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Review

Circular cities: an evidence map of research between 2010 and 2020

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Received: 19 September 2021 / Accepted: 9 November 2021
Published online: 17 November 2021

Abstract
Worldwide, cities are implementing circular economy (CE) strategies to reduce the resources they consume and their environmental impact. To understand the CE strategies and sectors cities have been focusing on, we have conducted an evidence map describing the literature published in the last ten years. The main outputs are a searchable database comprising 178 publications showing which cities have been discussed, what CE strategy they are focusing on, and the sectors under review. The results show that most research has focused on European countries. Those efforts mainly concentrate on waste and wastewater management, and recycling and recovery strategies are considered the "lower-level" strategies in the CE taxonomy. It highlights the potential for further research in other cities and regions, looking across sectors and analyzing strategies that tackle the "higher-level" CE strategies. Higher-level strategies include reducing, repurposing, remanufacturing and reusing opportunities to achieve the potential attributed to a CE model by governments across the world.

Keywords Circular economy · Cities · Evidence mapping · Urban transitions · 10R principles

1 Introduction

The Circular Economy (CE) is rapidly gaining momentum in political and corporate discourses as a vision and a mechanism to transition towards a more sustainable future. It has been hailed as one of the solutions to help solve the climate crisis and reduce the overall environmental impact of the economic activity [1–4]. With CE envisioned as an alternative model to the unsustainable linear 'take-make-waste economic model [5], cities have been stepping up efforts to accelerate the transition towards a more circular urban model globally [6–8].

The most recent and most cited definitions of CE agree that the CE is an economic system aimed at keeping products in the economic system for as long as possible, thereby reducing the environmental impact of a linear economy in which products are made, used, and subsequently thrown away. The literature has proposed different definitions and outlined multiple CE principles [9–11]. Oftentimes, different stakeholders attribute different principles to it, in line with specific interests and priorities [12–15]. In one of the most comprehensive reviews to date, 114 different CE definitions were extracted from literature, showcasing the heterogeneity of CE definitions [14]. CE has also been divided along three levels: micro-level (product), meso-level (industry park) and macro-level (city or national level) [14]. Often, the CE is linked to "R frameworks", based on principles such as reduce, reuse, and recycle: currently, the list of R's stands at 10 [16], ranging from refusing to reducing, reusing, remanufacturing to recycling and recovery. In [17], a comparison of how the R-frameworks apply to different definitions of CE is given. The highest in the typology ranking R principle (R0 refuse)

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also relates to the concept of sustainable consumption and production, also one of the 17 Sustainable Development Goals (SDGs), aimed at decoupling economic growth from material usage and the environmental consequences that come with it [18]. Aside from SDG12 on Sustainable Consumption and Production, the progress in transitioning to CE has also been directly linked to the progress on other goals, including SDG 6 on Clean Water and Sanitation, SDG 8 on Decent Work and Economic Growth, SDG 11 on Sustainable Cities and Communities, SDG 13 on Climate Change, SDG 14 on Life below Water and Goal 15 on Life on Land [19–21] describes in more detail how the CE and sustainability compare, finding different goals, motivations but most particularly different stakeholders responsible for achieving sustainability or CE, with different levels of agency.

With CE being a contested concept, a single universal definition of the CE is probably impossible, as the concept is also dynamic, constantly evolving [10] and interdisciplinary [22, 23]. In the last decade, the number of articles covering the topic of CE has increased significantly across a diverse suite of subtopics, and over 1600 reviews have now been undertaken to show how CE has been conceptualized,[1] what works and what does not, and what the research gaps are.

Along with scholarly interest, national (see, e.g., [24] for an overview of strategies within the EU at the national level) and supranational governments (see, e.g., [1, 3]), municipal governments have also started incorporating CE strategies, all with the aim that it could reduce negative environmental impacts [25] and save costs, for example, in the management of waste services (see, e.g., [26] and increase revenue, for instance, through the generation of taxes. Reaching the goals of an ambitious CE agenda has been estimated to increase gross domestic product by 2%, increase employment opportunities by 1.6% and reduce carbon dioxide emissions by almost 25% by 2030 [27]. At the EU level, it has been estimated that the CE could generate 700,000 jobs by 2030 [28]. Scholars also examined how cities are approaching the implementation of CE. For instance, [29] reviewed the CE plans of 89 cities and developed a framework with four target urban systems (infrastructure, social consumption, industries and businesses, and urban planning) and 21 types of initiatives. Others reviewed the plans of six cities [7], as did [30, 31].

As the conceptual debate around the circular model itself is unsettled, defining what constitutes a circular city is taxing. Nevertheless, there are a few attempts in the literature to define a circular city to facilitate both academic debate and urban application of circular economy model principles. Several scholars have examined how the principles of the CE model are translated to the city-level and conceptualized the notion of circular cities from several perspectives (e.g., [6, 7, 32–34]). Some scholars attempted to define circular cities by organizing the findings in the literature on circular cities into enablers and challenges, and then, in a workshop, collected opinions around what the definition should entail [6]. They subsequently defined a circular city as being "*based on closing, slowing and narrowing the resource loops as far as possible after the potential for conservation, efficiency improvements, resource sharing, servitization, and virtualization has been exhausted, with remaining needs for fresh material and energy being covered as far as possible based on local production using renewable natural resources*" (p. 6). Others define a circular as a city that "*practices CE principles to close resource loops, in partnership with the city's stakeholders (citizens, community, business and knowledge stakeholders), to realize its vision of a future-proof city*" ([7] p. 176) or a circular city that *aims "to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology. It is also framed as a city that "seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens while aiming to decouple the creation of value from the consumption of finite resources*" [35, 36]. Similarly, [37] approach city-based on a circular model of development as: "a city that in provision of urban service deliberately prioritizes and practices circular economy principles to close resource loops to the highest degree possible, to minimize the need for virgin material and energy resources, to reduce its resource footprint beyond city borders based on the principles of equitable contribution and common welfare in the transition to a circular model". A definition that is proposed by [35]: …"a circular city embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative, accessible and abundant by design. These cities aim to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology…[a] circular city seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens, while aiming to decouple the creation of value from the consumption of finite resources" (p. 7). It includes technical, economic, and social aspects, and emphasizes the role of digitalization.

Yet, despite the growing body of research about CE practices, there remains a gap about the potential of urban circular transitions and various interpretations of the meaning of CE transitions in cities. Understanding how CE works within a city, moving from the potential and challenges that products and sectors could provide, could allow to improve connections in the city, but also allow to uncover gaps in approaches, and assess policy implications of CE viewpoints.

[1] Search of The Lens.org on 08/06/2021 using title/abstract/keyword/field of study terms matching ("circular economy" AND review); https://link.lens.org/a5a7xpYLhlh.

