Urban vulnerability in the EMME region and Sustainable Development Goals: a new conceptual framework

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Abstract

Crises have shocked the global population and forced entire nations to shift their operations and priorities. The adverse effects of these crises primarily impact cities and their inhabitants; nevertheless, inherently, they have the potential to overcome them. Urban centres are home to around half of the global population, and often they are correlated to high standards of life, mostly in the Western world. Nevertheless, cities are highly flawed and, at times, are coming up short when it comes to accommodating human needs. Thus, the motivation of this work is to investigate urban vulnerabilities linked to the broader topic of climate change, focusing on urban centres in the Eastern Mediterranean and the Middle East region. This study has a dual purpose: to introduce a content-based approach of analysis, akin to bibliometrics, using proxies and links to recreate a research landscape and investigate urban vulnerability under specific conditions and how it affects public health; ultimately, offering a tentative definition of it. The novelty of this study is the proxies and links approach, through which we have identified the major trends in urban vulnerability research, as well as possible under-explored themes, by interpreting qualitative findings into more tangible ones.

1 Introduction

Vulnerability comes in many forms and as a result of different factor combinations. When encountered in urban settings, it is nearly impossible to be defined under a single lens. Urban planners, architects, environmental

scientists, human rights experts, medical workers and policy or economic analysts are some of the experts researching urban vulnerability. The United Nation's Sustainability Goals (UN SDGs) are one of the frameworks which could adequately represent the multiple facets of urban vulnerability, useful in describing and quantifying it [1]. A total of 17 goals and 169 targets are introduced, aiming to achieve a more sustainable mode of living by 2030, and most of them can be related to some aspects of urban habitats and the challenges faced by residents. The goals are versatile and reflect the challenges of the modern world, many of which are related to urban environments. For example, there have been studies on the role of companies towards urban sustainability, as well as vulnerability maps aiming to reduce the fragility of populations to climate impacts [2,3]. To simulate what urban vulnerability might look like, imagine living the life of Anna, a fictional character introduced in Figure 1. The use of a comic strip is favoured, as previous research has shown that this form of communication reflects cultural norms and resonates with specific social contexts [4]; therefore, the challenges of urban life become relatable to the everyday life of any urban dweller.

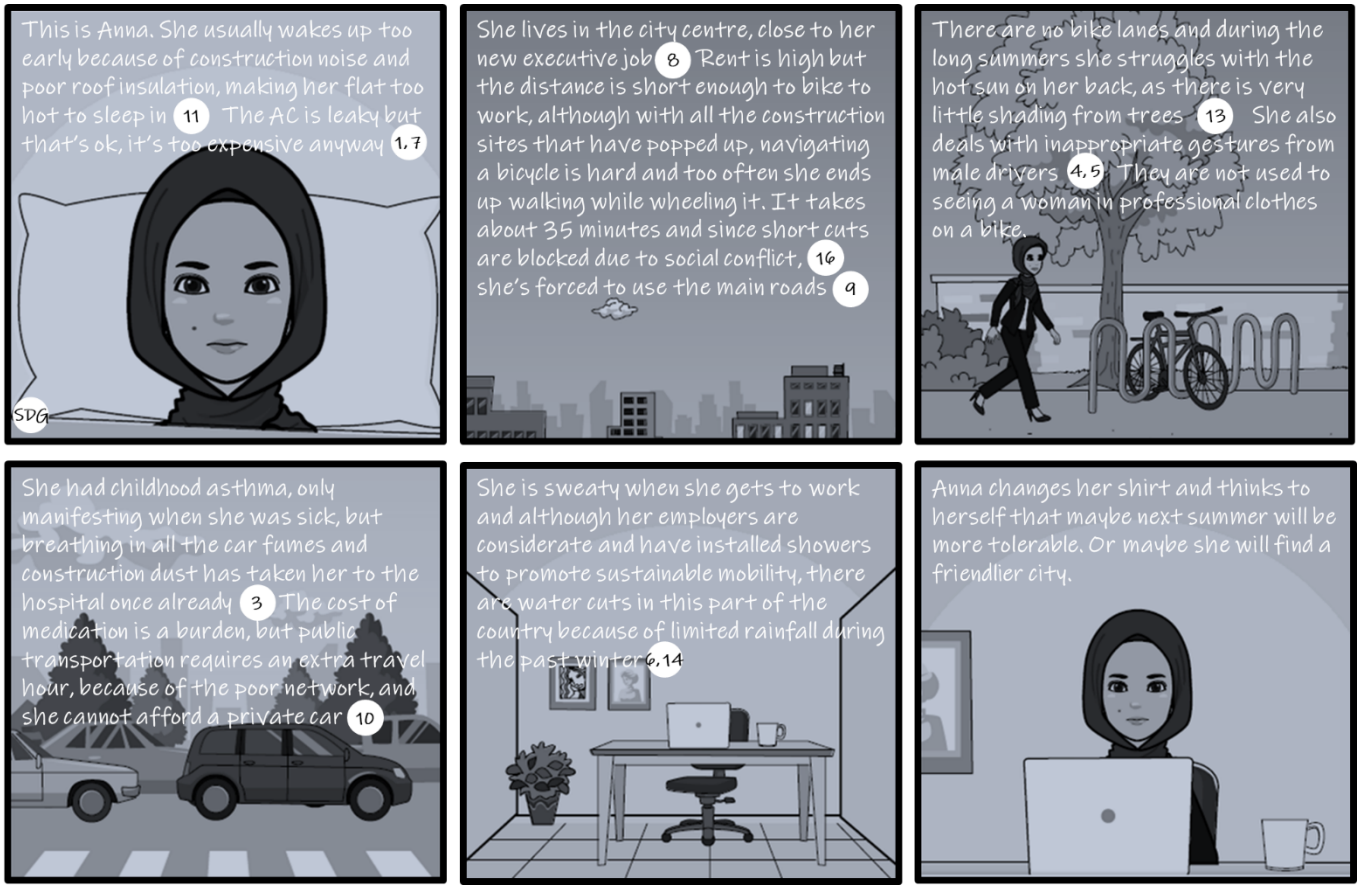

Figure 1. Difficulties in the life of Anna, a fictional character. Comic strip created with the online tool Pixton (https://app.pixton.com/) and narrative developed by the authors.

The narrative following Anna is subjective and used purely to highlight aspects of daily life, illustrating how urban environments can become challenging. Anna is a city dweller who has had to deal with noise and air pollution,

excessive heat, energy poverty and monetary hardships, endangering herself due to inappropriate urban infrastructure and poor urban design, excess visits to the hospital due to respiratory distress as a result of poor air quality, gender discrimination and poor water management on behalf of the city, resulting in lack of access to water. Collectively, in this specific story, these vulnerabilities can be associated with more than ten SDGs. Vulnerability is a term with a non commonly accepted definition. It is generally referred to as a susceptibility to harm in relation to the impact of a specific threat [5] or the potential for loss due to a hazardous event [6]. Its definition, therefore, shifts according to the context it is placed in. According to Lankao and Qin (2011), among others, urban vulnerability may be viewed from multiple perspectives. For example, certain approaches view urban vulnerability either as an outcome of a series of situations or as an inherent condition, created exactly due to the "decreasing ability of a city or its populations to cope with a set of societal and environmental hazards and stresses of which climate change is but one" [7]. On the one hand, exposure to natural hazards and stresses creates conditions of vulnerability in urban settings, impacting the health of its inhabitants. On the other hand, poor socioeconomic and urban development strategies are the enhancers of decreasing coping mechanisms of cities. Not being able to cope with natural hazards and stressors automatically creates a vulnerable situation for cities [7]. In other words, this lineage of research looks into the causes of urban vulnerability rather than its impacts.

