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Past, present, future: engagement with sustainable urban development through 35 city labels in the scientific literature 1990-2019

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Abstract

SDG11 – 'making cities and human settlements inclusive, safe, resilient and sustainable' – draws attention to the criticality of urban governance in the quest for sustainable development. Reflecting this, diverse city labels, such as 'sustainable city' and 'smart city', have been mobilized by urban actors and scholars to consider cities' responses to various challenges of urban transformation. Consequently, this study interrogates: (1) the growing use of city labels in the scientific literature over three decades; (2) the conceptual dimensions of individual city labels and their mutual interdependencies; and (3) likely future trajectories. This is accomplished through a comprehensive bibliometric analysis of 35 city labels: we examine their (co-)occurrences during 1990-2019 based on 11337 articles harvested in Scopus; analyse their conceptual associations drawing on a corpus of 22280 author keywords; and make a future forecast based on logistic growth modelling. The findings significantly take forward recent bibliometric research by demonstrating: the rapid growth in scientific outputs; the diversification of city labels beyond 'smart' and 'sustainable'; and the evolution of an intricate conceptual field made up of different constellations of city labels. Beyond the contribution to scholarly discourse, the findings have implications for urban policy and practice: regarding ongoing concerns about how to achieve synergies, rather than trade-offs, between SDGs, the conceptual field points to possible ways for relating SDG11 to other dimensions of sustainable development. More broadly, the clarification of individual city labels' conceptual underpinnings should help policymakers and practitioners make considered choices when mobilizing city labels in support of urban transformation efforts.

Keywords: *city label; sustainable development; cities; bibliometrics; sustainable city; smart city*

1. Introduction

The Sustainable Development Goal (SDG) 11, alongside the New Urban Agenda, encapsulates not only international recognition of cities' critical contribution towards sustainability, but also the broad approach pursued: 'make cities inclusive, safe, resilient and sustainable' (UN 2016). Mirroring this, the 'sustainable city' has become a popular, overarching term in policy and academic discourse, although not the only one (e.g. de Jong et al. 2015). Particularly, the 'smart city' has surged forward, premised on digital technologies and big data rendering cities more (resource-)efficient (Joss et al. 2019). Numerous other city labels abound, albeit often expressing more specific focus, such as 'low-carbon city' and 'entrepreneurial city'. Indeed, this study identifies 35 city labels (the selection of which is described in section 3) in the scientific literature that variously engage with sustainable urbanism (as such, they also relate to several other SDGs apart from SDG11; see Discussion). This prompts questions about the individual distinctiveness of city labels; their conceptual interrelationships (including overlaps); as well as the implications, for policy and practice, of different terms offering alternative developmental pathways in response to urban challenges. As Zhang et al. (2016) suggested, different city labels should in principle each express particular characteristics as catalysts for urban transformation, so that e.g. 'regenerative city' and 'learning city' signify different choices. Research by de Jong et al. (2015), however, revealed a complex conceptual field, in which several key city categories interrelate while also exhibiting individual distinctiveness.

This study extends recent bibliometrics research into the significance of different city categories in three new directions: first, it takes a comprehensive approach encompassing 35 city labels, allowing for direct comparison and consideration of their singular and joint contributions to conceptualising sustainable urban development. This contrasts with bibliometrics on individual categories, such as 'sustainable city' (Perea-Moreno et al. 2018), 'eco city' (Li et al. 2019; Türkeli et al. 2018), 'creative city' (Rodrigues and Franco, 2019; Lazzaretti et al. 2017) and, reflecting surging interest, especially 'smart city' (Zheng et al. 2020; Guo et al. 2019; Dominguez and Sanguino 2019; Corsini et al. 2019; Mora et al. 2019; Li 2019; Winkowska et al, 2019; Fernandes et al. 2019; Tiwari et al. 2019; Moradi, 2019; Li 2019; Waheed et al. 2018; Muhamedyev et al. 2018; Komninos and Mora 2018; Tomaszesska and Florea 2018; Duran et al. 2018; Alcaide-Munoz et al. 2017; Mora et al. 2017; Zheng et al. 2020). Notably, so far only three studies have followed a comparative perspective, juxtaposing five (Fu and Zhang, 2017), seven (Wang et al. 2019) and twelve (De Jong et al. 2015) categories, respectively. Second, additionally to analysing the status *anno* 2019, the study charts the co-evolution of the 35 city labels across three decades (1990-2019), thereby revealing differing temporal fortunes of city labels in the rapidly expanding scientific literature. Third, applying a logistic growth model, we seek to forecast future trajectories, to gauge which city labels may shape the sustainable urbanism discourse in the coming period.

The next section outlines the significance of city labels in both policy and academic debate and summarises key findings from recent bibliometric studies. The subsequent method section explains the chosen bibliometric approach and procedures for data collection and analysis. The results section comes in four consecutive parts: (a) frequencies of city labels; (b) co-occurrences among city labels; (c) keyword co-occurrences; (d) future forecast. The interpretation of the results and their implication for research and policy follow in the discussion and conclusions sections, respectively.

2. City labels as conceptual categories of sustainable urbanism

The aforementioned bibliometric literature may have varying focus – e.g. on authors/institutions (e.g. Mora et al. 2017); research output distribution across journals/subject areas (e.g. Wang et al. 2019); keyword network analysis (e.g. Min et al. 2019) – but its common denominator is the use of composite search terms: 'smart city', 'liveable city' etc. Methodologically, city labels serve as essential procedural device to systematically harvest and analyse relevant scientific literature. In deploying these search terms, the analyst understands that city labels carry both conceptual significance as scholarly categories, and policy and practice significance in the wider world. Indeed, the goal of bibliometrics is to elaborate what substance attaches to various city labels.

Three examples illustrate the prevalence of city labels as carriers of normative, analytical and programmatic information, and the related cross-fertilisation between academic and policy/practice discourses. The 'resilient city' emerged as a distinctive category in the early 2000s, influenced by broad engagement with the ecological concept of resilience across several academic disciplines (e.g. Leichenko, 2011; Folke et al. 2010; Jabareen, 2013). Its conceptual perspective of systems resilience, and applied focus on shock/disaster management distinguish it from other categories. At policy level, the label was prominently adopted in 2013 by the Rockefeller Foundation through its '100 Resilient Cities' (nd) initiative, which has since engaged 100 cities across six continents. A similar example is India's '100 Smart Cities Mission' (nd), launched in 2015. As part of a five-year plan, approx. US$14bn was to be spent on the major development of 100 Indian cities. While the initiative's approach to 'smart city' is strongly shaped by the particular politics of the Indian government, it concurrently relates to the international smart city literature and its broad engagement with governance, innovation and sustainability (e.g. Datta 2018). On its part, the term 'eco city' can be traced back to the 1970s when it was first elaborated by the urban ecology movement (Register, 1973). It has since enjoyed prominent policy applications, e.g. from the early 2000s in a series of national 'eco city' initiatives in China (e.g. de Jong et.al, 2016; Caprotti 2014; Chang and Shepherd 2013), as well as the French '*ÉcoCité*' and '*ÉcoQuartier*' initiative launched in 2009 (e.g. Joss and Cowley 2017). The latter is noteworthy because it explicitly uses 'label' (*'Le label ÉcoQuartier'*) in its official terminology.

In the world of urban policy and management, thus, city labels have a potentially important role to play as a form of policy discourse and corporate storytelling (Hollands, 2008; Söderström et al. 2014). Of course, city labelling can occasionally be seen to be superficially engaged in language games (Söderström et al. 2014): urban actors may use it for self-promotion with comparatively little impact on actual urban change, or even deploy it as ecological window-dressing to cover up processes of capital accumulation through land development (de Jong, 2019). At the same time, city labels can be seen to exercise a useful performative role in enabling the envisioning of urban futures and, thus, driving policy action. In particular, they may be deployed by cities as part of serious strategic development and branding aimed at urban and industrial transformation (de Jong et al. 2018), or by governments as part of national innovation programmes (Cowley and Joss, 2020). Altogether, the fashionable and often playful use of city labels by various urban actors can make it difficult to pinpoint their underlying meaning as well as the differences that exist between conceptual relatives such as 'smart', 'digital', 'information' and 'innovation' city (Nam and Pardo, 2011). Here, bibliometric studies can provide a powerful means of clarifying conceptual underpinnings, associations and interdependencies.

While other studies refer to 'city category' (e.g. de Jong et al. 2015) and 'city term'/'concept' (e.g. Zhang et al. 2016), this article uses 'city label' to denote various composites signalling cities' targeted engagement with sustainable urban development. It is chosen here because it accentuates the linguistic meaning of a marker attached to an object (the city) and related information given about it. As such, a city label is (def.) *a classifying phrase that succinctly expresses essential features of urban development goals*. This prompts analytical questions e.g. about how concisely and accurately a city label encapsulates what are complex and multifaceted subject matters (e.g. 'knowledge city' referring to knowledge-based economic processes, high value-added production etc.), and what to make of the appearance of multiple, often seemingly overlapping labels (e.g. 'virtual'/digital'/'smart' city). Consequently, the present analysis centres upon three core research questions: (1) *Which city labels designating (aspects of) sustainable urban development have been used in the scientific literature in the period 1990-2019, and how have their respective frequencies changed over time?;* (2) *What are conceptual dimensions (distinctive as well as shared) encapsulated by individual city labels, and what is the conceptual interrelationship among the city labels analysed?*; and (3) *What predictions can be made, based on developments over the last 30 years, about the likely future trajectories of city labels in debates about sustainable urbanism?*

One key finding from earlier bibliometric studies was the significant increase in scientific outputs in recent times: de Jong et al. (2015) calculated an exponential growth for twelve city categories for 1996-2013, with the 'sustainable city' coming top overall and the 'smart city' emerging as frontrunner at the end of that period. Similarly, Wang et al. (2019) demonstrated accelerating exponential growth during 1992-2016 for 'sustainable city' and six sister terms. Mora et al. (2017) showed a rapid increase in 'smart city' literature in the last three years of 1992-2012, a finding echoed by Dias (2018) and Maestre-Gongora and Colmenares-Quintero (2018). The present study takes these findings forward by extending analysis to the most recent period (up to end of 2019), which covers the release of the UN's SDGs and the New Urban Agenda as well as numerous recent smart city initiatives. As such, it provides new insight not least into the apparent contemporary duopoly of 'sustainable city' and 'smart city'.