To our knowledge, there is yet no interactive, searchable database of research on CE strategies at a city level, organized according to CE strategy and per sector, that highlights gaps and clusters of evidence on the topic, explaining the focus and methods of the literature at a global scale that is openly available. This paper aims to address this gap and synthesize qualitative evidence of cities' experiences with circular economy and identify central themes around urban circularity. Our analysis is guided by two questions: (1) What is the nature of the evidence base related to CE in cities? and (2) What has been the focus of the evidence in terms of sectors of implementation and application and in terms of developing urban circular strategies? To provide insights into the body of evidence around circular economy model uptake in cities, we apply an evidence mapping methodology informed by systematic mapping guidance produced by the Collaboration for Environmental Evidence [38, 39].

As a result, this review provides an overview of urban circular economy transitions' spatial and sectorial distribution, by searching the academic literature for case studies on the application of CE within cities, with some additions from grey literature. The results may contribute to a better understanding of the potential and the abilities to adapt CE practices and principles in the urban environment based on the existing experience.

This paper is organized as follows: in the Sect. 2, we describe our research design, search process, and coding process. In the Sect. 3, we report on our review findings, starting with a general overview of the corpus, followed by an overview of knowledge clusters and gaps. In our discussion and conclusion, we place the research on CE at the city level in the broader conceptualization of the CE and discuss what further research is needed to support CE transitions at the city level.

2 Materials and methods

2.1 Choice of evidence synthesis method

Evidence mapping facilitates understanding of the landscape of research literature in a specific field for a given period [39, 40] and is a valuable methodology for describing and organizing existing knowledge on the broad research focus and identifying research gaps. A systematic literature review approach aims to optimize the transparency, repeatability, procedural objectivity, and comprehensiveness of searching for, screening and data extraction, and coding relevant research [41]. Evidence mapping differs from a systematic review. It aims not to synthesize study findings but rather describe the nature of an evidence base: highlighting gaps that warrant further primary research and clusters that are amenable to complete synthesis, for example, in a meta-analysis or thematic synthesis [39]. Evidence is used is its broadest sense, to mean empirical literature. Table 3 in Sect. 2.2 provides further detail on the type of evidence we incorporated in this study.

Our evidence mapping exercise is guided by systematic mapping methodology [39] but aimed for a more resource-efficient process that omits some recommended stages of systematic mapping. Our review conforms to the ROSES standards for reporting systematic evidence syntheses [42]. More specifically, the research process consisted of six steps: (1) defining the search strategy and eligibility criteria; (2) carrying out the search; (3) checking the corpus for comprehensiveness; (4) preparation of the final corpus; (5) screening of articles; and (6) data extraction. In the section below, we describe the six steps in detail.

2.2 Defining the search strategy and eligibility criteria

In a first step, we defined our search strategy, including our search engines, search string, period, language, and eligibility criteria. Following an initial assessment of the materials and methods of other reviews (Table 1), we decided on the following:

- Databases: Web of Science Core Collection (WoS), Google Scholar (GS), followed by manual additions (see Sect. 2.3). The WoS collection consists of the following databases: Science Citation Index Expanded (1945-), Social Sciences Citation Index (1956-), Arts & Humanities Citation Index 1975-), Conference Proceedings Citation Index- Science (1990-), Conference Proceedings Citation Index- Social Science & Humanities (1990-), Emerging Sources Citation Index (2015-). We searched Google Scholar as a valuable tool for finding academic and grey literature [43].
- Language: English.
- Period: 2010–2020.
- Search string: we defined two strings (Table 2).

Table 1 Search string and databases from other reviews

Review	Search string	Database used
[21]	"Circular economy", sustainability and "circular economy" AND sustainability	Web of Science
[44]	"PSS" OR "servitization" OR "industrial product service system" OR "industrial product service systems" OR "product service systems" OR "product Service system" OR "integrated service product" OR "industrial product service system" OR "product-service systems" OR "product-service system" OR "ISP" OR "IPS2" AND "circular economy"	Scopus
[45]	Circular economy query: "Reduc*" AND "Reus*" and "Recycl*" AND ("sustainability" OR "sustainable") OR ("circular economy")	Scopus and Web of Science
[9]	"Circular economy"	ISI Web of Knowledge, Web of Science Core Collection and Scopus
[46]	"Circular economy" and "environment"	Web of Science
[47]	"Circular economy" AND "performance assessment" AND "methodology"; "circular economy assessment"; "circular economy performance"; "end of life" AND "performance assessment" AND "methodology"; "end of life assessment"; "end of life performance"	Science direct and Scopus
[48]	"circular economy"	Web of Science, Google Scholar and Scopus
[49]	"Circular economy", "cities" and/or "circular cities"	Dimensions

Note: Truncation symbols, such as *, allows different variations of words to be picked up in the search. For example, recycl* could be recycle, recyling, recycled

Table 2 Search string and databases for our evidence map

Engine	Search string
WoS	ALL FIELDS: (Circular*) AND ALL FIELDS: [(Cit* OR urban OR municipal*)]
GS	All in the title: circular economy municipal OR urban OR cit*

Table 3 Inclusion criteria

Criteria	Description
Relevant literature	Any published, or unpublished, traditional academic or grey literature
Relevant population	Any city or cities globally. Here, we define cities as urban areas, with the OECD classifying them with at least 50,000 inhabitants [54]. In our review, we did not exclude cities with less than 50,000 inhabitants but relied on the classification of the original authors
	Relevant interventions: any study of CE, applying at least one of the 10Rs as put forward in the definition of [16]. Articles that did not focus on the CE (e.g., articles on sustainable cities, smart cities, green cities) were excluded
Relevant study design	Any case study, impact evaluation, observational study, or experimental or quasi-experimental design
Relevant study type	Any qualitative, quantitative, and mixed methods studies

2.3 Carrying out the search

We conducted our search in February 2021, firstly in WoS and then in GS. Additionally, we added publications from organizations that we knew work with municipal governments to develop CE plans by looking through their websites and adding their publications manually. The organizations that have publications on CE in cities are the OECD (see, e.g., [50]), Circle Economy (see, e.g., [51]), and Metabolic (see, e.g., [52]).

2.4 Checking corpus for comprehensiveness

To ensure that our search was comprehensive, we cross-checked the corpus against a list of articles that we knew were relevant to the topic of circular cities. A list of these 13 articles is available in the research data for this article at (https://doi.org/10.5281/zenodo.5207331). All articles were found.

2.5 Preparation of final corpus

Following our comprehensiveness check, we assembled a library of records for screening in the web-based review management software EPPI Reviewer [53]. Records were deduplicated to remove multiple copies of the same article using the built-in deduplication algorithm in EPPI Reviewer.

2.6 Screening records for relevance

The remaining records were then screened for relevance against a predefined set of inclusion criteria (Table 3). Articles that were excluded did not focus on circular economy per se (e.g., covered low carbon pathways, migration) or covered CE at product, national or supranational level. Records were screened in full at two levels: title and abstract level and full-text level. Articles where relevance was not entirely clear at title and abstract level were retained to the full-text screening stage to be conservative. After the screening was completed, we re-screened 3444 of the 9840 excluded articles (35%) for quality assurance. We found no discrepancies in the consistency of the application of the inclusion and exclusion criteria.