Another approach involves urban resilience, i.e. looking further than the causes or impacts of vulnerability and into the different attitudes of response after a disaster strikes. In cases of vulnerability and hazardous situations, accumulative disaster impacts may be mitigated through the appropriate coping and adaptive responses of cities [7]. The impacts of climate change are integrated into urban vulnerability research, identifying critical challenges in a constantly changing world and calling for multi-level governance and change in urban sociotechnical systems to improve the resiliency of cities [8]. This requires an understanding of physical parameters related to climate change (e.g., temperature mean and variability and precipitation patterns), as well as the complexities of urban development, social inequalities, hazards-of-place, economics and politics [9–11]. Historically, climate change research has had a rural focus, which has now become more urban [12]. Intense urbanisation and industrialisation have created dense urban centres and megacities [13], draining rural areas of their populations and creating systems of voracious consumption of energy, water and materials. Consequently, cities become centres of increased emissions, pollution of air, soil and water and augmented temperatures. Moreover, public health is

affected by urbanisation, increasingly poor air and water quality, natural hazards such as dust storms and artificial hazards such as war conflicts.

This study offers a timely review of research on urban vulnerability issues within the Eastern Mediterranean and the Middle East (EMME) region, a recognised climate change hotspot [14] and aims to examine the impact of different aspects of climate change on urban vulnerability and public health within the realm of the built environment. This is done by systematically reviewing the scientific literature and developing and applying a novel analytical method that uses proxies and links of research, elaborated in the Methods section. Urban vulnerability is a multi-fold topic, but its scientific domain is still an evanescent and ambiguous matter. Thus, this study takes on a specific research question, discussing major trends and gaps in the literature for the EMME region under the inspiration of the UN's SDGs. Moreover, an attempt is made to identify aspects of urban vulnerability and deduce a tentative definition applicable to the broader spectrum of pathways towards sustainable cities.

2 Methods

2.1 Systematic literature review

When introducing a new research framework, its every aspect should be detailed and justified. Starting from the terminology, this has been selected in order to best describe the individual units of the proposed approach. A proxy is often used in social sciences to measure an unobservable quantity of interest. It is also common practice to employ several proxies when investigating a composite subject to create a representative landscape. For this reason, the "proxy" is the fundamental unit used to explore an intricate subject and "links" are the associations already existing between proxies. On this occasion, the Proxy approach is used to investigate the thematic of urban vulnerability under the umbrella of a systematic literature review. Further elaboration on the Proxy approach is provided in section 2.2.

Furthermore, in order to allow reproducibility, the detailed method of a newly introduced framework should be presented at length. The systematic literature search was conducted utilising the PRISMA [15] (Preferred Reporting Items for Systematic reviews and Meta-Analyses) and CIMO (Context, Intervention, Mechanism and Outcome) schemes (Figure 2). Under PRISMA, there are four steps to finding the correct set of papers to review: Identification, Screening, Eligibility and Inclusion [16]. In response to the first step, the CIMO logic was adopted to formulate the

research question and identify appropriate search queries to be run in the leading databases of scientific documents, Scopus and Web of Science. Each element of this approach was identified, and keywords for each element were selected through an iterative database searching process. The iterative process is necessary to ensure that the body of literature resulting from the query is pertinent to the chosen topic and representative of the overall issue of urban vulnerability. The ultimate research question was: “How has climate change (M) affected urban vulnerability (I) in the EMME region (C), and which are the impacts on human health (O)?”. In order to capture the main research themes linked to climate change, keywords such as “heat waves”, “flood”, “dust”, and “air quality” are used under the Mechanism element of CIMO.

For this reason, it should be noted that not all publications are directly linked to climate change, but all are connected to some aspects that climate change has impacted upon. Likewise, under Intervention, urban vulnerability is reflected through keywords such as “inequality”, “urban planning”, “urban design”, and under Outcome, health is represented by “respiratory”, “circulatory”, “wellbeing” etc. Under Context, all the countries of the EMME region are listed, as well as the terms “East Mediterranean” and “Middle East”.

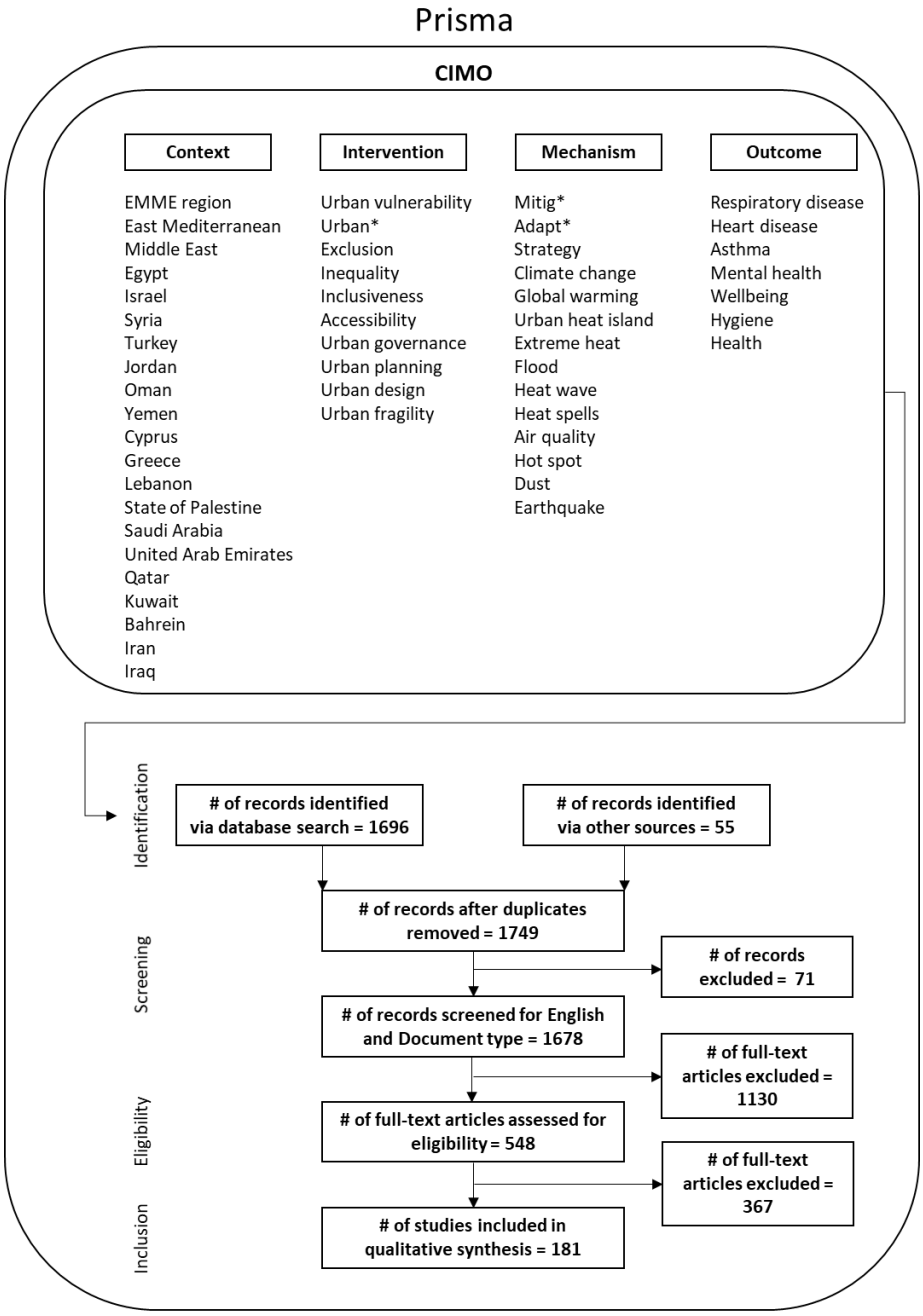

Figure 2. Prisma and CIMO schemes for this systematic literature review.

