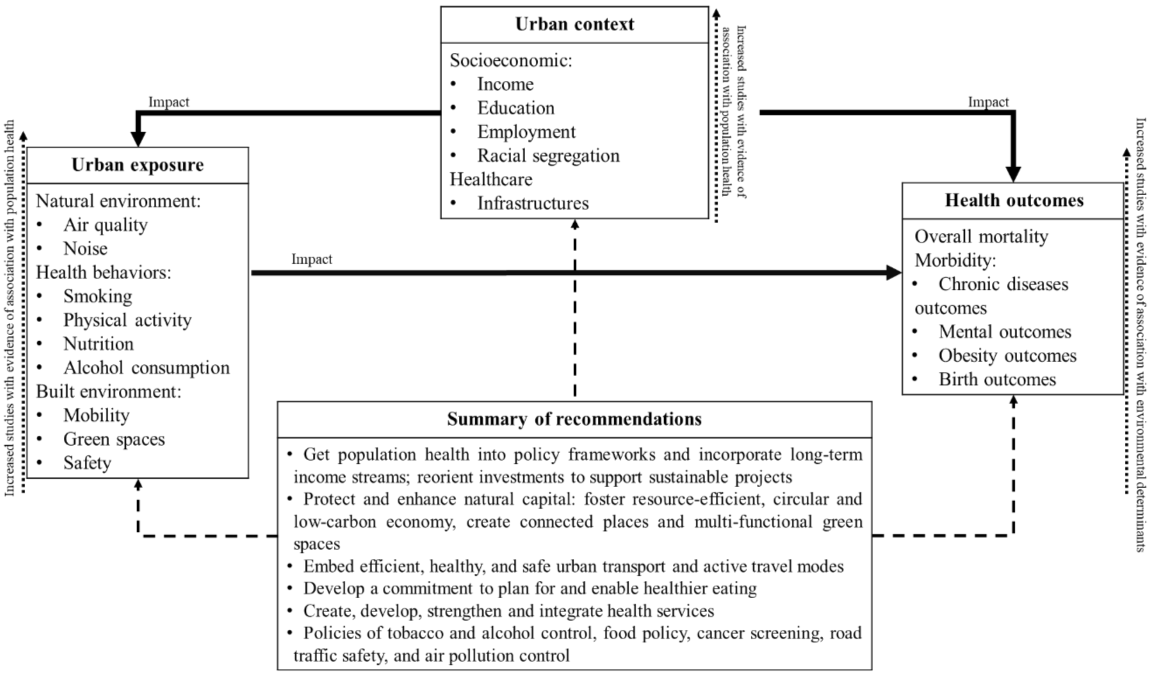

Figure 6 Summary of environmental determinants and dimension based upon the review, deemed as relevant for urban contexts, and synthesis of preventive recommendations to promote PH in urban contexts.

5. Discussion

5.1. Sample of reviewed studies

This systematic review was performed to elucidate the nature and state of current evidence on the relationship between environmental determinants and indicators and health outcomes in urban settings. It was based on 94 studies with a clear heterogeneity of methodological approaches, targeted populations and association measures which can explain why a high percentage of studies entailed high risk of bias (78%) with risk of bias being mainly attributed to issues in outcome assessment. Most of the studies were performed with populations from USA, Brazil, and Europe. This predominance can be explained by the fact that the most urbanized regions include Northern America (82% living in urban areas in 2014), Latin America (80%), and Europe (73%). African and Asian countries remain mostly rural, with 40% and 48% of their respective populations living in urban areas (United Nations 2015b).

Our strict inclusion criteria guaranteed that only studies assessing a clear relationship between an environmental determinant and an outcome were included. This was to objectively appraise that relationship, as well as the risk of bias and facilitate the interpretation of the evidence to increase validity of results and constancy across the data extraction.

5.2. Evidence on environmental determinants and associations

The evidence presented in the studies included in this systematic review demonstrated the importance of understanding the complex interdependency of health, society, socioeconomic condition, built and natural environment (Schule and Bolte 2015; Renalds, Smith, and Hale 2010; Lovell et al. 2014; Gong et al. 2016), as well as an increasing consensus about the repercussions of surrounding environment on population health, and also on the specificities of environmental population health measurement in urban contexts.

The overall findings suggest that socioeconomic determinant have been the most studied area, evidencing strong and consistent associations with all health outcomes appraised in this review. Lorenzoni et al. (2019) and Pickett and Wilkinson (2015) shows that income inequality, measured mainly as median household income, has a strong impact on health what is aligned with the inverse associations found in this review, that indicate that improvements in indicators like income, education, employment status and racial inclusion, could result in a reduction in mortality and morbidity outcomes improving overall population health. Indeed, lower mortality and morbidity rates among socioeconomically advantaged people have been observed for hundreds of years, and in recent decades these observations have been replicated using various indicators of socioeconomic (percentage of people working or ranking like blue vs white collar) status and while considering multiple disease outcomes. A careful analysis of the results revealed an additive influence on the impact of these indicators with the outcome, meaning that improving more than one indicator simultaneously could result in a higher improvement on health. From a policy perspective, as well as from an etiological perspective, it is important to understand which of the components is critical - for instance, if education is found to be important, the policies that may be implemented would differ from the policies needed if income was found to be the most influential factor. In fact, most research has not tested such competing hypotheses directly, although the indicators used in each study are explicitly identified.

The constant need to monitor the state of the natural environment to check if the international targets are being achieved and if policy actions are having the desired effects (European Environment Agency 2019a) can explain natural environment determinant emerging as the second area with the most evidence on associations with population health. Evidence was found that improvements in ambient air pollution (PM2.5, PM10, NO_2, SO_2, O_3, total suspended particles (TSP)) and noise levels (L_{den}, L_{night}) resulted in lower rates of mortality, as well as in decreased numbers of birth complications, chronic diseases such as cardiovascular, cancer and respiratory, and mental outcomes. In general, the studies reviewed evaluated separately the impact of air pollution and noise on health supporting the evidence that environmental noise should be considered an independent risk factor to health separated from air pollution (Stansfeld 2015; Liu et al. 2014). Another perspective shows that there is a relationship between air pollution and noise generated by traffic road traffic in cities (Montes-González et al. 2018). In fact, depending on which health outcome is being analyzed and which types of pollutants are being measured the effect could be independent or cumulative. These perspectives should lead to the adoption of common measures for each category of health outcomes and of common mitigation strategies in urban environments. It was not found any evidence relating soil quality indicators and health, in urban settings. The restriction to cities, where agriculture has few expression in daily life can explain the lack of evidence or as mention by Morrison, Fordyce, and Scott (2014) there is a link between soil and air pollutants, but the associations between air quality and health are more pronounced. The studies assessing the impact of built environment indicators on health are heterogeneous.

This could be related to variations in measures and tools used across studies, making difficult to compare findings and obtain uniform results (Maharana and Nsoesie 2018). There has been a weak evidence that improving built environment indicators is associated with improvement of health outcomes, but it is necessary more information to infer a causal relation between them (McCormack and Shiell 2011). Within a context of increasing urbanization, urban green spaces are gaining a growing interest for their role as an important element for sustainable and healthy societies in an urban context (Knobel, Dadvand, and Maneja-Zaragoza 2019). Green space contributes to the urban ecosystem through air purification, water and climate regulation, reduce air pollution by absorbing certain airborne pollutants from the atmosphere, biodiversity, providing benefits to urban residents (recreation, social interaction and inclusion, health benefits and wellbeing), produces economic value by improving the quality of landscapes and the attractiveness of the city within the context of increasing competition (Soares et al. 2011; Andersson 2016). Additionally, green areas, including urban gardening, parks and other natural areas, have been associated with lower stress scores, decrease of obesity rates (Mylona et al. 2020), increased physical activity, and improved well-being and health in general (Xue et al. 2020; Rojas-Rueda et al. 2019; Karmeniemi et al. 2018). No study proved that housing conditions have a relation with health outcomes, and sanitation indicators was analyzed only by Cau, Falcao, and Arnaldo (2016) and de Souza et al. (2012) showing that increasing wastewater treatment and quality of drinking water are associated with mental health improvements.

The evidence about relationship between behavior indicators and population health shows many positive associations, especially in studies in which improvements in more than one indicator of behavior were analyzed - improvements in behavior-related indicators should improve health outcomes like mortality, chronic diseases, mental and obesity disorders.

Lastly, a scarce number of studies reported the relationship between healthcare indicators and mortality outcomes - evidence was reported only in American and Brazilian populations and showed a positive association between improvements in hospital care and improvements on population health.

Jia et al. (2017) suggests that the role of health behaviors and healthcare indicators are tied to demographic characteristics and socioeconomic inequality, acting as an indirect pathway with impact on health and the results of this review can be explained by this. As a healthcare determinant works as a mediating pathway of inequality to mortality, the evidence about the association of healthcare indicators and population health is limited.

5.3. *Evidence on health outcomes*

Overall mortality and chronic diseases morbidity were the most studied outcomes in the reviewed studies. Associations with all the determinants evaluated were found, as well as for mental outcomes. Obesity outcomes appear as the fourth health consequence in population health more influenced by environmental determinants, followed by birth outcomes. Within all the outcomes included in chronic diseases, HIV indicators were referred to be influenced only by socioeconomic indicators. Given that, the number of individuals newly infected with HIV has declined over the years but some groups remain at high risk (UNAIDS 2018), this can be an explanation for the present evaluation of the impact of environmental determinants on HIV indicators. However, the small number of studies may act as a bias and an indication that using HIV indicators to evaluate population health should be carefully discussed considering the specific urban context under analysis.

Evidence also showed that different measures to assess overall morbidity were used among the literature and in fact it may be a cofounding aspect that can generate divergences. To overcome this divergence, disability-adjusted life years (DALYs) or other health related quality of life metrics can be used to define and quantify the burden of disease, so as to measure the gap between current health status and an ideal situation free of disease and while combining mortality and morbidity indicators ('Metrics: Disability-Adjusted Life Year (DALY)').

5.4. *Implications for environmental health analyses and policies in urban settings*

The health of people living in cities is deeply determined by their living conditions. While there are considerable inequalities across regions, there are also inequalities within cities among various dimensions. The health challenges that need to be tackled to reduce population health inequities in urban environments are different from the ones found in rural environments in terms of, for example, air quality or access to health infrastructures, and must be analyzed differently (Mberu et al. 2016). These geographic differences reinforce the need for a differentiated environmental health assessment, using the right indicators and determinants to evaluate population health in urban environments and improve equity (Zhou et al. 2018; Fan, Wen, and Wan 2017). Acknowledging the complexity and interconnectedness of population health assessment and their specificities for urban contexts, the purpose of collecting data related to determinants of population health in cities was to facilitate more evidence-based, rational, and prioritizing policy making.

Our results from the framework (Figure 6) are consistent with the fact that health policies of tobacco control, alcohol control, food policy, and air pollution control have made significant contribution to advances in population health over the past decades, and remain an integral part of the political decision-making process in the context of urban settings (Mackenbach and McKee 2015). To improve the link between evidence and policy actions, an extra box is added with recommendations measures (Aguilar-Palacio, Gil-Lacruz, and Gil-Lacruz 2012; Belon, Barros, and Marin-Leon 2012; Ceccon et al. 2014; de Sousa Gdos et al. 2014; Hu et al. 2008; Lovasi et al. 2012; Ribeiro Dos Santos et al. 2016) which are also aligned with recommendations from recent international reports and studies ("Putting Health into Place: Develop and provide Health Care Services" ; "Putting Health into Place: Design, deliver and manage" ; "Putting Health into Place: Plan, Assess and Involve" ; Hogan et al. 2018; 2019) for urban settings to promote population health.

6. Strengths and limitations

This review has several strengths. As the main aim of this review is to report on associations, not to prove or refute causality, it presents an analysis of a wide and exhaustive range of influences between environmental determinants and health outcomes in urban settings. This urban settings focus enables an up-to-date identification of potential risks to population health. Although 25% of the reviewed studies were from Portuguese-speaking countries, the limitation to only select English and Portuguese written studies could have limited the evidence appraised in this review and to introduce a geographic location bias. Also, cities are spatially dynamic and can include suburban areas or slums contributing to the inherent complexity in mapping and in evaluating the quality of the heterogeneous data. Different populations, different methods, and measures of evaluation, from the included studies and the variability of existing definitions of each determinant/dimension and outcome that were not standardized as might be expected may contribute to a misclassification bias. This heterogeneity should be considered when interpreting the high risk of bias of the reviewed studies. To minimize these issues, only peer review publications were included, and grey literature was excluded for the analysis.

7. Conclusions

Our results provide a comprehensive synthesis of environment health determinants and indicators, outcomes and of associations between determinants and outcomes in urban settings, as well as identifies important gaps and methodological limitations in this field of research. Environmental health indices should be redesigned to reach consensus on definitions and measurements and to be meaningful to planners, policymakers, and researchers.

Ultimately, this review helps to identify those aspects of a city that influences and contribute to improve population health and suggests a hierarchy of determinants where actions to improve them should be taken to promote population health in urban settings.

Future work should look to improve flexible tools capable of evaluate modifications in environmental health determinants related to population health taking into account the dynamic of the urban setting to help target action areas, allocate resources and provide information to improve interventions and policies and to support decision making about health services and urban planning policies.

Chapter 3

Selecting indicators to monitor and assess EH in the Lisbon urban area: a participatory approach.

Rationale

Selecting the key indicators to assess and monitor EH in the Lisbon city is a key activity for developing decision aid tools with a potential to support organizations, industries and decision-making processes. For the purpose of selecting the relevant dimensions and indicators for the evaluation of EH in Lisbon – informed by evidence, by data, and by the views of experts and stakeholders – a multi-methodology was implemented in this work.

Being such an interdisciplinary field, where various and cross-sectorial experts are involved, it is important to implement participatory approaches that allow to collect the information of the wider group of experts possible. We implemented an approach that frames a set of semi-structured interviews with a sequential validation process through a Web-Delphi questionnaire.

The results from the systematic review of literature were used as an input to the semi-structured interviews. In the interviews, 12 Portuguese experts are asked: 1) to make a detailed analysis of the results on EH dimensions from the literature; 2) to analyse the built and natural environment determinant indicators from national and local databases, and 3) to assess missing information on indicators that should be included in order to evaluate EH.

The information collected during the interviews informed a two-round Web-Delphi to promote agreement among a larger panel of experts towards the validation of a final set of dimensions and indicators to assess and monitor EH in Lisbon.

Overall, the sound methodology proposed in this study intends to be a valid and flexible approach to select data for the development of decision aid tools in health contexts. This is particularly important when is paramount to gather the views of a large number of experts that are geographically dispersed.

The following study was performed by **Marta Salgado (MS)**, Ana C. L. Vieira (ACLV), Anália Torres (AT),) and Mónica Oliveira (MO).

MS was involved in the conceptualization; investigation, writing-original draft preparation and visualization; ACLV in validation and writing-review & editing; AT in supervision; and MDO in the conceptualization; supervision, validation, and writing - review & editing. All authors have read and agreed to the published version of the manuscript.

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Selecting indicators to monitor and assess environmental health in a Portuguese urban setting: a participatory approach.

Abstract

Environmental health (EH) is influenced by complex interactions between the built and natural environments and health, there being little research on its specificities in urban settings. The use of suitable indicators to monitor and assess EH is fundamental to inform evidence-based interventions at the local level. A participatory approach to select indicators to inform the monitoring and assessment of EH in Lisbon is herein considered. Evidence derived from a systematic review of literature and data from Lisbon and Portuguese databases were analyzed by 12 Portuguese experts in individual semi-structured interviews. The interviews aimed at identifying relevant indicators and important emerging issues in the Lisbon urban setting. The outputs from the interviews were validated by a two-round Web-Delphi process in which panelists (22 experts) from different areas of expertise expressed their views regarding the relevance of the indicators for the analysis of EH urban settings. Seventeen indicators were validated in the Web-Delphi process. High participation achieved along this process supports the view that this participatory approach was useful for validation. Results from the adopted participatory approach point out gaps in the collection of noise and mobility indicators data and raise emerging issues that require further research on housing indicators. The results also suggest the need for local action to improve indicators and tools to help the monitorization of EH in urban contexts. The adopted participatory approach can be replicated for other Portuguese and European urban settings.

Keywords: environmental health indicators; urban settings; participatory approach; interview; Web-Delphi

1. Introduction

The United Nation 2030 Agenda for sustainable development goals (SDGs) recalls the importance of placing at the top of political agendas the pursuit of good health and wellbeing (SDG-3) and the promotion of sustainable cities and communities (SDG-11) (United Nations 2015a). Pursuing such goals requires the use of health information systems that enable monitoring and assessing health in multiple dimensions, with such systems entailing specificities across geographical settings (Oliveira et al. 2019; Oliveira, Vidal, and Maia 2019). Within such settings, it is recognized that health outcomes have a strong relationship with the built and natural environment, with this link becoming more evident in urban areas (Costa et al. 2019; Ramirez-Rubio et al. 2019). Although the disparities between urban-rural settings have been narrowing, residents in urban areas are more affected by physical factors (Qiu et al. 2020; Wu et al. 2017). As cities are home to more than 60% of the world's population (United Nations 2018; Ramirez-Rubio et al. 2019), the growing understanding of these relationships in the way cities are planned and built and how this impacts health has evolved over the years (Sardain, Tang, and Potvin 2016). Nowadays, sustainable cities have come to the forefront of environmental health (EH) priorities (Ceretti, Medeiros, and Slovic 2019).

The environmental health field comprises the monitorization and surveillance of the built and natural determinants, like air quality, noise, green spaces area, and walkability, and it is concerned with the prevention of disease and with the creating of health-supportive environments (Guidotti 2018a; Brousmiche et al. 2020). One of the most demanding challenges for researchers and policymakers within the field is to isolate built and natural environment dimensions and their interactions and to be able to define an approach to manage these interactions, in order to create value. Associated with this challenge, comes the need to do so while collecting population' intelligence through collaborative practices and to support innovation in EH interventions (Djalali et al. 2020; Rydin et al. 2012). EH indicators are particularly important to monitor and assess the environment status and its trends in urban settings (Maroosi et al. 2019), in order to improve interventions, allocate resources, and investigate the effectiveness of health policies (Lichtveld et al. 2019). It is known that the collection of monitorization and surveillance data is a key task for many governmental organizations and industries charged with ensuring the wellbeing of the population (Eyles and Furgal 2002b). Environmental interactions are difficult to quantify and evaluate, and to gather evidence-based information for decision-making is far from straightforward (Hunter 2009; Ceretti, Medeiros, and Slovic 2019). As it is essential to build evidence-based tools for the development of EH interventions, there must be a rationale on how to select the dimensions and indicators to assess EH (Freitas et al. 2018). Nevertheless, using this type of evidence to inform the design and evaluation of policies in urban settings is an under-researched area (Salgado, Madureira, et al. 2020). Mason et al. (2018) and Pineo et al. (2017) reported that researchers and policymakers value data and expertise about the local context. Literature also recalls that built and natural environment indicators must have a proven effect on health and that their selection should be based on a sound approach, so that they can be a sound resource in identifying potential risks to health (McMillan, King, and Tully 2016).

Methods for selecting indicators vary from statistical and causal models (Maroosi et al. 2019), to systematic reviews of the literature (Harbers, Verschuuren, and de Bruin 2015; Badland et al. 2014), and participatory processes (Jiang et al. 2018; Firth et al. 2019; Chun and Nam 2019; Pikora et al. 2003). The use of participatory processes in EH research is especially important because of the complexity of the EH concept and of the interactions between EH determinants and health outcomes, as well as because of the importance of engaging experts with different knowledge to express their views and discuss local EH problems (Ratnapradipa, Brown, and Wodika 2013; Allen et al. 2019). Also, the perception of the complexity and specificities of urban settings makes it crucial to consider a variety of experts' views to increase the probability that the selected indicators will be considered credible, scientific, and relevant to EH interventions (Ratnapradipa D 2015). Multiple qualitative methods, like interviews, surveys, or Delphi have been used for understanding complex issues related to EH analysis. Interviewing is referred as a way of collecting data and can be used in various situations to cover a wide range of health topics (Alshenqeeti 2014). Yet, Brewerton and Millward (2001) argues that interviews can have low reliability due to the openness to different types of bias. To overcome issues of validity and reliability of the findings of an interview, other methods must be applied to serve as a guarantee of the participant's performance. Another qualitative method widely used in health research is the Delphi process which captures experts' opinion and can be used to promote consensus (N.C. Dalkey 1963). The Web-Delphi is being increasingly explored due to the use of technological platforms has the advantage of not requiring face to face contact, removing geographical barriers, and allowing to involve a large number of experts (Vieira, Oliveira, and Costa 2020). Delphi processes have been used to identify the criteria to characterize and differentiate models of palliative care in healthcare services (Firth et al. 2019), to define core areas of EH (Ratnapradipa, Brown, and Wodika 2013), and to compare scenarios to improve urban sustainability development (Perveen et al. 2020; Wang and Peng 2020). In this article, we propose using a Web-Delphi process as a tool to validate the information collected for a set of built and natural indicators.

Lisbon has been recently selected as European Green Capital 2020 with an ambitious agenda for the next decade, under the motto "Choose to evolve: measures for 2030" (Kotchian 1997). This agenda is fully aligned with the SDGs-2030 Agenda and implementing its goals requires setting the data to be collected in the urban context to monitor EH and to assess the extent to which goals are achieved. Accordingly, there is an opportunity and need to develop tools (for instance based on dashboards and/or in on composite indicators) that enable the monitorization and improvement of EH by local authorities and industries.

Thus, with a view to collecting key information for improving EH, this study explores an integrated participatory process to involve EH stakeholders and experts in the selection of the relevant dimensions and indicators from built and natural environment determinants to monitor and assess EH in the Lisbon city, Portugal.

2. Materials and Methods

For the purpose of selecting relevant dimensions and indicators relevant for the evaluation of EH in Lisbon – informed by evidence, by data, and by the views of multiple EH stakeholders and experts – we designed a multi-methodology with three stages (see Figure 7 for an overview). The first stage comprises a systematic review of the literature that focused on environmental determinants in urban settings and which is described in detail in Salgado, Madureira et al. (Salgado, Madureira, et al. 2020), and a search and collection of data from Portuguese and Lisbon databases relevant to assess EH in urban settings. In the second stage, the outputs of the literature review were used as an input to semi-structured interviews. In the interviews, a restrict panel of Portuguese experts from relevant EH backgrounds made a detailed analysis and evaluation of the collected evidence and data and discussed which dimensions and indicators should be used to monitor and assess EH in Lisbon. Interviews were selected as they are powerful for eliciting narrative and complex data and allow researchers to investigate experts' views in greater depth (Alshenqeeti 2014). The third stage was based on the knowledge collected during the semi-structured interviews and consisted of a two-round Web-Delphi process to promote a commitment among a larger panel of national experts towards consensus regarding the inclusion of the final set of dimensions and indicators in a tool to monitor and assess EH in Lisbon, as well as for collecting insights and issues related to those indicators. The Web-Delphi was used as a validation stage with the aim of providing complementary completeness, plausibility, credibility, and confirmation of the knowledge acquired in the semi-structured interviews (Subiyakto et al. 2015), while enabling experts to interact in an anonymous format. Stages 1, 2 and 3 are detailed below (Figure 7).

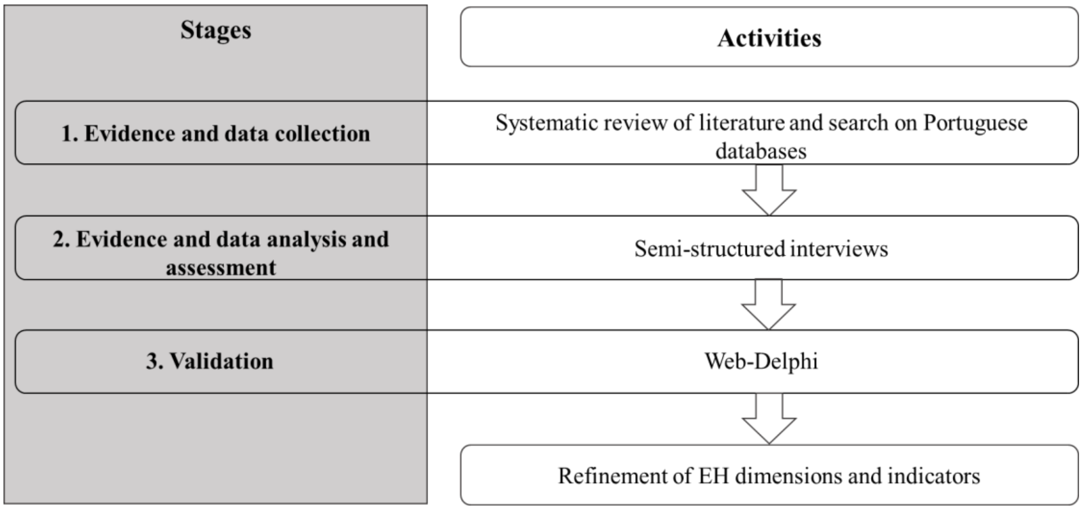


Figure 7 Overview of the approach used to select the key dimensions and indicators, from built and natural environment determinants, to evaluate EH in the Lisbon urban setting.

2.1. Evidence and data collection: systematic review of literature and search on Portuguese databases

The systematic review of literature reported in Salgado, Madureira et al.(Salgado, Madureira, et al. 2020) aimed at identifying the dimensions and indicators within the socioeconomic, built environment, natural environment, healthcare, and behaviors determinants that impact on health in urban settings. For that purpose, the review used a search strategy based on the keywords "population health", "city OR cities OR town OR "metropolitan area" OR "urban environment", "indicators OR determinants". The period covered in the search was from 2008 to 2018 and searches were performed in PubMed, Web of Science, Scopus and SciELO Portugal databases. Through the screening of the literature, 94 studies were selected and included for analyses. The review detected case-control, cohorts, cross-sectional and ecological studies quantifying causal inferences that provided direct evidence to link an environmental risk factor, measured by indicators, to a health outcome (Petrisor, Keating, and Schemitsch 2006). The results from the systematic review that focused on the physical determinants – built and natural environment – were summarized and used to build an initial list of potential dimensions and indicators relevant to evaluate EH in urban settings within the scope of this study.

A search in Portuguese national and local open-access databases – Instituto Nacional de Estatística (National Institute of Statistics, INE, Portugal) (Lawrence 2008), Lisbon city council (Maroosi et al. 2019), and PORDATA ('PORDATA, Base de Dados de Portugal Contemporâneo' 2020) – was performed to collect data and analyze available information for each indicator proposed in the initial list, and to inquire about the spatio-temporal availability of those indicators for the Lisbon city. Accordingly, a list of thirty-four indicators grouped into nine dimensions was gathered. The indicators and dimensions were organized according to being within the built or natural environment. Along with the list of indicators, a description of each indicator was defined, together with information concerning geographical availability and measurement periodicity.