At the same time, the inclusion of a comprehensive set of 35 city labels allows for closer analysis of multiple interrelationships. Previous studies not only highlighted complex boundary work within single city labels – e.g. Mora et al. (2017), Dias (2018) and Maestre-Gongora and Colmenares-Quintero (2018) discerning a socio-technical bifurcation of 'smart city'; and Wang et al. (2019) discerning six complementary perspectives of 'sustainable city' – but also between city labels. Fu and Zhang (2017), based on a keyword cluster analysis of articles published during 1980-2015, found the 'sustainable city' and 'smart city' quite distinctive with only limited shared perspectives, whereas 'eco city' and 'low-carbon city' constitute hybrids connected to 'sustainable city'. In contrast, according to De Jong et al. (2015)'s conceptual network analysis, 'sustainable city' and 'smart city' form the central axis among twelve labels analysed, with 'eco city' closely interconnecting with both. Wang et al. (2019) subsumed six city labels ('eco', 'ecological', 'low carbon', 'zero carbon', 'resilient', 'sponge') under 'sustainable city', without differentiation. In short, the question of thematic constellations and interconnections among diverse city labels, as part of the scientific (and wider policy and practice) discourse, remains to be fully answered.

3. Materials and methods

This study combined several established bibliometric techniques, to produce an integrated analysis of 35 city labels across present, past and future timespans. Specifically, it mobilised: De Jong et al. (2015)'s and Min et al. (2019)'s network analysis approach for city labels and keywords; Corsini et al. (2019)'s use of sequential time period analysis; and Zeng et al. (2018)'s bibliometric application of a logistic growth model. The methodological approach entailed four main consecutive steps, as illustrated in Fig.1 and elaborated in the following paragraphs. Box 1 provides further technical detail, intended to aid replicability for future research.

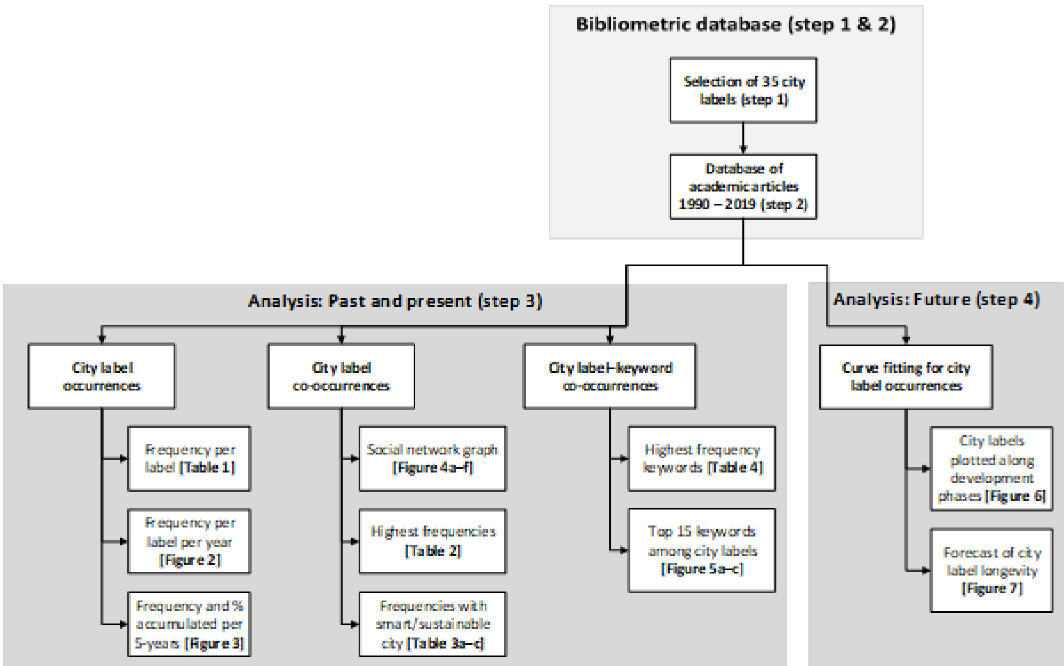

Fig.1. Research design.

Box 1: Methodological Procedures

Step 1: Selection of 35 city labels

- Check existing bibliometric studies on multiple city labels (de Jong et al. 2015; Fu & Zhang 2017; Wang et al. 2019), thereby identifying 12 city labels
- Input the 12 city labels as search query in Scopus to retrieve further city labels from author keywords of retrieved articles, resulting in 148 city labels
- Delete any duplicate city labels; carry out qualitative review (triangulated among researchers) based on three joint criteria (derived from de Jong et al. 2015): only select city labels that: (i) conceptually relate to (aspects of) sustainable urban development; (ii) have an established presence in the academic literature; (iii) have a presence in policy/practice discourse
- Result: list of 35 city labels

Step 2: Compilation of bibliometric database

- Formulate the 35 city labels as search query: see footnote 1
- Enter search query in Scopus, setting 1990-2019, thus retrieving 11,337 articles [executed 06/01/20]
- Collect bibliometric data: (i) title; (ii) abstract; (iii) author keywords
- Result: Database of 11337 articles: titles; abstracts; 22820 keywords

Step 3: Past & present (co-)occurrences: 1990-2019

- Arrange 5-yearly temporal incisions resulting in 6 cumulative periods: 1990-1994; 1990-1999; 1990-2004; 1990-2009; 1990-2014; 1990-2019
- **Occurrence analysis of city labels:** count all articles in database mentioning a given city label at least once (an article is counted only once even if given city label is mentioned twice or more); repeat for each of the 35 city labels
  - Tabulate city labels from highest to lowest counts, across six cumulative time periods
  - Result: Table 1
  - Draw line graph showing yearly counts 1990-2019 for all city labels; apply logarithmic scale for legibility
  - Result: Figure 2
  - Draw scatter plot showing relative positions (cumulative frequencies) and new entry points of 35 city labels across six time periods
  - Result: Figure 3
- **Co-occurrence analysis of city labels:** count all articles mentioning a pair of city labels (e.g. ‘sustainable city’ AND ‘smart city’) at least once; repeat for all unique pairs of city labels; and repeat for each cumulative period
  - Store all counts of unique pairs in 6 matrices (35 x 35 cells) representing the 6 cumulative periods
  - In Pajek software, draw a social network graph using each of the 6 square matrices
  - Result: Figure 4.a-f
  - Use 6th matrix (1990–2019) to list 10 highest co-occurrence frequencies in ranking order
  - Result: Table 2
  - Use 6th matrix (1990–2019) to list city labels co-occurring with ‘sustainable city’, and ‘smart city’, respectively, in order of strength of connection
  - Result: Table 3.a-b
- **Co-occurrence analysis of keywords and city labels:** count all articles mentioning at least one city label and at least one keyword (e.g. ‘sustainable city’ AND ‘planning’); repeat for all unique pairs of city labels and keyworks; store resulting counts in large 35 x 22820 matrix
  - Calculate degree of centrality (co-occurrence with no. of city labels) of all keywords; rank the keywords with 15 highest degrees (cut-off at degree of centrality 10)
  - Result: Table 4
  - Harvest and rank the 15 most frequent keywords for each city label, yielding a total of 149 keywords
  - Filter and store 149 keyword counts in 35 x 149 matrix, and draw social network graph in Pajek
  - Result: Figure 5.a
  - Draw two graphs based on extracted cluster (A) ‘smart’-‘intelligent’-‘digital’-‘ubiquitous’-‘future’-‘creative’-‘connected’ and cluster (B) ‘sustainable’-‘low-carbon’-‘liveable’-‘green’-‘eco’-‘compact’ (informed by Table 3)
  - Result Figure 5.b & 5.c

Step 4: Future forecast of city label occurrences

- Extrapolate future trajectory of city labels from occurrence rates 1990-2019, by applying Logistic Growth Model Curve to city label occurrences as follows:
  - Extract from database city label occurrences per year
  - Following General Limit Theorem, exclude city labels with <30 occurrences, thus withdrawing 10 city labels
  - For each of the 25 retained city labels, create a regression model based on occurrences between cumulative growth of articles (Y) per year (X): y=L/(1+e^(b-kx)) where *L* represents the total estimated capacity of no. of articles that a city label could carry; *b* and *k* represent the slope of the curve which follows a natural logarithm
  - Plot no. of articles over time following general logistic growth pattern in the shape of S-curve
  - Lock the position of each of the city labels on S-curve at final complete publication year: 2019
  - Normalize S-curve to relative growth, where L=100%, then plot all locked-in city labels
  - Draw development stages 'infant', 'growth', 'mature' (Zeng et al. 2019) onto S-curve
  - Result: Figure 6
  - For each of the 25 city labels, use regression model to predict start and finish of three development stages (Zeng et al. 2019), and store predictions in matrix
  - Sort city labels by predicted longevity, from 'open city' (till 2077) to 'ubiquitous city' (till 2024), and draw stacked bar chart of 25 city labels with development stages shown
  - Result: Figure 7

3.1.Selection of 35 city labels denoting sustainable urbanism

Step 1 consisted of assembling a comprehensive list of city labels based on three criteria: (1) the selected labels must conceptually relate to (aspects of) sustainable urban development; (2) they must have an established presence in the academic literature; and (3) they must resonate in policy and practice discourse (as exemplified above). Based on 12 city labels previously identified (de Jong et al. 2015; Fu and Zhang, 2017; Wang et al. 2019), a preliminary harvest of articles was undertaken in Scopus and the associated keywords checked for additional city labels, resulting in 148 labels altogether. Each of these was considered against the above three criteria, producing the 35 city labels listed in Table 1. (The full dataset of 148 city labels, selection results and methodological details – e.g. concerning synonyms 'ecological'/'eco city'; 'liveable'/'livable city' – are available from the lead author's institutional repository: [to follow].)

3.2 Data collection

Step 2 comprised the data harvesting process. Scopus was chosen as authoritative scientific database; it entails complete journal publication records, irrespective of changing ISI status (unlike Web of Science), dating back to 1996. For the earlier period 1990-1995, which covers the foundational UN sustainable development conference ('Earth Summit') in 1992, the Scopus records may be partially incomplete; however, this should have minimal effect on the overall results, as article output (<100) in this period was dwarfed by exponential growth in the subsequent periods. Only journal and review articles were harvested (thus excluding conference proceedings etc.), as they represent the gold standard of peer-reviewed scientific output. For each article, *title*, *abstract*, and *author keywords* were extracted; these encapsulate the essence of scientific findings and are typically used for bibliometric analysis. (Note: as the Scopus keyword operator includes index keywords, its function was altered to author keywords only.)