The search query was produced by connecting the keywords under each CIMO element. Keywords were associated with the "OR" function within parentheses, and then the four parentheses were connected with the "AND" function. Exclusion criteria were applied for each step of the PRISMA process, including removal of duplicates, limiting the document type (scientific journals, reviews and conference proceedings) and language (English) and exclusion of misleading categories of subject areas such as veterinary and the arts.

In order to compliment the query search, different combinations of keywords were also manually searched for, in specific journals dealing with urban vulnerability and in Web of Science. The ultimate pool of research documents

obtained from the structured search query and the manual search included 181 contributions (accessed on 4/1/2021). Also, it should be noted that no publication year limitations were applied in the literature search.

Each of the contributions was then characterised by a number of keywords describing its main scope and recurrent keywords among the pool of literature became the main proxies of investigation.

2.2 The Proxies Approach: Estimation of proxy and link strength

The innovation of this study is the introduction of proxy and link analysis, which is a visual representation of an adapted weight matrix. This approach allows immediate identification of main concepts and relationships between them, as well as more insights on weaker links. The proxy analysis method also enables detection of gaps in bodies of literature, specific areas or links with potential for strengthening and recommendations for future work. This concept may be similar to bibliometric analysis; however, it allows elaboration on the basis of the content of studies, rather than considering simply documents' metadata such as authorship, affiliations, keywords. Proxies are used as the basic unit for creating a map of urban vulnerability research according to the scope depicted in the research question of this study. Links are used to indicate relationships between proxies, that is, to observe how each proxy is connected to the rest. Proxy strength (PS) indicates the frequency of a particular topic showing up in the documents finally included in the analysis. In contrast, link strength (LS) indicates the frequency by which two topics are examined together.

Each reviewed paper is tagged with a number of keywords representing its main scope and essentially the proxies of research it deals with. Following an initial assessment of the available literature on this topic, a number of recurring themes are detected and grouped into five dimensions of urban vulnerability: environmental, human, urban habitat, techno-economic and socioeconomic factors. Under each of these categories, between three-five individual proxies are listed, for a total of 19 proxies. A generic description is provided for each proxy (Table 1), highlighting the focal points reflected in the reviewed literature.

Table 1. Proxies and brief explanations.

Proxy	Explanation
Air and soil pollution (ASP)	Measurements or projections of pollution, including particulate matter, contamination with metals and relevance to WHO standards
Climate change (CC)	Climate change-specific analyses, including time-series and modelling of future patterns of various factors, e.g. mortality, temperature or pollution
Natural hazards (NH)	Extreme heat or cold events, floods, dust storms, drought, earthquakes
Urban heat island (UHI)	Urban heat island effects on the local scale, global patterns, projected scenarios and mitigation studies
Admissions (AD)	Measured and projected hospitalisations of urban populations

Health (HE)	Physical health, including public health concerns measured and projected morbidity related to cardiovascular, respiratory, carcinogenic effects
Mortality (MOR)	Measured or projected mortality and risk of premature mortality
Wellbeing (WE)	Mental health, thermal comfort, sustainable mobility, resource use and considerations of cultural aspects
Community participation (CP)	Perceptions and engagement of communities in commons, including interview citizen science
Greenspace (GS)	Large scale green open spaces in urban dwellers' everyday life and as a mitigation tool
Urban development (UD)	Urban planning, urban geometry, considerations on sustainability, industrial and traffic activity in urban centres, urban sprawl
Urban vegetation (UV)	Effects of urban centres on vegetation and vice versa
Water management (WM)	Vulnerabilities and management tactics related to water resources
Cost (CO)	Interpretations based on monetary costs
Modelling (MOD)	Use of modelling techniques
Technologies (TE)	Integration of technological findings in urban fabric, impact of technological advancements in urban life and abatement strategies
Economic crisis (EC)	Monetary poverty impacts
Energy poverty (EP)	Energy poverty impacts
History (HI)	Retrospectives and lessons from historical findings

Of course, categorisation is arbitrary, since UHIs for example, could be classified under each one of the clusters, depending on the intent of the study. Furthermore, the individual studies and overarching proxies are assessed with relation to their affinity with specific SDGs.

3 Findings of the Proxies approach

This section discusses the main thematic topics of research identified using the proxies approach. Table 2 presents the frequency by which combinations of topics were encountered together in studies and was used to create a map (Figure 3) to convey the strength of individual proxies, as well as their links with other proxies.

The most frequently investigated subject in this literature review is *ASP*, and the less studied one is *EE*. Other significant proxies are *HE*, *MOD*, *NH*, *WE* and *UD* (including the built environment). It should be noted that while all studies have the underlying thematic of human health and wellbeing, the synonymous proxies refer to physical health (i.e. respiratory or cardiac diseases, carcinogenic risk) and general wellbeing (mental health and comfort).

Although proxy strength indicates the frequency a topic is investigated upon, taking a closer look at other parameters can reveal significant information. For instance, the three most prominent proxies (*ASP*, *HE* and *MOD*) also have very high cumulative link strengths and are connected to all other proxies. Nevertheless, very low proxy strength topics, such as *CP* and *TE*, are also characterised by high link count but significantly lower cumulative link strength.

Table 2. Proxies and links to research topics. Numbers in cells represent the link strength between two proxies; cumulative link strength indicates how well connected each proxy is; link count indicates the number of proxies linked to it; proxy strength indicates frequency each

topic was investigated; cluster strength is the sum of its proxy strengths. This sum includes overlap between topics and therefore does not equate to the number of studies falling under each cluster.

	Environmental				***Human***				***Urban habitat***				***Technoeconomic***			***Socioeconomic***			
	ASP	CC	NH	UHI	AD	HE	MOR	WE	CP	GS	UD	UV	WM	CO	MOD	TE	EC	EP	HI
ASP	3																		
CC	9																		
NH	45	21																	
UHI	5	9	9																
AD	18	2	5	1															
HE	82	11	38	4	16														
MOR	23	4	10	3	8	20													
WE	19	19	27	16	2	20	6												
CP	6	2	3	1	1	8	2	17											
GS	6	6	8	5	na	4	2	16	8										
UD	20	14	22	7	1	17	4	33	13	17	1								
UV	10	7	8	5	na	4	3	11	3	12	13								
WM	8	13	14	3	na	7	2	na	6	7	19	7							
CO	11	2	2	na	4	8	8	6	3	2	4	1	4						
MOD	72	17	40	6	12	51	21	20	2	7	18	10	8	10					
TE	15	7	8	4	3	11	4	15	4	4	14	3	10	5	7				
EC	9	5	7	na	1	8	4	7	4	na	5	1	4	1	6	3			
EP	9	na	2	na	1	8	2	3	2	na	1	na	1	1	6	2	7		
HI	7	12	6	3	1	6	na	24	6	9	16	7	9	1	1	4	3	na	
Cumulative link strength	**377**	**160**	**275**	**81**	**76**	**323**	**126**	**261**	**91**	**113**	**239**	**105**	**122**	**70**	**314**	**123**	**75**	**45**	**115**
Link count	**18**	16	17	**14**	**14**	17	16	16	17	**14**	**18**	**15**	**15**	**15**	17	17	**15**	**12**	**15**
Proxy strength	**119**	**32**	**68**	**20**	**19**	**95**	**29**	**61**	**22**	**20**	**52**	**20**	**24**	**16**	**89**	**24**	**15**	**11**	**30**
Cluster strength	**239**				**204**				**138**				**129**			**56**			

Moreover, the minimum, average and maximum link and proxy strengths (see Figure 3) indicate polarisation and unequal distribution of research resources towards specific topics, suggesting that some topics receive heavy attention in several aspects or locations (e.g., pollution studies in different cities of the EMME region), whereas others are superficially explored in a wide arrange of themes. It should be noted that the map's purpose is to provide compelling visual evidence on the disproportionality in research topics and to convey the complexity of relationships among proxies. Detailed information on PS and LS can be found in Table 2.