2.2. Evidence and data analysis and assessment: semi-structured interviews

Given the complexity of the evidence and the nature of data collected, face-to-face semi-structured interviews were conducted for indicators and data analysis and assessment. This method was selected for two reasons. First, the associated bidirectional communication between interviewer and interviewee helps in obtaining more detailed and in-depth information. Tacit in this reasoning is that interviewees cannot share a common vocabulary and some aspects might have to be clarified considering the different areas of expertise, improving the validity of the results (Van Dijk 1989; Barriball and While 1994). Second, it allows asking other questions outside the semi-structured questionnaire to clarify data assessment and to ask follow-up questions. This flexibility in sharing knowledge was deemed appropriate for the context and helped generating unexpected insights.

Twelve semi-structured interviews were conducted with Portuguese experts working in Lisbon, chosen to represent equitably the variety in perspectives concerning EH: experts in built environment, natural environment, EH, and from national regulation institutions (see Table 1). Involved interviewees had to fulfill at least one of the following criteria: 1) more than five years of experience in EH-related research projects for the Lisbon area; 2) having publications related with air quality, urban sustainability, renewable energy consumption and production, influence of green areas on health, and water quality; or 3) being superior technicians from national regulation institutions. The experts received a formal invitation via email along with a description of the study and the informed consent. The experts who consented to be interviewed received the questionnaire template in advance (see Appendix 2) with the purpose of exploring the questions more systematically and comprehensively, as well as to keep the interview focused on the desired line of action. The questionnaire consisted of three parts. The first part collected interviewee's analysis of the results on EH dimensions from the literature. The second part included questions related to built and natural environment determinant indicators collected in national and local databases. The third part asked the opinion regarding missing information on indicators that should be included to evaluate EH.

Table 1 Profile of the participants in stages 2 and 3 of the approach used to select the key dimensions and indicators to evaluate EH in the Lisbon urban setting.

	Stage 2	**Stage 3**	
Item	**Interviews**	**1st round Web-Delphi**	**2nd round Web-Delphi**
Gender, n (%)			
Female	6 (50%)	14 (48%)	10 (45%)
Male	6 (50%)	15 (51%)	12 (55%)
Main area of expertise, n (%)			
Built environment	3 (25%)	5 (17%)	5 (23%)
Natural environment	3 (25%)	9 (31%)	5 (23%)
Environmental health	3 (25%)	10 (35%)	8 (36%)
National health regulation institutions	3 (25%)	5 (17%)	4 (18%)

In the first part, the interviewees rated their level of agreement with the inclusion of each dimension to evaluate EH in Lisbon making use of a 5-level Likert scale (SA: strongly disagree, D: disagree, N: neither agree nor disagree, A: agree, SA: strongly agree), with an extra option of DNK/DNWA: do not know/do not want to answer. In the second part, the same rationale was followed for rating the level of agreement with the inclusion of the indicators previously collected from the national databases. The interviewees were also asked to analyze the categorization of indicators within the dimensions, and to indicate which indicators could be seen as redundant, i.e., which could be considered as capturing the same phenomena. In the third part, the participants were invited to state if indicators considered relevant to monitor and assess EH were missing, regardless of the availability of data for Lisbon, and if there was a possible strategy to measure those indicators. In the end, for each indicator for which data was only available for the national level, interviewees were asked whether the national data could be used as a proxy for the local data. The answers were written by the interviewer on interview sheets. When processing the information gathered in all the interviews, the dimensions and indicators were considered relevant if more than 50% of the interviewees stated, "strongly agree" or "agree" and, at the same time, did not have more than 25% of "strongly disagree" or "disagree" responses. Conversely, indicators with more than 75% of either "strongly disagree" or "disagree" were rejected. If any of the interviewees choose "DNK/DNWA" for any question, the answer was not considered for that dimension or indicator.

2.3. Validation: Web-Delphi process

The use of the Web-Delphi method had a two-fold objective. Firstly, it aimed at gathering opinions of a wide range of experts with diverse backgrounds regarding the relevance of the indicators for assessing EH in urban settings, and coming from various geographical locations, to validate the results from the interviews. Secondly, it exposed experts to alternative viewpoints from other experts, while allowing them to interact and reconsider their responses. The two-round Web-Delphi was conducted between February and March 2020.

2.3.1. Delphi panel

Evidence suggests that knowledge generation processes can be improved by ensuring diversity among the recruited participants (Dupras et al. 2020). For the purpose of this study, the Delphi panel members were defined as a group of members knowledgeable and with work experienced in the areas being studied and able to participate during the process (Cere, Rezgui, and Zhao 2019). The panel was chosen based on a "snowball" effect (Taylor and Bogdan 1984). The interviewees were not included in the panel but recommended at least two other experts to participate in the Delphi process. The panel included a variety of expertise like air quality, epidemiology, environmental health, national institutions of health regulation, noise, public health, and urban sustainability. Based on these criteria, 55 Portuguese experts were invited to participate in the Web-Delphi. There is no general or specific rule for an optimal number of panelists, with this number varying in many Delphi studies (Adam, Jones, and te Brömmelstroet 2018; Degeling et al. 2017; Nor 2019). In this study, the focus was on involving participants with heterogenous expertise and covering all relevant EH perspectives, as well as experts from national and local institutions (von der Gracht 2012; Cullerton et al. 2019). The main areas of expertise of Delphi participants are presented in Table 1.

2.3.2. Web-Delphi design

The information resulting from the interviews was taken as the input to the Web-Delphi process. If an indicator had an agreement for inclusion by a majority (more than 50%) of interviewees, that indicator was considered in the Web-Delphi rounds. The rounds' questionnaires were implemented via a web platform (available at www.welphi.com) (Welphi 2019). As evidence suggests that a high number of rounds can result in a lower response rate (Cere, Rezgui, and Zhao 2019; Hasson, Keeney, and McKenna 2000), and Dalkey, Brown, and Cochran (1970) notice that the best accuracy in response rates is obtained with two-round Delphi iterations, with the drop-out increasing after two iterations, a two-round process design was adopted.

The process started with the online invitation of each panelist, containing instructions to access the Welphi platform, the informed consent, information regarding the study and the first-round questionnaire. The participants were asked to answer within ten workdays of receiving the email. Two reminders were sent to those participants who did not complete the survey. The Welphi platform was used to communicate with the panelists. The participants who did not complete the round during the deadline were not invited to the second round.

In the first round, panel members were asked to indicate their level of agreement or disagreement with each indicator on a 5-level Likert scale (SD, D, N, A, SA), with the option of answering DNK/DNWA. Specific rules were applied to deal with differences in opinion and to measure the level of agreement. The rule adopted for the inclusion of an indicator was to have more than 50% of the panel members stating, "strongly agree" and "agree" (agreement), and at the same time having less than 33% of answers rating as "strongly disagree" and "disagree" (SA+A>50% and SD+D<33.3%) were approved by absolute majority. Additionally, an indicator receiving more than 75% of "SA" and "A" responses was then approved by qualified majority. Conversely, indicators with more than 50% of either "strongly disagree" or "disagree" responses were immediately rejected by absolute majority. In the second round, the rules for approval and rejection, as applied in the first round, were kept. The Web-Delphi questionnaire included the list of 17 indicators which resulted from the semi-structured interviews, along with information regarding the respective dimension and spatio-temporal availability for Lisbon. The participants also had the opportunity to make comments and suggestions about each indicator in a comment section provided in the Welphi platform. In the second round, panel members had the opportunity to see the results from the first round (both participants' choices and comments) and were invited to keep or revise their answers, according to what they considered appropriate.

2.3.3. Statistical analysis

The Web-Delphi process aimed at validating the results from the semi-structured interviews by promoting a higher level of agreement among the experts, towards a consensus, there being nevertheless an expectation of divergences of opinion regarding either the inclusion or exclusion of some of the indicators. To understand such differences in opinion, the Cronbach's α was calculated to understand the extent to which there was alignment in the opinion among all panelists. Cronbach's α has been used as an association index to measure the level of agreement among panelists (Meijering, Kampen, and Tobi 2013). Cronbach's α was used during each round of the Web-Delphi to estimate the association of the ratings in the unidimensional Likert scale (Tavakol and Dennick 2011). The meaning of the value of Cronbach's α depends on the context, but when Cronbach's α is close to 1.0 means that the participants' choices are strongly associated, while values close to 0 suggest that the participants' choices are highly unrelated to one another. A cutoff of the Cronbach's α of 0.70 was adopted, taking the view that values above 0.7 are aligned with the inclusion of the indicator within an environmental health monitorization tool (Lichtveld et al. 2019).

3. Results

3.1. Evidence and data collection: systematic review of literature and search on Portuguese databases

Based upon the review of the literature, a summary of the 34 indicators related with built and natural environment determinants and with the potential to impact health in urban settings was selected (see Table 2). The selection was based on the causal inferences reported mainly in cross-sectional and cohort studies included in the review of the literature to ensure the validity of the evidence withdrawn. To complement the evidence, an additional search in national and local databases was performed to acquire spatio-temporal availability information (see Appendix 2) for indicators measured in the Lisbon region and in Portugal. A description with details regarding the periodicity of measurement, geographical level and units of measure was made for each indicator (see Appendix 2). The indicators for which information is currently available for the national level were identified, as well as the indicators lacking data. The evidence and data collection process identified five dimensions (green spaces, housing, mobility, safety, and sanitation) and 18 indicators from the built environment, and four dimensions (air quality, noise, soil, and water quality) and 16 indicators for the natural environment. The indicators were grouped into the dimensions and an initial list of nine potential dimensions and 34 indicators was proposed to be analysed in the next stage (see Appendix 3 and Table 2).

Table 2 List of the 34 indicators retrieved from the literature and from databases search, and synthesis from experts' opinions collected in the semi-structured interviews regarding the relevance of indicators to monitor and assess EH in the Lisbon urban setting.

Built environment determinant

Dimension	*Indicator*	*Disagreement (%)*	*Agreement (%)*	*Included*
Green Spaces	Number of zoos, botanic parks, and aquariums*	75.0	0	No
	Protected area surface (km^2)	83.4	0	No
	Protected area proportion (km^2)	75.0	0	No
	Number of gardens and parks	75.0	0	No

	Area of leisure parks and gardens (m^2)	0	83.3	Yes
	Area of community gardens (m^2)	0	83.3	Yes
Housing	Number of classic family housing buildings*	83.3	0	No
	Number of buildings by geographic location and type*	75.0	0	No
Mobility	Built-up areas (km^2)*	66.7	0	No
	Road vehicles by type and fuel*	16.7	58.4	Yes
	Traffic accidents with victims/1000 inhabitants	66.7	0	No
	Cycle roads (km)	0	75.0	Yes
	Road network (km)	0	75.0	Yes
	Proportion of resident population using individual mode of transport while commuting*	66.7	0	No
	Proportion of resident population using public transport mode during commuting*	58.3	0	No
Safety	Police-reported crimes/1000 inhabitants*	58.3	0	No
Sanitation	Urban waste collection*	58.3	0	No
	Population served by wastewater drainage systems*	58.3	0	No
	Natural environment determinant			
Air quality	$PM_{2.5}$ (particulate matter)	0	83.3	Yes
	PM_{10} (particulate matter)	0	83.3	Yes
	O_3 (ozone)	0	83.3	Yes
	NO_2 (nitrogen dioxide)	0	83.3	Yes
	NO_x (nitrogen oxides)	8.33	75.0	Yes
	SO_2 (sulfur dioxide)	0	83.3	Yes
	CO (carbon monoxide)	0	83.3	Yes
	C_6H_6 (benzene)	8.33	75.0	Yes
Noise	Exposure to high noise	75.0	16.7	No
	Suffering from noise*	66.7	25.0	No
	L_{den} (day-evening-night equivalent sound level)	0	83.3	Yes

	L_n (day-night equivalent sound level)	0	83.3	Yes
Water quality	"Água segura"*,[a)]	0	91.7	Yes
	Public water supply*	58.3	0	No
Soil	Soil organic carbon content*,[b)]	100	0	No
	Soil sealing index*,[c)]	75.0	16.7	No

Legend: *indicators for which information is currently available only for the national level; a) "Água segura" is the Portuguese indicator that measures the percentage of compliance with the parametric values established in the legislation; b) amount of organic carbon capable of affecting groundwater; c) Percentage of unsealed soil.

3.2. Evidence and data analysis and assessment: semi-structured interviews

The 12 semi-structured interviews were performed with experts with the main expertise related to the built environment, natural environment, EH, and national health regulation institutions as shown in Table 1.

Each interview took a median of 55 minutes (range 45-70 minutes). The first part of the interview gathered the views from participants regarding EH dimensions to be used to monitor and assess EH in Lisbon. From the set of nine dimensions, six dimensions reached a high level of agreement - more than 50% agreement rate - about their relevance to evaluate EH in Lisbon. Over half of the interviewees stated to disagree with the inclusion of the safety and sanitation dimensions. Soil dimension was indicated to be important to evaluate EH in rural settings, but for cities, it was not seen as adequate for inclusion.

In the second part, the interviewees stated their agreement towards the indicators collected in the national and local databases search. An early finding at this stage was that experts were very concerned about the availability of the data to state their agreement regarding the inclusion and/or exclusion of the indicators, even if they had been instructed to consider indicators for which data might not exist. In some indicators, the interviewees chose not to state their opinion (DNK/DNWA). From the initial list of 34 indicators, a total of 16 indicators (47%) were considered as relevant to monitor and assess EH in Lisbon by the majority of the interviewees. The indicator "Public water supply" in the "Water quality" dimension was referred as important only for cities affected by drought episodes, which is not the case for the Lisbon city. The "Build-up area" indicator was considered redundant in detriment of other indicators included in the "Green spaces" and "Mobility" dimensions. The "Protected area surface", "Protected area proportion" and "Number of gardens and parks" indicators were also considered redundant. Indicators measuring the area of leisure parks and community gardens achieved a higher agreement than the indicators considered redundant (see Table 2).

The last part of the interview gathered the opinions regarding missing information that should be included to monitor and assess EH with six interviewees proposing an additional indicator- “energy poverty vulnerability index” - for the housing dimension.

Based on the evidence and information collected during the semi-structured interviews, a final set of indicators and dimensions was organized. Hence the built environment determinant was divided into three dimensions - green spaces, housing, and mobility- and the natural environment determinant into other three dimensions - air quality, noise, and water quality dimensions. These six dimensions encompassed a total of 17 indicators, six in the built environment determinants, and 11 in the natural environment determinant. This set of dimensions and indicators was the input for the Web-Delphi process in the validation stage.

3.3. Validation: Web-Delphi process

3.3.1. Panel participation

From the 55 experts invited for the Web-Delphi process, 29 experts accepted the invitation and completed the first round of the Web-Delphi questionnaire (53% response rate). In the second round, 22 experts completed the questionnaire (76% response rate). A high response rate was achieved from the built environment’ experts where all participants completed both rounds. The group of respondents in the final round had a balanced number of experts from all areas of expertise (see Table 1).

3.3.2. Indicators

A list of 17 indicators, grouped in six dimensions, resulted from the interviews, and was validated as relevant to monitor and assess EH in Lisbon city, as captured by the high agreement rate among experts in the Web-Delphi. In summary, ten indicators were validated by absolute majority (SA>50% and SD+D<33.3%): nine from the natural environment determinant and one from the green spaces dimension (“Area of leisure parks and gardens” indicator). Seven indicators were validated by qualified majority (SA+A>50%): five from the built environment and two from the natural environment. The five indicators from built environment included the “Area of community gardens” from green spaces dimension and the four indicators in housing and mobility dimensions. The two indicators included from natural environment were the SO_2 and L_{den} indicators. Results show that the larger group validated the work taken from evidence and data collection and from the interviews. The "Energy poverty vulnerability index" and the "Água segura" indicators reached the highest level of agreement (Table 3).

Table 3 Indicators approved by majority decision rules after the second round, grouped by the built and natural environment determinants.

	Dimension	Indicators	Agreement rate (%)	Inclusion by
Built environment determinant	***Green spaces***	Area of leisure parks and gardens	63.6	Absolute
		Area of community gardens	54.5	Qualified
	Housing	Energy poverty vulnerability index	95.5	Qualified
	Mobility	Cycle roads	86.4	Qualified
		Number of road vehicles	81.8	Qualified
		Road network	77.3	Qualified
Natural environment determinant	***Air quality***	$PM_{2.5}$	86.4	Absolute
		PM_{10}	63.6	Absolute
		O_3	63.6	Absolute
		NO_2	63.6	Absolute
		NO_x	59.1	Absolute
		SO_2	86.4	Qualified
		CO	59.1	Absolute
		C_6H_6	54.5	Absolute
	Noise	L_{den}	90.9	Qualified
		L_n	63.6	Absolute
	Water quality	"Água segura"	95.5	Absolute

3.3.3. Group agreement analysis

Analyzing the Cronbach's α index results and the distribution of the group's response along the two rounds of the Web-Delphi process, it is possible to understand if the heterogeneity of Delphi panel members (in terms of expertise) translated into variability in Delphi answers in each indicator. Cronbach's α for the first round of the Web-Delphi process was 0.80, indicating substantial agreement among the panelists' answers from the beginning of the process. 22 experts completed the second round, having the opportunity to see the results from the first round and to revise the answers, with the Cronbach's α increasing from 0.80 to 0.84. An alpha higher than the reliability cutoff established of 0.70 indicates that, despite the different areas of knowledge from experts, they had similar views regarding the relevance of the indicators to monitor and assess EH in Lisbon.

4. Discussion

Our results contribute to deepening the knowledge about which indicators are relevant to monitor and assess EH in urban settings, as well as answered to the need, identified in other studies, for developing new approaches to select indicators to monitor and assess EH and to improve collection of EH-related data (Tisch et al. 2014). This is, to the best of our knowledge, one of the first studies attempting to combine empirical evidence, collected data, and experts' views in the selection of dimensions and indicators to monitor and assess EH in a city in a holistic way, taking the view that the selection of indicators is at the cornerstone of the monitorization and assessment of EH (Goldman and Coussens 2004).

4.1. Methods

The proposed multi-methodology was designed to help structuring a transparent and tendentially more informed set of indicators useful to analyze EH in the Lisbon urban area. The combination of interviews and Delphi processes was successful in promoting agreement on a set of indicators.

In this study, the level of agreement was used instead of consensus because it is easily interpretable, being consensus a specific case of agreement (perfect agreement) (Frumkin 2010). To our knowledge there are few studies in which the Delphi method using a web-platform was employed as a validation tool. The high level of agreement achieved in the two rounds proved sufficient to validate the inclusion of the indicators obtained from a smaller group of experts in a set of semi-structured interviews. The opportunity given in the Web-Delphi process to the experts to change their opinion, as a result of considering the views of their peers, revealed to be a strength of the process. The Cronbach's α association index higher than 0.80 indicates that, besides of having different areas of expertise, the experts appeared to have a shared knowledge of which indicators should be included to assess EH in Lisbon, and they were aware of the need to monitor EH with suitable indicators for the urban setting context.

4.2. EH in urban settings

Previous research has shown that EH has distinct patterns across urban and rural settings (Luo, Zhang, and Liu 2020), with the results of our study providing evidence aligned with literature. In rural settings, water and sanitation dimensions have been shown to have more impact on health (Nelson-Nunez, Walters, and Charpentier 2019); and Badland, H., et al. (Badland et al. 2014) showed that air pollution, housing, public open spaces, and transport are the most important aspects to assess health in urban settings. The set of green spaces, housing, mobility, air and water quality, and noise indicators validated in our study corroborate these findings, as well as revealed information gaps in the data collected for the indicators used to analyze EH within the built and natural environment dimensions.

Although there is a lack of data for some built environment indicators in the Lisbon city, a high level of agreement was achieved on which of these indicators were relevant to monitor EH. Out of the 6 indicators validated in the Web-Delphi for built environment dimensions the “Area of community gardens” indicator was the one with the lower agreement. Home and Vieli (2020) state that urban agriculture performed in community gardens can meet some basic nutrition needs of urban population and potentially provide some economic, social, and mental and wellbeing benefits. During the interviews, the advantage of including this indicator was clear (83% agreement rate) while in the Web-Delphi this indicator achieved a rate of agreement of 55%. The difference in the results could be explained by the controversy around the importance of this type of green spaces deprecated regarding the availability of parks and gardens. The agreement attained towards the inclusion of the “Road network” and “Number of road vehicles” indicators can be further associated with the recognition of their impact on air and noise pollution (Perveen et al. 2020; Nieuwenhuijsen 2016). In fact, to improve EH in the Lisbon context some interventions have been trying to control the number of cars in the city and to increase the number of cycling roads (Kotchian 1997; Perveen et al. 2020; Nieuwenhuijsen 2016). The surprising result from our participatory approach was the inclusion of the energy poverty vulnerability indicator in the housing dimension. Despite the need for data collection, this result corroborates that energy poverty vulnerability is a growing societal challenge that puts the welfare of the population at risk. The access to suitable housing conditions is one of the SDGs targets, and our results are in agreement with the idea that in Portugal there is growing awareness and research on the housing conditions dimension (Gouveia, Palma, and Simoes 2019).

As opposed to the lack of information regarding built environment indicators, a larger number of natural environment indicators is regularly measured in Portugal. The air and water quality indicators are publicly available, updated, and achieved a high rate of agreement in the Web-Delphi. From the air quality indicators, the SO_2 indicator was the only one included by qualified majority (an absolute majority was observed for the other air quality indicators). In fact, SO_2 is one of the most important pollutants in the atmosphere that contributes to the degradation of buildings, and the main source is industry; and exposure to high SO_2 concentrations can lead to cardio-respiratory mortality and morbidity (Wu et al. 2020). However, one should note that Lisbon is not an industrialized city, which could possibly influence the results achieved in the Web-Delphi. Another dimension validated in our process was noise. The causality of the effect of noise on health has not been sufficiently elucidated, and this dimension is often missing from frameworks to assess health (Dzhambov et al. 2017). However, the results of our study show that its potential impact on health should not be neglected, and measures of sound level should be up to date, and part of tools designed to monitor EH in urban contexts. Overall, our results regarding the natural environment are aligned with the evidence showing air quality and access to good quality water as major concerns to urban residents (Strosnider et al. 2017) and point out the importance to include noise dimension.

Many policies have been adopted in Lisbon assuming the interconnectivity between the built and the natural environments. For instance, interventions in mobility, such as reducing cars in the city and improving shared commuting, have been adopted for reducing the negative impact of air and noise pollution on health (Oliveira, Vidal, and Maia 2019; Kotchian 1997). Another example is the awareness to improve access to green spaces, which also recognizes the need to pay proper attention to soil-related indicators like the presence of unsealed soils (Teixeira da Silva et al. 2018). In our study, soil did not reach the level of agreement to be included as relevant to assess EH in Lisbon. This may potentially be explained by the fact that soil is generally taken as relevant for health in rural settings and perceived as a mere supporting platform in urban areas. Nevertheless, literature has pointed out that urban soils can improve the wellbeing of residents and mitigate the effects of the current climate crises, and it may be necessary to start collecting data for these indicators at local level (Calzolari et al. 2020).

Following the findings of our study, it is clear that there is a need for gathering diverse and robust evidence to be further used to inform not only the monitoring of EH in urban settings but also to inform the design and to analyze the impact of EH policies. Framing the list of indicators that resulted from this study within SDGs and within the scope of an European Green City, they can be a starting point to identify entry points for planning interventions targeting to increase EH in Lisbon; and the set of indicators and dimensions could be the base to discuss indicators and data collection in other European urban settings, and the development of EH related information systems. The next stage of our work could involve structuring the set of selected and validated indicators in tools on which the EH improvements could be assessed and monitored (for instance within a dashboard or within a EH index for urban settings).

4.3. Strengths and limitations

The complex and multisectoral nature of EH required a multi-disciplinary approach to develop a robust and comprehensive set of key dimensions and indicators to improve health in the Lisbon context. The adopted approach guaranteed that indicators from different areas of concern were canvassed in the final recommendations. Also, by requiring that the initial set of indicators to be filtered, analyzed, discussed, and validated through the experience of Portuguese experts, this study serves as a test for the adequacy of the selected indicators to monitor EH in the Lisbon city and a template for comparison with other cities. The Web-Delphi process was structured and transparent and has shown to be useful as a validation tool. In addition, the use of a web-platform to build and deliver the questionnaire and to follow-up the process increased the efficiency of the process. To address the potential bias of the Delphi studies, feedback was provided in an impartial way for not influencing the responses. The anonymity of the experts was also assured.

Despite these aspects, this study design has several limitations. Semi-structured interviews allow the interviewer to discuss the questionnaire, but may be subject of bias, although the researcher was aware of the need to stay open to the suggestions of the interviewees. A further limitation of the study was the method used to identify the experts for the semi-structured interviews and for the Web-Delphi. While the recruitment protocol aimed to engage a multidisciplinary sample of experts, it should be acknowledged that a degree of convenience sampling was unavoidable and could have been tackled with a broad search to identify experts. Other limitation includes the lack of guidance on Cronbach's α thresholds, with 0.70 being adopted as the level after which there is a concordance between experts. Given the complexity of the EH concept, the results of this study could be improved if a higher number of experts were involved.

5. Conclusions

Aligned with the SDGs and with the current labelling of Lisbon as the European Green Capital 2020, this study led to the identification of six dimensions and 17 indicators essential to monitor EH in the Lisbon city. A key finding of this study is that a lack of data precludes the use of relevant indicators to monitor and assess EH in the Lisbon urban context. It is common that indicators are insufficiently tracked, and that many researchers and policymakers favor using fewer indicators with already collected data over compiling a list of relevant indicators and then pushing for data collection. The adopted participatory approach highlights the usefulness of involving relevant experts from key fields of expertise in the selection of dimensions/indicator's regarding EH; and the combined use of evidence, interviews and of a Web-Delphi process provides to consensualises a list of key indicators has shown to be transparent and flexible for replication in other EH contexts. The work developed in this study can inform the construction of tools to monitor EH, as well as may help policymakers in the definition of improvement goals and also in monitoring the extent to which those goals are fulfilled.

Chapter 4

Requirements for a dashboard to monitor EH in the Lisbon city

Rationale

Health and urban dashboards have been used for assessing health in their multiple dimensions, but the way they are constructed often lacks theoretical foundations and user requirements, compromising their usability (Schall et al. 2017). The design of a dashboard involves multiple actors, including end-users and dashboard developers. In a participatory design approach, end-users intervene in the design process, provide feedback to help the creation of a customized tool to meet the user or organization needs. This feedback is important at different stages of the dashboard design and involves a large amount of communication between the users and the dashboard developers.