Table 4 Codebook for our data extraction

Category	Code
City	Label the city
Country	Add the country label
I (intervention/indicator)	The R—the strategy—as per [16]
	1. Refuse
	2. Rethink
	3. Reduce
	4. Reuse
	5. Repair
	6. Refurbish
	7. Remanufacture
	8. Repurpose
	9. Recycle
	10. Recover
Sector	Building on [55]:
	1.Extractive industries: agriculture, forestry and fishing (A); mining and quarrying (B)
	2. Manufacturing (C)
	3. Energy: electricity, gas, steam and air conditioning supply (D)
	4. Water and sanitation: water supply; sewerage, waste management and remediation activities (E)
	5. Construction (F)
	6. Transport and storage (H)
	7. Public administration and defence; compulsory social security (O)
	8. Social: education (P); human health and social work activities (Q); arts, entertainment and recreation (R); other service activities (S)
	9. Other: wholesale and retail trade; repair of motor vehicles and motorcycles (G); Accommodation and food service activities (I); information and communication (J); financial and insurance activities (K); real estate activities (L); professional, Scientific and technical activities (M); administrative and support service activities (N); activities of households as employers; undifferentiated goods and services; producing activities of households for own use (T); activities of extraterritorial organisations and bodies (U)

2.7 Data extraction and coding

We used a predefined codebook (including meta-data extraction) to describe the final set of included studies. The variables chosen to be extracted and levels of coding in the codebook were developed based on the assessment of a small number of studies assessed during initial scoping.

Our codebook (Table 4) consisted broadly of the following information: (1) a description of the setting—the names of the cities and countries discussed in the article, along with latitude and longitude coordinates for plotting; (2) the CE strategy investigated—coded against the 10Rs (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) following [16]; (3) the outcome context—a description of the sectors addressed in the article, with the categorizations based on the Nomenclature of Economic Activities (NACE) codes [55]. NACE codes are the EU's industry-standard classification system for production and economic activities. There are 21 main categories (e.g., construction) broken down into sub-categories and economic activities (e.g., demolition). As all outlined conceptualizations above included in their approach, focus and limitations the R-principles of the CE economy, therefore, following the suggestions from the literature, we employed the R-principles to guide our analysis.

Where no cities and countries were referenced in the article, we left this information blank. Still, we reported their latitude and longitude as the central Atlantic Ocean for transparency. Included articles were not critically appraised, in line with guidance in systematic mapping [39]. We acknowledge limitations in our evidence base and with our selected methodology. First, in terms of limitations in the evidence base, we focused only on publications available in English. However, we know of other cities developing CE plans, e.g., cities in Belgium, France, and Spain. Yet, we

did not actively search for websites of different cities to collate that data, nor did we contact municipal governments associations in different countries to add to the evidence map. Also, studies done by less-known organizations or smaller consultancies might not have been picked up in our search. In the included studies, we noted, at times, a lack of detail on the cities, countries, sectors, and applied R-strategy, which could have led to an under-representation of results. In addition, our evidence map pointed to a lack of consideration for the higher-level R-frameworks, especially the R0 refuse strategy. However, this strategy might not have been not labelled as CE, but instead, as sustainable consumption and production, or instead of focusing on cities, cover household level initiatives. In addition, the potential of certain R's (repair, remanufacture, repurpose) could have been considered at product or sectoral level instead of at city level. For example, [56, 57] were excluded as they did not focus on city level, but the impacts of more CE in businesses will have an effect on the CE level of the city.

As for the limitations of our chosen methodology, we employed an evidence mapping process informed by systematic mapping guidance produced by the Collaboration for Environmental Evidence [38, 39]. We have modified our methods due to resource constraints since more accurate systematic maps have been shown to require substantial resources to conduct well [58]. As a result, there is a risk that our final set of included studies may not be as comprehensive as could have been obtained through complete systematic mapping. However, our deviations from standard best practices in systematic mapping are minor. In particular, we did not publish an a priori protocol and searched a limited number of academic and grey literature resources. We believe our results are likely to be highly relevant and representative of the true evidence base, directly resulting from the many methodological steps that we have taken directly from standard systematic mapping and systematic review best practice. In particular, we have transparently outlined our methods in full and following best practices from ROSES (Reporting Standards in Systematic Evidence Syntheses, [42]). Our database contains a substantially larger dataset than other reviews [59–61].

3 Results

3.1 The included evidence

Our searches resulted in a total of 44,870 hits across all resources and 10,021 unique records. These were screened at the title and abstract level and then at full-text level, resulting in a final set of 178 articles that were included in the evidence map. Figure 1 shows the results of the synthesis process, and the list of the 178 included articles can be found at (https://doi.org/10.5281/zenodo.5207331).

Our final map database was converted into an interactive evidence atlas (a geographical information system for visualization of studies across geographical space) using the Open-Source tool EviAtlas [62]. The project website (https://www.sei.org/projects-and-tools/projects/urban-circularity-assessment-framework/) hosts the evidence atlas. Figure 2 presents a snapshot of the evidence atlas.

3.2 Number of articles and study setting

The evidence shows a steadily increasing trend in publications over the decade (Fig. 3), perhaps indicative of something approaching the start of exponential growth. In addition, looking at country focus, we see that the number of articles focusing on the EU has increased substantially since 2015. This could be since the European Commission then put the CE forward as one of its political priorities [1].

A total of 45 countries and 103 cities (mentioned by name) are represented in the map (Fig. 4a and b, respectively). The most frequently studied country was China (n = 26 of 178), followed by the Netherlands (n = 20 of 178). A relatively small number of studies did not report the study country in any way (n = 15 or 8% of 178). The most frequently studied cities were European, followed by Asia and South America. Amsterdam (n = 16 of 178) and Beijing (n = 9 of 178) were the most frequently reported cities. In the evidence atlas, 15 articles did not report a city, one article covers 40 cities in the People's Republic of China [63], one paper assesses employment opportunities for 43 cities in the EU [64], and one article details CE in 89 cities across the world [29]. The median and the mean number of cities covered in an article are 1 and 2.87, respectively.