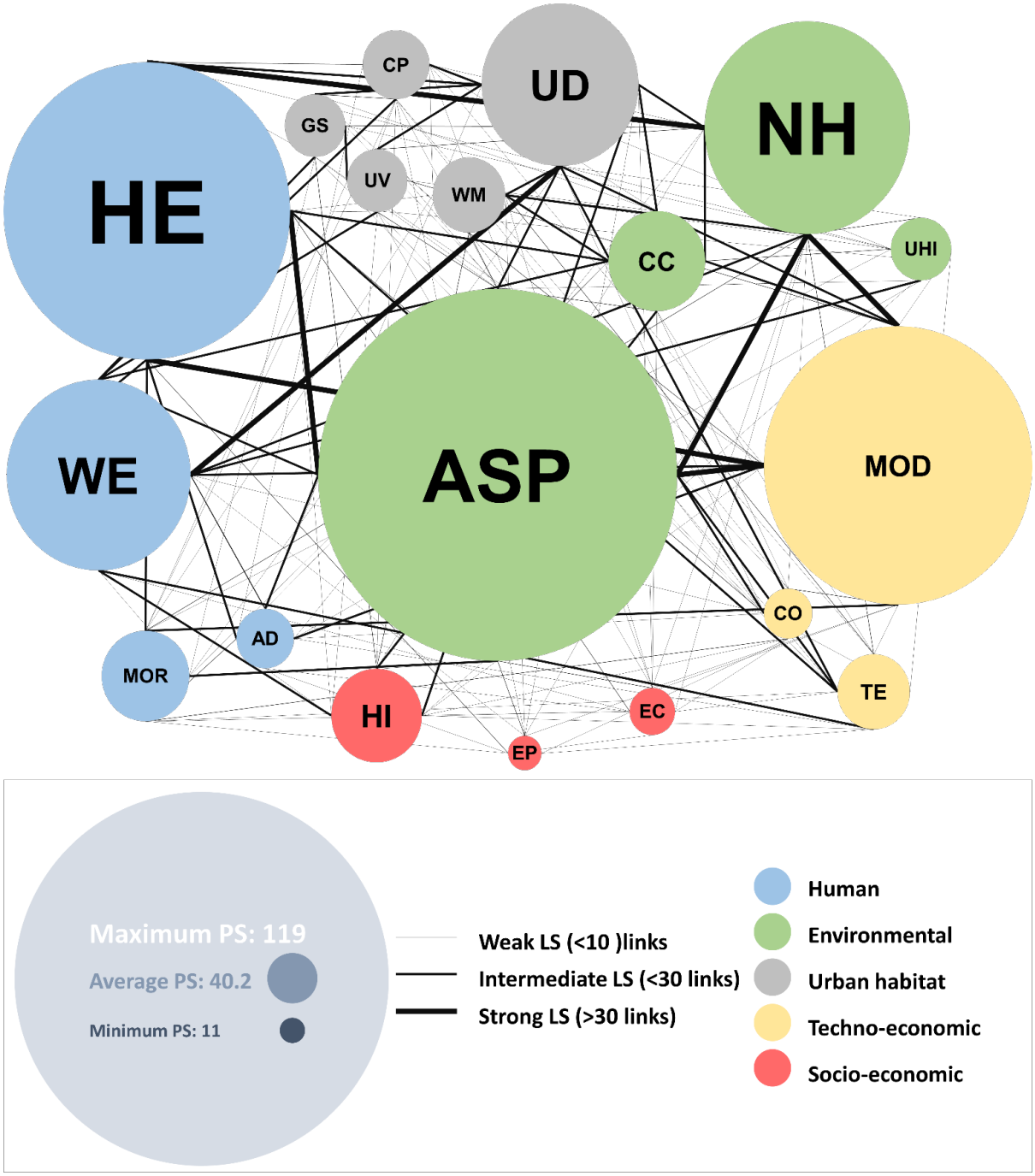

Figure 3. Map of proxies and proxy links, with legend at the bottom. Each bubble is a proxy, and each line is a link. The size of bubbles refers to PS and indicates the frequency of a particular topic showing up in literature, whereas line width refers to LS, indicating the frequency by which two topics are examined together.

3.1 Environmental cluster

ASP, *CC*, *NH* and *UHI* studies are included in this cluster. Together, they constitute the majority of the reviewed literature and the primary concerns of researchers of urban vulnerability in the EMME region. Particulate matter and settled urban dust are the most popular topic, followed by *NH*, mainly referring to dust storms, flooding and to a lesser extent, earthquakes. Some studies are merely describing the state of pollution in certain areas, while others

link pollution levels with national and international legislation and standards. There are more specialised investigations exploring specific impacts of urban pollution, for example, assessing the level of lead in the blood of construction workers.

The most popular proxy, *ASP*, is strongly linked to *HE*, *MOD* and *NH* and has the highest link count and cumulative link strength relative to all other proxies.

This means it is very well connected – not just in the number of linked topics, but also in depth, acquired through multiple contributions per link. In fact, *ASP* is only one of two proxies containing studies purely examining the subject matter, (i.e. without linking it to different topics), and it happens on three separate occasions [17–19]. Most linked research relates to *HE*, ranging from carcinogenic risk to particulate matter impact on respiratory and cardiovascular conditions and including *MOD* approaches for source apportionment and forecasting pollution, with the possibility to serve as early warning systems [18,20,29–38,21,39–43,22–28]. In some cases, *UV* was used as a proxy to estimate pollution levels or as a mitigation technique – often accompanied by *WM* strategies that also act as cooling mechanisms [44–52]. Water was also discussed in terms of quality control [53–55] or as an additional vulnerability of urban regions that are arid and in water stress [56,57]. Moreover, proxies such as *AD* and *MOR* are intricately connected to urban pollution studies, as polluted atmospheric environments have been linked to aggravation of respiratory and cardiac conditions [23,28,58–62].