To implement a customized dashboard, flexible to be used by industries, organizations and decision-makers, it is advantageous to explore the design of non-face-to-face participatory processes – as online group interviews – to promote a shared knowledge among the potential users and to gather requirements to inform the construction of EH dashboard. Following a user-centered approach, three online group semi-structured interviews, involving eleven potential end-users, were conducted with different organisations group interviews were conducted, to collect their visualisation preferences. A set of design cards was built using Power BI software features. The design cards presented different visualisation options for the 17 indicators of built and natural environment indicators. Along with the design cards, open-ended questions were performed to gather more visualisation requirements. The visualisation preferences were synthesized into a set of 11 requirements for a dashboard to monitor EH in Lisbon.

Overall, the requirements proposed provides guidance to inform the design of a dashboard to monitor EH in urban settings, and it could serve as a reference for dashboards for other contexts.

The following study was performed by **Marta Salgado (MS)**, Paulo Jorge Nogueira (PJN), Anália Torres (AT) and Mónica Oliveira (MO) and is under submission to International Journal of Environmental Research and Public Health.

MS was involved in the conceptualization; investigation, writing-original draft preparation and visualization; PJN in validation and writing-review & editing; AT in supervision; and MDO in the conceptualization; supervision, validation, and writing - review & editing. All authors have read and agreed to the published version of the manuscript.

Salgado, M.; Nogueira, P.; Torres, A.; Oliveira, M.D. Setting requirements for a dashboard to inform Portuguese decision-makers about Environment Health in an urban setting.

Setting requirements for a dashboard to inform Portuguese decision-makers about Environment Health in an urban setting

Abstract

The integration of evidence and data into decision aid tools to assess and monitor environmental health (EH) in urban settings requires careful design. For instance, EH dashboards need to be user-friendly and consider user views and needs. Departing from EH evidence and making use of the views of EH stakeholders and experts, this study aimed at defining requirements for a dashboard to inform decision-makers analysing and visualizing EH information using the context of Lisbon city as an example.

A user-centered approach was employed to engage end-users and collect their visualisation preferences: three online group semi-structured interviews, involving eleven potential end-users from different organisations were conducted, including design cards with a set of visualisation options regarding 17 indicators of built and natural environment determinants. The feedback obtained from the semi-structured interviews was synthesised into a framework of four separate, but interrelated features, and operationalised into eleven requirements for a dashboard to monitor EH in Lisbon.

The framework described in this study provides guidance to inform the design of a dashboard to assess and monitor EH in urban settings. It could serve as a reference for other researchers to design dashboards for other contexts.

Keywords: urban environmental health, dashboard requirements, design-cards, user-centered approach

1. Background

Translating evidence, data and research into evidence-based healthcare decisions and policies is crucial to improve human health (Lauriola et al. 2020). Large and quickly available databases have been emerging in health contexts, but systematics reviews and expert consultations offer a large amount of data that can be used to inform decision-making (Tricco et al. 2016; Dobbins et al. 2007). Yet, the way these data are being reported for organisations and policymakers is far from enabling structured analyses and identifying relevant health interventions (Linzalone et al. 2019). By creating evidence-based decision-aid tools that make available a synthesis of data and inform the extent to which specific goals are attained, evidence becomes more understandable and makes it more likely to be used in local policymaking (Garcia-Retamero and Cokely 2017).

The use of large volumes of data within decision aid tools has been a resource for competitive advantage for many institutions and industries (Dash et al. 2019). Like every other industry, health and environmental institutions are also collecting data at a tremendous rate and starting to apply it in visualisation tools (Janssen, Donnelly, et al. 2020). For instance, the European Environment Agency has developed a visualisation tool in which it is possible to track and compare the national data being collected annually for European countries concerning air quality, noise, mobility, and housing conditions indicators (EEA). Such a monitorisation system is a powerful tool to enable an EH network among multinational authorities, but considerations concerning EH also need to be made at the local and national levels in which such systems are not so much used (Máchová and Lnenicka 2017). The integration of data focused on EH in urban settings has been pointed to as an important instrument to better understand complex EH issues at the local level and improve interventions (Ban et al. 2019; Liu et al. 2012). However, the complexity of monitoring EH demands the availability of built and natural environment indicators' data to address their multifactorial effects on health; access to quality and completeness data can explain why the lack of tools to monitor EH remains a global problem (Lauriola et al. 2020). Strategies to overcome these barriers include the engagement of the organisations responsible for data collection in building such tools and the involvement of end-users in the early design of the decision-aid tools (Young and Kitchin 2020). Such an engagement can generate a shared awareness about data concerns and motivate organizations to manage the data consistently and accurately to support such tools (Janssen, Donnelly, et al. 2020; Balduccini, Steingard, and Garwood 2020).

Many decision-aid tools have been presented in the form of dashboards (Nogueira et al. 2017), with recognised usefulness in the health field: health dashboards have been widely used to portray information from various databases using a visual display focused on indicators whose performance has evidence of impacting health outcomes (Few 2006; Nogueira et al. 2017); and have been attracting interest from academia and industry which generate and collect the data, and from the government which often wishes to implement such dashboards to monitor the evolution of health indicators and for evidence-based decision-making (Dameri 2017). However, designing a dashboard is far from straightforward as it needs to be adapted not only to the data displayed but also to the audience and decision context (Vázquez-Ingelmo et al. 2020). To counter these data and user specifications, approaches like user-centered design and design card methodologies have been used in the building of dashboards. The user-centered design engages end-users in gathering their analytical needs and selecting data, information, and visualisation preferences to meet their goals (Imbesi and Scataglini 2021). This approach was implemented to develop urban dashboards to monitor indicators such as quality of life and urban sustainability for cities like London, Dublin, and Chicago (Kitchin, Lauriault, and McArdle 2015; Gourevitch et al. 2019). The design card methodology has been used to facilitate a shared understanding and communication among designers and end-users, help kick off the design discussion, and guide and structure the discussion (Dolcetti et al. 2021). The combination of user-centered design with design card has already been used in other contexts such as in the development of game-based learning practices (Tahir and Wang 2020) and in the development of cardiovascular devices for older adults (Ahmed et al. 2019).

Although the monitorisation of EH in urban settings has been considered essential to improve health and EH interventions, there are few tools to monitor EH, and there is no consensus on how to develop such tools (Liu et al. 2012; Lauriola et al. 2020). In the particular case of Portugal, with the recent nomination of Lisbon as European Green Capital 2020, several initiatives have shown the need and scope to develop and implement tools like dashboards to evaluate EH in Lisbon.

This study combines a user-centered approach with design cards. It engages potential end-users in the format of online group interviews for identifying the requirements for a dashboard to monitor EH in Lisbon. Further insights concerning EH dashboards are obtained through this consultation process.

2. Methods

Aiming to identify the requirements for a dashboard to be potentially useful for key stakeholders monitoring EH in urban settings, taking Lisbon as a case study, this work succeeds two previous studies: in a first study of the evidence on which indicators are relevant for analysing EH in urban settings was gathered through a systematic review of literature described in detail in Salgado, Madureira, et al. (2020); and in a second study a participatory approach was implemented with Portuguese EH stakeholders and experts to select a comprehensive set of built and natural environment indicators suitable to assess and monitor EH in the Lisbon urban context (Salgado, Vieira, et al. 2020). This study aims to further define the requirements for a dashboard to support EH monitoring in the Lisbon urban context. Accordingly, results from the two previous studies are an input to this study. Potential end-users participate in setting the requirements for the dashboard by consulting information and data relevant to the analysis and monitoring of EH in Lisbon. Participants involved in this study have not participated in the previous studies.

2.1. Selected indicators to monitor EH in urban settings

A systematic review of the literature reported in Salgado, Madureira, et al. (2020) identified built and natural environment dimensions and indicators for which there was evidence of impact on health outcomes in urban settings. It resulted in a summary of 34 indicators grouped into nine EH dimensions. An additional search of data complemented this search for evidence to calculate these indicators in Portuguese national and local databases that could be used to analyse EH in Lisbon.

Drawing on the evidence and data collected, Portuguese EH experts were involved in selecting and validating the key built and natural environment indicators relevant to monitor EH in Lisbon (details in (Salgado, Vieira, et al. (2020)). Through a set of 12 semi-structured interviews and a two-round Web-Delphi process, a list of 17 relevant indicators was selected as relevant for monitoring monitor EH in the Lisbon urban setting (Table 4).

Table 4 Indicators selected and validated as relevant to monitor EH in Lisbon city by Salgado, Vieira, et al. (2020), organized by EH dimensions and determinants.

EH determinant	Dimension	Indicators
Built environment	Green spaces	Area of leisure parks and gardens
		Area of community gardens
	Housing	Energy poverty vulnerability index+
	Mobility	Cycling roads
		Number of road vehicles+
		Road network
Natural environment	Air quality	$PM_{2.5}$ (particulate matter)
		PM_{10} (particulate matter)
		O_3 (ozone)
		NO_2 (nitrogen dioxide)
		NO_x (nitrogen oxides)
		SO_2 (sulphur dioxide)
		CO (carbon monoxide)
		C_6H_6 (benzene)
	Noise	L_{den} (day-evening-night equivalent sound level)
		L_n (day-night equivalent sound level)
	Water quality	"Água segura"*

+ indicators without collected data in Lisbon; *Portuguese indicator that measures the percentage of compliance with the parametric values established in the legislation.

2.2. *Designed approach for setting users' requirements*

This study encompassed a series of semi-structured interviews with potential end-users from different local organisations. A user-centered approach was used to facilitate a ground-up conceptualization of data requirements from the user standpoint (Tao et al. 2017; Kairy et al. 2021). The semi-structured interviews focused on assessing the design of existing dashboards; choosing the best visualization options for natural and built environment indicators; discussing user needs and additional features for a dashboard to monitor EH in Lisbon city.

2.2.1. Participants

Potential end-users of the dashboard were selected from local institutions engaged in environmental and health regulation, policymaking, and urban sustainability. No prior experience with dashboards use was needed. Four participants received a formal invitation via email with a description of the work. Due to the desire to capture the views of as many participants as possible, invited participants were given the opportunity to choose between a group interview and an individual interview. The members who consented to be interviewed had to communicate whether their co-workers would be part of the interview and provide their email addresses. All the participants received the instructions and the semi-structured interview template, and the informed consent before the interviews.

2.2.2. Data preparation and visualisation formats

A search in local open-access databases - “Lisboa Aberta” (Lisboa 2020), QualAR (APA 2019) and “Entidade Reguladora dos Serviços de Água e Resíduos” (ERSAR 2019) - was performed to collect the available data for the 17 indicators validated as relevant to monitor EH in Lisbon (vide section 2.1). The data were analysed with Microsoft Power BI® software. A series of design cards were developed with different visualizations options for the group of indicators within each EH dimension (as defined in Table 1). The visualisation options were developed following data visualization principles such as simple representations with no background, neutral colours, consistent layouts, and labels (Few 2006; Brown et al. 2016; Hartzler et al. 2015). The design cards included visualization options such as bar plots, line graphs, pie charts, tables, and maps.

2.2.3. Design of semi-structured interviews

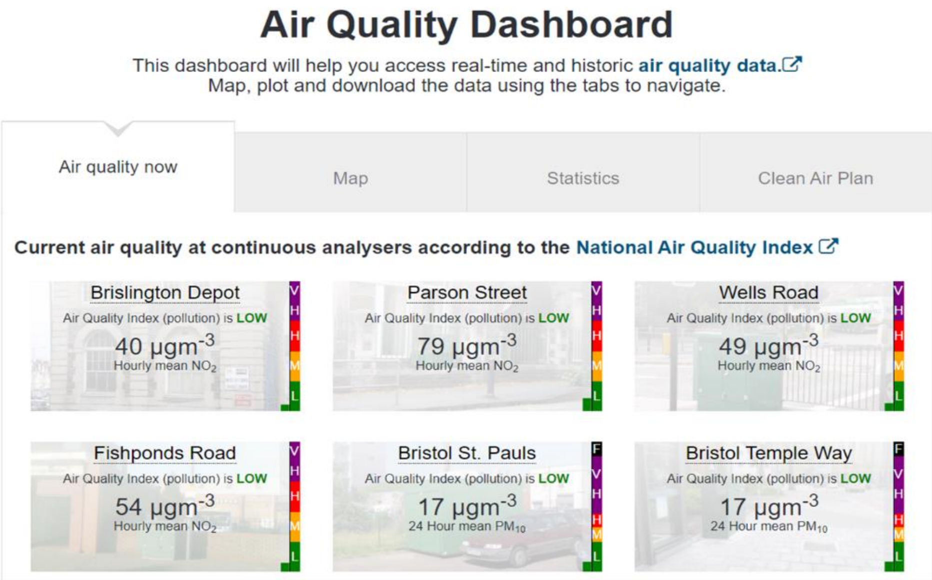
Online semi-structured interviews were conducted between December 2020 and January 2021 and lasted for about 1 hour. The screen was shared during the interview to allow the interviewees to add comments and interact with the interviewer and answer questions regarding the design cards. The interviewer wrote the answers in the template file. Due to institutional constraints, the interviews were not recorded.

The semi-structured interviews consisted of four parts. In the first part, the interviewees had the chance to see four examples of public dashboards (Doğan, Saboori, and Can 2019; Kirschke, Borchardt, and Newig 2017; Bierbaum and Cowie 2018; Underdal 2010). Despite not being EH-related dashboards, these examples were chosen for being city or country dashboards used to monitor key urban metrics (Young and Kitchin 2020), and as a starting point for discussion: the interviewees were asked to select the preferred option and to discuss the characteristics in each example that they considered of key-value to the dashboard (Table 5).

Table 5 First part of the interview: examples of public dashboards.

<table>
<tr><td>1.1- From the following examples of public dashboards, select the option that you prefer?</td></tr>
<tr><td>

<u>Option A</u>



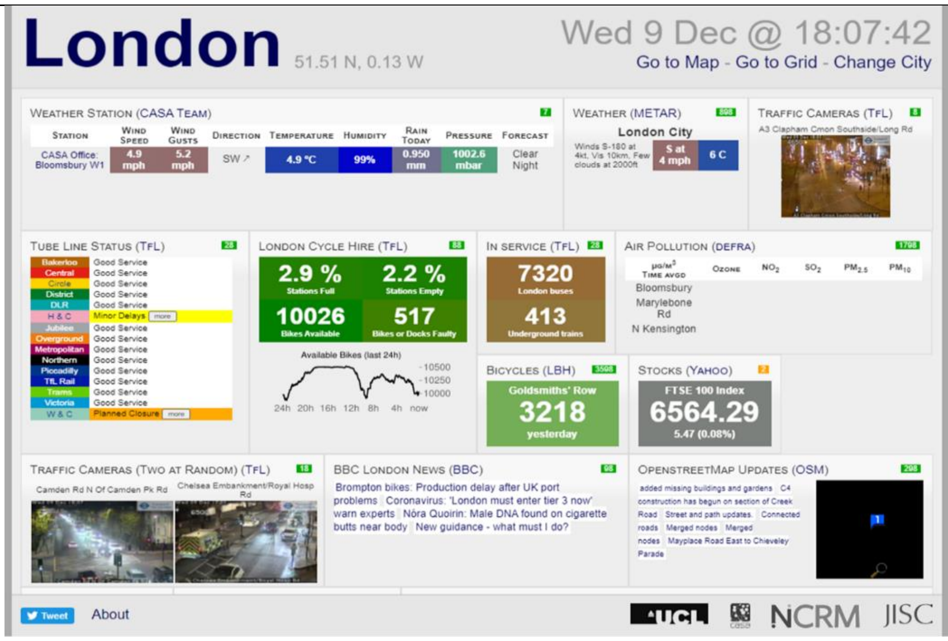
https://opendata.bristol.gov.uk/pages/air-quality-dashboard-new

</td></tr>
<tr><td>

<u>Option B</u>

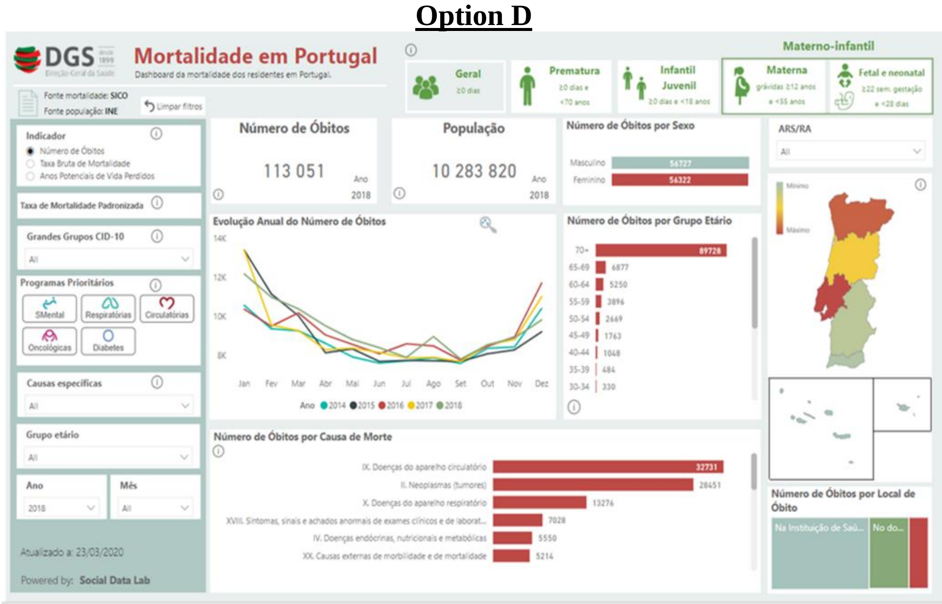
https://www.dublindashboard.ie/

</td></tr>
<tr><td><u>Option C</u></td></tr>
</table>



https://citydashboard.org/london/

Option D



https://www.sns.gov.pt/noticias/2019/11/11/dgs-plataforma-da-mortalidade/

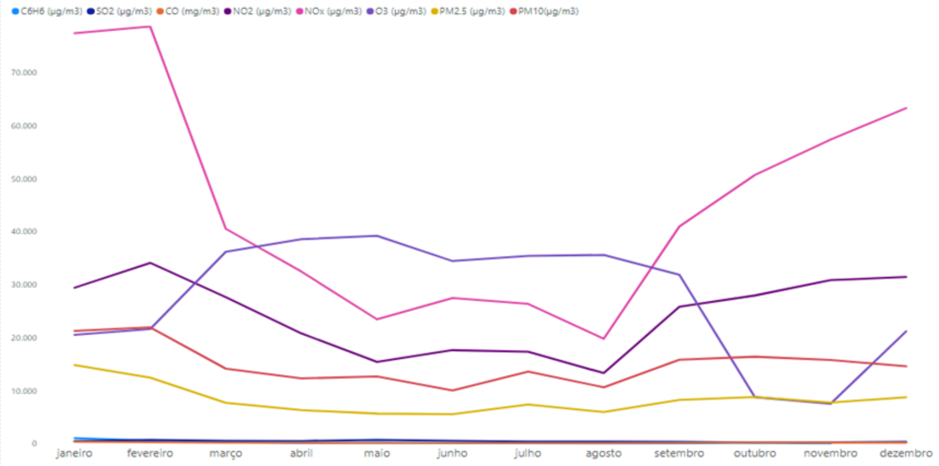
1.2- Can you please justify your choice and state the feature(s) that you appreciate more?
1.3- Is there any feature from the other examples that you particularly appreciate?

In the second part, alternative design cards were presented for the group of indicators related to natural environment determinants. The visualisations options included simple representations to quickly highlight trends and deviations such as bar plots, line charts and tables (Dixit et al. 2020). Every interviewee expressed his preference towards the best option to visualize the indicators' data. The design cards used for the indicators of air quality dimension are shown in Table 6. Additionally, open-ended questions were performed to understand which features and useful information should be added to each visualization for all the group of natural and built environment indicators.

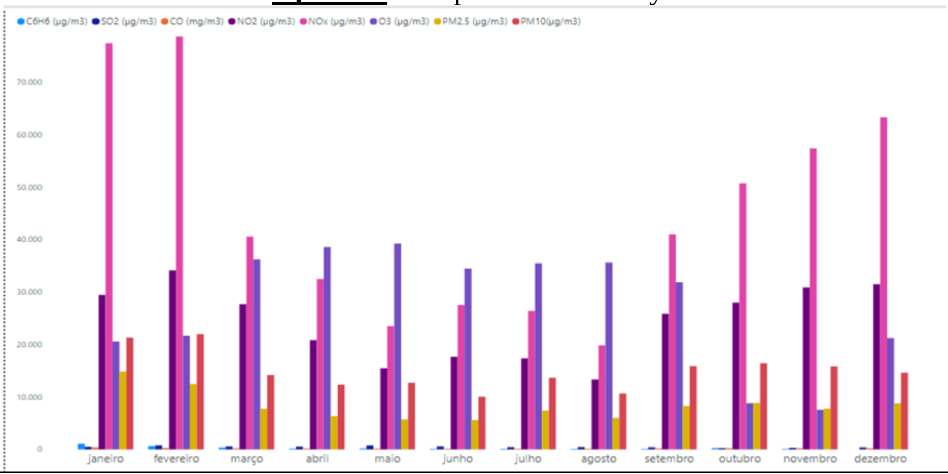
Table 6 Second part of the interview: design cards for air quality indicators. The visualisation options were created using Microsoft Power BI®.

2.1. In the following design cards are represented all the indicators from air quality. Could you please select the best option to visualize the indicators?

<u>Option A</u>- Line graph with monthly data.



<u>Option B</u>- Bar plot with monthly data.



<u>Option C</u>- Table with monthly data.

Mês	C6H6 (µg/m3)	SO2 (µg/m3)	CO (mg/m3)	NO2 (µg/m3)	NOx (µg/m3)	O3 (µg/m3)	PM2.5 (µg/m3)	PM10(µg/m3)
janeiro	1.088,80	507,46	379,80	29.475,44	77.510,75	20593	14.861,25	21.323,16
fevereiro	632,20	771,99	288,39	34.173,73	78.792,41	21686	12.483,28	21.995,40
março	354,00	573,16	208,38	27.706,99	40.601,80	36267	7.761,97	14.190,53
abril	161,20	540,98	193,46	20.848,53	32.516,02	38622	6.361,43	12.352,54
maio	196,00	764,53	177,95	15.481,86	23.517,73	39285	5.716,74	12.718,38
junho	137,30	572,06	151,92	17.690,30	27.541,84	34508	5.598,53	10.067,38
julho	131,00	425,79	159,71	17.377,73	26.419,74	35498	7.411,44	13.662,69
agosto	23,00	446,37	158,53	13.352,57	19.844,36	35662	6.009,42	10.669,95
setembro	76,30	402,24	206,89	25.869,80	41.033,85	31900	8.282,54	15.892,51
outubro	243,20	252,70	241,91	28.012,59	50.770,87	8820	8.843,35	16.447,15
novembro	19,50	300,70	234,18	30.905,28	57.443,66	7562	7.785,60	15.833,96
dezembro		381,26	234,17	31.517,01	63.381,11	21243	8.797,10	14.633,73

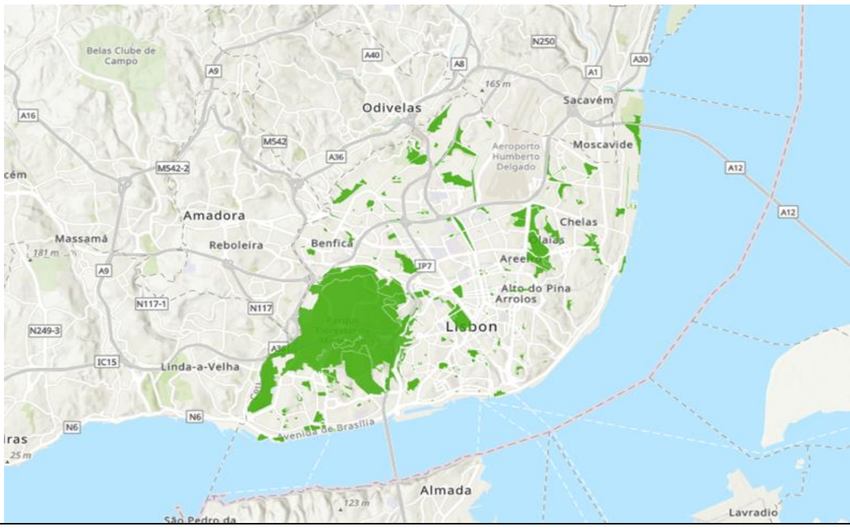
2.1. Can you please justify your choice?
2.2. Do you prefer to visualize all the indicators at the same time or separately?
2.3. With which periodicity would you like to visualize the data (for instance, daily, monthly, quarterly)?
2.4. Do you consider useful to include benchmark information?
2.5. Do you have any further comments?

In the third part of the interview, participants were invited to analyse the indicators in the built environment determinant, using the same questioning protocol adopted for the natural environment indicators (Table 7). Nevertheless, the design cards included different map-based visualizations with the location of the metric measured by each indicator (Jing et al. 2019). Having different visualisation options available in a group discussion allows the participants to refer to visualisation elements to support their idea generation and discussion. The visualisation options act as a conveyor of the data and as a reference point for all the participants in the group interview (Gill et al. 2013; Bresciani 2019). For the indicators without available data collected for Lisbon, the interviewees were asked to indicate which would be the best way to visualise the needed data.

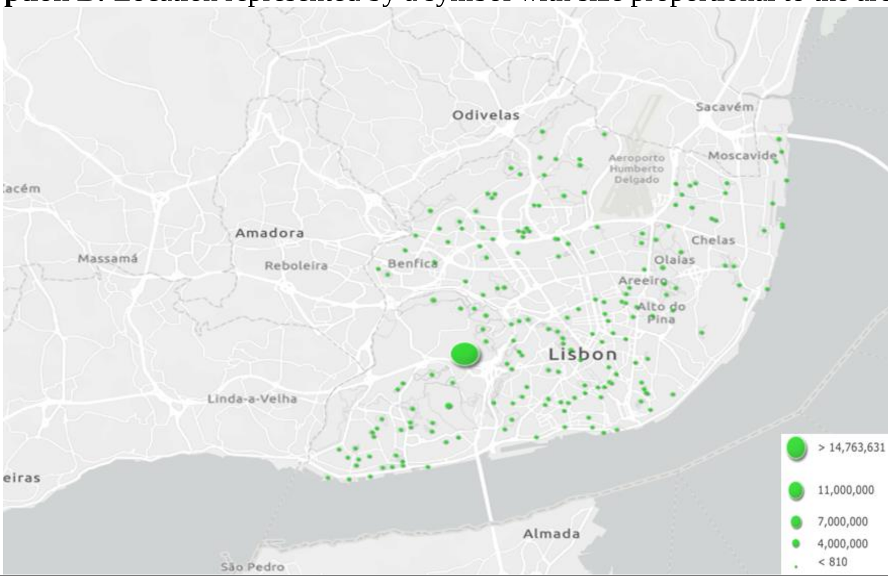
Table 7 Third part of the interview: design cards for area of leisure parks and gardens indicator. The visualisation options were created using Microsoft Power BI®.