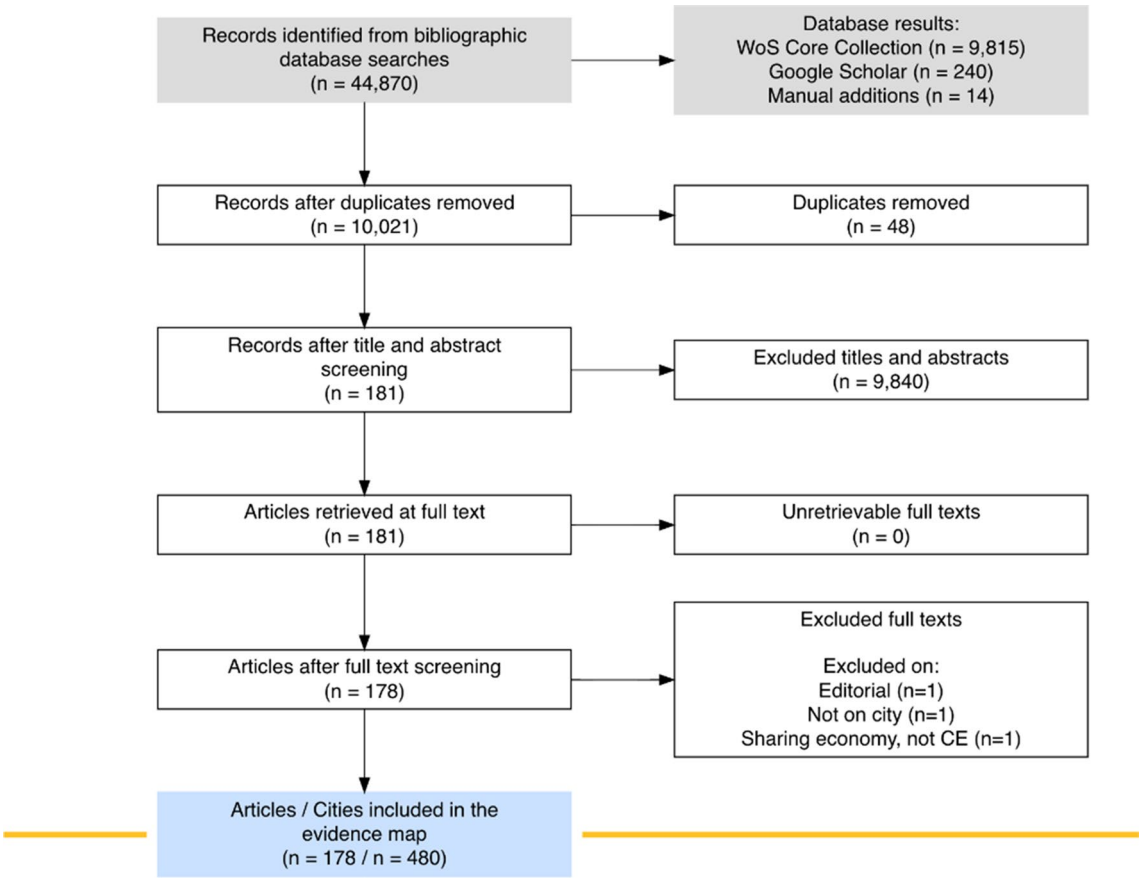


Fig. 1 PRISMA flow diagram illustrating the search results and the articles excluded or included at each stage of the review process

3.3 The study sector and R-frameworks

The waste and wastewater industry was the most studied sector (n = 96 of 178), followed by construction (n = 42 of 178) (Fig. 5).

The most-reported 'R' was 'recycle' (n = 102 of 178), followed by 'recover' (n = 60 of 178), with very few articles focusing on 'rethink' (n = 2 of 178) or refuse (n = 1 of 178) (Fig. 6a). Figure 6b shows the number of articles reporting multiple 'R's in the same manuscript. Some 54 articles did not report an 'R', while 45 and 49 articles reported one or two 'R's, respectively. Few articles reported more than 2 'R's together (n = 30 articles of 178). The most commonly co-reported 'R's were 'recover' and 'recycle' (n = 39 of 178), with far fewer combinations for other combinations (Fig. 6c).

3.4 Heat maps

Figure 7 shows the spread of evidence in the final included studies across two dimensions: country and sector (Fig. 7a), sector and 'R' (Fig. 7b), and country and 'R' (Fig. 7c). These figures demonstrate where knowledge clusters (dark regions with higher numbers of studies) and knowledge gaps (lighter or empty regions with lower numbers of studies) exist. These clusters and gaps may represent subtopics where further research, including primary research and meta-analyses, is warranted in the form of systematic reviews.

Figure 7a indicates that the evidence from China is focused on the waste and wastewater industry, while other countries have a more even distribution across sectors (e.g., the UK). There is also an indication of a slightly more significant number of studies in Asia focusing on construction than other regions. Figure 7b demonstrates a strong focus on recycling and recovery in the waste and wastewater sector, while 'R's are more evenly distributed for other