The search query[1] encapsulating the 35 city labels (singular and plural forms) was executed on 6 January 2020. This generated a total of 11337 articles which were downloaded and cleansed (e.g. removing the erroneous result 'connected. City' due to inter-punctuation).

3.3 Data analysis

Step 3 combined the following complementary data analytics.

3.3.1 Occurrences of city labels

The frequency of a city label refers to the number of articles in which said label occurs at least once in the title, abstract, and author keywords (where an article includes several mentions of the same label, this is counted as one occurrence). For example, a total of 410 articles mentioning 'future city' were identified for the period 1990-2019 (see Table 1). The frequency, then, is a measure of the prevalence and influence of a given city label in the scientific literature. Comparing the occurrences among the 35 city labels, and across time periods, offers

- [1] Search query: (TITLE-ABS ("biophilic city" OR "biophilic cities" OR "circular city" OR "circular cities" OR "compact city" OR "compact cities" OR "competitive city" OR "competitive cities" OR "connected city" OR "connected cities" OR "creative city" OR "creative cities" OR "digital city" OR "digital cities" OR "eco city " OR "eco cities " OR "ecological city" OR "ecological cities" OR "entrepreneurial city" OR "entrepreneurial cities" OR "experimental city" OR "experimental cities" OR "future city" OR "future cities" OR "green city" OR "green cities" OR "inclusive city" OR "inclusive cities" OR "information city" OR "information cities" OR "intelligent city" OR "intelligent cities" OR "knowledge city" OR "knowledge cities" OR "learning city" OR "learning cities" OR "liveable city" OR "liveable cities" OR " livable city" OR "livable cities" OR "low-carbon city" OR "low-carbon cities" OR "open city" OR "open cities" OR "playful city" OR "playful cities" OR "post-carbon city" OR "post-carbon cities" OR "productive city" OR "productive cities" OR "regenerative city" OR "regenerative cities" OR "renewable city" OR "renewable cities" OR "resilient city" OR "resilient cities" OR "safe city" OR "safe cities" OR "sharing city" OR "sharing cities" OR "smart city" OR "smart cities" OR "sponge city" OR "sponge cities" OR "solar city" OR "solar cities" OR "sustainable city" OR "sustainable cities" OR "ubiquitous city" OR "ubiquitous cities" OR "virtual city" OR "virtual cities" OR "zero-carbon city" OR "zero-carbon cities") OR AUTHKEY ("biophilic city" OR "biophilic cities" OR "circular city" OR "circular cities" OR "compact city" OR "compact cities" OR "competitive city" OR "competitive cities" OR "connected city" OR "connected cities" OR "creative city" OR "creative cities" OR "digital city" OR "digital cities" OR "eco city " OR "eco cities " OR "ecological city" OR "ecological cities" OR "entrepreneurial city" OR "entrepreneurial cities" OR "experimental city" OR "experimental cities" OR "future city" OR "future cities" OR "green city" OR "green cities" OR "inclusive city" OR "inclusive cities" OR "information city" OR "information cities" OR "intelligent city" OR "intelligent cities" OR "knowledge city" OR "knowledge cities" OR "learning city" OR "learning cities" OR "liveable city" OR "liveable cities" OR " livable city" OR "livable cities" OR "low-carbon city" OR "low-carbon cities" OR "open city" OR "open cities" OR "playful city" OR "playful cities" OR "post-carbon city" OR "post-carbon cities" OR "productive city" OR "productive cities" OR "regenerative city" OR "regenerative cities" OR "renewable city" OR "renewable cities" OR "resilient city" OR "resilient cities" OR "safe city" OR "safe cities" OR "sharing city" OR "sharing cities" OR "smart city" OR "smart cities" OR "sponge city" OR "sponge cities" OR "solar city" OR "solar cities" OR "sustainable city" OR "sustainable cities" OR "ubiquitous city" OR "ubiquitous cities" OR "virtual city" OR "virtual cities" OR "zero-carbon city" OR "zero-carbon cities")) AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND PUBYEAR < 2020 valuable insights into how individual city labels have fared and how the field overall has evolved. Related findings are shown in section 4.1 (Table 1; Figures 2 & 3).

3.3.2 Co-occurrences of city labels

Drawing on social network analysis, the co-occurrence analysis of city labels serves to identify mutual connections among the 35 labels. It counts the number of articles containing specific combinations of two labels in the title, abstract, and keywords. For example, the results reveal 165 articles which concurrently mention 'sustainable city' and 'smart city', whereas only one article combining 'information city' and 'playful city'. By registering all instances (number of articles) where city labels are used in conjunction with other city labels, a network of relationships among the 35 labels emerged. This can be visualised using Pajek software's social network analysis (Batagelj and Mrvar, 2011; based on Kamada and Kawai, 1989), whereby the greater the number of co-occurrences, the more central the position of a given city label within the web of relationships (such that, following the above example, the 'playful city' sits on the periphery and, conversely, the 'sustainable' and 'smart' city at the centre, of the complex network). Related findings are shown in section 4.2 (Fig. 4; Table 2 & 3).

3.3.3 Co-occurrences of keywords with city labels

The analysis of conceptual interrelationships was further deepened by examining the co-occurrences of city labels and keywords. The latter encapsulate essential theoretical and empirical information and associations, chosen by authors to define and categorise their research. Co-occurrence here was established by counting the number of articles which mention a given city label together with a specific keyword. Given N=22820 keywords (across all 11337 articles), this produced a multitude of combinations. Hence, the focus is primarily on the most frequent keyword co-occurrences as a means of identifying a city label's substantive underpinnings. For each city label, therefore, the 15 most frequent keywords were selected (or fewer where keywords with identical frequencies were jointly assigned the lowest rank, thereby falling outside the top 15). Beyond individual city labels, this analysis is also particularly useful to depict the complex network of conceptual relationships among the city labels and keywords. For example, by identifying the most frequent keywords, and their degree of centrality, across all 35 city labels articles, this provides insight into what commonly defines the conceptual field spanning the 35 labels. Moreover, a comparison of keywords between city labels helps reveal their common association, as well as distinctive features. Related findings are shown in section 4.3 (Fig. 5, Table 4.).

3.3.4 Present and past temporal analyses

The results of these (co-)occurrence analyses were considered from different temporal perspectives, giving useful insight into the co-evolution of the 35 city labels across distinct time periods. First, the study examined the *status quo* at the end of 2019: this provides the cumulative picture of all articles generated across the three decades. Next, the data was divided into six equal periods (five years each), to enable analyses of the co-evolution and maturation of 35 city labels across time. This not only established the overall trajectory of the field, but also the development of individual city labels. A further, methodologically different, temporal analysis concerns the future outlook, as follows.

3.3.5 Future forecast

The Logistic Growth Model (LGM) was used to predict the future trajectory of city labels in the scientific literature, by extrapolating from the occurrence rates of each city label across the 1990-2019 period. LGM is a regression model based upon a set of observations between cumulative growth of the number of articles (Y) per year (X): $y = \frac{L}{(1+e^{b-kx})}$; where L represents the total estimated capacity in number of articles that a city label could carry; b and k represent the slope of the curve which follows a natural logarithm. Consequently, the cumulative number of articles plotted over time follow a general logistic growth pattern in the shape of an S-curve. City labels were included in LGM if the total number of articles across the six periods were > 30 (General Limit Theorem, such that the spread can take on a normal distribution), which was the case for 25 out of the 35 labels. These 25 were compared with one another by (a) normalizing the growth curves through equalizing the L to 100% for each label; and (b) plotting the labels on the growth line where their last accumulated year of publications (end of 2019) left them on the curve. To this, Zeng et al. (2019)'s three development stages (infancy: up to 10% of publication output; growth: 10%-90% of publication output; maturity:) were applied. To establish goodness for fit, each city label was tested, with the R^2 coefficients found to be close to 1. Related findings are shown in section 4.4 (Fig. 6; 7).

4. Results

4.1 A fast expanding field led by 'sustainable' and 'smart' city

The occurrence analysis of the 35 city labels points to two remarkable overarching developments: first, the exponential cumulative growth of the scientific literature across the three decades; and, second, the dominance, in quantitative terms, of articles on 'smart' and 'sustainable' city. Figures 2 and 3 visualize the results; the underlying data is listed in Table 1.

In the first measurement period (1990-1994), in what may be considered the nascent phase, just 77 articles covering 16 city labels were published (see Table 1). Each subsequent period saw significant cumulative growth by factors of >2 or >3, with new city labels added, so that by the end of 2019 a total of 11337 had accumulated. Two periods stand out: the second five-year period (to 1999) saw a 368% output increase, led by more than five-fold growth in 'sustainable city' as well as a trebling of 'compact city' articles, among others. This correlates with the global uptake of sustainable development marked by the inaugural UN 'Earth Summit' in 1992 and the UN-Habitat II conference in 1996. The most recent five-year period (to end of 2019) is more remarkable still: it saw an unprecedented increase from 3560 to 11337 articles (+318%). Again, articles discussing the 'sustainable city' contributed centrally to this (more than doubling, from 799 to 1753), but by far the largest increase relates to the 'smart city', jumping tenfold from 514 to 5161 articles.

Table 1. Article frequencies for 35 city labels, cumulative across six time periods 1990-2019.
(New entrants highlighted in grey.)