3.1. Could you please select the best option to visualize the indicator?

Option A: Location with solid colour filling all the area.



Option B: Location represented by a symbol with size proportional to the area.



3.1. Can you please justify your choice?
3.2. Do you consider important to include a zoom option?
3.3. Which type of information do you consider more important to be accessible in this visualisation?
3.4. Do you have any further comments?

The last part of the interview was based on a set of open-ended questions to explore issues concerning the data quality, periodicity, and potential limitations. The interviewees were asked, for example, to discuss if the inclusion of the data source of each indicator or demographic data of Lisbon would be appreciated in the dashboard.

The answers provided by each participant were treated, analysed, and aggregated to identify the requirements for an EH dashboard and emerging issues. Simple statistics, such as percentages, were applied to the answers to create a list of data requirements. To ensure the comprehensiveness of requirements, the working list was sent by email to each interviewee for analysis to provide feedback and a final adjusted and validated list.

3. Results

3.1. Elicitation of users' requirements

Three online group interviews with Lisbon and Tagus Valley Regional Health Administration members, the Sustainability Cities Organization, and the Lisbon City Council were conducted involving 11 participants. Each interview lasted between 60-90 minutes. The interview with the Regional Health Administration included members from the sanitation and public health department (N=3). From the Sustainability Cities Organization, members from the urban planning department participated (N=3). The interview with the Lisbon City Council integrated members from the department of environment, energy, and climate change (N=4) and from the department of environment and green spaces (N=1).

The analysis of the interview' answers identified the preferences towards the options available in each part of the interview, shown in Table 8. The suggestions to visualise the indicators without collected data in Lisbon were also gathered in this analysis.

Table 8 User's preferences for each part of the semi-structured interview.

Interview part		**Users' preferences (%)**			
Part 1		**Option A** Bristol dashboard	**Option B** Dublin dashboard	**Option C** Dublin dashboard	**Option D** Portugal dashboard
		0	72,73	0	27,27
	Indicators	**Option A** Line graph with monthly data	**Option B** Bar plot with monthly data	**Option C** Table with monthly data	
Part 2	*Air quality*	45,45	54,55	0	
	Noise	36,36	45,45	18,18	
	“Água segura”	81,82*	9,09*	9,09*	
		Option A Location with solid color filling all the area	**Option B** Location represented by a symbol with size proportional to the area		
Part 3	*Area of leisure parks and gardens*	27,27	72,73		

	Area of community gardens	36,36	63,64
	Energy poverty vulnerability index	9,09*	90,91*
	Cycling roads	0	100
	Number of road vehicles	18,18*	81,82*
	Road network	0	100

*Preferences suggested for the indicators without collected data in Lisbon

Together with the users' preferences, a careful analysis of the answers to the open-ended questions of the interviews allowed to identify 11 requirements grouped within four groups of requirements to build a dashboard to monitor EH in Lisbon city was performed. The summary of the requirements was sent by email to all the interviewees for validation. Six interviewees from the three organizations replied and stated an agreement with the requirements proposed. The requirements are presented in Table 9, with each group of requirements being explained afterwards.

Table 9 Requirements for a dashboard to monitor EH in Lisbon city.

Dashboard features		Requirement	Users' agreement (%)
Communicate data	1	Allow users to select which EH indicators are displayed.	100
	2	Use simple and easy to understand visualisations such as bar plots.	54,4
	3	Use discrete and distinct colours to orientate the reading of the data.	72,7
	4	Disaggregate data whenever possible.	100
Monitor performance	5	Include evidence-based standards, legal limits and political goals defined to improve EH.	100
	6	Provide selection of time periods, trends over time, and its changes.	100
Identify causes	7	Enable an interactive functional use of data.	81,8
	8	Enable users do "drill-down".	70,0
	9	Provide maps with the zoom option.	100
Data quality	10	Include timely data measured with the same metrics.	100
	11	Provide sources of data.	72,0

3.1.1. Communicate data

In the first part of the interview the participants had the chance to analyse and compare four examples of city dashboards. The first identified requirement was the need to display the information in a way useful for the user. The dashboard should be designed to help the users to identify problems and to keep track of trends. These needs change according to the organization. Therefore, the dashboard must be customizable to enable the user to select which indicators to analyse and flexible enough to be used by different organizations (*Requirement 1*).

In the second part of the interview, interviewees were asked about their preferences regarding visualisation options for natural environment indicators. All the interviewees agreed that the indicators from air quality should be visualised in the same graph, but no clear consensus was reached about the best way to visualise them. Bar plots were the choice of 54,5% of the interviewees, while 45,4% preferred line graphs. A similar choice was observed for the indicators of noise dimension. Only for the water indicator was clear the agreement to visualise it using a line graph. The pie chart was considered a "hard to read" option, while tables were considered only as an additional feature to the initial graphic. Overall, the features more appreciated by the interviewees to visualise natural environment indicators were the use of easy-to-understand graphics, with adequate font size, and minimal information displayed. It would help the users to acknowledge at a glance an overall picture of all the indicators (*Requirement 2*).

In the third part of the interview, participants were asked about the built environment indicators. The data of these indicators were available in the public databases only in the map format. For the indicators without available data, a consensus was reached among the interviewees to use maps to visualise the data needed for the indicators. Design cards were presented to the interviewees including maps options with different types of legends and symbols to locate the area of the city under analysis. The maps in which coloured circles identified the location with size proportional to the area were selected by 72.7% of the interviewees. The use of symbols with solid colours was a feature largely appreciated for the built environment indicators (*Requirement 3*).

While discussing the options for the indicators, the need to disaggregate the data was frequently discussed among the interviewees. Regardless of the option chosen, a graph or map, all interviewees acknowledged that it was essential to add the ability to access additional and detailed information of a particular indicator (*Requirement 4*). For instance, such feature would allow the user to see daily values in a specific location instead of monthly means for Lisbon city. The ability to depart from general data and overall assessments to more comprehensive and specific data would help understand the numbers' reasons.

3.1.2. Monitor performance

Two monitorisation requirements were identified related to which information should be provided in a dashboard and how it should be presented. One of the features discussed was the added value of comparing the data being collected against evidence-based standards, legal limits, or political goals legal standards (*Requirement 5*). Users from the political and sustainability organizations were especially concerned with this aspect. The inclusion of a benchmark would help the end-users follow the indicators' performance, identify EH issues, and design strategies to deal with the situation.

The second feature to monitor the data is the ability to access historical data selecting specific periods for trends analyse (*Requirement 6*). This feature would be particularly important in the case of indicators in which they may expect to see fluctuations over seasons instead of daily or monthly alterations. Interviewees talked about wanting the possibility to choose a particular indicator and to select specific months and compare them with previous years.

3.1.3. Identify causes

Being able to identify causes or extreme events for any particular indicator was an element discussed in all the interviews. For 81,8% of the interviewees, the dashboard should be interactive and include features like the ability to see alerts whenever an outlier value was detected for a particular indicator selected by the user (*Requirement 7)*. Another feature discussed by more than 70% of the interviewees was the ability to "drill down" into the data or "drill up" to view general data (*Requirement 8*). In a drill-down dashboard, the users would be able to navigate different data layers to see specific and detailed information of a particular indicator without overcrowding the dashboard. Moreover, regarding the indicators visualised using maps, a consensus was achieved related to the inclusion of a zoom option (*Requirement 9*). The dashboard should be designed with the feature to view the data on specific areas by simply dragging the mouse over the part of the map the user wishes to explore. By focusing on the area of interest, users could easily detect potential problems or acquire a deeper understanding of trends.

3.1.4. Quality data

In the last part of the interview, participants discussed the quality of data to include in the dashboard, with key requirements being timeless and access to data. The lack of timely data with standard metrics was a constraint faced by the organizations involved in this study (*Requirement 10*). All the interviewees stated that public databases' data are often perceived as out-of-date to be useful for short-term decision-making. Furthermore, the use of different metrics increases the time spent analysing the data and can lead to wrong inferences about the performance of an indicator. Also, 72% of the interviewees expressed the relevance of including the data source (*Requirement 11*). Having the information to access the original database would increase the users' trust as they would be able to check inconsistent values or clarify potential doubts.

4. Discussion

Organizations are slowly adopting health and urban dashboards as tools to support decisions and delivering large-scale feedbacks to healthcare providers and policymakers (Lock et al. 2020). Such tools are often designed without suitable evidence and structured procedures (Brehaut et al. 2016). To address this gap, this study adopted an approach informed by scientific evidence and expert opinions, within a user-centered approach, to identify a set of requirements to design and implement a dashboard to monitor EH in Lisbon city.

Our findings provide a first step towards the design of a user-friendly tool with the potential to be adapted to different settings and organisations to inform EH interventions. Furthermore, findings from this study also highlight several recurring data constraints of both built and natural environment indicators that impact the design of a dashboard for the Lisbon context.

As Tao et al. (2017) and Keshavarz Mohammadi et al. (2020) suggested, the selection of the information to be displayed in a dashboard should be performed through social interaction. Such selection creates opportunities for experts and policymakers to lend their views and expertise and increase their trust in the tool. The set of indicators used within the user-centred approach adopted in this study were selected through literature review and experts' participation in previous studies. Although the interviewed participants of this study were initially cautious about the inclusion of such heterogeneous data into a single dashboard, all indicators were deemed relevant, and no additional indicators were suggested.

Furthermore, the requirements derived from this study are based on indicators selected to monitor EH. Still, they can serve as a guideline for other contexts trying to build tools using indicators with similar metrics. We discuss results from the lens of methods and EH and discuss the study's strengths and limitations.

4.1. Elicitation of user's requirements

Designing an efficient dashboard is only successful if user requirements are fulfilled (Nelson et al. 2016). Therefore, these requirements must be clearly identified and easily understood. Our findings suggest that combining group interviews with the use of design cards is a suitable approach to engage end-users in the early stages of the dashboard design.

Consistent with prior research (Ahmed et al. 2019; Teka, Dittrich, and Kifle 2018), the user-centered approach allowed the participants to understand the dashboard's aim and easily define the elements and requirements for its design. The participants drew on their professional expertise to critically analyse the data. They were able to collaboratively reach an agreement towards the best visualisation option for all the indicators and the critical features to be included in the dashboard.

The design cards approach proved to be useful in helping the users to transmit their ideas on how to communicate the data in a tangible form. Having different options to compare, the interviewees were able to easily identify which data was missing or needed to be updated, and at the same time, define features for each indicator. In the case of indicators without available data for Lisbon, the interviewees were already comfortable to make inferences about what they expected to see, which data should be collected, and the best way to visualise it. For instance, for the indicator "number of cars", a consensus was reached to use a map to visualise the indicators and collected data disaggregated by type of fuel and type of vehicle - public or private.

Overall, the interviewees sought a combination of simple and interactive visualisations at a glance with the ability to access detailed visualisations to analyse indicators' data deeply. The end-users' preferences are aligned with the data visualisation research, which has shown that users can quickly understand data displayed in both bar plots and line graphs (Pelayo et al. 2019; Ospina-Pinillos et al. 2018; Few 2006). For example, bar plots or line graphs should be used to visualise the overall trends of the indicators and combine with access to tables with detailed data for specific locations and periods.

A shared agreement was achieved about the requirements to guarantee the proper monitorisation of data and the identification of causes. Features such as zooming options and inclusion of legal limits or local goals were required for all the participants. Having a benchmark would help the user get a clear notion of how the indicator is evolving and support anticipating different scenarios and strategies to deal with it (Ladu 2020). Another critical element discussed concerning data quality. A requirement for the dashboard implementation is the investment in identifying databases for all the indicators, request access to the databases, and the normalization of the metrics to make comparisons among indicators and benchmarks (Máchová and Lnenicka 2017). Furthermore, it is important to note that the essential requirement for a successful dashboard is the need to provide dynamic information. A dashboard should enable users to tailor the indicators' information in which they are most interested. The fulfilment of this requirement would allow the design of a dashboard flexible enough to be implemented in different organizations.

Furthermore, the Microsoft Power BI proved to be a suitable software to support this integrated approach. Power BI has a library with several standard visualisation options to inform the development of the design cards and the dashboard's design. This software had the advantage of connecting a large volume of data and model it in different ways (Ibrahim et al. 2020). It also revealed great compatibility with the different databases used in this study.

Finally, as Saarijarvi and Bratt (2021) show in their study, online interviews are a suitable alternative method to face-to-face interviews. The online group interviews implemented in this study have proved to be successful in attaining the study objectives.

4.2. Environmental health implications

This work provides key information for decision-makers creating a new system to monitor the status of EH in the Lisbon urban area. Although urban dashboards include some of the environmental indicators deemed key to monitoring EH, they focus on urban management instead of health monitorisation. For this reason, the engagement of experts and end-users in this integrated approach to design a dashboard reflects its unique ability to help stakeholders and decision-makers focus on both the health needs and the environmental drivers (Khairat et al. 2018; Young, Kitchin, and Naji 2020). Engaging end-users from organizations with different perspectives and roles regarding monitorisation of EH in Lisbon allowed us to gather the different needs and to identify the issues about data collection. Requirements such as the inclusion of legal limits for benchmarking or the need for up-to-date databases with similar metrics showed the concern with the comparability of data to support environmental decisions. The data should be presented to the user to allow a detailed search to compare and summarize the information. A clear understanding of the relationships between different environmental indicators would help identify locations, detect potential sources, define the trends, and serve as a baseline for further investigation to inform EH interventions.

The implementation of a dashboard to monitor EH at the local level can be a solution to catalyse efforts to improve EH at the national level and replicated in other settings. Moreover, using these kinds of tools can become a research resource to explore the impact of local policies on health. It can pave the way for cross-sectional efforts between researchers, industries, and policymakers to improve EH interventions (Young and Kitchin 2020).

4.3. Strengths and Limitations

The methodology implemented in this study was guided by existent research (Ledel Solem et al. 2020; Young and Kitchin 2020; van Deen et al. 2019; Janssen, Donnelly, et al. 2020) using user-centered approach to facilitate mutual learning and shared understanding among potential end-users. By involving different end-users in the early-stage design, the requirements provided insight into how the dashboard to monitor EH can be applied in practice suggested real-world usability and dealt with user experience issues. This approach also helped to engage users and promote the willingness to participate in future stages. To the best of our knowledge, this study is the first attempt to describe an approach to design a dashboard to monitor EH. Although urban dashboards are increasingly becoming a tool for policymaking, no EH dashboard was found as a reference. The users involved in this study revealed a shared awareness of the need for a dashboard to monitor EH. They agreed with the indicators identified as relevant to monitor EH in Lisbon.

Despite these contributions, the authors learned several important lessons through the challenges experienced in such transversal themes as EH. First, the pandemic required the authors to adapt the methods to online and interactive interviews instead of face-to-face interviews. A series of design cards were prepared for friendly visualisation helping the participants to engage in the interview to overcome this issue. Another challenge that is common when implementing new tools in healthcare and political organizations is the difficulty users can envision the design for tools that they never conceived before. Designing an EH dashboard for Lisbon city can be challenging for some users when asked to foresee how they want to view and use data. The use of design cards with visualisation options can overcome the difficulty of envisioning design and introduce some bias since users often asked for a mix of data or agreed that all options would work well.

Finally, some questions can be raised regarding the generalisation of findings to other contexts or dashboards because of the small sample of interviewees. This study involved a non-probabilistic sample in obtaining in-depth inputs from organisations developing EH interventions and regulations. Such kind of sample may result in biases since those are the most concerned with implementing tools that help improve EH in Lisbon city and may be more prone to make time to participate. Nevertheless, it did provide the advantage of obtaining the requirements from the users most likely to use and integrate the dashboard into their organisation. Its discussion provides valuable insights about the dashboard's formats and contents and EH monitoring in urban settings

5. Conclusions

Integrating EH dashboards into environmental, healthcare, sustainable, and policymaking organisations has the potential to improve either quality of life or health outcomes. It is undeniable that shortcomings in requirements elicitations can lead to inadequate implementations (Teixeira et al. 2014). Particularly in the phase of requirements elicitation, the inclusion and collaboration of potential users are essential. Throughout iterative and targeted approaches, after selecting the indicators to be included in the dashboard, the authors identified the requirements to design a dashboard with the potential to help organizations and policymakers planning successful interventions. In this study, an integrated approach was followed to engage potential users from diverse organisations in the collaborative development of design requirements for a dashboard to monitor EH in Lisbon city. Critical insights were obtained into data needs and visualisation preferences of potential end-users, including how to communicate data, monitor indicators' performance, and identify causes and issues of data quality.

The integrated approach described can guide the design of health and/or urban dashboards and serve as a reference for other researchers to design new tools to answer the needs of new organisations in other settings.

Chapter 5

Discussion and conclusion

1. General discussion

The research and practice in EH have evolved in relation to the challenges faced due to the overlapping of environment, sustainable development and public health (Linzalone et al. 2019). Advancing in the knowledge regarding EH may promote its contextualization and the design of tools that enable monitoring and measuring EH in urban settings and enhance decision-making.

The motivation for this PhD project was threefold. First, a literature analysis aimed at disclosing the environmental determinants that impact population health in urban settings. Secondly, the evidence collected was used to inform a participatory approach to select suitable indicators to monitor EH in the Lisbon context. Then, stakeholders from different organizations in Lisbon were consulted regarding which critical requirements should be considered in the design of a dashboard to monitor EH in Lisbon.

The methodology followed throughout this work is sensitive enough to reflect the evolution of evidence about the impact of built and natural environment on health outcomes but makes a contribute producing and systematizing evidence and data to inform decision-making. This work aims to launch insights and debate for the advancement of EH monitorisation in national and international urban settings and the improvement of EH interventions.

During the PhD project, some issues were identified in each study and will be discussed in more detail in the following sections. It will be presented the main contributions to advancing the knowledge of EH in urban settings, the overall limitations of this thesis, as well as suggestions for future work.

1.1. *Environmental determinants of health in urban settings*

The first objective of this work was directed at identifying the environmental determinants of health in urban settings. We have performed a systematic review of literature that resulted in 94 studies with evidence on which environmental dimensions and indicators impact health outcomes. The analysis of the studies was performed within strict criteria to guarantee the results' robustness and comparability with the Portuguese context. Each study was analysed regarding environmental determinant, dimension and indicator, categorised by health outcome, and type of relationship between indicator and health outcome. From the 94 studies assessed, five dimensions – air quality, education, employment, income, mobility – were identified as having the most substantial evidence of impacting health in urban settings.

The first consideration taken from the systematic review of literature is the slight predominance of studies assessing environmental determinants' impact on health outcomes related to morbidity from chronic diseases. Such fact can generate some bias in the results, but it was somehow expected since there is a great concern with the rising rates of chronic diseases and its burden on healthcare systems. The upward trajectory in life expectancy has been followed by an increasing number of individuals spending a significant proportion of their lives coping with sickness rather than enjoying health (Sears and Genuis 2012). This reality presents challenges for decision-makers in the allocation of health resources, and it also calls for improved knowledge about the relationship between surroundings and chronic diseases (Rosella et al. 2018).

Second, the evidence came from a broad spectrum of research areas that hindered synthesising the data. Throughout the literature, complexity was a defining characteristic in the screening of evidence. For example, many studies defined the health outcome as physical activity (Brazdova et al. 2015; Chen et al. 2016) or sleep quality (Anders et al. 2014; Hoefelmann et al. 2013). Substantial evidence has been provided about the impact of physical activity in relation to obesity prevention and the impact of good sleep quality in mental diseases. However, physical activity and sleep quality should be seen as contributors to disease instead of health outcomes (Janssen, Clarke, et al. 2020). The use of different definitions or classifications of diseases can compromise the ability to assess the evidence. Specific guidelines should be adopted regarding (1) what is a health outcome, (2) how should it be quantified, and (3) which is the international statistical classification of diseases (ICD), to overcome such issue.

Third, it is important to highlight the inclusion of a high number of cross-sectional and cohort design studies. The type of evidence derived from our systematic review of literature can be criticised by the absence of randomised controlled trials (RCTs) since they are considered the "gold standard" study design in health research (Allen, Barn, and Lanphear 2015). As Brownson, Gurney, and Land (1999) and Glasgow and Emmons (2007) argue, ethical questions and financial restrictions can explain the lack of RCTs in studies assessing the impact of environmental determinants on health outcomes. RCTs' critical question is whether it is ethical to provide a potentially beneficial intervention to a population and subject another population to unfavourable conditions (Allen, Barn, and Lanphear 2015). Other important factor is the timescale of the exposure to environmental determinants and the development of disease. It may be very expensive and difficult to develop an RCT for studying health outcomes with long latency periods, such as cancer or cardiovascular disease.

Lastly, many of the studies assessed in the systematic review of literature provided country-specific evidence which cannot be generalised for the rest of the world and, in particular, for Portugal. For example, in developed countries, water-borne diseases incidences are significantly low (Forstinus et al. 2016). Thus, given the regional heterogeneity reported in the literature, the evidence's analysis should be conducted systematically to identify comparable data and reduce the bias in the results.

1.2. *Key indicators to assess and monitor EH in Lisbon city*

Selecting the appropriate data is a key stage in the process of developing decision-aid tools. Within this frame, we implemented a participatory approach that, through semi-structured interviews and Web-Delphi process, allowed to understand which indicators are essential to assess and monitor EH in the Lisbon urban area. This study also answered the need to develop new approaches to select indicators to evaluate EH and improve EH-related data collection (Lauriola et al. 2020; Joas et al. 2018; Tisch et al. 2014).

To the best of our knowledge, both processes were never combined to use Web-Delphi as a validation method. Nevertheless, using a Web-Delphi process to validate the information collected by semi-structured interviews can potentially cover some of both processes' weaknesses. The semi-structured interviews allowed the experts to engage in the methodology generating unexpected insights and eliminate indicators that were not suitable to assess and monitor EH in Lisbon city. It was valuable the involvement of experts from public health, epidemiology, built environment and natural environment across academia and national institutions to select the indicators. As EH assessment is influenced by a wide range of dimensions and indicators, the engagement of experts from sectors beyond health is a requirement to progress towards a holistic approach (Pineo et al. 2018; Allen et al. 2019).

Moreover, it is paramount to collect information from a large group of experts in health contexts to ensure the representativeness of different expertise (Ratnapradipa, Brown, and Wodika 2013). Using a Web-Delphi process, it was possible to gather opinions from a wider group of geographically dispersed experts. Overall, acknowledging the limitations of semi-structured interviews and the potential of Web-Delphi as a validation tool, we believe that the participatory approach implemented is robust enough to inform policies and EH interventions.

Additional reflections can be taken from the application of this participatory approach. First, choosing a face-to-face approach to perform the initial assessment of a complex set of data was critical to refining the information collected previously and to include some emergent concerns. The suggestion to include the energy poverty indicator to monitor EH in the Lisbon urban area revealed the growing awareness about the impact of housing conditions on health. Portugal has been pointed out as being among the most vulnerable countries to energy poverty in the European Union (Horta et al. 2019). The struggle of the population to cool down or heat the houses has become more evident with the increasing frequency of extreme weather events such as heat waves. However, until recently this issue has been overlooked by national decision-makers (Gouveia, Palma, and Simoes 2019). The identification of this emergent issue by the experts made it clear the need to consider the housing dimension when designing policies and strategies for tackling EH (Oliveras et al. 2021). The interviews also helped to clarify concepts and doubts, and understand some issues such as language terminology, that we should avoid in designing a Web-Delphi questionnaire.

Second, the low drop-out rate in the Web-Delphi process contributed to the process results' representativity and reliability (Vieira, Oliveira, and Costa 2020). That was probably achieved by having a Web-Delphi process within one month of duration, which prevents experts from getting tired of the process.

Third, the high agreement rate achieved in the Web-Delphi revealed a shared knowledge among the heterogeneous panel. EH's awareness in urban settings is rising, and it is transversal to the areas of expertise selected for our participatory approach.

Fourth, the inclusion of medical doctors specialized in cardiovascular, respiratory or mental diseases instead of only included public health specialists could be important to obtain other views of the health sector.

Lastly, it was impossible to analyse the Web-Delphi results according to the expert's background and assess stability between the rounds due to the small number of rounds and experts in the panel. It would be noteworthy to use a larger panel of experts and more rounds to analyse answers' potential differences.

1.3. *Requirements for a decision-aid dashboard*

The use of dashboards has been increasingly applied in health management but using such tools to monitor EH is far from being everyday practice. Data integration and design issues may preclude dashboard use to monitor EH (Lauriola et al. 2020).

Designing an efficient dashboard is only successful if user requirements are fulfilled. Therefore, these requirements must be clearly identified and easily understood (Teixeira et al. 2014). The motto for this last study was to make use of the evidence and to apply a user-centered approach design to gather a set of requirements for the development of a dashboard to monitor EH in Lisbon.

The user-centered design relied on a user-driven process to empower potential users and give them an active role in the early dashboard design stages. The approach implemented in this study involved potential users from local institutions engaged with health regulation, urban sustainability and policymaking. These users were considered better informed about the characteristics of the city, strengths and limitations of the data, monitorisation trends and the EH goals defined for Lisbon city.

Some reflections of the work developed are worthwhile mention as a starting point to future improvements. Firstly, the use of design cards in online group interviews is relatively new. Some authors (Holeman and Kane 2020; Teixeira et al. 2014; Ahmed et al. 2019) pointed to sketching approaches as the favourite strategy for eliciting users' requirements through flexibility and real-time feedback. However, due to pandemic restrictions, face-to-face iterations were not recommended. More, the sketching process can be time-consuming, given the number of indicators we had to analyse. Hence, to ease the process of requirements elicitation, the design cards proved to be a suitable approach. Using design cards, the participants had the opportunity to communicate their ideas and explore scenarios in a more tangible form, acknowledge the data we could provide via public databases and explain which features were appreciated to visualise each indicator.

Secondly, highlight the advantage of online semi-structured interviews. Using online platforms to conduct the interview was possible to engage several users simultaneously, which otherwise could be difficult. Group interviews were performed instead of an individual interview, which enabled the participants to share ideas with their peers and have insightful discussions in each group. However, individual participants' ideas might have been lost by the influence of peer' opinions. Hence, all the participants had the chance to validate individually the set of requirements and propose modifications. It is important to highlight the importance of this validation stage to mitigate potential bias in the analysis of the user' opinions.