Spatial distribution of diverging interests can be noticed: in southern Europe, the variants of this line of research focused on descriptions of the current pollution levels and sectors related to emissions (mostly focussing on industry and transportation), heat stress, the economic crisis, the turn of populations to conventional fuel for residential heating and the impacts of this type of pollution on urban health [43,44,69–78,50,79–88,55,89–93,63–68]. In other parts of the EMME region, the research included the expected atmospheric characterisation studies and health impacts, with very few contributions in heat stress or UHIs, despite the extreme weather conditions [17,51,52,56,94,95]. These studies highlighted more intensely the effects of heavy traffic and natural hazards such as dust storms [17,21,56,58,59,61,94,96–100,29,101–110,33,111–119,39,46,48,51,53,54]. The matter of conventional fuel utilised for residential purposes is not highlighted as a consequence of economic hardship in these countries but rather as a cultural phenomenon or a lived reality for the populations at hand [54,120–122]. Nevertheless, a common attribute across the EMME region is that urban pollution renders children more vulnerable, imposing higher health risk relative to carcinogenic and non-carcinogenic effects [17,34,123–

129,37,39,40,73,98,102,112,118]. Another thematic that EMME countries across the EU divide show high interest in is *UHIs*, which are highly related to the thermal comfort of urban populations, as well as *CC* [95,130,139,131–138]. These common research interests indicate that regardless of regulatory frameworks, EMME countries are concerned with those factors most affecting public health and welfare, urban pollution and the challenges of extreme urban heat within the context that applies to each country.

3.2 Human cluster

The most significant proxy of this cluster is *HE*, followed by the *WE* of urban dwellers. *HE* refers to clinical vigour, including national and international standards on pollution, carcinogenic risk and respiratory or cardiovascular morbidity. *WE* refers to the comfort of citizens, including thermal stress and satisfaction with the urban environment. The cluster is completed with the *MOR* and *AD* proxies, referring to assessments of morbidity and mortality as affected by various conditions (e.g., extreme heat or polluted ambient conditions).

HE was mostly linked to urban pollution and is the second-largest proxy overall and the dominant proxy of the human cluster. It is also highly connected to other themes of research and has the second-highest cumulative link strength. Aside from *ASP*, *HE* is also strongly linked to *MOD* and *NH*, as well as *MOR* and *WE*. The type of research dominating this field is almost identical to that of *ASP*. However, on the few occasions where health is discussed in the absence of pollution, it is done so relative to *NH* (heat stress and dust storms) and *WM* with specific attention to wastewater treatment [135,140–145]. Another distinct research pathway links health to socioeconomics through assessments of the healthcare cost or the burden that could be mitigated under different scenarios [146,147].

Moreover, some standing out contributions can be found related to *HE* and *CP*, a small proxy of the urban habitat cluster – for example, perceptions of health are examined through the lens of large-scale religious aggregations, typical of many EMME countries [148]. Another study examined the participatory process in creating sustainable urban spaces with the correct infrastructure in Muscat, in Oman, where urban planning became a public health issue [149]. This study too referred to religious activities and cultural phenomena as a primary factor of consideration, touching upon the subject of gender too. In this study, the health benefits of increasing walkability in an urban environment by integrating elements of religion in the design phase would benefit only men since the mosque is accessible only to them. In other examples of *HE* and *CP* crossovers, researchers found it difficult to

obtain balanced sex ratios in surveys because it was not culturally acceptable for male researchers to be talking to female participants [148,150–152] or noticed that women had specific roles to fulfil (or to abstain from) [53,153,154]. Steering away from gender issues, *CP* studies include further out of the box enquiries, such as examining the willingness to pay in return for reduced mortality and monitoring the lived experience of urban dwellers throughout daily routines, reflecting impacts on their health and wellbeing [77,78,155].

3.3 Urban habitat cluster

This thematic unit contains the proxies of *UD*, *CP*, *GS*, *WM* and *UV*. *UD* is the largest topic of the cluster and an overall highly ranked topic, although its strength is significantly lower than *ASP*, *HE* and *MOD*. It is linked to all other topics and is the only proxy aside from *ASP* to contain a contribution solely focusing on the subject matter [156]. The high number of links and low proxy strength indicates that *UD* includes a wide range of sub-thematics, each of which is lightly investigated, often in conjunction with *WE*.

Indicative studies illustrating some of the diversity in this cluster examine displacement of populations and the role of collective memory in *UD* [150], the function of *TE* in building interventions such as green roofs and envelope modifications [44,157], as well as the resiliency of the built environment in the face of *NH* such as earthquakes, flooding and desertification [158–161]. Moreover, numerous studies focus on aspects of the two-way relationship between *GS* and public engagement, for instance, the impact of public spaces on human health, wellbeing and environmental consciousness, and the influence of the public's perceptions on the design of urban spaces [149,162–166]. The issue of urban mobility is not defined as a single proxy but is found in studies investigating the shaping of sustainable urban environments through mobility [57,129,154,167], but also in studies of exposure to pollutants owed to various transport modes [78,88].

In addition, geographic distinctions are once again apparent since, in the European part of the EMME region (Greece and Cyprus), a narrow focus is detected, with fewer contributions. In Greece and Cyprus, research mostly associates *UD* with *ASP* [44,55,63,64,67,78,88,91], whereas in the rest of the EMME region, this proxy contains an amalgamation of links with *ASP*, *GS*, *UHIs*, *NH* and *WM*, among others [48,51,173–176,52,129,138,168–172].

3.4 Technoeconomic cluster

The penultimate smallest cluster holds the proxies of *MOD*, *TE* and *CO*. The *MOD* proxy is the strongest one here and the third overall, following *ASP* and *HE*. In fact, these three proxies are highly interlinked with the majority of contributions examining past, present and future trends and sources of pollution, forecasting impacts on public health and assessing the levels of pollution against health standards set by the World Health Organisation or other analogous national authorities [177–182]. In addition to high proxy strength, the *MOD* proxy also shows high link count and strength, indicating a favoured methodological approach in various aspects of urban vulnerability.

Within the technoeconomic cluster, it is interesting to note that while the *TE* and *CO* proxy both show low proxy strengths, the former is connected to all other topics. This too indicates that technologies are another favoured approach in examinations of urban vulnerabilities, whether that concerns mitigating options against urban heat [130,157,183] or implementations of greywater systems, essentially focusing on the resilience of urban environments [184–186].

Relative to urban heat, a number of studies examined different aspects of health and wellbeing through a *MOD* lens. For instance, in the context of *CC*, one study has examined the relationship of mortality and ambient temperature in Beirut, while another offered a wider perspective on outdoor thermal comfort, relating it also to urban development, green spaces and historical reflection, suggesting that local vernacular architecture approaches simulated a higher level of thermal comfort [136,187]. Moreover, the mitigating role of *UV* and the susceptibility of greenery and drinking water systems in urban settings were assessed employing different techniques [173,188–190], as well as vulnerability to *NH* such as flooding, earthquakes and heatwaves [133,191,192].

3.5 Socioeconomic cluster

This is the smallest cluster, however, not the least significant one. It includes the *HI*, *EC* and *EP* proxies. *HI* is the strongest proxy; however, in relation to all the rest, this proxy is intermediate in strength and linkage. Notably, almost all studies invoking historical aspects are dealing with *WE* and *UD* as well [136,149,153,154,159,167], indicating that past experiences are mostly recalled as a remedy for some type of affliction caused by the improper design of the urban environment. Another frequent interaction of history exists with *WM* techniques and *NH*, including past techniques that could be adapted to modern urban environments, the recycling of water resources in arid regions and combatting urban heat against desertification and heatwaves [52,137,141,184,193,194].