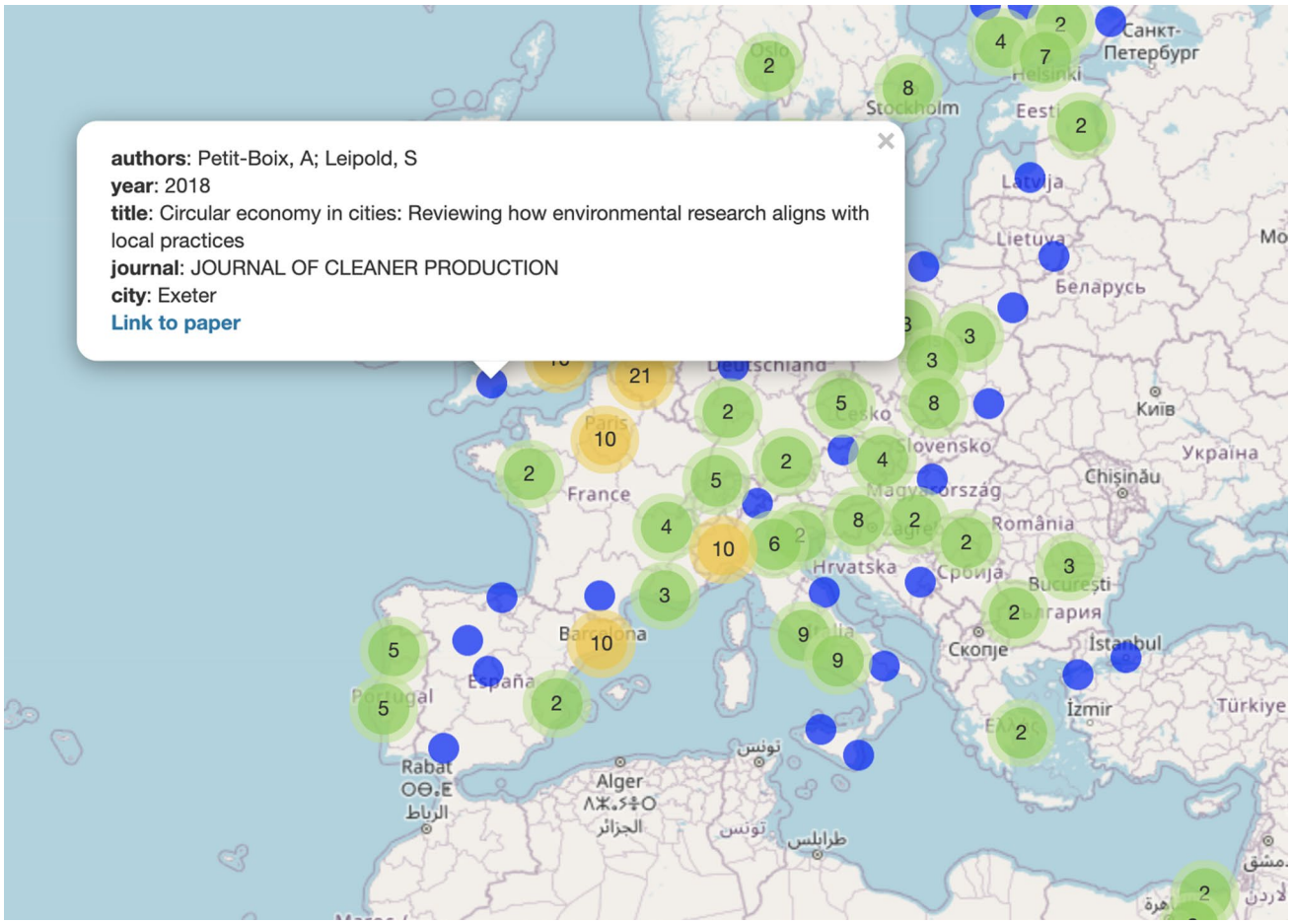


Fig. 2 Snapshot of the interactive evidence atlas available at (own website—to be added)

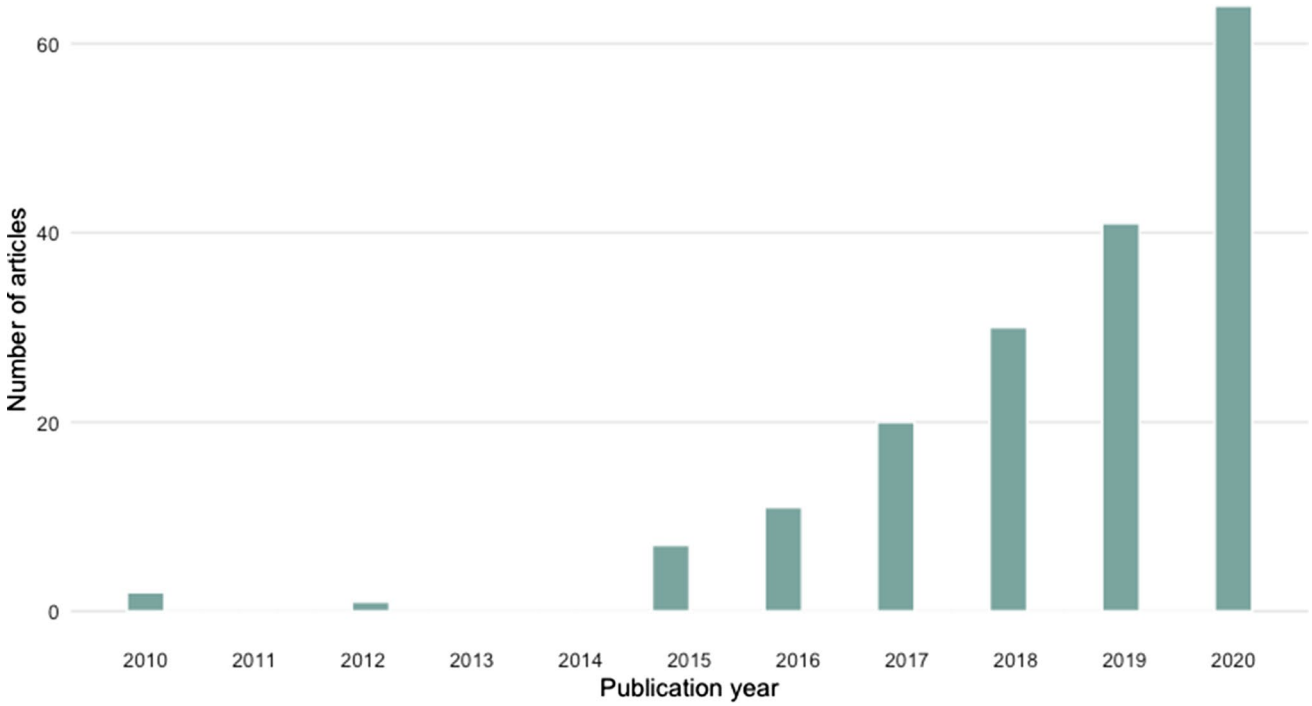
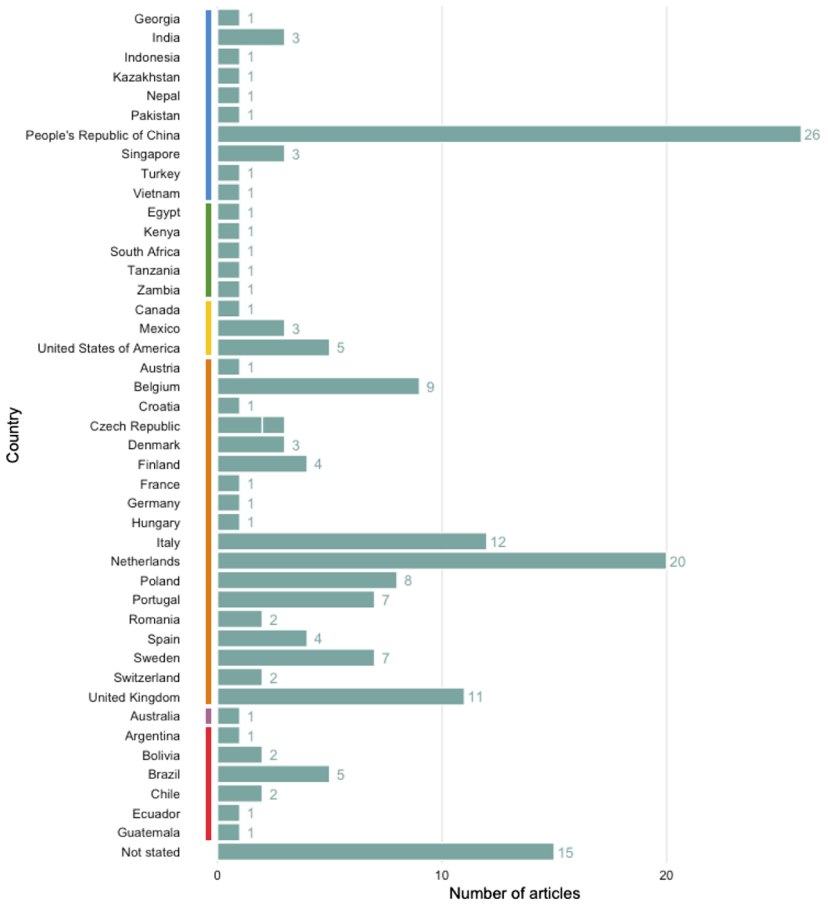
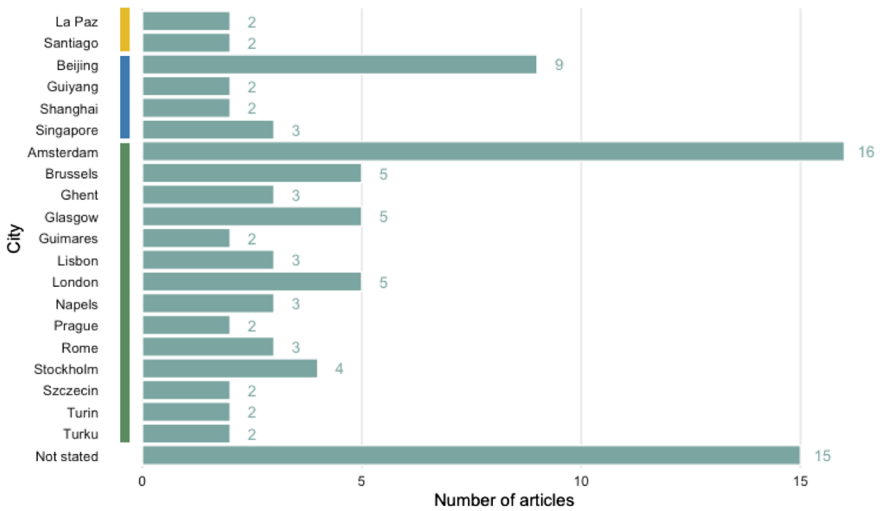