	1990 - 1994	1990 - 1999	1990 - 2004	1990 - 2009	1990 - 2014	1990 - 2019
1	sustainable city (16)	sustainable city (92)	sustainable city (178)	sustainable city (361)	sustainable city (799)	smart city (5161)
2	future city (15)	compact city (37)	compact city (92)	compact city (178)	smart city (514)	sustainable city (1753)
3	compact city (11)	open city (21)	virtual city (53)	virtual city (104)	compact city (361)	compact city (671)
4	open city (9)	virtual city (20)	digital city (43)	digital city (102)	creative city (274)	creative city (529)
5	information city (4)	future city (19)	future city (40)	eco city (87)	eco city (236)	eco city (458)
6	intelligent city (4)	green city (14)	open city (36)	creative city (84)	digital city (197)	future city (410)
7	green city (4)	liveable city (13)	liveable city (30)	future city (61)	virtual city (168)	green city (364)
8	safe city (3)	safe city (11)	green city (24)	liveable city (52)	future city (161)	digital city (304)
9	entrepreneurial city (3)	eco city (10)	eco city (23)	knowledge city (47)	green city (147)	low-carbon city (301)
10	liveable city (3)	information city (8)	safe city (20)	open city (46)	low-carbon city (122)	resilient city (273)
11	productive city (2)	entrepreneurial city (7)	entrepreneurial city (18)	green city (45)	knowledge city (114)	virtual city (255)
12	eco city (2)	competitive city (6)	competitive city (16)	entrepreneurial city (42)	liveable city (92)	sponge city (237)
13	solar city (1)	smart city (6)	creative city (16)	circular city (35)	open city (86)	liveable city (235)
14	connected city (1)	circular city (5)	circular city (15)	safe city (32)	entrepreneurial city (76)	open city (162)
15	virtual city (1)	intelligent city (4)	information city (12)	competitive city (29)	resilient city (65)	knowledge city (157)
16	creative city (1)	digital city (4)	knowledge city (11)	solar city (16)	safe city (56)	safe city (112)
17		creative city (4)	smart city (8)	smart city (16)	circular city (52)	intelligent city (109)
18		productive city (3)	learning city (5)	information city (15)	competitive city (49)	entrepreneurial city (109)
19		learning city (3)	intelligent city (5)	connected city (13)	intelligent city (47)	inclusive city (91)
20		solar city (2)	connected city (4)	learning city (12)	ubiquitous city (37)	circular city (91)
21		connected city (2)	experimental city (3)	intelligent city (11)	connected city (32)	competitive city (76)
22		experimental city (1)	productive city (3)	inclusive city (9)	learning city (30)	connected city (71)
23			inclusive city (3)	ubiquitous city (8)	solar city (22)	ubiquitous city (53)
24			solar city (2)	resilient city (8)	inclusive city (22)	learning city (49)
25			resilient city (2)	experimental city (4)	information city (20)	solar city (48)
26			ubiquitous city (1)	productive city (4)	productive city (10)	information city (28)
27				sponge city (3)	zero-carbon city (9)	sharing city (23)
28				zero-carbon city (2)	experimental city (6)	productive city (19)
29				low-carbon city (2)	post-carbon city (6)	zero-carbon city (17)
30				post-carbon city (1)	regenerative city (3)	post-carbon city (15)
31				sharing city (1)	sharing city (3)	biophilic city (13)
32					sponge city (3)	experimental city (12)
33					renewable city (2)	regenerative city (11)
34					biophilic city (2)	renewable city (4)
35						playful city (4)

	77 articles (total)	**283 (+368%)**	**641 (+227%)**	**1380 (+215%)**	**3560 (+258%)**	**11337 (+318%)**

Comparison between this ‘duopoly’ is revealing. The ‘sustainable city’ generated the most articles up until 2014 (see Fig. 2; 3). Two likely explanatory factors for this are: first, as mentioned, from the early 1990s, sustainable (urban) development has enjoyed policy endorsement at the highest international level (notably UN-Habitat), with subsequent engagement at national and local levels (e.g. through Local Agenda 21, Aalborg Charter). Second, conceptually, sustainable development is commonly defined through the ‘triple-bottom line’ of environment, economy, and society. Hence, authors are likely to choose ‘sustainable city’ as it affords broad engagement with questions of urban planning and development, while also signaling policy relevance. The latter appears to be in play in the most recent period (to 2019), too: coinciding with the adoption of the SDGs and New Urban Agenda, a further significant increase in ‘sustainable city’ articles can be registered for 2016-2019 (see Fig. 2).

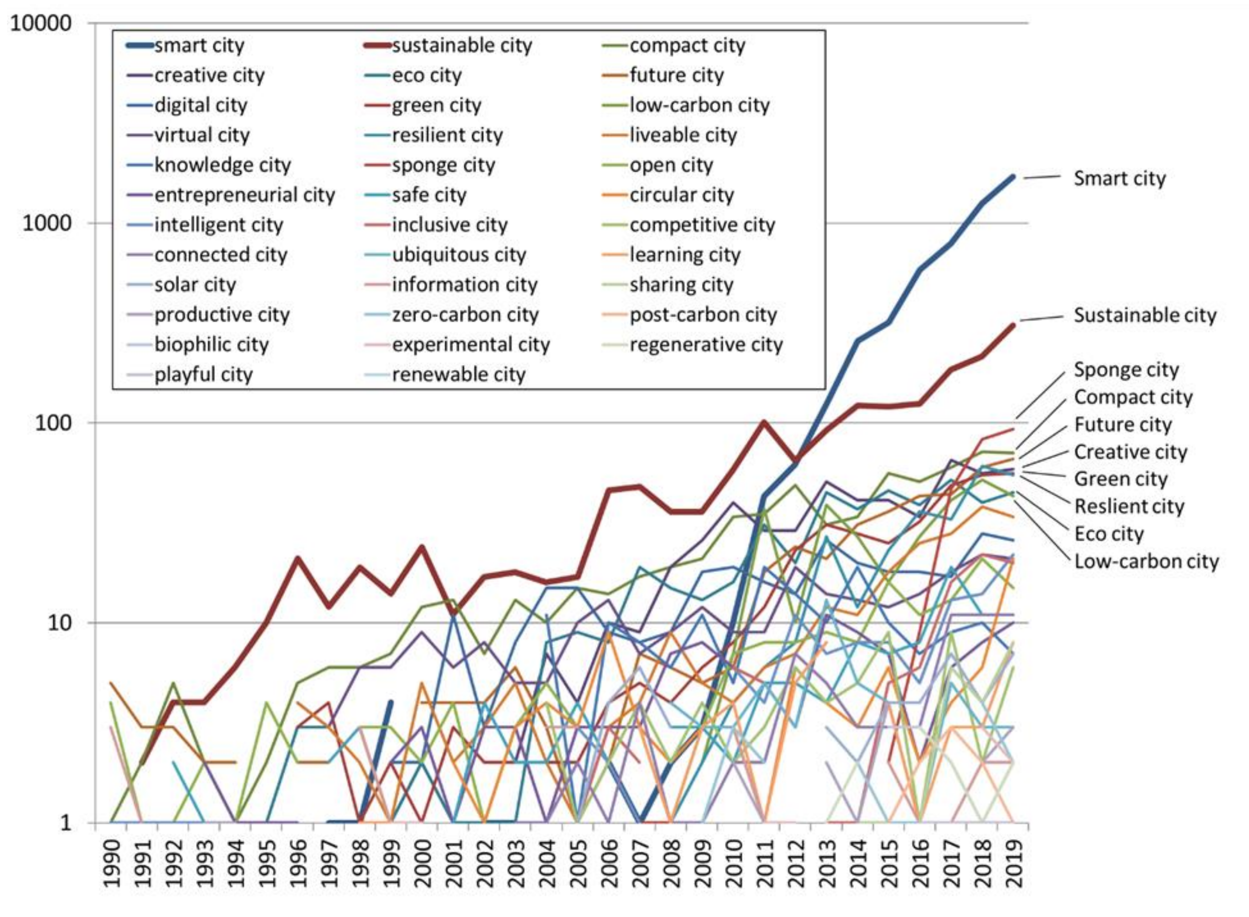

Fig. 2. Evolution of 35 city labels 1990-2019 (cumulative article frequencies).
N.B. Logarithmic scale.

Nevertheless, undoubtedly, the ‘smart city’ has taken over as most researched concept in the recent period. Its ascendancy is stark: after only 16 articles were published altogether during 1995-2010, by 2014 it closed in on ‘sustainable city’, before overtaking it at accelerated speed. With 5161 articles, by the end of 2019 it made up almost half (46%) of the total output produced over 30 years. Here, the explanatory factors may be different, as the 'smart city' does not have the same global policy endorsement as 'sustainable city'. Rather, it ascendancy may reflect, on one hand, broad engagement across research disciplines including significant productivity by the computing and engineering sciences (e.g. Dias 2018; Maestre-Gongora and Colmenares-Quintero 2018) and, on the other, the fast assimilation of smart technology in urban infrastructure, governance and everyday life (e.g. Kitchin 2014a).