In *EP* research, the effects of energy efficiency improvements in households in Greece have been assessed in a recent study [195]. Aside from this contribution, there is considerable overlap between *EP* and *EC*, mostly detected in Greece, where financial hardship of a large portion of the population intensified urban air pollution due to biomass burning for residential heating in two cities, Athens and Thessaloniki [81,82,86,87,90,196]. Findings related to biomass burning and increased pollution were also reported for other EMME regions as well. However, these reports were not explicitly related to *EP* and unrelated to the economic crisis [120–122]. *EC* impacts were investigated mostly in the nexus of *ASP* and *EP*, frequently integrated with *NH*, *HE* and *WE* [82,108,196,197], without a discernible geographical distinction. The investigations of indoor and outdoor atmospheric quality across the EMME region, even if the research is not placed under the *EP* umbrella *per se*, highlight once again the geographical divide, which in this case is noticeable only because of diverging regulating frameworks and not due to a lack of interest.

3.6 Bridging Proxies and Sustainable Development Goals

Urban vulnerability research themes identified in this review are further explored with regards to their association with the United Nation's Sustainable Development Goals (UN SDGs). Each contribution was assessed and assigned to the SDGs most representative of its primary motivation.

The sum of studies falling under each SDG is presented in Figure 4a, indicating that the majority of literature falls under SDGs 3, 11 and 13 titled *Good health and wellbeing*, *Sustainable cities and communities*, and *Climate action*, respectively [198]. In Figure 4b, the overlap between proxies and SDGs can be observed, indicating that one proxy

may correspond to multiple SDGs, depending on the nature of the study. Moreover, the total lack of contributions related to specific SDGs, namely SDGs 2, 4, 14 and 17 (*Zero hunger*, *Quality education*, *Life below water* and *Partnerships for the goals*, respectively), can also be observed. In addition to these, several UN's goals are severely under-represented in the examined literature, including SDGs 5, 8, 10 and 16 (*Gender Equality*, *Decent work and economic growth*, *Reduced inequalities* and *Peace, justice and strong institutions*, respectively). The remaining targets, SDGs 1, 6, 7, 9, 12, 13 and 15 (*No poverty*, *Clean water and sanitation*, *Affordable and clean energy*, *Industry, innovation and infrastructure*, *Responsible consumption and production, Climate action* and *Life on land*, respectively), also have unexplored gaps.

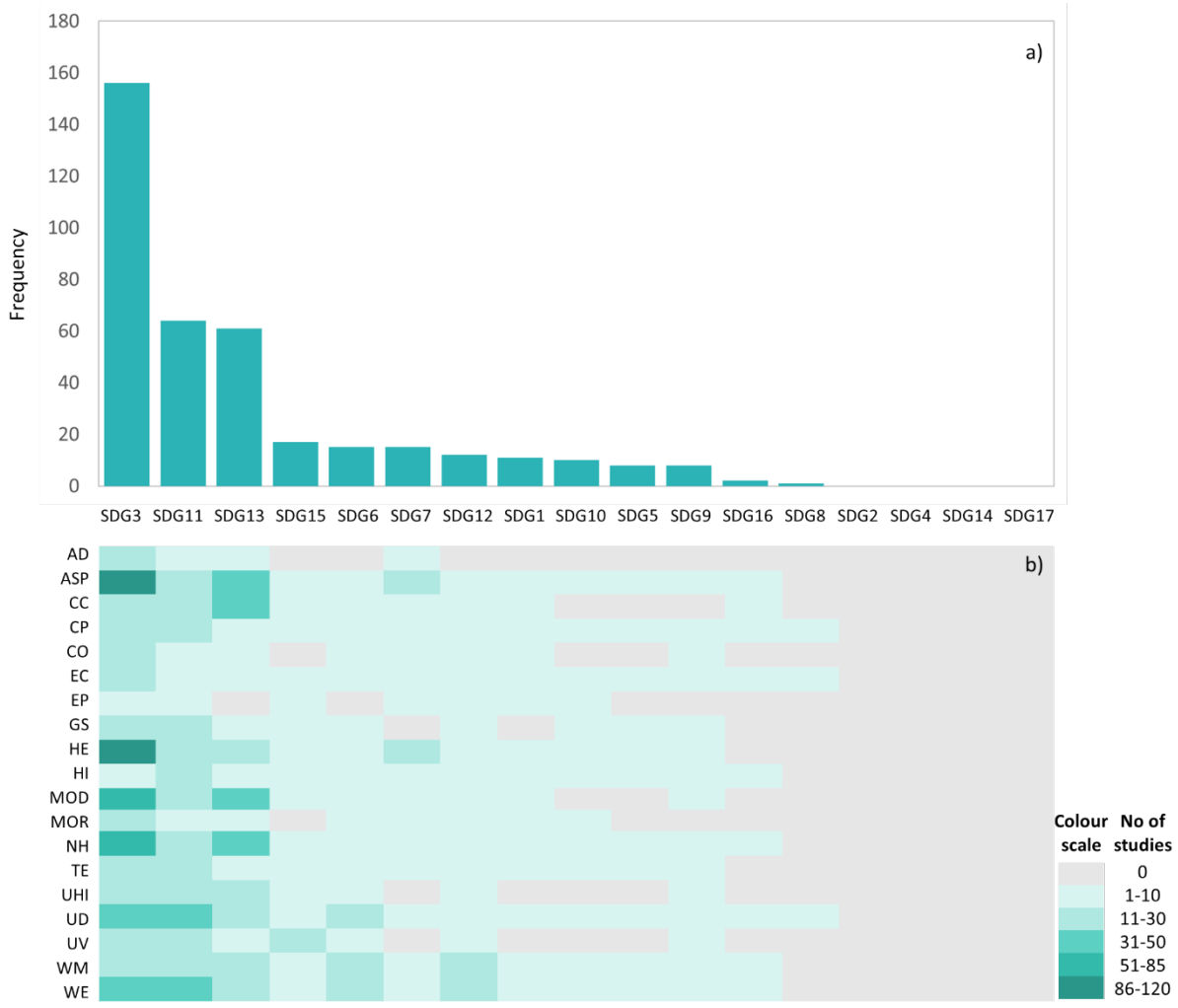

Figure 4. a) Number of studies related to SDGs and b) matrix of individual proxies to SDGs.

For instance, *No poverty* (SDG1) is under-represented here because although numerous low-income countries and studies referring to monetary costs are included in this review, they do not explicitly deal with low-income populations or financial hardships. For instance, potential annual economic benefits of reduced atmospheric

pollution or economic losses due to pollution are estimated without making any connections to monetary poverty [82,115,146].

The full range of unexplored aspects of urban vulnerability research in the EMME region, in regards to SDGs, is presented in Figure 5. This figure does not interpret the depth of research found between certain SDGs and proxies; it merely highlights the existence or lack of associations among proxies and SDGs. For instance, although SDG3 and SDG11 have explored all of the urban vulnerability aspects discussed in this work, this does not mean that research on those topics is ill-advisable. Good health and wellbeing and the development of sustainable cities and communities are topics that always need to stay updated, and the relationship of these SDGs to certain proxies may still be underexplored (e.g. both SDGs to EP are minimally explored). Instead, the diagram illustrates which aspects of urban vulnerability remain significantly unexamined under each of the UN's sustainability targets for 2030.