Fig. 3 The number of articles included in the evidence map by publication year



(a) Countries studied across the included articles. Colour indicates continent: blue is Asia, green is Africa, yellow is North America, orange is Europe, purple is Australasia, and red is South America.



(b) The cities described across the 178 included articles; yellow is South America, blue is Asia, green is Europe. Cities shown are those reported in more than one article. Cities reported in only one article are: 20 municipalities in Calatonia, 41 Romanian counties, Almaty, Basel, Bern, Bilbao, Birmingham, Bo'ai, Boulder, Central Bohemia, Chaco, Charlotte, Chicago, Chongqing, Copenhagen, Cuenca, Curitiba, Dalian, Espirito Santo, eThekwini, Florianopolis, Gothenburg, Groningen,

Fig. 4 **a** Countries studied across the included articles. Colour indicates continent: blue is Asia, green is Africa, yellow is North America, orange is Europe, purple is Australasia, and red is South America. **b** The cities described across the 178 included articles; yellow is South America, blue is Asia, green is Europe. Cities shown are those reported in more than one article. Cities reported in only one article are: 20 municipalities in Calatonia, 41 Romanian counties, Almaty, Basel, Bern, Bilbao, Birmingham, Bo'ai, Boulder, Central Bohemia, Chaco, Charlotte, Chicago, Chongqing, Copenhagen, Cuenca, Curitiba, Dalian, Espirito Santo, eThekwini, Florianopolis, Gothenburg, Groningen, Guadalajara, Guangzhou, Guatemala City, Gujranwala, Hamburg, Helsinki, Hezuo, Hjärring, Ho Chi Minh City, Istanbul, Jastrebarsko, Kathmandu, Krakow, Leiria, Leuven, Liuzhou, Lodz, Londrina, Lusaka, Malmö, Marklowice, Marneuli, Matera, Melbourne, Metro City, Mwanza, Nagpur, Naivasha, Nanterre, Nashik, New York City, Nijmegen, Odense, Pecz, Pori, Porto, Port Said, Pune, Rio de Janeiro, Rotterdam, San Cristobal de las Casas, Seville, Staten Island, Suzhou, Syracuse, Tangshan, The Hague, Tianjin, Tijuana, Timisoara, Trento, Umeå, Urumqi, Valladolid, Vancouver, Venice, Vienna, Wafangdian, Wielun, Yichun, Zagreb and Zengcheng

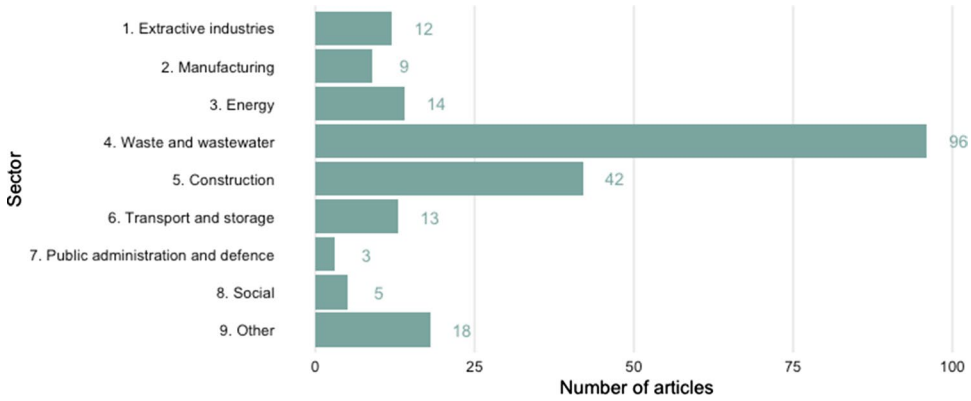


Fig. 5 Sectors examined across the included articles

sectors. Figure 7c suggests a strong focus on recycling and recovery in China, while much of Europe has a more even spread across 'R's, except for Italy, which also focuses on recovery, recycling, and refurbishing.

Overall, the evidence points to knowledge clusters in the following industries and countries: waste and wastewater in PR China and the Netherlands; and the construction industry in the Netherlands. Associated with the waste and wastewater industry are the R-frameworks of recycling and recovery and the recycling n construction and demolition industry. There is also a knowledge cluster on recycling and recovery of resources in China and Italy.

4 Discussion

Applying systematic evidence mapping to the aspects of CE in cities has enabled us to find more cities and countries than previously discussed in the literature. The most extensive study to date is the one of [29] that covers 89 cities, while our analysis has expanded that range to 103 cities in 45 countries worldwide. Some of our findings align with what other researchers have pointed out: a prevalence of the narrow focus on recycling and waste management practices leads to knowledge concentrations in specific sectors, certain lower-level R-frameworks, and certain sectors countries and cities.

Overall, our analysis shows that there is still quite a narrow focus on recycling and waste and energy recovery, which confirms the conclusions by [14, 65]. As reported in other studies, the literature on CE focused on PR China initially and has seen a shift to Europe, and to a lesser extent, to the US in more recent years [9, 59]. This distribution can be explained partly by PR China formally accepting a national CE strategy already in 2002 [66], and the European Union only did so from 2015 [1]. Similarly to [67], we confirm that a narrow focus on the waste sector still prevails. Not surprisingly, these tendencies are established predominately in countries with high material and energy demand and consumption, where resources are continually wasted [68]. As developing nations grow economically, it will be essential to decouple economic prosperity from material and energy consumption, which has not been proven by the CE [69–71]. In terms of city focus, we would also encourage more spatially diverse research to include cities other than extensively studied Beijing and Amsterdam, providing essential insights into different contexts and different underlying enabling or disabling conditions within the cities.