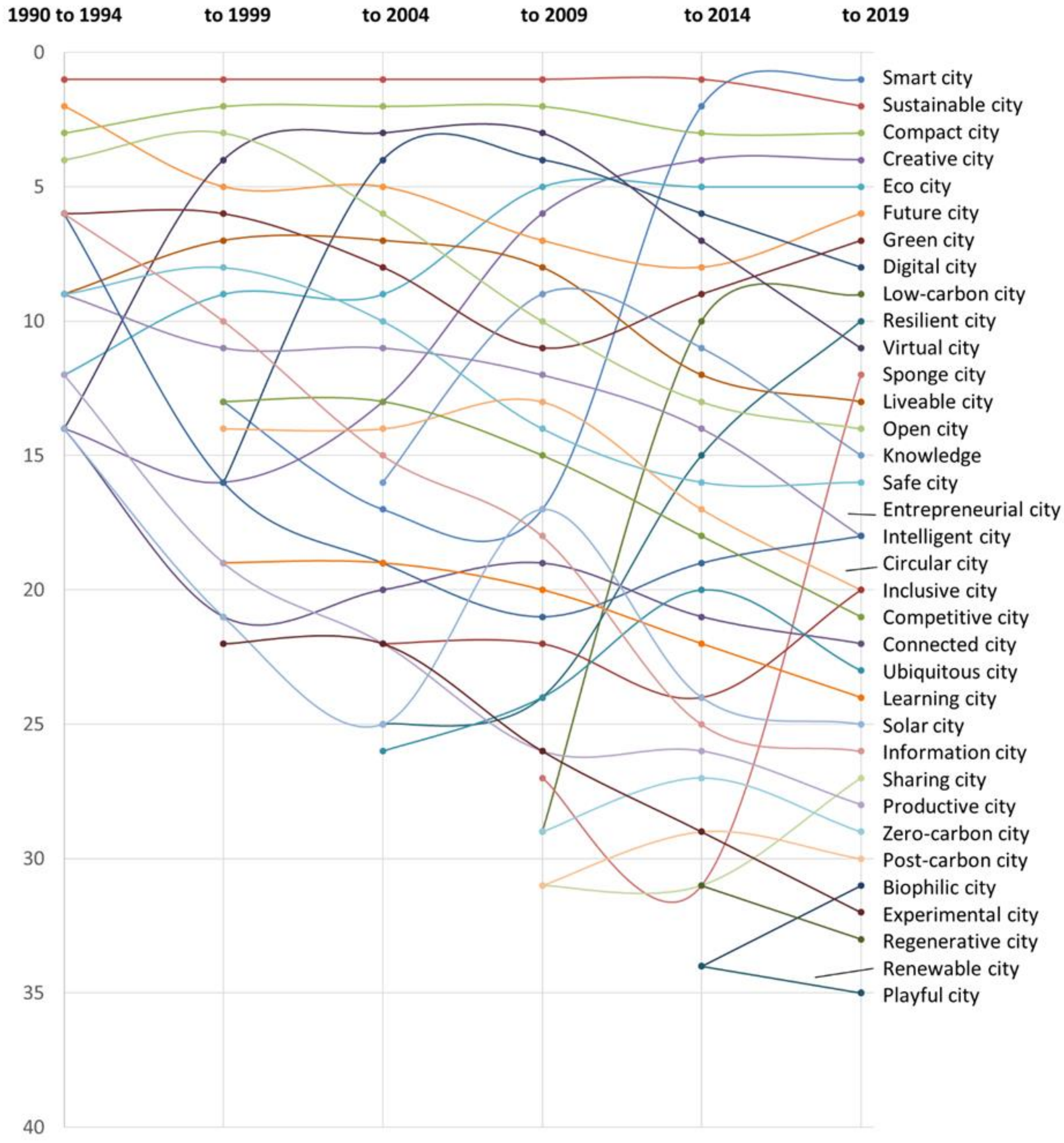

Fig. 3. Relative positions of 35 city labels across six time periods 1990-2019 (article numbers; cumulative frequencies).

Equally important to note are other city labels which have emerged, albeit seemingly in the shadow of 'smart' and 'sustainable' city. Figure 3 visualizes the waxing and waning of the other 33 labels (which make up 39% of total output) in relation to one another. Some labels, notably the 'compact city', consistently grew across the entire period to significant size. Others have shown rapid recent growth, such as 'resilient city' (quadrupling between periods 5 and 6), 'low carbon city' (4^{th} period entrant) and 'liveable city' and 'sponge city' (5^{th} period entrant). Then again, others appear on a downward trend – comparative to the rest of the field – including 'entrepreneurial city' and 'information city'. Several labels are newcomers, such as 'biophilic' and 'playful' (entering in the 5^{th} period) and 'renewable' city (6^{th} period). Twelve city labels (in descending order: 'learning'; 'solar'; 'information'; 'sharing'; 'productive'; 'zero-carbon'; 'post-carbon'; 'biophilic'; 'regenerative'; 'renewable'; 'playful') each have <50 articles for the entire period, which suggests that they have made a marginal or niche contribution, especially ones (e.g. 'productive'; 'experimental') that have been around since early on.

It is worth adding a brief methodological note to the above results: a phenomenon of recent scholarship has been the generally increased rate of scientific outputs, especially in the form of journal articles (e.g. Matia et al. 2005; Monroy and Diaz, 2018; Wong, 2019). This prompts the question whether the observed increase in article volume might somewhat be distorted by heightened academic publishing practice. In order to gauge this, we calculated in Scopus the yearly increases in overall article outputs (all subject areas) for the 30-year period. This showed a steady growth rate of 4.5% p.a.[2], or an average of 22.5% for each five-year period. In comparison, Table 1 shows much larger percentage increases across the six timespans. Hence, it is safe to state that, while the noted phenomenon is a contributory factor, it is relatively small and in the main the observed increase in article volume is clearly due to growing scholarly engagement with the 35 city labels analyzed.

4.2. Interconnected city labels

Turning to the co-occurrence of city labels, this provides key information on the connectedness among various labels. Table 2 lists the top ten co-occurrences between two labels, while Figure 4.a-f visualizes the connections among all 35 labels cumulatively across the six time periods. The immediately most striking findings are: first, that 'sustainable city' and 'smart city' have a high degree of co-occurrence between themselves (165 articles); and, second, they each have significant co-occurrences with other city labels, in Table 2 sharing nine places between themselves. Consequently, in Figure 4.f (1990-2019), they occupy a central axis in the overall network. Together with their high occurrence rates (visualized by the size of the dots), this underscores their dominant position and influence.

[2] Calculation carried out 19 May 2020: Scopus counted 795.023 articles published in 1993; gradually growing to 1.150.729 by 2003, then to 1.966.728 in 2013 until 2.480.335 articles published in 2019, thus indicating fairly constant growth totalling up to 312 % over these 26 years, equalling a ~4,47 % yearly increase.

Table 2. Top 10 co-occurrences among 35 city labels.
(Total of 11,337 articles.)

Rank	Co-occurrence of city labels		# articles
1	smart city	sustainable city	165
2	smart city	future city	58
3	smart city	intelligent city	57
4	smart city	digital city	53
5	sustainable city	eco-city	51
6	sustainable city	compact city	46
7	sustainable city	green city	31
8	smart city	eco-city	30
9	sustainable city	future city	25
10	eco city	low-carbon city	23

Table 3.a-b. City label co-occurrences: 'smart city' and 'sustainable city'.

A. City labels leaning to 'smart city'

City label	**Co-occurrences with**		**Diff.**
	sustainable city	**smart city**	
intelligent city	2 (3%)	57 (97%)	55
digital city	4 (7%)	53 (93%)	49
future city	25 (30%)	58 (70%)	33
ubiquitous city	1 (6%)	15 (94%)	14
connected city	2 (13%)	14 (88%)	12
creative city	9 (32%)	19 (68%)	10
safe city	2 (20%)	8 (80%)	6
knowledge city	5 (33%)	10 (67%)	5
learning city	0 (0%)	4 (100%)	4
entrepreneurial city	1 (17%)	5 (83%)	4
open city	0 (0%)	4 (100%)	4
sharing city	3 (33%)	6 (67%)	3
experimental city	1 (20%)	4 (80%)	3
information city	1 (20%)	4 (80%)	3
competitive city	2 (33%)	4 (67%)	2
zero-carbon city	2 (40%)	3 (60%)	1
playful city	0 (0%)	1 (100%)	1

B. City labels leaning to 'sustainable city'

City label	**Co-occurrences with**		**Diff.**
	sustainable city	**smart city**	
compact city	46 (87%)	7 (13%)	39
eco city	51 (63%)	30 (37%)	21
low-carbon city	19 (73%)	7 (27%)	12
green city	31 (58%)	22 (42%)	9
liveable city	17 (63%)	10 (37%)	7
solar city	5 (100%)	0 (0%)	5
circular city	2 (100%)	0 (0%)	2
resilient city	15 (54%)	13 (46%)	2
post-carbon city	2 (67%)	1 (33%)	1
inclusive city	8 (53%)	7 (47%)	1
biophilic city	2 (67%)	1 (33%)	1
renewable city	1 (100%)	0 (0%)	1

Table 2d. City labels with equal co-occurrence

city label	**sustainable city**	**smart city**	**Diff.**
sponge city	1 (50%)	1 (50%)	0
regenerative city	1 (50%)	1 (50%)	0
virtual city	1 (50%)	1 (50%)	0
productive city	1 (50%)	1 (50%)	0

Considering the evolution of the network across time (Fig 4.a-f), early on a small cluster formed around 'sustainable city', including 'future' and 'compact' city. This progressively grew to include further connections, notably with 'green', 'liveable' and 'eco' city (to 1999). Through this central network, other sub-networks began to form, e.g. 'liveable'—'green'—'compact'—'virtual' city (to 2004), and 'knowledge'—'competitive'—'compact' city (to 2009). Interestingly, while the 'smart city' first appeared in the second period (to 1999), the connection to 'sustainable city' was only established in the fifth period (to 2014), to become the central axis. In the intervening time, the 'smart city' formed its own sub-network: tellingly, 'green' and 'liveable' (to 1999) and furthermore 'future' and 'eco' (to 2004) were the first connections; as such, it was quite similar to that of the 'sustainable city' (except for the latter's additional link to 'compact city'), although 'smart' and 'sustainable' themselves only interconnected in the 2010s. By then, the 'smart city' sub-network included major additional connections: 'connected', 'intelligent', and 'digital', among others, thereby differentiating itself from 'sustainable city'.