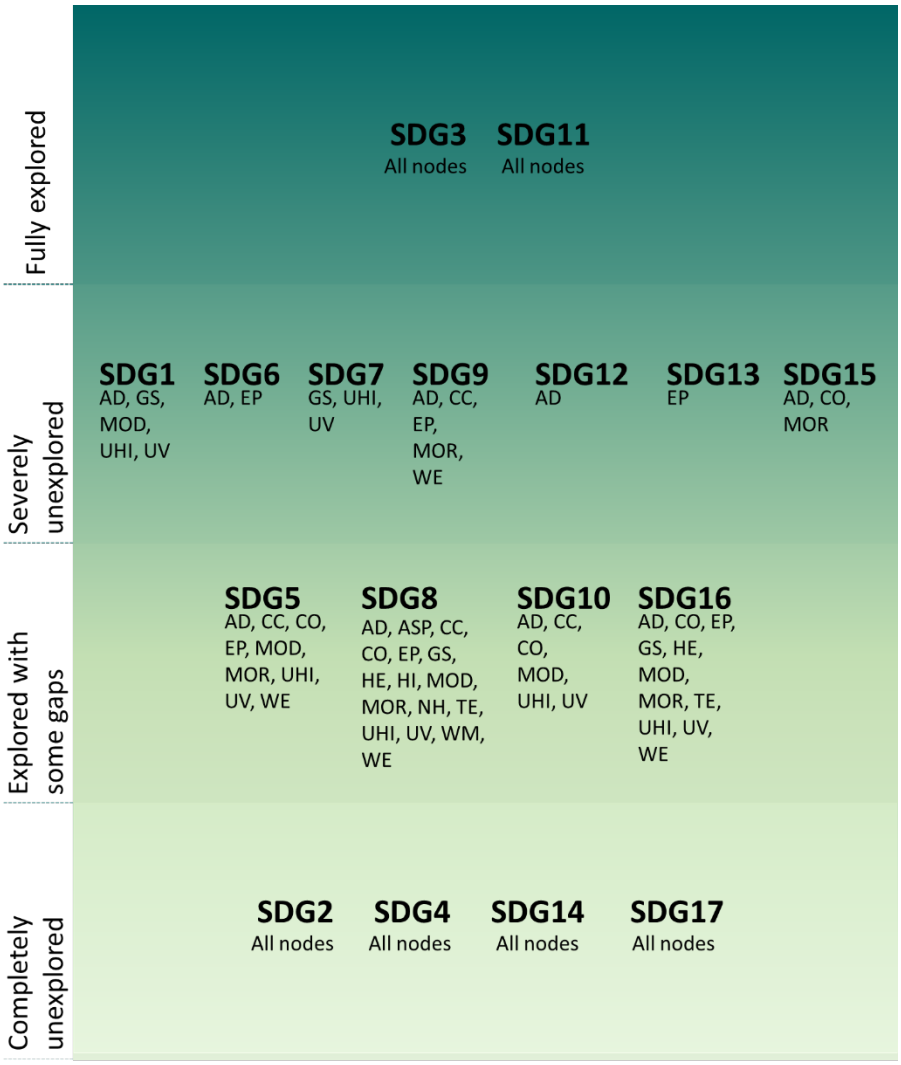

Figure 5. Identified gaps in urban vulnerability research in the EMME region, aggregated by mildly-completely unexplored SDGs.

Priority should be given to goals completely missing from the literature on this topic, as well as those which encompass essential aspects of urban vulnerability in the EMME region. For instance, the goal on *Life below water* (SDG14) may at first glance seem unrelated to urban vulnerability, but considering the locale discussed here, the narrative changes. The Mediterranean Sea is a life source for the EMME region, regulating services relevant to freshwater and food resources, climatic conditions, nutrient and carbon cycles and even the oxygen we breathe. Its protection should therefore be a priority not only for coastal cities but all urban centres of the area and can be investigated to a number of the proxies presented in this work. Similarly, *Partnerships for the Goals* (SDG17) is an interdisciplinary target with huge potential since region cooperation can enhance security, improve the economy and have real impacts on the lives of urban dwellers of the entire EMME region and beyond. This target too can be related to a number of urban vulnerabilities, for instance, a unified response to climate change or early warning systems against natural hazards common to the area (e.g., dust storms, extreme temperatures, flooding), ensuring that citizens of neighbouring countries are equally and sufficiently protected. In this context, current efforts are undergoing in the Cyprus Government Initiative for Coordinating Climate Change Actions in the Eastern Mediterranean & Middle East region [199], an action with research groups comprised of expertise from many EMME countries. Due to its recent nature, no publications have been produced yet, but the various reports expected from this work will be an important step towards implementation of SDG17. Moreover, the extensive absence of *Peace, justice and strong institutions* (SDG16) from the pool of collected urban vulnerability studies is another alarming gap, given the history of conflicts and social unrest in the extended EMME region.

Findings of this SDG-proxy crossover analysis suggest that while heavy resources have been poured towards topics that affect public health in real-time and need immediate attention, what is missing is the study of topics that can be instrumental in long-term structural change towards a sustainable transition.

4 Timeline of publications

A temporal perspective is provided in Figure 6, which shows the accumulative publications and accumulative proxy clusters per year; in other words, the topics investigated each year across all publications (studies of 2021 were excluded since the year is ongoing). The latter includes an overlap of publications since a single study is described by multiple proxies. While no time limitations were implemented in the original search query, the bulk of

publications was produced in the last two decades, with the final quartile accounting for the biggest part. Relating to the prominence of clusters, environmental and human aspects seem to be dominating the field and socioeconomic factors receive the least attention. It can be noted that some clusters are stronger at specific points in time. For instance, socioeconomic issues were virtually non-existent until 2014, that is well after the economic crisis and possibly following exhaustive research on other (more prominent) aspects of the crisis.

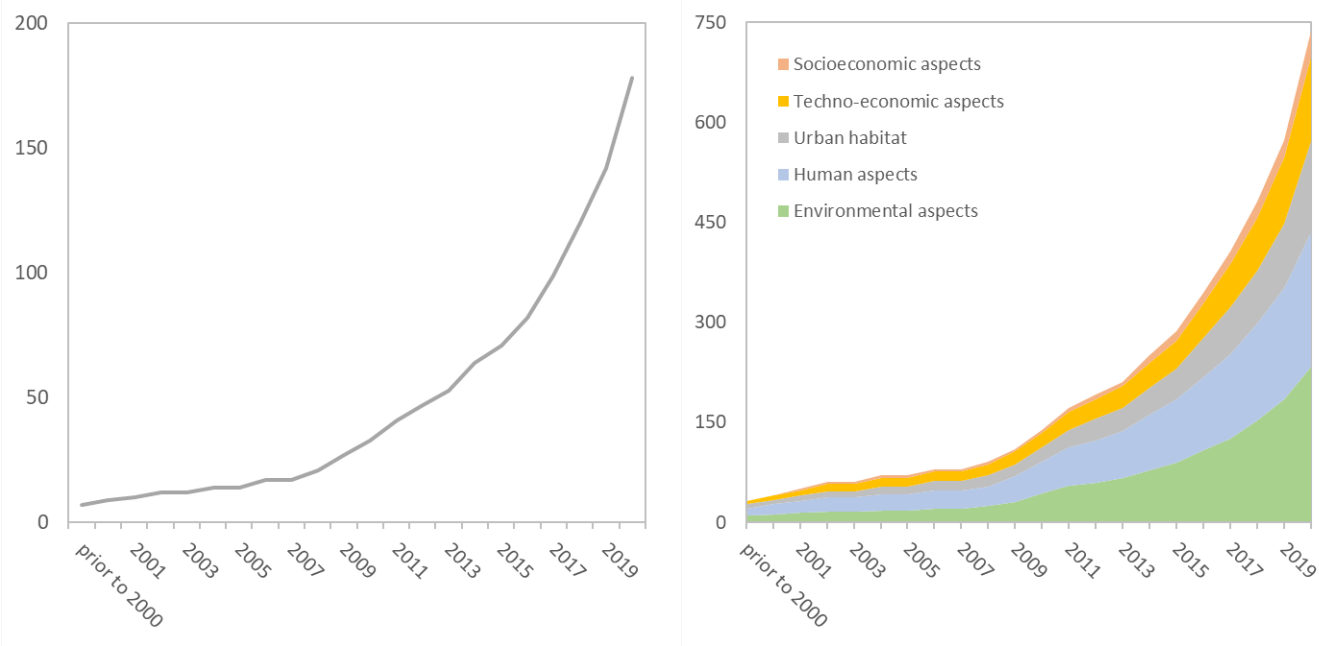

Figure 6. Accumulative publications per year (left) and accumulative proxy clusters within publications per year (right), up to 2020.