Thirdly, the use of a single EH dashboard for different organisations needs to be investigated. It can be challenging to realise the ideal dashboard design for various reasons. Organisations have different goals and tasks; the consensus concerning how to visualise the indicators and which type of data should be seen was difficult to achieve.

Finally, despite the sounding theoretical foundations of the requirements elicitation process, its effectiveness needs to be confirmed using Power BI to develop the dashboard interface. Issues regarding the data availability, and the comparability of data metrics should be assessed.

2. Main contributions

As discussed at the beginning of this PhD thesis, the world is calling for new and broader approaches to improve health, to protect the environment, and to promote a sustainable EH development. There is a raising awareness towards the need to monitor and measure EH with a shared participation of industries, organisations, and decision-makers to improve EH interventions. The work presented in this thesis was inspired by this need of advancing the knowledge regarding EH monitorisation in urban settings, and the implementation of tools to support decision-making.

The systematic literature review performed in this thesis allowed to frame the problem by summarizing a high number of studies assessing environmental determinants, by identifying gaps, and collecting the information needed to be use in monitoring tools.

Furthermore, it is also important to highlight the fundamental role of the participatory methods adopted throughout this thesis. The participatory processes were designed to incorporate the largest number of perspectives and views of experts and stakeholders to make sure that our results reflected the broader view of EH assumed throughout the thesis. Involving the key experts and stakeholders within the process makes it easier to implement and deliver the research. Through the use of specifically designed participatory processes, it was possible to gather new insights and experience an increasing in sharing knowledge between researchers and stakeholders from local industries and organizations.

Generically, this thesis has methodological and policy implications by bringing robustness and transparency to the decision-making processes in industries and organisations with the goal of optimizing environmental and urbanization policies and decisions regarding EH interventions.

3. Study limitations

Through this research project was possible to acquire deeper knowledge on the issues and type of challenges encountered during the implementation of decision-aid tools to assess and monitor health in urban settings. This research explores a broader approach of EH considering built and natural environment determinants to monitor EH in Lisbon. Some limitations were identified during this research project; some could not be addressed due to the study's focus and the time limit.

First, studies involving qualitative approaches, by the bias of data analysis, are always a limitation. Validation processes and sound methodologies were conducted to minimise potential bias.

Second, the role of evidence in underpinning EH is critical and still needs improvements. A narrowed systematic review of literature could be performed to assess the available evidence. Addressing the impact of the built environment and the natural environment dimensions separately could have provided a better understanding about the relation between specific dimensions and their impact on health outcomes in urban settings. On the other hand, the exclusion of studies assessing the effects of the climate change on health may have excluded an emergent and urgent topic from the monitorisation of EH.

In terms of the participatory approach proposed to select the key indicators to monitor EH in Lisbon, it is important to bear in mind the Web-Delphi limitation as a validation method. It would be possible to gain new insights about this method's adequacy by increasing the panel, involving a higher number of medical doctors with different specializations, and including experts from more national organisations and stakeholders from industries.

The elicitation of requirements for the dashboard only included local organisations focusing on health regulation, environmental and urban sustainability. Although the sample represents a key group of potential users, not all types of users were represented. Users from industries, researchers and general population could be included to gather more insights.

Lastly, criticism can be made due to the absence of health outcomes indicators in the proposed model. The difficulty in evaluating and selecting health outcome indicators observed during this project's early phases led us to focus on built and natural environment indicators.

4. Conclusions

The research carried out throughout this PhD project permitted to enhance the knowledge on the assessment of EH to inform the design of a dashboard to monitor EH in Lisbon.

As discussed at the beginning of this thesis, while important successes have occurred in the treatment of specific diseases, the overall burden of disease caused by the impact of built and natural environment on health has not decreased. The work presented in this PhD thesis was inspired by a necessity to assist organisations and industries in understanding which environmental indicators are critical to monitor EH in Lisbon, and how to design monitorisation tools to inform EH interventions. The adoption of combined methods presented throughout this work has great potential to bring positive impact to the decision-making processes of the organisations and industries facing environmental pressure from national legislation and global goals. Building on the findings, actions to monitor EH in Lisbon should cover gaps to 1) ensure intersectoral work to support sustainable EH development, 2) allow the sharing of expertise among researchers, decision-makers and institutions, and 3) promote the continuous generation of high-quality data.

The investment in improving EH could help alleviate the global health care systems burden (Pruss-Ustun et al. 2019). It may also have multiple co-benefits such as increase health equity, economic development, improvement of technology and industry-related processes, and climate change mitigation. This work demonstrates that only with an integration of theory and tools that incorporate scientific, institutional, and community stakeholders will interventions be devised to allow substantial gains in EH.

5. Future perspectives

The research developed in this thesis left unanswered question and raised some issues, mainly data-related challenges, that still deserve further research.

It will be essential to implement sound practices to manage data collection. The overload of data, different data formats, inconsistencies in databases, and the complexity in selecting indicators, strongly hamper building tools upon that data. A refinement of existing databases should be performed in order to organize the data with, for example, similar units of measure or assessed in similar periods of time.

A systematic review of literature assessing the impact of temperature should be performed to complement the set of indicators. The potential inclusion of temperature indicators in the monitorisation tool could help the decision-makers having an even broader picture of the status of EH in urban settings.

The surprising result regarding the inclusion of energy poverty indicator to monitor EH in Lisbon could be a starting point for studies: 1) to assess the potential relationship between the housing thermal comfort and health outcomes such as mortality rates or respiratory exacerbations, 2) to help identify the most vulnerable populations to the extreme weather events in the Lisbon city, and 3) to serve as a baseline to monitor the impacts of climate change in EH in Lisbon.

The proposed methodology can be seen as one iteration of the design process. The upload of all the needed databases should be done using Power BI and a data treatment should be performed to create the visualizations for all the indicators. A dashboard prototype should be built and tested by a higher group of users. It would be important to include more users from different organizations and industries, with different needs and expertise about the use of a dashboard. This type of knowledge would help to increase the usability and robustness of such tool. Further iterations must be conducted to create the dashboard and to refine the features. A pilot study should be performed to implement the dashboard in different organisations and industries.

While this study provided knowledge to inform the development of a dashboard to monitor EH in the Lisbon city, we believe it can be adaptable to other contexts. Data from other Portuguese cities could be used to validate the methodology proposed and to create a national EH dashboard. The same methodology could be applied to rural contexts or even to international cities.

Questions in dealing with large amounts of data are also a challenge for industries. This sector is suffering the pressure of adapting processes and comply with the legislation in short times. It is necessary to verify the methodology's usefulness and applicability to build decision aid tools for industrial settings.

Finally, integrating the methodology followed in this work with the development of other tools, such as an overall EH index including health outcomes indicators, represents an interesting path to be explored.

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Supplementary Material

Appendix 1

Table 10 Risk of bias assessment (source: Rojas-Rueda D, 2019)

	Bias due to exposure assessment	**Bias due to confounding**	**Bias due to selection of participants**	**Bias due to health outcome assessment**	**Bias due to not blinded outcome assessment**	**Total risk of bias**
Low	A clear description of the exposure assessment and exposure unit; based on measurements or modeling.	All-important confounders are considered either through matching or, restriction or in the analysis. (e.g., age, gender, etc.)	Participants randomly sampled from a known population, AND response rate higher than 60%, AND attrition rate less than 20% in follow-up studies.	The health outcome of interest is objectively measured OR taken from medical records OR taken from questionnaire or interview using a known scale or validated assessment method	The health outcome of interest is assessed blind for exposure information in cohort and cross-sectional studies or exposure is assessed blind for being a case in case-control studies	At least 4 at low risk of bias. One “high” or “unclear” out of five is allowed
High	Not clear description of the exposure assessment or exposure unit OR/AND performed by unqualified staff	Only 1 or no confounder is taken into account; OR subjects in exposed and unexposed groups differ for one or more important confounders and there is no adjustment in the analysis	No random sampling OR response rate less than 60% OR attrition rate higher than 20%.	The health outcome of interest is self-reported and not assessed using a known scale or validated assessment method.	The health outcome and/or exposure assessment is not blinded.	Any other

Unclear	Not enough information is available to judge the above	Less then all to > 1 important confounder taken into account, OR Insufficient information to decide on one of the above.	No information to judge the above.	Not enough information reported to assess the above.	Not enough information reported to assess the above.	
Not apply	N/A	N/A	N/A	N/A	N/A	

Table 11 Risk of bias assessment for all reviewed studies

Reference	Bias due to exposure assessment	Bias due to confounding	Bias due to selection of participants	Bias due to health outcome assessment	Bias due to not blinded outcome assessment	Total risk of bias
Aguilar-Palacio, I. (2012)	High	Low	Low	High	Unclear	**High**
Akarolo-Anthony, S.N. (2014)	Low	Low	Low	Low	High	**Low**
Albaladejo, R. (2014)	Low	Low	Unclear	High	High	**High**
Ali, M.K. (2016)	Low	Low	Low	Low	High	**Low**
Artaud, F. (2013)	Low	Low	High	High	Unclear	**High**
Banerjee, D. (2010)	High	Low	Low	High	High	**High**
Bastos, L.N.V. (2018)	Low	Low	Unclear	Low	High	**High**
Belon, A.P. (2012)	High	High	Unclear	High	N/A	**High**
Borrell, C. (2014)	Low	Low	Unclear	Low	High	**High**
Buot, M.L. (2014)	Low	Low	Low	Low	N/A	**Low**
Cabral, D.M. (2014)	Low	Low	Low	High	Low	**Low**
Cau, B.M. (2016).	Low	Low	Low	High	Unclear	**High**
Ceccon, R.F. (2014)	Unclear	Unclear	N/A	Low	N/A	**High**
Cheng, E.R. (2012)	Low	Unclear	N/A	Low	N/A	**High**
Christiani, Y. (2015)	Low	High	High	Low	High	**High**

Cordoba-Dona, J.A. (2012)	Low	High	Unclear	Low	High	**High**
de Carvalho Cremm, E. (2012)	Low	Low	Low	Low	High	**Low**
de Sousa Gdos, S. (2014)	Low	Unclear	High	Low	N/A	**High**
de Souza, O.F. (2012)	Low	Unclear	Low	Low	Unclear	**High**
Duarte-Salles, T. (2011)	Low	High	Unclear	Low	High	**High**
Dzhambov, A.M. (2016)	Low	Low	Low	Low	High	**Low**
Eibich, P. (2016)	Low	Low	Low	Low	High	**Low**
Eisele, M. (2015)	Low	Low	Unclear	High	High	**High**
Enroth, L. (2013)	Low	High	High	High	High	**High**
Faresjo, T. (2010)	Low	Unclear	High	High	High	**High**
Fatema, K. (2013)	Low	Low	High	High	High	**High**
Ferreira-Junior, O.M. (2015)	Low	Low	Low	Unclear	Unclear	**High**
Fleischer, N.L. (2008)	Low	Low	High	Low	High	**High**
Franca, M.H. (2017)	Low	Low	Low	High	High	**High**
Franca, V.F. (2016)	Low	High	Unclear	High	Unclear	**High**
Garcia-Subirats, I. (2011)	Low	High	Low	Low	High	**High**
Goulart, M.D. (2016)	Low	Low	Low	Low	High	**Low**
Grazuleviciene, R. (2015)	Low	Low	Low	Low	High	**Low**

Grelat, N. (2016)	Low	Low	Low	High	High	**High**
Gronlund, C.J. (2015)	Low	Low	Low	Low	High	**Low**
Habermann, M. (2012)	Low	Unclear	N/A	Low	N/A	**High**
Habib, R.R. (2013)	Low	Low	Low	High	High	**High**
Harlan, S.L. (2013)	High	Low	N/A	Low	N/A	**High**
Hayward, I. (2012)	Low	Low	Low	Low	N/A	**Low**
Hu, W. (2008)	Low	Unclear	N/A	Low	High	**High**
Huang, J.V. (2017)	Low	Low	Unclear	High	High	**High**
James, W.L. (2012)	Low	Low	High	Low	N/A	**High**
Kioumourtzoglou, M.A. (2016)	Low	Unclear	N/A	Low	Unclear	**High**
Lacerda, J.T. (2008)	Low	Low	Low	High	High	**High**
Lange, D. (2011)	Low	High	Unclear	Low	High	**High**
Lee, J. (2014)	Low	Low	Unclear	Low	N/A	**High**
Lemke, L.D. (2014)	Low	Unclear	Unclear	Unclear	High	**High**
Li, H. (2015)	Low	Unclear	N/A	Low	Low	**High**
Liu, C. (2014)	Low	Low	Low	Low	High	**Low**
Lopes, E.M. (2015)	Low	Unclear	Low	Low	High	**High**
Lovasi, G.S. (2012)	High	Low	Unclear	Unclear	High	**High**

Lovasi, G.S. (2011)	Low	High	Unclear	Low	High	**High**
Lovasi, G.S. (2009)	High	Low	Unclear	Low	High	**High**
Luo, K. (2017)	High	Unclear	N/A	Low	High	**High**
Maniecka-Bryla, I. (2013)	Low	Low	Unclear	High	High	**High**
Martin-Fernandez, J. (2014)	Low	Low	Low	Low	High	**Low**
Melis, G., et al. (2015)	Low	Low	Unclear	Low	High	**High**
Mendes, L.L. (2013)	Low	Low	Low	High	High	**High**
Migliore, E. (2009)	Low	High	Low	High	High	**High**
Modig, L., et al. (2009)	Low	Unclear	Unclear	High	High	**High**
Modrek, S. (2011)	Low	Low	Unclear	Low	High	**High**
Morisco, F. (2017)	Low	Low	Low	Low	High	**Low**
Neuberger, M. (2013)	Low	Unclear	N/A	Low	High	**High**
Nolasco, A. (2015)	High	High	Unclear	Low	N/A	**High**
Nolasco, A. (2014)	High	High	Unclear	Low	N/A	**High**
Pasetto, R. (2013)	High	High	Unclear	Low	High	**High**
Patel, M.M. (2010)	Low	Low	Low	High	High	**High**
Pinto-Sarmento, T.C. (2016)	Low	Low	Unclear	Low	High	**High**
Piovesan, C., et al. (2010)	Low	Low	Low	Low	High	**Low**

Pizzo, G. (2010)	Low	Low	High	High	High	**High**
Ramsay, S.E. (2008)	Low	High	Low	High	High	**High**
Ribeiro, A.I. (2016)	Low	Unclear	Unclear	Low	N/A	**High**
Ribeiro Dos Santos, E. (2016)	Low	Low	Low	High	High	**High**
Ristovska, G. (2009)	Low	Unclear	Low	High	High	**High**
Rosicova, K. (2015)	Low	Low	Unclear	Low	High	**High**
Sanchez-Barriga, J.J. (2012)	High	High	Unclear	Low	N/A	**High**
Sanderson, M. (2015)	Low	Low	High	Unclear	Unclear	**High**
Santiago, B.M. (2013)	Low	Low	Low	High	Unclear	**High**
Santos, S.L. (2016)	Low	Low	N/A	Low	N/A	**Low**
Scazufca, M. (2010)	Low	Low	Low	Low	High	**Low**
Schulz, A.J. (2008)	Low	Low	Low	Low	N/A	**Low**
Smigielski, J. (2013)	Low	Low	Unclear	Unclear	Unclear	**High**
Steer, S. (2014)	Low	Unclear	Low	Low	High	**High**
Sulander, T. (2012)	Low	Low	High	High	High	**High**
Sun, G. (2017)	Low	Unclear	Unclear	Low	High	**High**
Thorn, L.K. (2011)	Low	Low	Unclear	Low	High	**High**
Trachtenberg, A.J. (2014)	Low	Low	Unclear	Low	High	**High**

Tucker-Seeley, R.D. (2013)	Low	Low	High	High	High	**High**
Unrath, M. (2014)	Low	Low	Low	Low	High	**Low**
Vandenheede, H. (2014)	Low	Low	Low	Low	N/A	**Low**
Walsh, D. (2010)	Low	High	Unclear	Low	N/A	**High**
Willers, S.M. (2016)	Low	Unclear	N/A	Low	High	**High**
Wong, C.M. (2008)	Low	Unclear	N/A	Low	High	**High**
Yang, B.Y. (2017)	Low	Low	Low	Low	High	**Low**

Appendix 2

Table 12 Studies of socioeconomic dimensions and analysed indicators and health outcomes with evidence of association

Health outcome	**Reference**	**Overall aim**	**City/Cities Country**	**Study population**	**Study design**	**Health outcome measure**	**Association measure**	**Dimension/ Indicator**	**Relation between indicator and PH**
Overall Mortality	Belon, A. P. (2012)	To identify the magnitude of per capita income differences in mortality rates among adults' residents in a city of one million people.	Campinas; Brazil	Adults (+20 years old) †	Ecological	Age adjusted mortality rates *(years)*	Rate ratios	Income *Monthly income* *Men*: RR=1.17; 95%CI= 1.13, 1.20 *Women:* RR=1.30; 95%CI=1.25, 1.34	+

	Borrell, C. (2014)	To explore inequalities in total mortality and socioeconomic indicators between men and women in small areas of 16 European cities	Finland, Sweden, Belgium, France, Netherlands, UK, Switzerland, Czech Republic, Slovakia, Hungary, Italy, Portugal, Spain	Adults (+25 years old) *n= 26,229,104 inhabitants*	Cross-sectional ecological	Standardized mortality ratios (SMR)	Relative risk	Education and occupation *Deprivation index (%) for men* *Finland:* RR=1.144; 95%CI=1.108, 1.181 *Sweden:* RR=1.194; 95%CI=1.170, 1.219 *Belgium:* RR=1.022; 95%CI=1.011, 1.032 *France:* RR=1.060; 95%CI=1.035, 1.086 *Netherlands:* RR=1.037; 95%CI=1.020, 1.054 *UK:* RR=1.050; 95%CI= 1.043, 1.058 *Switzerland:* RR=1.051; 95%CI= 1.022, 1.081 *Czech Republic:* RR=1.227; 95%CI=1.020, 1.455 *Slovakia:* RR=1.101; 95%CI=0.975, 1.239 *Hungary:* RR=1.137; 95%CI=1.103, 1.174 *Italy:* RR=1.055; 95%CI=1.048, 1.062 *Portugal:* RR=1.058; 95%CI=0.991, 1.130 *Spain*: RR=1.046; 95%CI=1.039, 1.052	+

	Ceccon, R. F. (2014)	To correlate suicide mortality and work indicators in six Brazilian metropolises.	Porto Alegre, Recife, Salvador, Belo Horizonte, Rio de Janeiro, São Paulo; Brazil	Adults (+18years old)†	Ecological	Number of suicides	β coefficient	Employment *% of employed population* β=0.014; 95%CI= 0.006, 0.022	+
								Income *% of people with income less then minimum wage per month* β=-0.005; 95%CI=-0.383, 0.373	+
	Cheng, E. R. (2012)	To describe the association premature mortality among counties with broadly differing levels of income.	3,139 USA counties	All individuals (to 75 years old) †	Cross-sectional*	All-cause, age-adjusted mortality rate per 100,000 population	β coefficient	Income *Median household income ($)* β=0.01, SE=0.02	+
								Racial segregation *% nonwhite/nonblack race* β=0.003, SE=0.005	
	de Sousa Gdos, S. (2014)	To analyze the possible relationship income and education indicators with homicide mortality.	Fortaleza; Brazil	All individuals *N= 35,266 deaths of which 1,815 were victims of homicide*	Cross-sectional ecological	Rate of mortality by homicides per 100,000 inhabitants	β coefficient	Education *Average years of study* β=-0.001; p=0.141	+
								Income *Per capta income* β=-9.02; p=0.049	
	James, W. L. (2012)	To understand if overall and race-specific mortality rates are combined with local	48 USA states	All individuals†	Ecological	Race-specific age/sex adjusted mortality rates per 100,000	Moran's I coefficient	Income *Household income* *Whites*: I=0.007; p<0.001 *Blacks*: I=0.009; p<0.05	+

		health infrastructure data, income inequality and racial segregation.						Racial segregation *Percentage of Black* *Whites*: I=0.238; p>0.05 *Blacks*: I=0.430; p>0.05	
	Lee, J. (2014)	To examine if adult mortality from injuries in South Korean metropolitan cities is affected adjusting for socioeconomic indicators.	Seoul, Busan, Incheon, Daegu, Gwangju, Daejeon, Ulsan; South Korea	Adults (≤34 years old) *n=10 583859*	Cross-sectional*	Number of deaths by suicide, traffic accidents, falls and all injuries	Risk ratio	Education *Worst deprivation index* *Traffic accidents*: RR=1.34; 95%CI= 1.05, 1.73 *Falls*: RR=1.63; 95%CI=1.20; 2.20 *Suicide*: RR=1.09; 95%CI= 1.01; 1.17 *All injuries*: RR=1.14; 95%CI= 1.07; 1.22	+
	Nolasco, A. (2015)	To describe inequalities in preventable avoidable mortality in relation to socioeconomic status in small urban areas of thirty-three Spanish cities.	Spain	All individuals†	Ecological	Number of deaths	Relative Risk	Education and Occupation *Socioeconomic status* *0-44years old:* RR=3.0; SE=0.7 (*SES1 vs SES3*) *45-64years old:* RR=2.3; SE=0.8 (*SES1 vs SES3*) *>64years old:* RR=1.7; SE=0.5 (*SES1 vs SES3*)	Men: +

	Nolasco, A. (2014)	To describe inequalities in preventable and amenable mortality in relation to socioeconomic status in 3 small urban areas.	Alicante, Castellón, Valencia; Spain	All individuals (0-74 years old)†	Transversal ecological	Frequency of amenable deaths in non-institutionalized individuals	Relative Risk	Education and Occupation *Socioeconomic status* Alicante *(SES3)* *Men*: RR=1.5; 95%CI=1.1, 1.9 *Women*: RR=1.8; 95%CI=1.3, 2.4 Castellón *(SES3)* *Men*: RR= 1.4; 95%CI= 0.9, 2.1 *Women*: RR=1.7; 95%CI=1.7; 1.1, 2.6 Valencia *(SES3)* *Men*: RR=1.4; 95%CI=1.2, 1.6	+
	Ribeiro, A. I. (2016)	To evaluate the spatial distribution of old-age survival and its relationship with built environment and deprivation.	Porto; Portugal	Elderly (75–84 years old)†	Cohort*	Old-age survival	Odds ratio	Income *European Deprivation Index* *Men*: OR=1.31; 95%CI= 1.05, 1.63 *Women:* OR=1.53; 95%CI= 1.24, 1.89	+

	Sanchez-Barriga, J. J. (2012)	To determine and to establish an association between education with mortality from hypertension.	31 Mexico states	Adults (+18 years old)†	Ecological	Age-adjusted mortality rates nationwide per 100 000 inhabitants	Relative Risk	Education *Education level* *Incomplete elementary school:* RR=1.462; 95%CI= 1.442, 1.482 *Complete elementary school:* RR= 0.251; 95%CI= 0.245, 0.257 *High school or equivalent:* RR= 0.171; 95%CI= 0.167, 0.176 *Senior in high school or equivalent:* RR= 0.098; 95%CI= 0.095, 0.102 *College:* RR= 0.121; 95%CI= 0.117, 0.125	+
	Santos, S. L. (2016)	To identify factors associated with infant mortality by a hierarchical model based on socioeconomic determinants like maternal education and maternal occupation.	Teresina; Brazil	Newborns (Mother age: +10 years old) *n=13,882*	Cohort	Number of love births and numbers of death births	Odds ratio	Education *Education level* *Low:* OR=1.85; 95%CI=1.43, 2.32 *Intermediate:*1, p< 0.001 *High:* OR=1.28; 95%CI=1.10, 1.47	-
								Employment *Mothers occupation* *With remuneration: OR= 2*.03; 95%CI=1.48, 2.44	

	Vandenheede, H. (2014)	To quantify and compare socioeconomic inequalities measured by education level and deprivation, in all-cause mortality in urban population samples from 10 cities.	Czech Republic, Russia, Poland, Lithuania	Adults (45–69 years) *n=2750*	Cohort	Number of all-causes deaths	Hazard ratios	Education *Education level* *Lower secondary:* HR=1.8; 95%CI=1.5, 2.1 *Upper secondary:* HR=1.4; 95%CI=1.3, 1.6	Men: +
								Income *Income deprivation* *Yes:* HR=1.4; 95%CI=1.2, 1.6	
	Walsh, D. (2010)	To analyze the relation between income deprivation and overall mortality.	Glasgow, Liverpool, Manchester; UK	All individuals†	Cohort*	Number of deaths	Standardized mortality ratio	Income *Scottish Index of Multiple Deprivation (SIMD)* SMR=114.4; 95%CI=113.2, 115.5	+
Morbidity related with birth outcomes	de Souza, O. F. (2012)	To investigate the prevalence of malnutrition associated with socioeconomic conditions, access to services and childcare.	Acre; Brazil	Children (<5 years old) *n= 667*	Cross-sectional	Prevalence by height for age and weight for height deficits	Prevalence ratio	Education *Education level* *Having an illiterate father or stepfather:* PR=1.82; 95%CI=1.01, 3.27	+
								Income *Household wealth index* PR=1.74; 95%CI=0.95, 3.18	