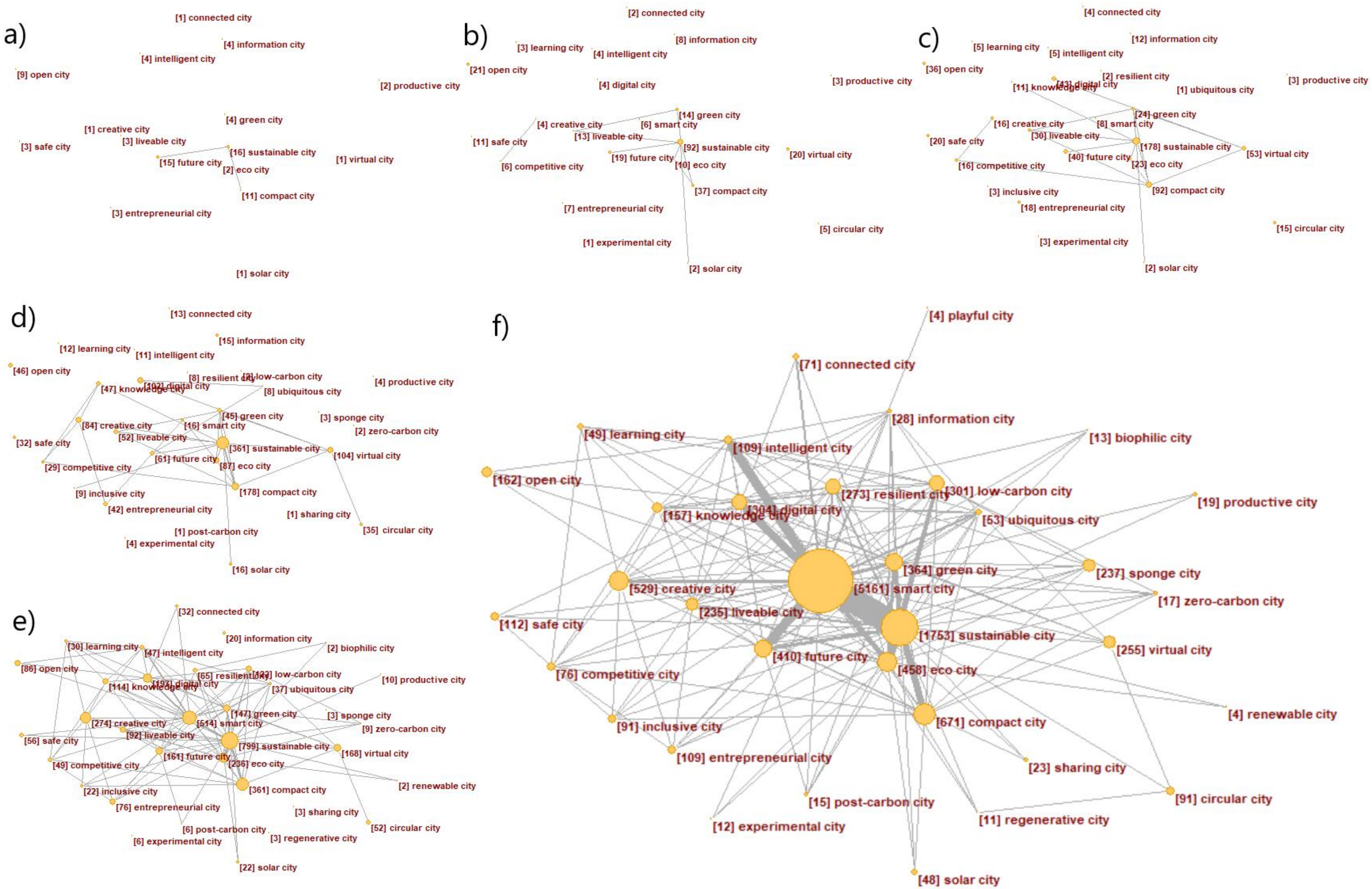

Fig. 4.a-f. Co-occurrences of 35 city labels (in article titles, abstracts, author keywords) across consecutive time periods 1990-2019. (4.a: 1990-1994; 4.b: 1990-1999; 4.c: 1990-2004; 4.d: 1990-2009; 4.e: 1990-2014; 4.f 1990-2019). *For enlarged version, see [reference] (open access).*

Again, it is worth noting that, away from the center, several city labels display relatively few interconnections. This peripheral position is often exacerbated by the comparatively low article occurrences. Among these are: ‘playful city’ (1 connection); ‘productive’ and ‘renewable’ (2 con.); ‘connected’, ‘circular’, ‘experimental’, ‘regenerative’, ‘sharing’ and ‘solar’ city (3 con.). While not too much weight should be attached to this regarding ‘playful’ and ‘regenerative’ city – since they only appeared in the 2010s – it is significant regarding the ‘productive’ and ‘solar’ city (entrants in 1st period) and ‘connected’, ‘circular’ and ‘experimental’ city (2nd period) (see Fig. 2). The latter have had a long shelf life without, however, generating much scientific output (although noting even among this group some considerable differences, such as the ‘experimental city’ with only twelve articles in total, against 91 for ‘circular city’).

Back to the central ‘smart’—’sustainable’ relationship, Table 3.a-c provides a comparison of the co-occurrences of city labels with ‘smart’ and ‘sustainable’ city, respectively. This shows that three labels (‘intelligent’; ‘digital’; ‘future’) are very strongly, and a further three (‘ubiquitous’; ‘connected’; ‘creative’) strongly connected to ‘smart’ rather than ‘sustainable’ city. Conversely, two city labels (‘compact’; ‘eco’) are very strongly, and three (‘low-carbon’; ‘green’; ‘liveable’) quite strongly connected to ‘sustainable’ rather than ‘smart’ city. Hence, at the end of 2019, the two clusters ‘smart’ and ‘sustainable’ display a significant degree of differentiation: the former clearly connected to future-oriented digital and intelligence-based urbanism, and the latter oriented towards environmental-spatial aspects. Crucially, at the same time, they also share several of the above city labels and, indeed, additional ones, too (Table 3.b-c).

4.3 Conceptual relations

The bibliometric exercise produced a corpus of 22820 author keywords across the 11337 articles. This provides an abundant data mining opportunity to inquire into the association of city labels with key conceptual and empirical perspectives. Given the large dataset, the following analysis necessarily focuses on extracting major patterns and trends. One critical insight can be gained from viewing keywords that display a high degree of centrality through association with multiple city labels (see Table 4). For example, the keyword ‘sustainability’ (with an overall frequency of 379) is mentioned in connection with 19 city labels. Altogether, both ‘sustainability’ and ‘urban planning’, and related variations (‘sustainable development’, ‘urban design’, ‘urban regeneration’ etc.), enjoy high degrees of centrality across the field of 35 city labels. As such, they act as common denominators. In turn, this demonstrates the 35 city labels’ broad conceptual engagement with sustainable urban development.

Table 4. Top 15 keywords with highest degree centrality across 35 city labels.

(Cut-off for degree of centrality: 10.)

Author keywords	**Degree of centrality** (co-occurrences with no. of city labels)	**# of Occurrences** (total frequencies)
Sustainability	19	379
Urban planning	18	215
Sustainable development	15	208

Cities	15	119
Urban design	15	60
Climate change	13	142
Planning	13	93
Urban development	13	87
City	13	68
China	12	148
Urbanization	11	115
Governance	11	106
Urban sustainability	11	105
GIS	10	73
Urban regeneration	10	50
India	10	48
Land use	10	46

At the same time, a two-mode network of keywords with city labels also reveals significant conceptual differentiations, as shown in Figure 5.a-c. To maintain legibility, only the 15 most frequent keywords for each city label are visible on the graph. The more lines radiating from keywords, the greater the number of interconnections with multiple city labels (mirroring Table 4) and, hence, the more central their positioning. Conversely, keywords with single lines, pushed to the periphery, indicate unique associations with given city labels. It is important to reiterate that the networks in Fig.5.a-c were generated by keyword co-occurrences with city labels and, so, are algorithmically different from the networks in Fig 4.a-f (which depict co-occurrences between city labels).

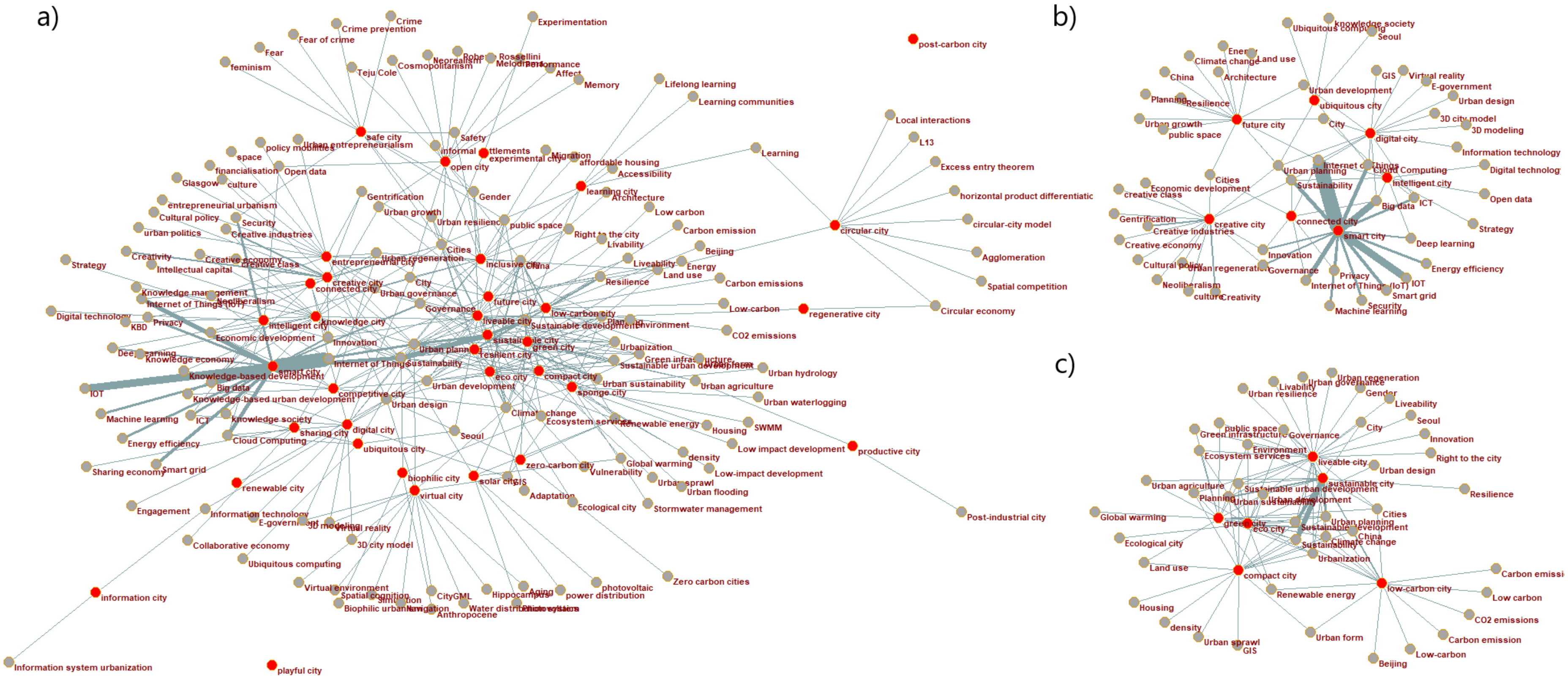

Fig. 5. Conceptual network structure of author keywords (top 15) associated with 35 city labels, 1990-2019. (4.a: 35 labels; 4.b: ‘smart’-‘intelligent’-‘digital’-‘ubiquitous’-‘future’-‘creative’-‘connected’ cluster; 4.c: ‘sustainable’-‘low-carbon’-‘liveable’-‘green’-‘eco’-‘compact’ cluster. N.B. Where <15 keywords, this is due to keywords with identical frequencies jointly assigned the lowest rank, thereby falling outside the top 15.)

For enlarged version, see [reference] (open access).