This timeline of research reveals that urban vulnerability in the EMME region, in conjunction with climate change and public health impacts, has originated around the start of the millennium but only started to gain momentum a decade later. Some years are characterised by overall low publication numbers. For example, in 2003, 2005 and 2007, there were no publications fulfilling the criteria of this research query. During the past decade, the accumulated number of publications follows an exponential growth, which at times may have been affected by geopolitical and social episodes, such as the Syrian civil war in 2011, marking the start of a prolonged refugee crisis and shifts in global migration patterns [200]. Such socio-political events may, on the one hand, have amplified research into the effects of intense urbanisation, such as urban pollution, and on the other hand enabled content-specific research that was not otherwise present in the literature, such as the effects of population displacement. While momentum was building up from 2008 up to 2011, urban vulnerability research in the EMME region went into hiatus for the following two years, recovering around 2014. Diachronically, socioeconomic topics are not as

well represented as natural sciences. Nevertheless, there is no doubt that research is accumulating, reflecting the growing interest of the research community in detecting and addressing urban vulnerability.

5 A tentative definition for urban vulnerability

While urban vulnerability is a term already used in general communication and scientific writing, its clear and precise description and definition are still evanescent and ambiguous. This study has proposed a framework that uses five dimensions (namely environmental aspects, human aspects, urban habitat, technoeconomic aspects, and socioeconomic aspects) to provide a conceptual foundation to develop a possible definition of this term.

Findings of this study indicate that **urban vulnerability** is the state of any urban system – city, infrastructures, inhabitants, etc. – that expresses its sensitivity to the adverse effects of one or several external agents. It can be assessed by quantifying the degree of exposure and endurance with respect to environmental aspects, human aspects, urban habitat, technoeconomic aspects, and socioeconomic aspects. The lineages of urban vulnerability found in the literature [7,201] can be elaborated upon each of these dimensions, forming an urban vulnerability sphere that can be explored holistically.

6 Gaps and Limitations

Inherently, this study is limited by its systematic approach and may not be described as an objective view of urban vulnerability in the EMME region. That is because the selected query keywords and designated clusters determine the research and its outcome on all levels. When following the selected approach, studies which may be relevant but do not fulfil all of the elements of CIMO, are left out. For instance, while urban slums and informal structures are a major hindrance in EMME cities, this theme did not show up in the literature review and is therefore not included as a main proxy. Nevertheless, this investigation aims to introduce the proxies approach and offer insights into some aspects of urban vulnerability in the EMME region – subject to the authors' selection of themes. Moreover, the proxies approach adopted in this study allows to observe the most prominent research subjects in urban vulnerability, however, being two-dimensional, it is limited. That is because most studies investigated three or more topics simultaneously, something which cannot be observed in this two-dimensional space.

As for gaps, the research question posed here involves a multi-domain approach and a limited set of countries, which may not have been prolific in terms of scientific publications on all of the investigated themes. Integration of all the mentioned domains may have been a challenge; however, it may also be the case that scientific publications are not the typical way to present results across the EMME region or that research in specific areas has focused on topics of particular interest according to national circumstances.

7 Conclusions

In this study, the objective was to investigate the impact of climate change on urban vulnerability and public health in the EMME region by means of a novel approach. The development of a new way to discuss findings through a proxies and links approach and their association with universal indicators, such as the UN's sustainable development goals (UN SDGs), is presented here, illustrating the utility of such approaches in identifying specific gaps in research. The Proxies approach may be similar to bibliometrics, but it allows elaboration on the basis of the content of studies instead of aspects such as authorship. Furthermore, it enables the detection of gaps and specific areas or links with potential for strengthening. An array of specific intersections of urban vulnerability and SDG research have been identified to be missing from the collected literature, most of which are crucial for sustainable development in the particular region in question. Therefore, the outcomes of this study present opportunities to initiate probes in matters not previously discussed, but holding the potential for long-term structural change towards sustainability while strengthening and updating elements with real-time impacts on the public health of EMME cities. After all, considering the beginning of this study with the lived experience of Anna, a woman living in a demanding urban centre in the EMME region, it's clear that individuals have both short- and long-term challenges to face. Research and informed policy making should, therefore, take more holistic, anthropocentric approaches on how to reshape cities and alleviate vulnerabilities within them.

This systematic literature review identified main trends and gaps based on five thematic clusters. The environmental and human clusters are highly related, as the topic of *urban pollution* is often discussed regarding impacts on physical *health*. *Natural hazards*, including dust storms, flooding, extreme heat events and earthquakes, are another significant subject for this region since the EMME is described as a hotspot for climate change and therefore expecting to face such phenomena in higher intensity and frequency. Through *modelling* studies, largely

representing the technoeconomic cluster, early warning systems aiming to reduce negative impacts on public health have been described, whether that relates to air pollution or natural hazards. As for the urban habitat cluster, *urban development* dominates the scene but is highly diversified and includes innovative contributions, highlighting the role of *community contribution* in out of the box investigations. The least investigated thematic is the socioeconomic one, reflecting the increasing interests of a research community coping with intense physical ramifications of *climate change*. These trends are also observed when the pooled literature is examined under the lens of the SDGs since urban vulnerability in the EMME region currently addresses only a handful of targets, namely *Good health and wellbeing*, *Sustainable cities and communities* and *Climate action*. Most SDGs remain in the margins of popular research related to urban vulnerability, whereas some have not been assessed at all.

These findings suggest that urban vulnerability research in the EMME region focuses on the physical impacts and parameters affecting climate change but fail to adequately address the social and financial vulnerabilities of living in urban centres. For instance, while thermal stress is investigated with respect to building technologies, urban design, green spaces, hospitalisations and even hormonal response, there is very little research into the impact of increased cooling or heating energy demand on the socioeconomic conditions of urban populations, such as their diminished incomes. The neglect of socioeconomic vulnerabilities of urban life is evident in the individual proxies of research stipulated here, as well as within the SDGs addressed so far.

Another novel element is the elaboration of tentative definition for urban vulnerability, which is described as the susceptibility to harm most prevalent in urban centres, resulting from amalgamations of different personal circumstances, improper design of urban habitat, environmental, socioeconomic and political factors, all of which impact upon human health and wellbeing.

As for the temporal evolution of research interest in urban vulnerability in the EMME region, it can be deduced that global and regional disturbances (e.g., economic crisis, political conflicts and civil wars) have almost certainly had an impact on predominant and emerging research topics, as well as the amount of research carried out through the end of the publication stage. In essence, the proxies approach is a tool to organise literature review analysis into research themes, identify underlying conditions and explore gaps with potential for future work. In exploring urban vulnerability in the EMME region, it has successfully identified over- and under-represented themes hoping that findings can be exploited to create a more holistic research agenda in nations of the region towards sustainable, resilient and socially responsible urban environments.

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Competing interests

The authors declare no competing interests.