	Garcia-Subirats, I. (2011)	To describe economic inequalities in low birth weight, preterm birth and small for gestational age births, in urban neighborhoods.	Barcelona; Spain	Newborns (Mother age: 12–49 years old) *n=192,921 live births*	Cross-sectional ecological	Prevalence of Low birth weight, Preterm Small for gestational age births	β coeficient	Employment *Unemployment rate* *Low birth weight*: β=0.10; 95%CI= 0.07, 0.12 *Preterm*: β=0.06; 95%CI= 0.04, 0.08 *Small for gestational age*: β=0.10; 95%CI= 0.07, 0.12	+
	Hayward, I. (2012)	To investigate if socioeconomic status might be viable target of interventions to reduce differential risk of small gestational age.	Vancouver; Canada	Newborns (Mother age:20-35 years old) *n=59,039 live, singleton births*	Cross-sectional*	Small gestation age (SGA)	Odds Ratio	Income *Average income quintile* *($24,444–$28,440)*: OR=0.9; 95%CI=0.8, 1.0 *($28,440–$32,954)*: OR=0.9; 95%CI=0.8, 1.0 *($32,986–$38,832):* OR=0.8; 95%CI=0.7, 0.9 *($38,837–$509,269)*: OR=0.8; 95%CI=0.7, 0.8	+
Morbidity related with chronic diseases	Banerjee, D. (2010)	To determine the role of education in the association of functional status, chronic disease and civic participation with SRH.	Houston; USA	Elderly (>60 years old) *Weighted n= 127*	Cross-sectional	Self-reported health (SRH) *% prevalence of chronic conditions*	Odds Ratio	Education *Literacy level* *Arthirtis*: OR=1.99; 95%CI=0.92, 4.30 *Diabetes*: OR=2.12; 95%CI=0.93, 4.81 *Hypertension*: OR=4.29; 95%CI=1.85, 9.98	+
	Buot, M. L. (2014)	To examine the relationship between income inequality, poverty, educational	USA	Adults (+18 years old)†	Cohort*	Average HIV incidence	HIV Association Factor	Education *High School level or More* HIV=1.51; 90%CI= 1.17, 2.00	+

		attainment, residential segregation and HIV incidence across eighty large cities.						Employment *% unemployment* HIV=1.76; 90%CI= 1.42, 2.17	
								Income *Median household income* HIV=1.49; 90%CI= 1.20, 1.86	
								Racial segregation *Black isolation* HIV=1.73; 90%CI= 1.40, 2.16	-
	Cabral, D. M. (2014)	To determine the prevalence of chronic pain and to identify sociodemographic, psychosocial, and occupational factors associated.	São Paulo; Brazil	Adults (+15 years old) *n= 1,108*	Cross-sectional	Chronic Pain Grade (CPG)	Prevalence ratio	Employment *% unemployment* PR=1.78; 95%CI=0.81, 3.91	+
								Education *≤4 Years of study* PR=1.28; 95%CI=1.09, 1.51	
	Cordoba-Dona, J. A. (2012)	To determine the relationship between HIV-TB and non-HIV-TB incidence and social deprivation indicators.	Campo de Gibraltar; Spain	All individuals†	Cross-sectional	Tuberculosis incidence by HIV status	Incidence rate ratio	Education and Occupation *Socioeconomic deprivation (Level 2)* *HIV-TB*: IRR=1.32; 95%CI=0.73, 2.37 *Non-HIV-TB*: IRR=1.25; 95%CI=0.79, 1.97	+

	Enroth, L. (2013).	To investigate socioeconomic differences in health and functioning among nonagenarian men and women.	Tampere; Finland	Elderly (+90 years old) *n=1283*	Cross-sectional	Functional ability, comorbidity, and SRH indicators	Prevalence ratio	Education *% high educated* *Functional ability*: PR=3.46; 95%CI=1.59, 7.53 *Comorbidity*: PR=4.28; 95%CI=1.93, 9.47 *SRH*: PR=1.66; 95%CI=0.56, 4.91 Employment *% Upper nonmanuals* *Functional ability*: PR=3.19; 95%CI=1.28, 7.98 *Comorbidity*: PR=2.39; 95%CI=0.96, 5.83 *SRH*: PR=1.86; 95%CI=0.50, 6.93	+
	Ferreira-Junior, O. M. (2015)	To assess prevalence of dental pain and associated contextual factors.	27 capital cities Brazil	Children (5 years old) *n=7280*	Cross-sectional	Dental pain in the last 6 months	Prevalence rate	Education *% incomplete primary education:* PR=1.03; 95%CI= 1.01, 1.06 Income *Per capita family income (U$)* *≤218:* PR=2.67; 95%CI=1.33, 5.32 *219–656:* PR=2.11; 95%CI=1.03, 4.32 *657–1093:* PR=1.22; 95%CI=0.49, 3.07	+

								Racial segregation *Black:* PR=1.10; 95%CI=0.88, 1.38 *Brown:* PR=1.20; 95%CI=*0.91*, *1.56* *Yellow (Asian descendants):* PR=0.63; 95%CI=*0.26*, *1.57* *Indigenous:* PR=1.97; 95%CI=1.19, 3.26	
	Fleischer, N. L. (2008)	To investigate the associations of individual- and area-level SES with chronic disease risk factors.	Buenos Aires; Argentina	Adults (+18 years old) *n=1510*	Cross-sectional	Percentage of High blood pressure (diagnosed at least once) and Diabetes (diagnosis)	Odds Ratio	Education *Secondary or universitary level* *Hypertension*: OR=1.48; 95%CI=0.99, 2.20 *Diabetes*: OR=4.12; 95%CI=1.85, 9.18 Income *Household monthly income (in pesos)* *Hypertension*: OR=1.50; 95%CI=0.99, 2.26 *Diabetes*: OR=2.43; 95%CI=1.14, 5.20	+

	Goulart, M. D. (2016)	To assess if adults living in cities with a relative increase on income inequality were more likely to have severe tooth loss and lack a functional dentition.	Capital cities Brazil	Adults (35-44 years old) *n=6366*	Cross-sectional	Tooth loss outcomes	Odds ratio	Income *Family monthly income (R$)* *Severe tooth loss* *1.501-2.500:* OR=1.09; 95%CI=0.65, 1.84 *501-1.500:* OR=1.42; 95%CI=0.89, 2.26 *<500:* OR=2.59; 95%CI=0.93, 2.70 *Lack of functional dentition* *1.501-2.500:* OR=1.63; 95%CI=1.26, 2.12 *501-1.500:* OR=1.95; 95%CI=1.53, 2.48 *<500:* OR=2.54; 95%CI=1.92, 3.37	+
	Lacerda, J. T. (2008)	To analyze the relationship between oral health conditions in adult's socio-demographic characteristics.	Santa Catarina; Brazil	Adults (35-44 years old) *n= 622*	Transversal	Oral Impacts on Daily Performances (OIDP)	Odds ratio	Education *<8 Years of study* OR=1.456; 95%CI= 0.76, 2.78 Income *Monthly household inccome until 3 minimum wages* OR=1.49; 95%CI=0.75, 2.95	+

	Lopes, E. M. (2015)	To analyze the relationship between pediatric AIDS cases and neighborhood socioeconomic indicators.	Fortaleza; Brazil	Children (<12 years old)†	Ecological	Number of AIDS cases	Moran index	Income *Monthly household income* I=0,6; p= 0,001	+
	Morisco, F. (2017)	To assess the prevalence of risk factors for hepatitis C virus (HCV) infection in a large metropolitan area.	Naples; Italy	Adults (+18 years old) *n=1315*	Cross-sectional	Prevalence of HCV	Odds Ratio	Education *Low level: elementary/secondary education only* OR=3.6; 95%CI=1.4, 9.3	+
	Pinto-Sarmento, T. C. (2016)	To investigate socioeconomic factors associated with the presence of dental caries in preschool children.	Campina Grande; Brazil	Children (3-5 years old) *n= 843*	Cross-sectional	Number of diagnosis of dental caries and lesion activity	Odds ratio	Education *≤8 Years of study* OR=2.15; 95%CI= 1.15, 4.00 Income *Monthly household income ≤U$ 312.50:* OR=1.83; 95%CI=0.96, 3.50	+
	Piovesan, C. (2010)	To assess the inequality in caries distribution and the association between socioeconomic indicators and caries experience of preschool children.	Santa Maria; Brazil	Children (1-5 years old) *n=455*	Cross-sectional	Prevalence decayed, missing and filled primary teeth (dmf-t index)	Rate ratio	Education *<8 Mother's level of education (years)* RR=2.03; 95%CI= 1.28,3.23 Racial segregation *% Non-white* RR=1.71; 95%CI= 1.11, 2.81	+

	Pizzo, G. (2010)	To investigate the prevalence of caries in children and assessed the relationship between socio-behavioral determinants and caries.	Palermo; Italy	Children (5 and 12 years old) *n=511*	Cross-sectional*	Dmf-t index	Odds ratio	Education *Mother's educational level Middle vs Primary* OR=0.07, 95%CI=0.02, 0.35	+
	Ramsay, S. E. (2008)	To examine the determinants of socioeconomic inequalities in disability and functional limitation in elderly men.	24 cities United Kingdom	Elderly (63-82 years old) *n=3981*	Cross-sectional	Activities of daily living (ADLs)	Odds Ratio	Income *Registrar Generals' Social Class Classification (class V vs I)* *ADL*: OR=3.13; 95%CI=1.64, 5.97 *ADL disability*: OR=2.87; 95%CI=1.49, 5.51 *Functional limitation*: OR=2.65; 95%CI=1.31, 5.35	+
	Steer, S. (2014)	To investigate the association between epilepsy and individual elements of deprivation in order to identify modifiable elements.	United Kingdom	Adults (+18 years old) *n=304,331*	Cohort*	Epilepsy prevalence (%)	Index of Multiple Deprivation	Education *Education and training deprivation* r=0.665, p<0.01 Employment *Employment deprivation* r=0.629, p<0.01 Income *Income deprivation* r=0.358, p<0.01	+

	Schulz, A. J. (2008)	To provide evidence of an effect linking socioeconomic indicators to cardiovascular disease (CVD) risk factors.	Detroit, Michigan; USA	Adults (≥25 years old) *n=919*	Cross-sectional*	Depressive symptoms, smoking status, physical activity, body mass index and waist circumference	β coeficient	Income *Monthly income ($)* *Depressive symptoms:* β=-0,03, p<0.001 *Smoking status:* β=0.14, p<0.001 *Physical activity:* β=-0.01, p<0.001 *Body mass index:* β=0,26 p<0.001 *Waist circumference*: β =0.24, p<0.001	+
	Thorn, L. K. (2011)	To evaluate associations between areas with deprived socioeconomic conditions and pneumonia incidence.	Goiania; Brazil	Children (<2 years old) *n=11 521*	Prospective	Radiograph-confirmed pneumonia (CXR+Pn)	Incidence rate ratio	Education *% of woman illiterate >10 years old* IRR=1.119; 95%CI=1.032, 1.213 Income *% of head of households earning >20 minimum wages* IRR=0.952; 95%CI=0.937, 0.967	+
	Trachtenberg, A. J. (2014)	To examined whether differences in patient demographics, ambulatory care use, or physician characteristics could explain disparities in chronic obstructive pulmonary disease and asthma hospitalizations.	Manitoba; Canada	Adults (18-70 years old) *n=34,741*	Cohort	Chronic obstructive pulmonary disease or asthma grouped together as obstructive airway disease	Odds ratio	Income *Income quintile* *Q1:* OR=2.93; 95%CI=2.19, 3.93 *Q2:* OR=2.51; 95%CI=1.86, 3.40 *Q3:* OR=1.54; 95%CI=1.11, 2.13 *Q4:* OR=1.41; 95%CI=1.01, 1.98	+

Morbidity related with mental illness	Aguilar-Palacio, I. (2012)	To identify the relationships between social factors and SRH.	Casablanca; Spain	Adults (+15 years old) *n=1032*	Cross-sectional	General health index	Odds ratio	Education *Primary or no education level* *Vulnerable group:* OR=1.00; 95%CI=0.99, 1.02	+
	Christiani, Y. (2015)	To examine unequally distribution of depression among women in Indonesia's major cities and investigate the factors contributed to the inequality.	Jakarta, Surabaya, Medan, Bandung; Indonesia	Adult (19-65 years old) *n=1117*	Cross-sectional*	Prevalence of depression	Concentration index	Income *Monthly household expenditure* CI=0.015, p<0.05 Education *Higher education level* CI=0.27, p<0.05	+
	Faresjo, T. (2010)	To analyze the relations of social conditions to SRH status in the populations in white-collar city and a blue-collar twin city.	Norrköping, Linköping; Sweden	Adults (20–64 years old) *n=13,440*	Cohort*	SRH	Probability of no difference	Education *High level (15 years or more)* β=0.11; p=0.004	+
	Franca, M. H. (2016)	To estimate the association of prevalence rates of mental disorders with employment status.	São Paulo; Brazil	Adults (+18 years old) *n= 5037*	Cross-sectional	12-month prevalence of 19 DSM-IV mental disorders	Odds ratio	Employment *% Working:* OR=1.0 *% Inactive:* OR=2.8; 95%CI=1.51, 5.12 *% Unemployed:* OR=1.4; 95%CI=0.64, 3.14	+

	Habib, R. R. (2013)	To evaluate the association between women's SRH and socioeconomic indicators.	Bebnine, Lebanon	Adult (+14 years old) *n=2223*	Cross-sectional	Self-reported health status	Odds Ratio	Education *Read/write-secondary* *Fair/Good:* OR=0.75; 95%CI=0.57, 0.99 *Poor/Good:* OR=0.51; 95%CI=0.30, 0.86 *Technical or university* *Fair/Good:* OR=0.64; 95%CI=0.49, 0.83 *Poor/Good:* OR=0.24; 95%CI=0.12, 0.48 Income *Household income* *Fair/Good:* OR=0.64; 95%CI=0.49, 0.83 *Poor/Good:* OR=0.24; 95%CI=0.12, 0.48	+
	Ribeiro Dos Santos, E. (2016)	To estimate the prevalence of depression associated with socio-demographic and economic characteristics, smoking habits, alcohol use, and physical morbidities.	Coari and Tefé; Brazil	Adults (+20 years old) *n=34,838*	Cross-sectional	Score of ≥10 on the Patient Health Questionnaire-9 (PHQ-9)	Prevalence ratio	Income *Personal monthly income (R$)* *500.00–1000.00*: PR=1.16; 95%CI=0.77, 1.74 *≤500.00*: PR=0.95; 95%CI=0.62, 1.46 Education *Educational level in years* *9–11*: PR=1.13; 95%CI=0.77, 1.64 *5–8*: PR=1.11; 95%CI=0.75, 1.65 *0–4*: PR=1.35; 95%CI= 0.91, 2.00	+

	Scazufca, M. (2010)	To estimate the proportion of cases of dementia attributable to illiteracy, non-skilled occupation and low income.	São Paulo; Brazil	Elderly (+65 years old) *n= 2003*	Cohort*	Number of individuals diagnose with dementia	Population attributable fraction	Education *% illiterate population* PAF=9.4%; 95%CI=0.0%, 26.6% Employment *% people with non-skilled occupation* PAF=29.2%; 95%CI=2.8%, 48.5% Income *% people with low income* PAF=23.8%; 95%CI=6.9%, 37.7%	+
	Sulander, T. (2012)	To examine the association of education and adequacy of income with SRH.	Helsinki; Finland	Elderly (+75 years old) *n=1395*	Cross-sectional	SRH	Cumulative odds ratios	Education *Men (85+ years)* *Middle school*: CORs=1.52; 95%CI=0.47, 4.98 *Elementary school*: CORs=1.23; 95%CI=0.40, 3.82 *Women (85+ years)* *Middle school*: CORs=0.84; 95%CI=0.50, 1.42 *Elementary school*: CORs=1.70; 95%CI=1.01, 2.87	+

								Income *Adquacy of income* *Men (85+ years)* *Average or less*: CORs=2.70; 95%CI=0.89, 8.17 *Women (85+ years)* *Average or less*: CORs=3.24; 95%CI=1.99, 5.26	
	Tucker-Seeley, R. D. (2013)	To determine the association between financial hardship and SRH.	Boston; USA	Adults (+18 years old) *n= 828*	Cross-sectional	SRH	Relative risk	Education *Educational level* *Some high school:* RR=1.24; 95%CI=0.90, 1.72 *High school graduate:* RR=0.77; 95%CI=0.57, 1.03 *Greater than high school:* RR=0.65; 95%CI=0.50, 0.85	+
								Employment *% Unemployed* RR=1.29; 95%CI=1.03, 1.61	
								Income *% In poverty* RR=1.16; 95%CI=0.94, 1.43	

Morbidity related with obesity outcomes	Akarolo-Anthony, S. N. (2014)	To examine the prevalence of overweight and obesity and its potential correlation with socio-economic status and occupation.	Abuja; Nigeria	Adults (+18 years old) *n=1058*	Cross-sectional	Body-mass index (BMI) (kg/m^2)	Prevalence ratio	Education *Education level* *≥Tertiary:* OR=1.13; 95%CI=0.92, 1.3 *None/Primary:* OR=1.39; 95%CI=0.30, 3.82 Employment *Professional/executive:* OR=1.00; 95%CI=0.86, 1.16 *Unskilled manual:* OR=0.84; 95%CI=0.59, 1.18 *Self-employed:* OR=0.79; 95%CI=0.38, 1.64	+
	Albaladejo, R. (2014)	To assess whether the relationship between childhood obesity is explained by family socioeconomic position and risk behaviors.	Madrid; Spain	Children (6–15 years old) *n= 727*	Cross-sectional*	Obesity (BMI) (kg/m^2)	Odds ratio	Education *Percentage of population with tertiary studies* *20.64-35.15:* OR=0.92; 95%CI=0.22, 3.86 *14.64-20.63:* OR=3.63; 95%CI=1.11, 11.87 *<14.64:* OR=3.42; 95%CI=1.00, 11.68	+

								Income *Per capita income* *€11,149.61-14,548.76*: OR=1.73; 95%CI=0.46, 6.49 *€9,724.29-11,149.60*: OR=3.10; 95%CI=0.91, 10.54 *< € 9,724.29:* OR=3.77; 95%CI=1.12, 12.70	
	de Carvalho Cremm, E. (2012)	To investigate the individual and family determinants of being overweight among children living in an urban area.	Santos; Brazil	Children (<10 years old) *n= 531*	Cross-sectional	BMI-for-age (kg/m^2)	Odds ratio	Education *Mother's education level* *Completed high school:* OR=1.98; p=0.04	+
	Duarte-Salles, T. (2011)	To describe social inequalities in obesity among adolescents, by sex.	Barcelona; Spain	Children (12-16 years old) *n= 903*	Cross-sectional	(BMI) (kg/m^2)	Prevalence ratio	Education *Education level* *Boys* *Secondary:* PR=1.24; 95%CI=0.63, 2.44 *Primary:* PR=1.49; 95%CI=0.60, 3.68 *Girls* *Secondary:*PR=1.66; 95%CI=0.78, 3.55 *Primary:* PR=3.30; 95%CI=1.34, 8.14	+

								Employment *Family's social class* *Boys* *Manuals:* PR=1.76; 95%CI=0.96, 3.23 *Girls* *Manuals:* PR= 1.64; 95%CI= 0.87, 3.08	
	Martin-Fernandez, J. (2014)	To determine whether food insecurity and obesity are associated.	Paris; France	Adults (+18 years old) *n=2967*	Cross-sectional	(BMI) (kg/m^2)	Odds ratio	Education *Education level* *Men* *Secondary*: OR= 2.77; 95%CI=1.70, 4.52 *None or primary*: OR= 2.38; 95%CI=1.17, 4.83 *Women* *Secondary*: OR= 1.24; 95%CI=0.85, 1.81 *None or primary*: OR=2.06; 95%CI= 1.21, 3.49	+
								Employment *Women* *Intermediate white-collar:* OR =1.18, 95%CI=0.65, 2.14 *Blue-collar*: OR =3.25, 95%CI=1.48, 7.14	

Note: positive (+): a desirable improvement in the indicator was associated with an improvement of PH and negative (-): a desirable improvement in the indicator was associated with a deterioration of PH. *"Study design" assigned by the authors

Table 13 Studies of socioeconomic dimensions and analysed indicators and health outcomes without an association not statistically significant (for the defined statistical level)

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall Mortality	Cheng, E. R. (2012)	To describe the association premature mortality among counties with broadly differing levels of income.	3,139 USA counties	All individuals (to 75 years old) †	Cross-sectional*	All-cause, age-adjusted mortality rate per 100,000 population	β coefficient	Education *% Adults with a 4-year college degree* β=-0.04, SE=0.01	0
	Modrek, S. (2011)	To evaluate the relation between income inequality and mortality in the context of Costa Rica.	Costa Rica	Adults (+15 years old)†	Longitudinal*	Deaths rate	Incidence rate ratios	Income *Gini index* IRR=0.978; 95%CI= 0.953, 1.004	0
	Nolasco, A. (2015)	To describe inequalities in preventable avoidable mortality in relation to socioeconomic status in small urban areas of thirty-three Spanish cities.	Spain	All individuals†	Ecological	Number of deaths	Relative Risk	Education and Occupation *Socioeconomic status* *0-44years old:* RR=2.4; SE=1.5 (*SES1 vs SES3*) *45-64years old:* RR=1.3; SE=0.5 (*SES1 vs SES3*) *>64years old:* RR=1.5; SE=0.9 (*SES1 vs SES3*)	*Women*: 0
	Rosicova, K. (2015)	To assess the associations between socioeconomic and ethnic neighborhood	Bratislava, Kosice; Slovak Republic	Adults (20–64 years old) *n=442,703*	Cross-sectional*	Standardized mortality per 100,000 inhabitants	Rate ratios	Education *Education level* *Low Education*: RR=1.004; 95%CI=0.998, 1.010	0

		indicators and the all-cause mortality.						Employment *Unemployment rate:* RR=1.011; 95%CI=0.993, 1.029 Income *Income (in Euro's):* RR=0.999; 95%CI=0.999, 1.000	
	Unrath, M. (2014)	To analyze the influence of unemployment as indicator of neighborhood socioeconomic status on mortality in a stroke cohort.	Dortmund; Germany	Adults (+18 years old) *n=1883*	Cohort*	Age- and sex-adjusted mortality risks	Hazard ratios	Employment *Quartiles of unemployment* *First*: HR=0.51; 95%CI=0.27, 0.97 *Second*: HR=0.77; 95%CI=0.48, 1.25 *Third*: HR=0.82; 95%CI=0.54, 1.27	0
	Vandenheede, H. (2014)	To quantify and compare socioeconomic inequalities measured by education level and deprivation, in all-cause mortality in urban population samples from 10 cities.	Czech Republic, Russia, Poland, Lithuania	Adults (45–69 years) *n=2750*	Cohort	Number of all-causes deaths	Hazard ratios	Education *Education level* *Lower secondary:* HR=1.8; 95%CI=1.4, 2.3 *Upper secondary:* HR=1.2; 95%CI=0.9, 1.4 Income *Income deprivation* *Yes:* HR=1.4; 95%CI=1.2, 1.7	Women: 0

Morbidity related with chronic diseases	Ali, M. K. (2016).	To examined distribution of cardiovascular disease (CVD) risks across the socioeconomic spectrum, defined as education, wealth, and occupation.	Chennai, Delhi; India Karachi; Pakistan	Adults (+20 years old) *n= 16,288*	Cross-sectional	Number of CVD risk factors	Age- and sex-standardized prevalence	Education *Educational level (diabetes reference)* *Up to Primary*: P=26%, p=0.008 *High/Secondary:* P=29%, p=0.008 *Graduate or higher:* P=25.5, p=0.008 Income *Household assets* *Tertile Low:* P=26, *p<0.001* *Tertile Medium:* P=28, *p<0.001* *Tertile High:* P=30, *p<0.001* Employment *Not working*: P=28.5, *p<0.001* *Semiskilled/Unskilled:* P=24.9, *p<0.001* *Trained/ Skilled:* P=27, *p<0.001* *White collar*: P=27.5, *p<0.001*	0
	Bastos, L. N. V. (2018)	To determine the incidence and association with environmental health indicators of cases of childhood and adolescent cancer.	Pernambuco; Brazil	Adolescents (<20 years old) *n= 1261*	Cross-sectional	Average Age-adjusted Incidence Rate of Cancer	Moran index	Income *Gini index* I=0.00161; P=0.017	0

	Cabral, D. M. (2014)	To determine the prevalence of chronic pain and to identify sociodemographic, psychosocial, and occupational factors associated.	São Paulo; Brazil	Adults (+15 years old) *n= 1,108*	Cross-sectional	Chronic Pain Grade (CPG)	Prevalence ratio	Income *Family socioeconomic classification* *B*: PR=1.11; 95%CI=0.67, 1.84 *C*: PR=1.12; 95%CI= 0.68, 1.86 *D*: PR=1.19; 95%CI=0.68, 2.07 *E*: PR=2.08; 95%CI=1.17, 3.69	0
	Schulz, A. J. (2008)	To provide evidence of an effect linking socioeconomic indicators to cardiovascular disease (CVD) risk factors.	Detroit, Michigan; USA	Adults (≥25 years old) *n=919*	Cross-sectional*	Depressive symptoms, smoking status, physical activity, body mass index and waist circumference	β coeficient	Education Education level (<High school) *Depressive symptoms:* β=0.05, p<0.001 *Smoking status:* β=0.40, p<0.001 *Physical activity:* β=-0.32, p<0.05 *Body mass index:* β=-0.49, p<0.001 *Waist circumference*: β =-2.03, p<0.001	0
	Piovesan, C. (2010)	To assess the inequality in caries distribution and the association between socioeconomic	Santa Maria; Brazil	Children (1-5 years old) *n=455*	Cross-sectional	Prevalence decayed, missing and filled primary teeth (dmf-t index)	Rate ratio	Employment *% Mothers unemployed* RR=1.24; 95%CI=0.79, 1.95	0

		indicators and caries experience of preschool children.						Income *<3 Brazilian minimum wage* RR=1.61; 95%CI=1.21, 2.75	
	Pizzo, G. (2010)	To investigate the prevalence of caries in children and assessed the relationship between socio-behavioral determinants and caries.	Palermo; Italy	Children (5 and 12 years old) *n=511*	Cross-sectional*	Dmf-t index	Odds ratio	Employment *Mother's employment status* *(data not showed)*	0
Morbidity related with mental illness	Christiani, Y. (2015)	To examine unequally distribution of depression among women in Indonesia's major cities and investigate the factors contributed to the inequality.	Jakarta, Surabaya, Medan, Bandung; Indonesia	Adult (19-65 years old) *n=1117*	Cross-sectional*	Prevalence of depression	Concentration index	Employment *% people in paid work* CI=0.005, p<0.0001	0
	Ribeiro Dos Santos, E. (2016)	To estimate the prevalence of depression associated with socio-demographic and economic characteristics, smoking habits, alcohol use, and physical morbidities.	Coari and Tefé; Brazil	Adults (+20 years old) *n=34,838*	Cross-sectional	Score of ≥10 on the Patient Health Questionnaire-9 (PHQ-9)	Prevalence ratio	Racial segregation *White (including Asian):*PR=1.20; 95%CI=0.82, 1.75 *Indigenous:* PR=1.06; 95%CI=0.62, 1.81	0

	Tucker-Seeley, R. D. (2013)	To determine the association between financial hardship and SRH.	Boston; USA	Adults (+18 years old) *n= 828*	Cross-sectional	SRH	Relative risk	Racial segregation *% Black non-Hispanic:* RR=0.74; 95%CI=0.48, 1.14 *% Hispanic:* RR=0.85; 95%CI=0.55, 1.30 *%Other:* RR=0.69 ;95%CI=0.42, 1.14	0
Morbidity related with obesity outcomes	Martin-Fernandez, J. (2014)	To determine whether food insecurity and obesity are associated.	Paris; France	Adults (+18 years old) *n=2967*	Cross-sectional	BMI (kg/m^2)	Odds ratio	Employment *Men* *Intermediate white-collar:* OR =0.67; 95%CI=0.33, 1.35 *Blue-collar*: OR =0.83; 95%CI=0.41, 1.68 Income *Income/consumption units €* *3,000 – 4,500:* OR=1.64; 95%CI= 0.96, 2.83 *1,865–3,000*: OR=1.52; 95%CI=0.87, 2.67 *≤1,865:* OR=1.65; 95%CI=0.93, 2.94	0