In addition, the lack of consideration for higher-level R-strategies, combined with a narrow sectorial focus of the CE uptake in cities, challenges the CE model's potential to contribute to sustainable societies. Without a system perspective and lack of understanding of rebound and spill over effects, together with crosscutting relationships between sectors and actors, the CE in cities could lock in all stakeholders (the public sector, businesses, citizens, civil society, and academia) in pathways that will fail to generate the transformative power of CE. Our analysis demonstrates that instead of focusing only on end-of-life stages (e.g., recycling and energy recovery), cities need to embrace and prioritize closer and more narrow loops (including refusing and rethinking consumption and production), which are yet to be addressed. These higher R's also call for changing consumer behaviour, which presents one of the major challenges for local policymakers to date [72].

5 Conclusions

With circular economy rapidly becoming a political and an industrial priority, more cities are embarking on circular economy model trajectories; our systematic map of the scientific and grey literature shows what research has been undertaken in the past decade on this topic. It allows, among others, policymakers, including municipal governments,

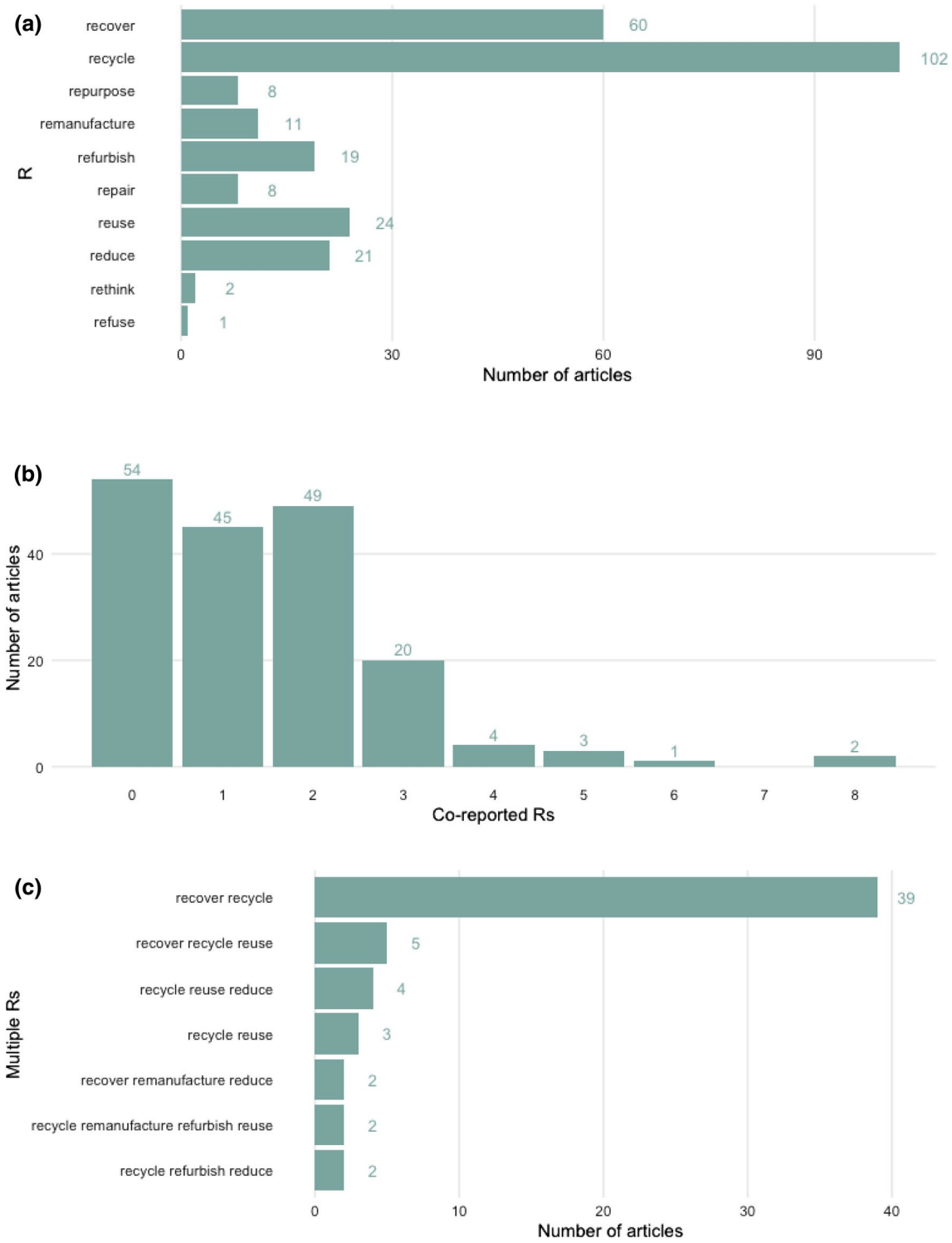


Fig. 6 **a** The 'R' reported across the included articles, **b** the number of articles co-reporting multiple 'R's, and **c** which R's were most commonly co-reported

to find examples of cities in their own country or of cities with similar sizes, similar sectoral approaches, and similar strategies. Overall, our evidence map contains publications covering 44 countries and some 105 cities worldwide, with most publications covering recycling and recovery and the waste and wastewater industry. Such interpretation is quite a narrow interpretation of what the CE could mean at the city level.