Yet, significantly, a very similar effect is produced; namely, an overall network with two central clusters: ‘sustainable’, and ‘smart’. The two clusters share a significant number of connector keywords between themselves, particularly ones with high degree of centrality: ‘sustainability’, ‘urban planning’, ‘urban development’, ‘urban regeneration’, ‘urban governance’ etc. (see also Table 4). Then again, each cluster shares keywords internally among neighboring city labels. This is highlighted in Fig. 5.b-c, where only the top 15 keywords are shown that interconnect with ’smart’-intelligent’-‘digital’-‘future’-‘ubiquitous’-‘connected’-‘creative‘ city labels (Fig. 5.b), and with ‘sustainable’-‘compact’-‘eco’-‘low-carbon’-‘green’-‘livable’ city labels (Fig. 5.c), respectively. Similar to the overall network (Fig. 5.a), each cluster is held together by connector keywords, while additional unique keywords are attached to specific city labels, thereby providing differentiation.

Apart from generic keywords such as ‘urban planning’, ‘urban development’, ‘city’ and ‘sustainability’, the ‘smart’ cluster is interconnected through several characteristic keywords including ‘Internet-of-Things’, ‘big data’, ‘cloud computing’, ‘deep learning’, ‘innovation’, ‘privacy’ and ‘governance’. With ‘smart city’ thus placed centrally, the cluster is further characterized by three distinct keyword groupings: one related to ‘creative city’ (‘creative class’, ‘economic development’, ‘gentrification’, ‘cultural policy’ etc.); one to ‘future city’ (‘energy’, ‘climate change’, ‘land use’, ‘public space’ etc.); and one to ‘digital’ and ‘intelligent’ city labels (‘digital technology’, ‘e-government’, ‘virtual reality’, ‘open data’ etc.). As such, this cluster has a particular techno—economic—environmental urban orientation with distinct digital inflection.

On its part, the ‘sustainable’ cluster has a larger number of generic connector keywords denoting (in various forms) ‘sustainable development’, ‘environment’, ‘urbanization’, ‘planning’, ‘cities’, and ‘urban agriculture’. These then also make up the top 15 keywords of ‘sustainable city’. More specialized keywords are associated with the other city labels in the cluster, notably: ‘housing’, ‘land use’, ‘density’, ‘urban sprawl’ etc. (‘compact city’); ‘right to the city’, ‘gender’, ‘urban regeneration’, ‘governance’ etc. (‘livable city’); ‘carbon emissions’, ‘low-carbon’, ‘CO_2’ etc. (‘low-carbon city’); and ‘global climate change’, ‘ecosystem services’, ‘governance’ etc. (‘green city’).

A further degree of specialization appears at work in the overall network’s outer regions (Fig. 5.a), where there are fewer connector keywords with lower degrees of centrality. Thus, for example, a distinctive set of keywords (‘agglomeration’, ‘horizontal product differentiation’, ‘spatial competition’ etc.) are associated with ‘circular city’; and even connecting keywords themselves are quite specialized (‘learning’, ‘circular economy’). Similarly, ‘crime’, ‘crime prevention’, ‘fear’ and ‘feminism’ selectively define the ‘safe city’.

Looking at the overall picture (Fig. 5), and considering how authors choose city labels and attach keywords to encapsulate their research topics, a dynamic interrelationship is likely at work: authors may start from a broad perspective (say, related to ‘sustainable city’), but then further specify their subject matter (say, with reference to ‘compact city’ and allied keywords). Conversely, the starting point may be quite specific (say, concerning the ‘right to the city’/’livable city’), but accompanied by broader referencing (say, ‘urban policy’/’sustainable city') to link up to wider discourse. Hence, through judicious choices of city labels and keywords, authors are involved (individually and collectively) in concurrently specializing and generalizing their subject matters. From such a networked perspective, one can see the 35 city labels working in concert and making complimentary contributions to charting the field of sustainable urban development.

4.4. Future outlook

The analyses of present and past developments tempt an inquiry into what the future might hold for city labels. While any promise of future prediction needs to be considered with healthy skepticism, the Logistic Growth Model used here is well-established and robust to allow a forecast. Figure 6 combines the related results, on a normalized curve, for 25 labels (ten labels were excluded as they did not meet the required article volume threshold; see section 3.5). This shows which city labels are presently at the infancy, growth, and maturity stages, respectively, based on the three development phases used by Zeng et al. (2018). At one end of the spectrum, five city labels (in ascending order, 'inclusive', 'liveable'; 'future'; 'open'; safe'; 'sustainable') are yet to leave their current infancy stage – that is, reaching beyond 10% of estimated eventual article output total. At the other end, 'knowledge' and 'ubiquitous' city have reached maturity stage (>90% of output total), with limited additional article outputs predicted. In between, there are two clusters currently at growth stage: at the lower end, with current output total of approx. 15-40%, are eight labels, from 'green' to 'resilient' city. At the higher, spanning approx. 60-80% of output total, there are nine cities, from 'eco' to 'digital' city. Taken together, this indicates that the overall field of city labels broadly engaged in sustainable urban development is very much still in the growth phase: significant additional research contributions can be expected in the years to come, thus providing opportunities to further define and develop the field.

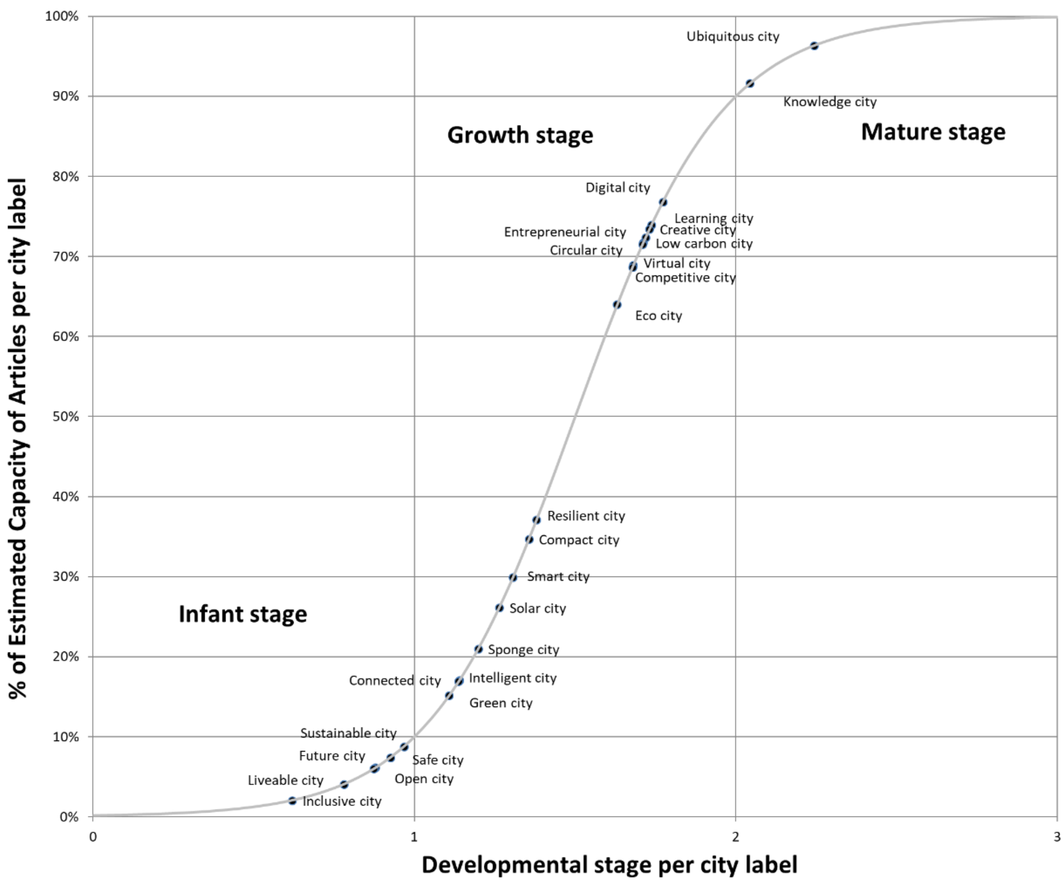

Fig. 6. Forecast of development potential (infancy; growth; maturity) for 25 city labels.

(Logistic Growth Model)

Once again, attention is drawn to how the 'sustainable' and 'smart' city fare. Intuitively, the longevity of 'sustainable city' might lead one to assume that it could soon reach maturity. However, the model places it at the end of the infancy stage (reaching approx. 10% of estimated output total). This can be explained by the continuously significant increase in article outputs across the six time periods, with the last period (to 2019) showing further acceleration. On its part, the 'smart city', at approx. 30% of estimated article output total, is calculated as having entered growth stage owing to its extremely rapid growth within recent time: one should, therefore, expect ongoing rapid growth in coming years. At the same time, it is predicted to reach maturity sooner than the 'sustainable city'.

The Logistic Growth Model can further be used to calculate the estimated length of the three-part life cycle for each of the 25 city labels: that is, the number of years it is predicted to take to move through the infancy, growth, and maturity stages, respectively. The corresponding results are shown in Figure 7.