*" Study design" assigned by the authors

Table 14 Studies of built environment dimensions and analysed indicators and health outcomes with evidence of association

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall Mortality	Gronlund, C. J. (2015)	To examine how area characteristics independently modified the extreme heat-mortality association.	Michigan; USA	Elderly (+65 years old) †	Time-stratified case-crossover	Number of primary causes of death	Odds ratio	Green spaces *% non-green spaces* *Low heat*: OR=0.97; 95%CI=0.89, 1.05 *Extreme heat*: OR=1.18; 95%CI=1.09, 1.28	+
	Habermann, M. (2012)	To assess the association between indicators of exposure to motor vehicle-related air pollution and cardiovascular mortality.	São Paulo; Brazil	Adults (≥40 years old) *n=9805*	Time-stratified case-crossover*	Mortality rates from cardiovascular diseases	β coefficient	Mobility *Road density:* β= 0.096, p=0.017 *Light traffic volume:* β=0.0000237, p=0.703 *Heavy traffic volume:* β= 0.0000821, p=0.636 *Traffic volume:* β=0.0000212, p=0.663	+
	Harlan, S. L. (2013)	To analyze neighborhood effects of population characteristics and built and natural environments on deaths due to heat exposure.	Arizona; USA	Elderly (+65 years old) †	Cross-sectional*	Number of heat-associated death	Odds ratio	Green Spaces *Unvegetated area* OR=1.19; 95%CI=1.02, 1.39	+

Morbidity related with birth outcomes	de Souza, O. F. (2012)	To investigate the prevalence of malnutrition associated with socioeconomic conditions, access to services and childcare.	Acre; Brazil	Children (<5 years old) *n= 667*	Cross-sectional	Prevalence by height for age and weight for height deficits	Prevalence ratio	Sanitation *Exposure to open wastewater*: PR=2.46; 95%CI=1.51, 4.00	+
	Grazuleviciene, R. (2015)	To investigate whether surrounding greenness levels and/or distance to city parks affect birth outcomes in singleton live-births.	Kaunas; Lithuania	Newborns (Mothers age: +20 years old) *n=3292 singleton live-births*	Cohort	Gestational age (GA, in weeks) Preterm birth (PB, <37 gestational weeks) Birth weight (BW, in g) Low birth weight (LBW, birth weight below 2500 g) Term low birth weight (TLBW, birth weight below 2500g Small for gestational age (SGA, birth weight below the 10th percentile)	Odds ratio	Green Spaces *Normalized difference vegetation index* (*NDVI-500 ≤ median)* *LBW*: OR=1.15; 95%CI=0.82, 1.61 *TLBW*: OR=1.92; 95%CI=1.29, 3.45) *PB*: OR=0.81; 95%CI=0.59, 1.09 *SGA*: OR=1.03; 95%CI= 0.79, 1.33 *BW*: β=3.44; 95%CI=−23.4, 30.3 *GA*: β=0.09; 95%CI =−0.31, 0.22	+

Morbidity related with chronic diseases	Dzhambov, A. M. (2016)	To explore the overall association of prevalence of Type 2 diabetes mellitus (T2DM) with exposures to road traffic, noise and air pollution.	Plovdiv; Bulgaria	Adults (+18 years old) *n= 513*	Cross-sectional	T2DM self-reported doctor diagnosis	Odds Ratio	Mobility *Self-reported traffic intensity*: *Moderate*: OR=1.15; 95%CI=0.30, 4.45 *High*: OR=1.40; 95%CI=0.48, 4.07	+
	Migliore, E. (2009)	To investigate if there were specific effects of cars and trucks traffic exposure on current asthma symptoms and cough or phlegm.	Turin, Milan, Rome; Italy	Children and adolescents (6–7/ 13-14 years old) *n=33,632*	Cross-sectional*	Asthma symptoms Severe asthma Cough or phlegm	Odds ratio	Mobility *High traffic density* *Asthma symptoms WITHOUT cough or phlegm*: OR=1.13; 95%CI=0.99, 1.28 *Cough or phlegm WITHOUT asthma symptoms*: OR=1.14; 95%CI=0.92, 1.41 *Asthma symptoms WITH cough or Phlegm*: OR=1.52; 95%CI=1.17, 1.96	+

	Santiago, B. M. (2013)	To investigate the relationship of neighborhood social capital with dental pain in adolescents, adults and the elderly.	Paraiba; Brazil	All individuals (15-74 years old) *n=624*	Cross-sectional*	Prevalence of reported dental pain in the last 6 months	Odds ratio	Safety *Individual-level social capital* *Bonding/Positive Interaction*: OR=0.88; 95%CI= 0.80, 0.91 *Neighborhood-level social capital* *High social capital*: OR=0.48; 95%CI=0.27, 0.85	+
Morbidity related with mental illness	Cau, B. M. (2016)	To examine associations factors with mental health (poor self-rated health).	Maputo; Mozambique	Adults (+ 40 years old) *n= 1768*	Cross-sectional*	SRH	Odds ratio	Sanitation *Treated drinking water:* OR= 0.49, p< 0.01	+
	Eibich, P. (2016)	To study associations between neighborhood characteristics and mental health and well-being of younger (aged 20–35) and older (aged 60+) residents.	Berlin; Germany	Adults (20-35/ +60 years old) *n=2200*	Cohort	Life satisfaction Health satisfaction Self-assessed health Physical health Mental health Morbidity index	Linear regression	Mobility *Access to public transport* *Life satisfaction*: β=0.67; ε=0.17 *Health satisfaction:* β=0.38; ε=0.19 *Self-assessed health:* β= 1.82; ε=0.34 *Physical health*: β= 1.86; ε=0.78 *Mental health*: β= 2.04; ε=0.94 *Morbidity index*: β= –0.30; ε=0.13	+

	Melis, G. (2015)	To analyze the association of density, accessibility by public transport, accessibility to services, green and public spaces and mental disorders.	Turin; Italy	Adults (20-64 years old) *n=547,263*	Longitudinal	Percentage of individuals who had any antidepressant prescription	Incidence Rate Ratios	Mobility *Public transport (high accessibility)* *Men*: IRR= 0.93; SE=0.87, 0.98 *Women*: IRR=0.95; SE=0.92, 0.98	+
Morbidity related with obesity outcomes	Lovasi, G. S. (2012)	To evaluate whether potentially attractive neighborhood features are associated with lower BMI, whether safety hazards are associated with higher BMI.	New York City; USA	Adults (+30 years old) *n=13,102*	Cross-sectional	BMI (kg/m^2)	Interaction p-values	Mobility *High walkability areas* p=1.1; 95%CI=0.0, 2.8	+
	Lovasi, G. S. (2009)	To test whether the association between walkable environments and lower body mass index was stronger.	New York City; USA	Adults (+30 years old) *n=13102*	Cross-sectional	BMI (kg/m^2)	Interaction p-values	Mobility *Public transit use:* p=-5.00 95%CI=-5.97, -4.02 *Subway access:* p=-0.40; 95%CI=–0.52, –0.29 *Bus access*: p=-0.07; 95%CI=–0.09, –0.05	+
	Mendes, L. L. (2013)	To evaluate variables within the built environment for their potential association with overweight and obesity.	Belo Horizonte; Brazil	Adults (+18 years old) *n=3404*	Cross-sectional	BMI (kg/m^2)	Prevalence ratios	Safety *Homicide rate*: PR=1.45; 95%CI=1.02, 2.05	+

Note: positive (+): a desirable improvement in the indicator was associated with an improvement of PH and negative (-): a desirable improvement in the indicator was associated with a deterioration of PH; † unclear information about population size; *"Study design" assigned by the authors

Table 15 Studies of built environment dimensions and analysed indicators and health outcomes without an association not statistically significant (for the defined statistical level)

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall mortality	Ribeiro, A. I. (2016)	To evaluate the spatial distribution of old-age survival and its relationship with built environment and deprivation.	Porto; Portugal	Elderly (75–84 years old)†	Cohort*	Old-age survival	Odds ratio	Green Spaces *NDVI* *Men* *-1 (least environmental deprived):* OR=1.02; 95%CI=0.90, 1.19 *+2 (most environmental deprived):* OR=1.04; 95%CI=0.92, 1.22 *Women* *-1 (least environmental deprived):* OR=1.03; 95%CI=0.91, 1.21 *+2 (most environmental deprived):* OR=1.02; 95%CI=0.89, 1.17	0

								Mobility *Walkability index* *Men* *1 (higher):* OR=0.90; 95%CI=0.72, 1.07 *10(lower):* OR=1.07; 95%CI= 0.91, 1.29 *Woman* *1 (higher):* OR=0.86; 95%CI=0.69, 1.02 *10(lower):* OR=1.10; 95%CI= 0.95, 1.34	
Morbidity related with mental illness	Eibich, P. (2016)	To study associations between neighborhood characteristics and mental health and well-being of younger (aged 20–35) and older (aged 60+) residents.	Berlin; Germany	Adults (20-35/ +60 years old) *n=2200*	Cohort	Life satisfaction Health satisfaction Self-assessed health Physical health Mental health Morbidity index	Linear regression	Safety *Crimes per capita (log)* *Life satisfaction*: β=0.20; ε=0.39 *Health satisfaction:* β=0.35; ε=0.47 *Self-assessed health:* β=2.12; ε=1.02 *Physical health*: β=2.86; ε=1.86 *Mental health*: β=1.19; ε=2.22 *Morbidity index*: β=0.05; ε=0.3	0
Morbidity related with	Lange, D. (2011)	To evaluate the influence of neighborhood characteristics on adolescent BMI.	Kiel; Germany	Adolescents (13-15 years old) *n=3440*	Cross-sectional	BMI (kg/m^2)	Linear multilevel associations	Mobility *Traffic density* r=0.00; p=0.05 Safety *Crime rate* r=0.01; p=0.05	0

								Green spaces *Nr of parks* r=0.07; p=0.05	
	Lovasi, G. S. (2012)	To evaluate whether potentially attractive neighborhood features are associated with lower BMI, whether safety hazards are associated with higher BMI.	New York City; USA	Adults (+30 years old) *n=13,102*	Cross-sectional	BMI (kg/m^2)	Interaction p-values	Safety *Homicide prevalence* p=−0.06; 95%CI=−0.37, 0.25	0
	Lovasi, G. S. (2011)	To examine which built environment characteristics correlates of physical activity and anthropometry among preschool children.	New York City; USA	Children (2–5 years old) *n=428*	Cross-sectional	BMI z-score	Regression models	Mobility *Walkability* *Population density*: α=−0.08; 95%CI=−0.38, 0.22 *Subway stop density*: α=−0.16; 95%CI=−0.33, 0.01 *Bus stop density*: α=0.10; 95%CI=−0.09, 0.30 Safety *Crime rate* *Homicide rate*: α=0.04; 95%CI=−0.19, 0.26	0
	Mendes, L. L. (2013)	To evaluate variables within the built environment for their potential association	Belo Horizonte; Brazil	Adults (+18 years old) *n=3404*	Cross-sectional	BMI (kg/m^2)	Prevalence ratios	Mobility *Population density* *2nd /3rd/ 4th quartile*: PR=0.85; 95%CI= 0.74, 0.98	0

		with overweight and obesity.						Green spaces *Parks/public squares/places for practicing physical activity* *Yes:* PR=0.99; 95%CI=0.72, 1.37	

† unclear information about population size; *" Study design" assigned by the authors

Table 16 Studies of natural environment dimensions and analysed indicators and health outcomes with evidence of association

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall mortality	Hu, W. (2008)	To investigate the effect of temperature and air pollutants on total mortality in summers.	Sydney; Australia	All individuals†	Ecological*	Number of daily mortality	Relative risk	Air quality *SO_2*: RR=22; 95%CI=6.4, 40.5	+
	Kioumourtzoglou, M. A. (2016)	To estimate effects between long-term $PM_{2.5}$ exposures and mortality.	207 cities, USA	Elderly (65 years old) *n=>35 million Medicare enrollees*	Cohort	Number of deaths	Hazard ratios	Air quality *$PM_{2.5}$* HR= 1.19; 95%CI=1.11, 1.28 *per 10 $\mu g/m^3$ increase in the annual PM2.5concentrations*	+
	Li, H. (2015)	To estimate the effects of outdoor air pollution on daily coronary heart disease mortality.	Beijing, Shanghai, Guangzhou, Hong Kong, Shenyang, Tangshan, Taiyuan, Xi'na; China	All individuals *n=48.3 million*	Cross-sectional*	Daily coronary heart disease mortality	Interquartile range	Air quality *PM_{10}*: IQR=0.36; 95%CI=0.12, 0.61 *SO_2*: IQR=0.86; 95%CI=0.30, 1.41 *NO_2*: IQR=1.30; 95%CI=0.45, 2.14	+

	Luo, K. (2017)	To assess the effect modification of cardiovascular mortality by air pollutants.	Beijing, Nanjing, Chengdu; China	Elderly (65 years old) *n=290 593 deaths*	Cross-sectional*	Daily mortality	Percentage increase mortality per 1ºC	Air quality *PM_{10}* *Time model (6 degree of freedom (DF)):* α=1.52; 95%CI=0.85, 2.11 *Temperature model (6 DF):* α=1.31; 95%CI=0.72, 1.92	+
	Neuberger, M. (2013)	To assess the effect of daily pollution on the relationship with daily mortality.	Vienna, Graz, Linz; Austria	All individuals†	Case-crossover	All causes daily mortality	Percentage increase risk	Air quality *Vienna (Lag 0–14 days)* *$PM_{2.5}$*: IR=2.6; 95%CI=1.1, 4.1 *PM_{10}:* IR=1.2; 95%CI=0.4, 2.1 *TSP (total suspended particles)*: IR=0.8; 95%CI=0.0, 1.6 *NO_2*: IR=2.9; 95%CI=1.6, 4.1 *Graz (Lag 0–14 days)* *PM_{10}:* IR=1.6; 95%CI=1.1, 2.0 *TSP*: IR=1.2; 95%CI=0.9, 1.5 *NO_2*: IR=2.6; 95%CI=2.0, 3.1 *Linz (Lag 0–14 days)* *$PM_{2.5}$*: IR=1.2; 95%CI=0.7, 1.7 *PM_{10}:* IR=0.6; 95%CI=0.4, 0.9 *NO_2*: IR=1.5; 95%CI=0.9, 2.2	+

	Willers, S. M. (2016)	To investigate the extent of neighborhood differences in mortality risk due to heat and air pollution in a city with a temperate maritime climate.	Rotterdam; Netherlands	All individuals (<45 years old) *n=73,178 deaths*	Case-crossover	Natural-cause mortality cases	Percentage increase risk	Air quality *PM_{10}* *Lag time 0:* IR=1.7; 95%CI= 0.8, 2.6 *Lag time 1:* IR=1.6; 95%CI= 0.6, 2.5 *Lag time 2:* IR=1.2; 95%CI= 0.2, 2.1	+
	Wong, C. M. (2008)	To examine whether people residing in socially deprived communities are at higher mortality risk from ambient air pollution.	Hong Kong; China	All individuals†	Ecological*	All registered deaths	Excess risk	Air quality *NO_2*: ER=0.16; 95%CI=-0.07, 0.39 *SO_2*: ER=0.45; 95%CI=0.03, 0.87 *PM_{10}*: ER= 0.04; 95%CI= -0.15, 0.22 *O_3:* ER=0.05; 95%CI= -0.16, 0.25	+
Morbidity related with birth outcomes	Huang, J. V. (2017)	To examine sex-specific associations of particulate PM_{10}, nitric oxide, sulfur dioxide, and nitrogen dioxide in different growth phases with clinically assessed pubertal stage.	Hong Kong; China	Children (9–12 years old) *n= 8327*	Cohort	Highest Tanner stage	Mean difference	Air quality *PM_{10} (in utero)* Boys: D_f=0.01; 95%CI=-0.01, 0.03 Girls: D_f=0.05; 95%CI=-0.08, -0.02 *SO_2*: Boys: D_f=-0.03; 95%CI=-0.05, -0.01 Girls: D_f=-0.03; 95%CI=-3.8e-3, 0.06 *NO_2*: Boys: D_f=0.03; 95%CI=-0.04, -0.02 Girls: D_f=-0.01; 95%CI=-0.03,0.01	+

Morbidity related with chronic diseases outcomes	Dzhambov, A. M. (2016)	To explore the overall association of prevalence of Type 2 diabetes mellitus (T2DM) with exposures to road traffic, noise and air pollution.	Plovdiv; Bulgaria	Adults (+18 years old) *n= 513*	Cross-sectional	T2DM self-reported doctor diagnosis	Odds Ratio	Noise L_{den}: OR=4.49; 95%CI=1.38, 14.68 Air quality $PM_{2.5}$: OR=1.32; 95% CI=0.28,6.24 *B[a]pyrene*: OR=1.76; 95% CI=0.52, 5.98	+
	Lemke, L. D. (2014)	To investigate ambient air quality across the border between and its association with acute asthma events.	Detroit, Michigan; USA Windsor, Ontario; Canada	All individuals (+5 years old) †	Cross-sectional*	Asthma prevalence	Pearson correlation coefficients	Air quality *VOCs (volatile organic compounds)* Þ=0.51; 95%CI=0.14, 0.75 *BTEX (benzene, toluene, ethylbenzene and xylene)* Þ=0.53; 95%CI=0.17, 0.77 NO_2 Þ=0.63; 95%CI=0.08, 0.88 PM_{10} Þ=0.61; 95%CI=0.06, 0.88	+
	Liu, C. (2014)	To investigate associations between long-term traffic-related air pollution and long-term noise exposure with blood pressure (BP) in children.	Munich, Wesel; Germany	Children (10 years old) *n=2368*	Cohort	Resting systolic and diastolic BP	Spearman's rank correlation coefficient	Noise L_{den}: β=1.00; p=0.05 L_{dnight}: β =0.92; p<0.001	+

	Modig, L. (2009)	To investigate the relationship between the cumulative incidence of asthma and onset of asthma among adults and vehicle exhaust concentrations at home.	Gothenburg, Uppsala, Umeå; Sweden	Adults (20–44 years old) *n=10,800*	Cohort	Cases and noncases of asthma	Odds Ratio	Air quality *NO_2* *Onset asthma*: OR=1.46; 95%CI=1.07, 1.99 *Incident asthma:* OR=1.54; 95%CI=1.00, 2.36	+
	Patel, M. M. (2010)	To examine associations of daily ambient black carbon concentrations with daily respiratory symptoms among asthmatic and non-asthmatic adolescents.	New York City; USA	Adolescents (13–20 years old) *n=249*	Longitudinal	Self-reported asthma	Odds Ratio	Air quality *NO_2* *Asthma:* OR=1.13; 95%CI=0.94, 1.36 *No Asthma:* OR=0.90; 95%CI=0.79, 1.02	+
	Sun, G. (2017)	To assess potential carcinogenic and non-carcinogenic health effects on children and adults due to exposure to street dust in China.	Zhuzhou; China	All individuals†	Cohort*	Lifetime average daily dose ($mg/kg^{-1}/day^{-1}$)	Hazard quotient	Air quality *As* *Adults*: HQ= 4.47×10^{-1} *Children*: HQ= 3.18×10 *Cr* *Adults*: HQ= 4.45×10^{-2} *Children*: HQ= 3.15×10^{-1}	+
	Yang, B. Y. (2017)	To evaluate the effects of long-term exposure to ambient air pollution PM_{10}, sulfur dioxide, nitrogen dioxide, ozone on prehypertension.	Shenyang, Anshan, Jinzhou; China	Adults (18-74 years old) *n=24,845*	Cross-sectional*	BP values	Odds Ratio	Air quality *PM_{10}*: OR=1.17; 95%CI=1.09, 1.25 *SO_2*: OR=1.11; 95%CI=1.00, 1.25 *NO_2:* OR=1.18; 95%CI=1.05, 1.32 *O_3:* OR=1.13; 95%CI=0.99, 1.28	+

Morbidity related with mental illness	Grelat, N. (2016)	To quantify the annoyance caused by noise in children and to assess the relationship between these children's noise annoyance level and factors in the surrounding urban area.	Besançon; France	Children (7–11 years old) *n=517*	Cross-sectional*	Children's Noise Annoyance	Odds Ratio	Noise *Ambient noise (dBA):* OR=0.77; 95%CI=0.51, 1.16	+
	Habib, R. R. (2013)	To evaluate the association between women's SRH and socioeconomic indicators.	Bebnine, Lebanon	Adult (+14 years old) *n=2223*	Cross-sectional	Self-reported health status	Odds Ratio	Water quality *Satisfaction with quality of drinking water* *Fair/Good*: OR=1.16; 95%CI=0.98, 1.62 *Poor/ Good*: OR=1.45; 95%CI=1.13, 1.88	+
	Ristovska, G. (2009)	To identify noise exposure indicators during day and night and to evaluate if there is an association between those and annoyance.	Skopje; Macedonia	Adult (18- 65 years old) *n=510*	Cross-sectional*	Annoyance with noise over the last 12 months	Spearman's rank order	Noise L_{day} *dB(A)*: r_s= 0.45; p<0.05 L_{night} *dB(A)*: r_s= -0.125; p<0.05	+

Note: positive (+): a desirable improvement in the indicator was associated with an improvement of PH and negative (-): a desirable improvement in the indicator was associated with a deterioration of PH; † unclear information about population size; *"Study design" assigned by the authors

Table 17 Studies of natural environment dimensions and analysed indicators and health outcomes without an association not statistically significant (for the defined statistical level)

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall mortality	Luo, K. (2017)	To assess the effect modification of cardiovascular mortality by air pollutants.	Beijing, Nanjing, Chengdu; China	Elderly (65 years old) *n=290 593 deaths*	Cross-sectional*	Daily mortality	Percentage increase mortality per 1ºC	Air quality *NO_2* *Time model (6 DF):* α=1.35; 95%CI=0.77,1.95 *Temperature model (6 DF):* α=1.16; 95%CI=0.49,1.85 *SO_2* *Time model (6 DF):* α=1.36; 95%CI= 0.77,1.94 *Temperature model (6 DF):* α=1.16; 95%CI=0.45,1.88	0
	Pasetto, R. (2013)	To assess all-cause mortality of the population living in a polluted area, built over an area with chlorinated organic compounds.	Ferrara; Italy	All individuals *n=3475*	Cohort	Mortality incidence	Standardized mortality ratio	Water quality *Chlorinated organic compounds* SMR=81;90%CI=73, 89	0

Morbidity related with chronic diseases	Liu, C. (2014)	To investigate associations between long-term traffic-related air pollution and long-term noise exposure with blood pressure (BP) in children.	Munich, Wesel; Germany	Children (10 years old) *n=2368*	Cohort	Resting systolic and diastolic BP	Spearman's rank correlation coefficient	Air quality *NO_2:* β =0.11; 95%CI=-0.45, 0.67 *PM_{10}*: β =0.25; 95%CI=-0.71, 1.21 *$PM_{2.5}$*: β =1.01; 95%CI=-0.90, 2.92	0
	Sun, G. (2017)	To assess potential carcinogenic and non-carcinogenic health effects on children and adults due to exposure to street dust in China.	Zhuzhou; China	All individuals†	Cohort*	Lifetime average daily dose ($mg/kg^{-1}/day^{-1}$)	Hazard quotient	Air quality *Pb* *Adults*: HQ= 4.36×10^{-1} *Children*: HQ=3.17×10 *Cd* *Adults*: HQ=7.40×10^{-2} *Children*: HQ=5.22×10^{-1} *Hg* *Adults*: HQ=1.09×10^{-1} *Children*: HQ=1.79×10^{-1} *Sb* *Adults*: HQ=5.14×10^{-2} *Children*: HQ=3.67×10^{-1}	0

† unclear information about population size*;* *" Study design" assigned by the authors

Table 18 Studies of healthcare dimensions and analysed indicators and health outcomes with evidence of association

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall Mortality	Cheng, E. R. (2012)	To describe the association premature mortality among counties with broadly differing levels of income.	3,139 USA counties	All individuals (to 75 years old) †	Cross-sectional*	All-cause, age-adjusted mortality rate per 100,000 population	β coefficient	Hospital care *Primary care providers per 1,000* β=0.01; SE=0.01	+
	James, W. L. (2012)	To understand if overall and race-specific mortality rates are combined with local health infrastructure data, income inequality and racial segregation.	48 USA states	All individuals†	Ecological	Race-specific age/sex adjusted mortality rates per 100,000	Moran's I coefficient	Hospital care *Health infrastructures* *Whites*: I=-2.031; p<0.01 *Black*: I=5.089; p>0.05	+

	Santos, S. L. (2016)	To identify factors associated with infant mortality by a hierarchical model based on socioeconomic determinants like maternal education and maternal occupation.	Teresina; Brazil	Newborns (Mother age: +10 years old) *n=13,882*	Cohort	Number of love births and numbers of death births	Odds ratio	Hospital care *Health infrastructures* OR= 1.28; 95%CI=1.11, 1.51	+

Note: positive (+): a desirable improvement in the indicator was associated with an improvement of PH and negative (-): a desirable improvement in the indicator was associated with a deterioration of PH; † unclear information about population size; *"Study design" assigned by the authors

Table 19 Studies of healthcare dimensions and analysed indicators and health outcomes without an association not statistically significant (for the defined statistical level)

Health outcome	**Reference**	**Overall aim**	**City/Cities Country**	**Study population**	**Study design**	**Health outcome measure**	**Association measure**	**Dimension/ Indicator**	**Relation between indicator and PH**
Morbidity related with chronic diseases	Bastos, L. N. V. (2018)	To determine the incidence and association with environmental health indicators of cases of childhood and adolescent cancer.	Pernambuco; Brazil	Adolescents (<20 years old) *n= 1261*	Cross-sectional	Average Age-adjusted Incidence Rate of Cancer	Moran index	Hospital care *Basic health facilities per capita* MI= 0.011225; p= 0.715	0
	Ferreira-Junior, O. M. (2015)	To assess prevalence of dental pain and associated contextual factors.	27 capital cities Brazil	Children (5 years old) *n=7280*	Cross-sectional	Dental pain in the last 6 months	Prevalence rate	Oral care *Dental visits* PR=1.14; 95%CI=1.20, 1.65	0

† unclear information about population size; *" Study design" assigned by the authors

Table 20 Studies of health behaviors dimensions and analysed indicators and health outcomes with evidence of association