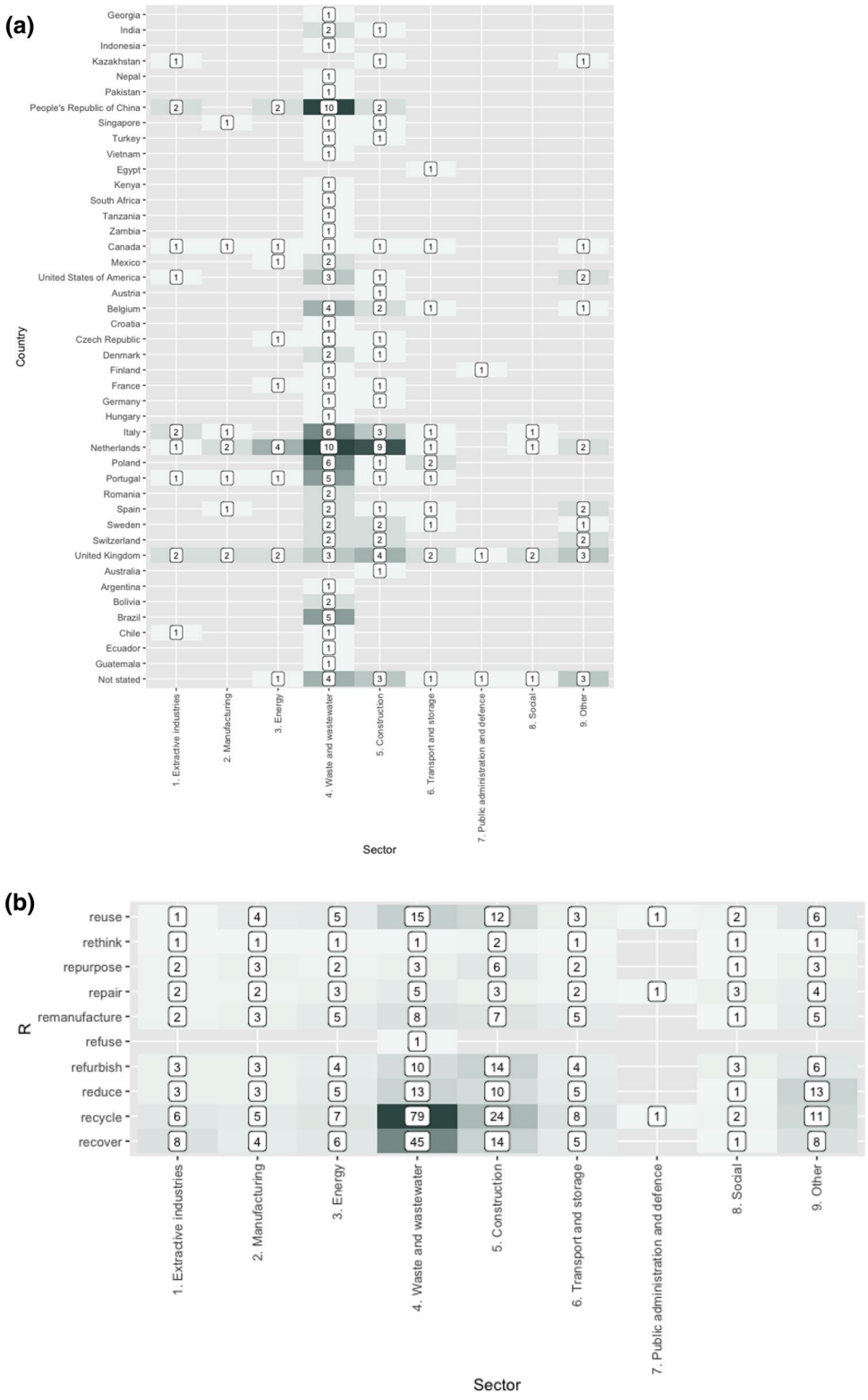
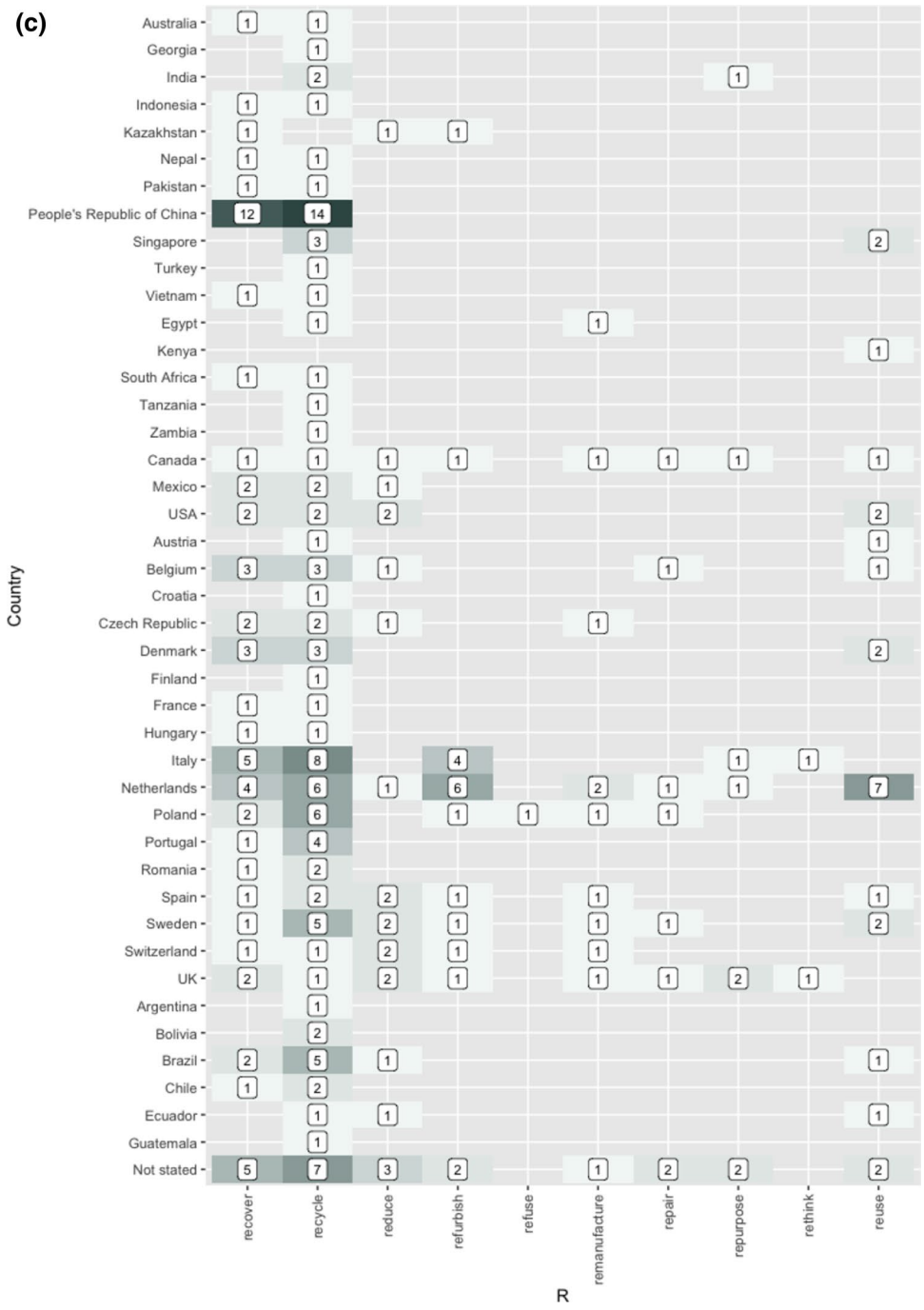


Fig. 7 Heat maps: **a** the number of included articles across countries and sector; **b** the number of included articles across 'R' and sector; **c** the number of included articles across countries and 'R'

Fig. 7 (continued)



Therefore, our evidence map identifies several knowledge gaps and calls to take a broader perspective (multiple sector and R-frameworks) and tackle higher-level R-frameworks in cities. To reduce the material and energy consumption and therefor the environmental impacts of cities, moving towards the reduce, rethink and refuse R's in the R-frameworks, the sharing economy and transition theory could provide additional insight. Only then will the CE live up to its ambitions and its transformative promise.

Authors' contributions FV—conceptualisation; methodology; coding of the dataset; formal analysis; writing original draft and reviewing draft. NH—visualisation; reviewing draft. MH—reviewing draft. All authors read and approved the final manuscript.

Funding This work was supported by Vinnova under Grant (2019-03237).

Data availability The research data for this article is available at: https://doi.org/10.5281/zenodo.5207331.

Code availability The codebook utilised for our dataset is described in Sect. 2.7 and Table 4.

Declarations

Competing interests The authors declare no competing interests.

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