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall Mortality	Cheng, E. R. (2012)	To describe the association premature mortality among counties with broadly differing levels of income.	3,139 USA counties	All individuals (to 75 years old) †	Cross-sectional*	All-cause, age-adjusted mortality rate per 100,000 population	β coefficient	Smoking *% residents who smoke* β=0.05; SE= 0.01	+
	Maniecka-Bryla, I. (2013)	To identify risk factors influencing the phenomenon of all cause's premature deaths.	Łódź; Poland	Adults (18-64 years old) *n=4000*	Cohort*	Number of premature deaths	Hazard ratio	Alcohol consumption *Drinking style* *drinks in moderation:* HR=0.486; 95%CI= 0.271, 0.869 *drinks excessively:* HR=1.444; 95%CI=1.191, 2.031	+
								Smoking *Smoking nicotine* *used to smoke:* HR= 1.125; 95%=CI= 0.515, 2.456 *smokes:* HR= 2.782; 95%=CI= 1.581, 4.891	
	Smigielski, J. (2013)	To identify the relationships on the mortality of men of subjective health assessment, nutritional	Łódź; Poland	Adults (18-64 years old) *n=1004*	Cross-sectional*	Recorded deaths	Survival probability	Alcohol consumption *Beer drinking:* C=1.99; p<0.05 *Wine drinking:* C=2.47; p<0.01	+

		habits, alcohol consumption and tobacco smoking.						Smoking *History of tobacco smoking:* C=1,92; p<0.05	
								Nutrition *Additional use of table salt at meals:* C=1.80; p<0.05	
Morbidity related with chronic diseases	Artaud, F. (2013)	To examine the individual and combined associations of unhealthy behaviors with hazard of disability among older French adults.	Bordeaux, Dijon, Montpellier; France	Elderly (+65 years old) *n= 3982*	Cohort	Hierarchical indicator of disability (no, light, moderate, severe)	Hazard ratio	Nutrition *Consumption of fruit and vegetables (<4 times a week):* HR=1.25, 95%CI=1.10, 1.41	+
								Smoking *Current smoker or short-term ex-smoker* vs *never smoker or long-term ex-smoker* HR=1.31, 95%CI=1.07, 1.60	
								Physical activity *Low or intermediate* vs *High* HR=1.72, 95%CI=1.48, 2.00	
	Cabral, D. M. (2014)	To determine the prevalence of chronic pain and to identify sociodemographic,	São Paulo; Brazil	Adults (+15 years old) *n= 1,108*	Cross-sectional	Chronic Pain Grade (CPG)	Prevalence ratio	Smoking *Current smoker* PR=1.22; 95%CI=1.02, 1.47	+

		psychosocial, and occupational factors associated.						Physical activity *Intense or heavy activity* PR=1.40; 95%CI=1.06, 1.86	
	de Carvalho Cremm, E. (2012)	To investigate the individual and family determinants of being overweight among children living in an urban area.	Santos; Brazil	Children (<10 years old) *n= 531*	Cross-sectional	BMI-for-age (kg/m^2)	Odds ratio	Physical activity *Transportation (walks/bikes)* OR=1.70; p=0.05	+
	Eisele, M. (2015)	To investigate factors influencing the course of health-related quality of life in older primary care patients and to derive non-pharmacological recommendations for improving their quality of life.	Bonn, Düsseldorf, Hamburg, Leipzig, Mannheim, Munich; Germany	Elderly (≥78 years) *n=1968*	Prospective longitudinal observational	Health-related quality of life (HRQoL)	β coefficient	Physical activity *Activity level* β=1.011, 95%CI=0.127, 1.895	+
	Pizzo, G. (2010)	To investigate the prevalence of caries in children and assessed the relationship between socio-behavioral determinants and caries.	Palermo; Italy	Children (5 and 12 years old) *n=511*	Cross-sectional*	Dmf-t index	Odds ratio	Nutrition *Frequency of snack consumption* *More than once a day* vs *Once a day:* OR= 1.92, 95%CI=1.04, 3.54	+

	Sanderson, M. (2015)	To determine whether physical activity and adult weight change, are linked to breast cancer risk.	Nashville; USA	Adult women (25 to 75 years old) *n=2614 incident breast cancer cases and 2306 controls*	Case-control	Population-based case-control	Odds ratio	Physical activity *Hours per day postmenopausal* *White* *0.1–1.4:* OR= 0.8, 95%CI=0.6, 1.0 *1.5–3.6:* OR=1.0, 95%CI=0.8, 1.2) *≥3.7:* OR= 0.8, 95%CI=0.6, 1.0 *Black* *0.1–1.4:* OR= 0.7, 95%CI=0.5, 1.2 *1.5–3.6:* OR= 0.7, 95%CI=0.4, 1.2 *≥3.7:* OR= 0.7, 95%CI=0.4, 1.1	+
	Schulz, A. J. (2008)	To provide evidence of an effect linking socioeconomic indicators to cardiovascular disease (CVD) risk factors.	Detroit, Michigan; USA	Adults (≥25 years old) *n=919*	Cross-sectional*	Depressive symptoms, smoking status, physical activity, body mass index and waist circumference	β coeficient	Smoking *Current smoker* *Body mass index:* β=-3.23, p<0.001 *Waist circumference*: β =-4.40, p<0.001	+
Morbidity related	Cau, B. M. (2016)	To examine associations factors with mental health (poor self-rated health).	Maputo; Mozambique	Adults (+ 40 years old) *n= 1768*	Cross-sectional*	SRH	Odds ratio	Physical activity *Intensive activity* OR=0.60; p<0.05	+

	Christiani, Y. (2015)	To examine unequally distribution of depression among women in Indonesia's major cities and investigate the factors contributed to the inequality.	Jakarta, Surabaya, Medan, Bandung; Indonesia	Adult (19-65 years old) *n=1117*	Cross-sectional*	Prevalence of depression	Concentration index	Smoking *Current smoker* CI= -0.151, p<0.05	+
	Franca, V. F. (2016)	To assess the association between unhealthy dietary habits and cognition in older adults.	Florianopolis Brazil	Adults (+60 years old) *n=1197*	Cross-sectional	Mini-Mental State Examination (MMSE)	β coefficient	Nutrition *Unhealthy dietary habits* *Women* *Fruits and Vegetables:* β=-1.004; 95%CI= -1.376, -0.631 *Fish:* β=0.073; 95%CI= -0.312, 0.458 *Red meat with fat:* β=-0.171; 95%CI= -0.873, 1.216 *Chicken skin:* β=0.290; 95%CI= -0.756, 1.336 *Men* *Fruits and Vegetables:* β=0.298; 95%CI= -0.393, 0.968 *Fish:* β=-0.441; 95%CI= -1.059, 0.177 *Red meat with fat:* β=0.505; 95%CI= -0.415, 1.424 *Chicken skin:* β=0.008, 95%CI= -1.103, 1.120	+

	Ribeiro Dos Santos, E. (2016)	To estimate the prevalence of depression associated with socio-demographic and economic characteristics, smoking habits, alcohol use, and physical morbidities.	Coari and Tefé; Brazil	Adults (+20 years old) *n=34,838*	Cross-sectional	Score of ≥10 on the Patient Health Questionnaire-9 (PHQ-9)	Prevalence ratio	Smoking *Current smoker* PR=1.12; 95%CI=0.82, 1.52	+
								Alcohol consumption *Risky alcohol use* PR=1.30; 95%CI=0.99, 1.77	

Note: positive (+): a desirable improvement in the indicator was associated with an improvement of PH and negative (-): a desirable improvement in the indicator was associated with a deterioration of PH; † unclear information about population size; *"Study design" assigned by the authors

Table 21 Studies of health behaviors dimensions and analysed indicators and health outcomes without an association not statistically significant (for the defined statistical level)

Health outcome	Reference	Overall aim	City/Cities Country	Study population	Study design	Health outcome measure	Association measure	Dimension/ Indicator	Relation between indicator and PH
Overall Mortality	Smigielski, J. (2013)	To identify the relationships on the mortality of men of subjective health assessment, nutritional habits, alcohol consumption and tobacco smoking.	Łódź; Poland	Adults (18-64 years old) *n=1004*	Cross-sectional*	Recorded deaths	Survival probability	Physical activity *Small or not at all vs. moderates vs. high*): C=0.064; $p<0.05$	0
Morbidity related with chronic diseases	Artaud, F. (2013)	To examine the individual and combined associations of unhealthy behaviors with hazard of disability among older French adults.	Bordeaux, Dijon, Montpellier; France	Elderly (+65 years old) *n=3982*	Cohort	Hierarchical indicator of disability (no, light, moderate, severe)	Hazard ratio	Alcohol consumption *Never, former, or heavy drinker* vs *light to moderate drinker* HR=1.00, 95%CI=0.92, 1.09	0
	Cabral, D. M. (2014)	To determine the prevalence of chronic pain and to identify sociodemographic, psychosocial, and occupational factors associated.	São Paulo; Brazil	Adults (+15 years old) *n= 1,108*	Cross-sectional	Chronic Pain Grade (CPG)	Prevalence ratio	Alcohol consumption *Hazardous alcohol use/dependence symptoms/harmful alcohol use* PR=0.84; 95%CI=0.61, 1.16	0

	Fatema, K. (2013)	To evaluate the proportion of urban adults suffering from chronic kidney disease as well as to have a preliminary idea about the determinants of this disorder.	Dhaka; Bangladesh	Adults (+18 years old) *n=634*	Cohort	"Likely CKD" according to Kidney Disease: Improving Global Outcomes	Odds ratio	Smoking *Current smoker* OR=1.7; 95%CI=0.9, 3.08	0
	Schulz, A. J. (2008)	To provide evidence of an effect linking socioeconomic indicators to cardiovascular disease (CVD) risk factors.	Detroit, Michigan; USA	Adults (≥25 years old) *n=919*	Cross-sectional*	Depressive symptoms, smoking status, physical activity, body mass index and waist circumference	β coeficient	Smoking Physical activity β =-0.65, p<0.001	0
Morbidity related with mental illness	Franca, V. F. (2016)	To assess the association between unhealthy dietary habits and cognition in older adults.	Florianopolis Brazil	Adults (+60 years old) *n=1197*	Cross-sectional	Mini-Mental State Examination (MMSE)	β coefficient	Alcohol consumption *No alcohol intake* p< 0.001 Smoking *Non-smoker* p=0.006	0
Morbidity related with	Albaladejo, R. (2014)	To assess whether the relationship between childhood obesity is explained by family socioeconomic position and risk behaviors.	Madrid; Spain	Children (6–15 years old) *n= 727*	Cross-sectional*	BMI (kg/m^2)	Odds ratio	Physical activity *≤1.01 Sport facilities per 1000 population* OR=1.10; 95%CI=0.53, 2.25	0

† unclear information about population size; *"Study design" assigned by the authors

Appendix 3

INTERVIEW TEMPLATE

This semi-structured interview will be performed to discuss the results obtained in a systematic review of literature and in a search to collect indicators in databases in Portugal, in view of selecting dimensions and indicators relevant to include in a framework for monitorization and evaluation of environmental health in urban settings, with focus on Lisbon.

This interview is structured in three parts. When answering to the questions, please bear in mind that the focus is the monitorization and evaluation of environmental health in Lisbon, but answers should not be constrained by the lack of data.

PART 1- ANALYSIS OF EVIDENCE FROM THE LITERATURE REVIEW

Discussing the results on environmental health dimensions from the literature

The following dimensions have been found to be determinants of environmental health in the literature:

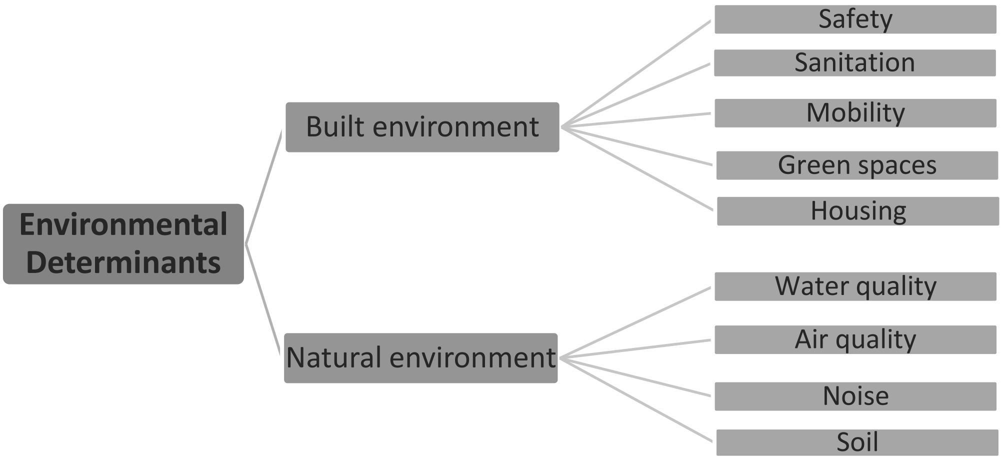


Figure 1 Environmental health dimensions

a) Do you agree that all the relevant dimensions in the natural and built environment are included in a framework (Figure 1) for monitoring and evaluating environmental health in Lisbon? Do you have suggestions of extra dimensions?

b) Within the natural environment component, past frameworks included **Soil** as a dimension to consider, but no evidence on association between soil and environmental health was found. Do you agree with the exclusion of Soil dimension to evaluate health in urban settings? If NO, why?

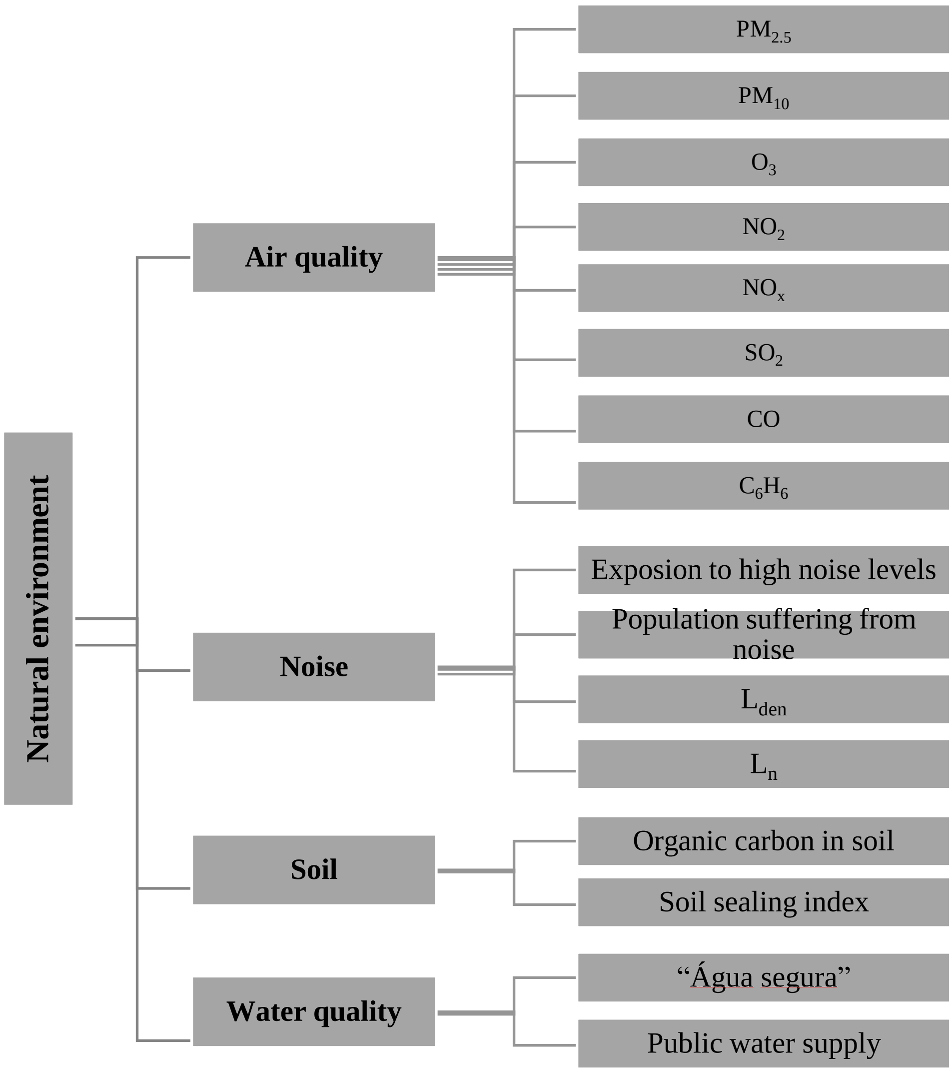
c) Within the built environment component, no evidence of association was found in the review between **Sanitation and Housing** indicators and health outcomes. Do you agree with the exclusion of these dimensions to evaluate health in urban settings? If NO, why?

PART 2- ANALYSIS OF INDICATORS AND DATA COLLECTED FROM PORTUGUESE DATABASES AND OF INDICATORS' AVAILABILITY

1. **Discussing on NATURAL ENVIRONMENT determinants' indicators collected for Portugal and/or Lisbon**

Having in mind the aim to build a framework to be applied to Lisbon, a list of available indicators from national databases were collected. We grouped those indicators within dimensions previously reported in literature.

Please see the overview of indicators and dimensions before answering the questions.



a) Please indicate the extent to which this indicator is relevant to monitor and evaluate environmental health in Lisbon:

Indicator	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Totally Agree	DNK/DNWA
$PM_{2.5}$						

PM_{10}						
O_3						
NO_2						
NO_X						
SO_2						
CO						
C_6H_6						
Exposure to high noise						
Suffering from noise						
L_{den}						
L_n						
Organic soil in soil						
Soil sealing index						
"Água segura"						
Public supply						

(DNK/DNWA: Do Not Know/Do Not Want to Answer**)**

b) Please indicate if each of the following indicators are included in the correct dimension:

Indicator	**Dimension**	**If you disagree with the inclusion of the indicator in this dimension, describe which would be the correct dimension**
$PM_{2.5}$	Air quality	
PM_{10}		
O_3		
NO_2		
NO_X		
SO_2		
CO		
C_6H_6		
Exposure to high noise	Noise	
Suffering from noise		
L_{den}		

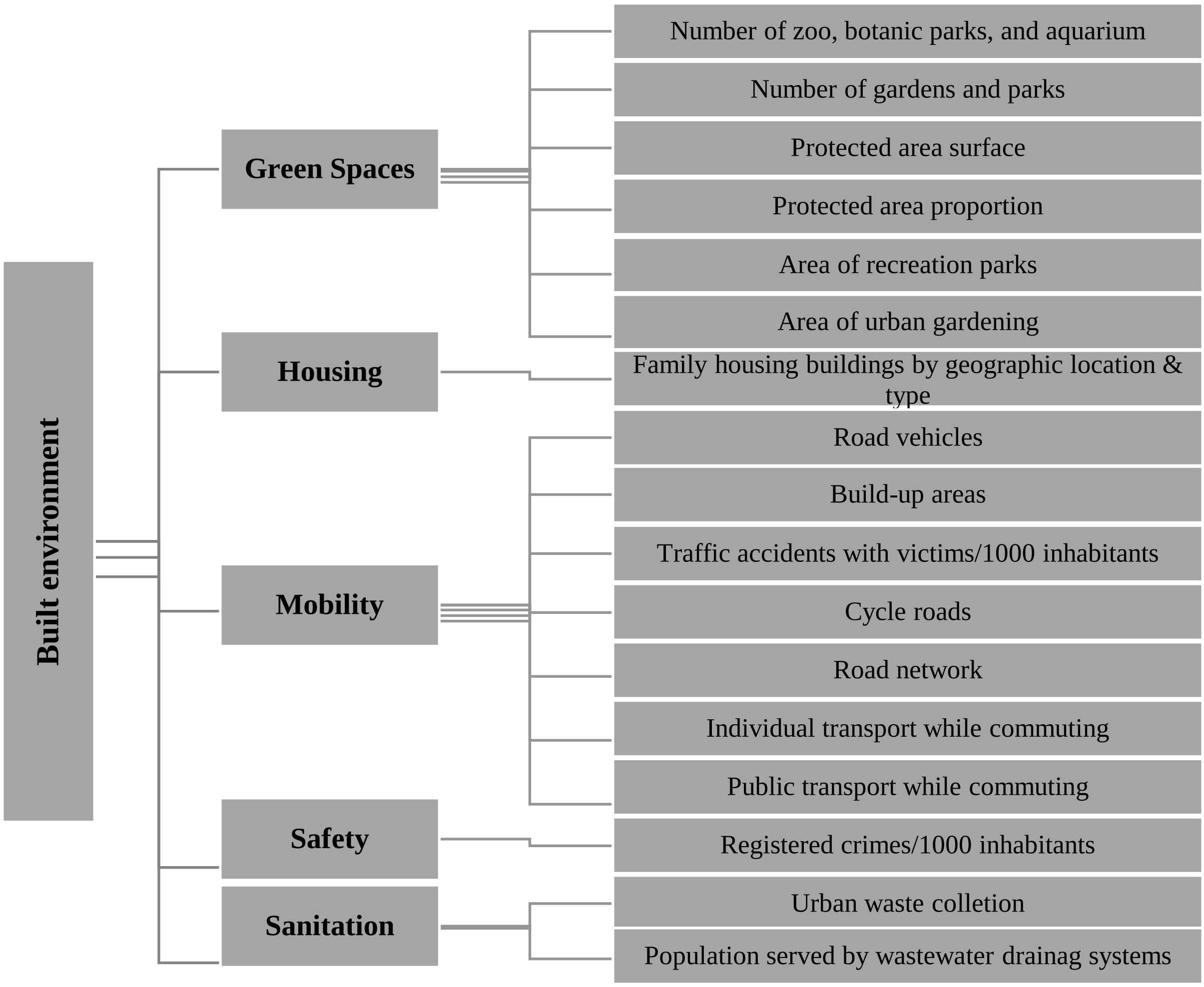
L_n		
Organic soil in soil	Soil	
Soil sealing index		
"Água segura"	Water quality	
Public supply		

c) Please make a cross on the indicators that may be seen as redundant (i.e. which capture the same phenomena):

	$PM_{2.5}$	PM_{10}	O_3	NO_2	NO_X	SO_2	CO	C_6H_6	Exposure to noise	Suffering from noise	L_{den}	L_n	Organic soil in soil	Soil sealing index	"Água segura"	Public supply
$PM_{2.5}$																
PM_{10}																
O_3																
NO_2																
NO_X																
SO_2																
CO																
C_6H_6																
Exposure to high noise																
Suffering from noise																
L_{den}																
L_n																

Organic soil in soil																
Soil sealing index																
“Água segura”																
Public supply																

2. **Discussing the results on BUILT ENVIRONMENT determinants' indicators collected for Portugal and/or Lisbon**



a) Please indicate the extent to which this indicator is relevant to monitor and evaluate environmental health in Lisbon:

Indicator	Strongly disagree	Disagree	Neither agree norm disagree	Agree	Totally Agree	DNK/DNWA
Nº Zoo, botanic parks, and aquarium						
Protected area surface						
Protected area proportion						
Number of gardens and parks						
Area of recreation parks						
Area of urban gardening						

Classic family housing buildings						
Buildings by geographic location and type						
Built-up areas						
Road vehicles by type and fuel						
Traffic accidents with victims/ 1000 inhabitants						
Cycle roads						
Road Network						
Proportion of employed or student resident population using individual mode of transport while commuting						
Proportion of employed or student resident population using public transport mode during commuting						
Police-reported crimes /1000 inhabitants						
Urban waste collection						
Population served by wastewater drainage systems						

b) Please indicate if each of the following indicators are included in the correct dimension:

Indicator	**Dimension**	**If you disagree with the inclusion of the indicator in this dimension, describe which would be the correct dimension**
Nº Zoo, botanic parks, and aquariums	Green spaces	
Protected area surface		
Protected area proportion		

Number of gardens and parks		
Area of recreation parks		
Area of urban gardening		
Classic family housing buildings	Housing	
Buildings by geographic location and type		
Built-up areas	Mobility	
Road vehicles by type and fuel		
Traffic accidents with victims/ 1000 inhabitants		
Cycle roads		
Road Network		
Proportion of employed or student resident population using individual mode of transport while commuting		
Proportion of employed or student resident population using public transport mode during commuting		
Police-reported crimes /1000 inhabitants	Safety	
Urban waste collection	Sanitation	
Population served by wastewater drainage systems		

c) Please make a cross on the indicators that may be seen as redundant (i.e., which capture the same phenomena):

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Nº Zoo, botanic parks, and Aquarius																		
2	Protected area surface																		
3	Protected area proportion																		
4	Number of gardens and parks																		
5	Area of recreation Parks																		
6	Area of urban gardening																		
7	Classic family housing buildings																		
8	Buildings by geographic location and type																		
9	Built-up areas																		
10	Road vehicles by type and fuel																		

11	Traffic accidents with victims/ 1000 inhabitants																		
12	Cycle roads																		
13	Road Network																		
14	Proportion of employed or student resident population using individual mode of transport while commuting																		
15	Proportion of employed or student resident population using public transport mode during commuting																		
16	Police-reported crimes /1000 inhabitants																		
17	Urban waste collection																		
18	Population served by wastewater drainage systems																		

PART 3- ANALYSIS OF MISSING DATA

1- After analyzing above the available indicators, in your opinion, **which indicators are missing** to adequately monitor and evaluate environmental health in Lisbon?

a) Please indicate your suggestions of what should be included even if you do not know if data is available.

Determinant	**Dimension**	**Possible indicator**
Built environment	Green spaces	
	Housing	
	Mobility	
	Safety	
	Sanitation	
Natural environment	Air quality	
	Noise	
	Soil	
	Water quality	

b) Can you suggest a possible strategy to find information on missing dimensions/indicators?

2- The indicators presented in the tables below are indicators measured at national level. Please indicate if the national indicator can be used as a proxy for the urban level in Lisbon?

Indicator	**Periodicity**	**Year**	**Proxy for urban level?**
"Água segura"	Annual	2017	
Access to public water supply	Annual	2016	
Population living in households considering that they suffer from noise, by poverty status	Annual	2018	

Organic carbon in soil		2010	
Soil sealing index	3 years	2015	

Indicators	**Periodicity**	**Year**	**Proxy for urban level?**
Buildings by geographic location and type	Ten-year	2011	
Built-up areas	3 years	2015	
Classic family housing buildings	Annual	2018	
Nº Zoo, botanic parks, and Aquarius	Annual	2017	
Proportion of employed or student resident population using individual mode of transport while commuting	Ten-year	2011	
Proportion of employed or student resident population using public transport mode during commuting	Ten-year	2011	
Road vehicles by type and fuel	Annual	2017	