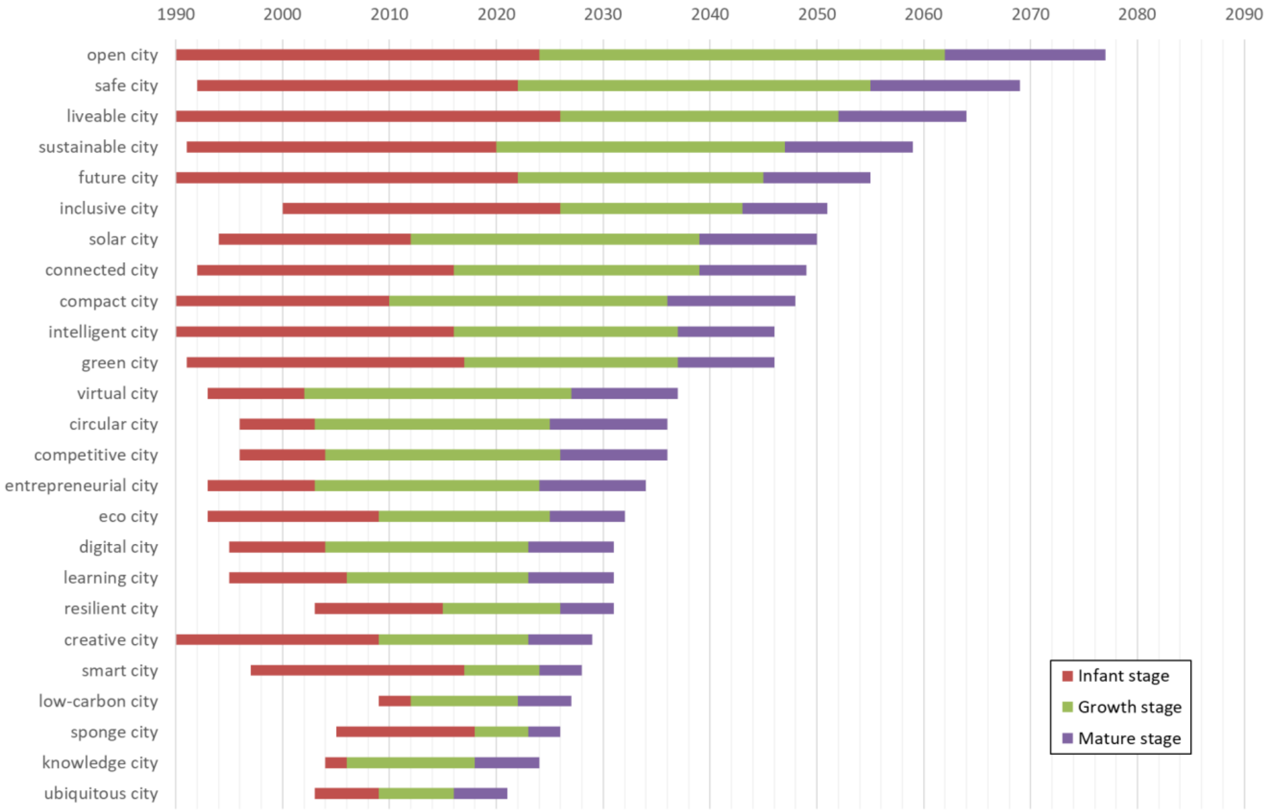

Fig. 7. Forecast of development potential (three stages, in years) for 25 city labels.

(Logistic Growth Model)

The model predicts for several more recent entrants (in the 2000s) a relatively short lifespan (into the 2020s) in the academic literature: namely, 'ubiquitous', 'knowledge', 'sponge', and 'low-carbon' city. The 'ubiquitous city', for example, arose in connection with a short-lived, nationally confined urban innovation programme in South Korea, which was superseded there by more recent 'smart city' policies (e.g. Shwayri 2013). Similarly, the 'low-carbon city' is mainly associated with same-named policy initiatives in the 2010s by the Chinese government (de Jong et al. 2016). At the other end of the spectrum, five labels – 'open', 'safe', 'liveable', 'sustainable', 'future' – appear to have a much more enduring lifespan: their early roots in the 1990s and continuously growing outputs predict a trajectory beyond the 2050s (in the case of the 'open city' into the 2070s).

It is important to bear in mind that these predictions may well change as new data becomes available in the coming years. Like other scientific fields, research on cities dynamically reflects, and responds to, events and policy developments in the real world. Major events, such as the COVID-19 pandemic, as well as less dramatic developments will influence the way in which scholars mobilise city labels in their work. However, given the wealth of data on which the above forecast is based, and given that cities and urbanisation are so closely intertwined with sustainable development and global climate change, it seems safe to assume that the field of city labels analysed here will grow and evolve significantly in the period to come.

5. Discussion

As set out previously in section 2, city labels carry both conceptual significance as scholarly categories and wider discursive and programmatic significance in policy and practice. Consequently, the findings of this study can now overall be considered in terms of their contribution to: (1) advancing bibliometric research on city labels within the scientific literature; (2) interpreting the rise of city labels against the background of policy and practice developments; and (3) conceptualising a network perspective of city labels that accentuates complementarity between different aspects of sustainable urban development and, thus, opportunities for synergies between SDG11 and other SDGs.

By significantly expanding previous bibliometric research (e.g. de Jong et al. 2015; Fu and Zhang, 2017; Mora et al. 2017; Wang et al. 2019) through a 30-year longitudinal analysis of a comprehensive set of 35 city labels, the study demonstrates that exponential growth in the scientific discourse has accelerated particularly strongly in the most recent period (2015-2019) and is forecast to continue on this trajectory based on logistic growth modelling. This, therefore, underlines the need for closer attention to how various city labels interrelate and jointly define the scientific knowledge field. In this respect, our findings differ from Wang et al. (2019), who *a priori* subsumed six city labels ('eco', 'ecological', 'low carbon', 'zero carbon', 'resilient', 'sponge') under 'sustainable city' without bibliometric differentiation: first, our results show that, while several of these labels are closely related, they are not conceptually synonymous; second, they also show that some labels ('resilient city', 'sponge city') are not as directly associated with 'sustainable city', whereas 'compact city' and 'future city' (not featured in Wang et al. 2019) are. There are also differences with the study by Fu and Zhang (2017): while they concluded, based on a different keyword cluster analysis, that the 'sustainable' and 'smart' city operate in largely separate conceptual fields, our findings demonstrate that – although the two indeed have partially different associations – they nevertheless also exhibit clear conceptual interlinkage and that this has strengthened over the last five years: thus, at the start of the 2020s, the co-occurrence axis between them is the strongest in the overall network (Fig 5.f). It is worth noting that although the 'smart city' nowadays most strongly interlinks with 'digital', 'information' and 'connected' city – reflecting partly growing attention to it from the computing and engineering disciplines – its cluster was originally formed with 'future', 'eco' and 'liveable' city. This is remarkable for two reasons: first, a common perception may be that the 'smart city' started out, and has since progressed, as a technology- and engineering-oriented proposition for urban development and planning, with sustainability-related characteristics coming to the fore only more recently as the concept has gone mainstream. Our findings indicate otherwise. Consequently, second, this study establishes that 'smart' and 'sustainable' city through their respective connections with 'future', 'eco', and 'liveable' city have been closely interrelated from an early stage.

More broadly, by interrogating 35 city labels, this study distinguishes itself from the majority of bibliometric studies (as cited in section 2) that have focused on single city labels, most notably 'smart' and 'sustainable'. It thereby generates a more comprehensive picture of city labels' interdependent conceptualization of sustainable urban development. As such, it shows two significant large clusters around 'sustainable city' ('compact', 'low-carbon', 'green', 'livable') and 'smart city' ('intelligent', 'digital', 'future', 'ubiquitous', 'connected', ‘creative’), respectively: thus, the former may be called ‘eco-cluster’; the latter ‘techno-cluster’. Furthermore, the study reveals significant other city labels (e.g. ‘inclusive’, ‘safe’, ‘open’) that point to alternative conceptual framings of urban challenges and strategies with greater social inflection. The forecast model suggests that several of these are currently at an infant stage, with considerable growth yet predicted. Future research will have to determine whether this has the making of an additional, competitive ‘socio-cluster’.

While the study findings emphasize a complex interplay of a multitude of city labels in the scientific discourse, the duopoly of ‘smart’ and ‘sustainable’ city nevertheless stands out. This mirrors their dominance in the wider realm of urban policy and practice, albeit for somewhat different underlying reasons. The ‘sustainable city’ owes its enduring pre-eminence to a succession of sustainable development policy initiatives at the highest international level, from the original Brundtland report (1987) and the first UN’s Earth Summit (1992) through to the more recent SDGs (2015) and New Urban Agenda (2016). This is reflected in our findings, for example, by a significant spike in articles (mentioning ‘sustainable city’) in the most recent period coinciding with the launch of the SDGs/New Urban Agenda (see Fig.2), and the frequent co-occurrence of keywords such as ‘sustainable urban development’, ‘SDG11’, ‘indicators’, ‘New Urban Agenda’, and ‘UN Habitat’. On its part, the recent meteoric rise of articles entailing ‘smart city’ cannot be explained in the same way, since there has been a relative absence of corresponding international polices. Rather, differently, it appears to be related to the rapid uptake of smart technologies (reflected in the study by high-frequency keywords including ‘IoT’, ‘big data’, ‘sensors’ and ‘smart grid’) and their increasing ubiquity in everyday life across towns and cities globally (Kitchin, 2014a; b). Tellingly, some recent policy initiatives – e.g. the ‘United for Smart Sustainable Cities’ (UNECE, nd), and the ISO 37122 smart city standard ‘Sustainable Cities and Communities’ (ISO, 2019) – have deliberately sought to conjoin ‘sustainable’ and ‘smart’ city, with the former broadly defining the goal of urban development and the latter the technological means of achieving it. Again, this confluence is mirrored in the prominent co-occurrence axis between ‘sustainable’ and ‘smart’ city (Fig 4.f).

The network perspective brought into view in this study (illustrated by Fig. 4 & Fig. 5) has a dual advantage over single perspectives on city labels: first, it shows that, as the challenges of urban transformation increasingly preoccupy policy and public discourse, a diversity of city labels are mobilized in response. While in practice this inevitably involves some (strategic) language games by urban actors resulting in occasional terminological conflations and contradictions (see section 2; Hollands, 2008; Söderström et al. 2014), underlying it is nevertheless a serious process of conceptual innovation, demarcation and diversification. As such, one can observe some city labels assembling around the main anchor points of ‘sustainable’ and ‘smart’ city, thereby adding further differentiation; conversely, one can observe other city labels staking out their own conceptual niches by more uniquely defining specific aspects of sustainable urban development. Relatedly, the second advantage afforded by this network perspective is its emphasis on interdependencies among city labels. This indicates opportunities to create synergies between different aspects of sustainable (urban) development. Applied to the SDGs, this opens up avenues for connecting SDG11 with its sister development goals. For example, a focus on ‘learning’ and ‘knowledge’ cities creates potential complementarity with SDG4 (education), ‘resilient’ and ‘sponge’ cities can be related to SDG6 (clean water), ‘renewable’ and ‘solar’ cities to SDG7 (affordable and clean energy), ‘competitive’ and ‘entrepreneurial’ city to SDG8 (economic growth), and so on. Given ongoing concerns about segmentation and trade-offs between SDGs (e.g. Kroll et al. 2019), the conceptual network of city labels presented here goes some way to forging useful synergies through the urban connection.

6. Conclusions

At first sight, city labels may rather superficially and simplistically capture the complex field of sustainable urban development. On closer inspection, this study demonstrates that there is more to city labels: they have significant conceptual underpinnings and, thus, help define and demarcate the field. At first sight, too, the 'sustainable' and 'smart' city and a few followers may seem all there is. Again, on closer look, this study brings into view a considerably more diverse group of city labels. It does so by addressing three main research questions (see section 2) concerning: (1) the occurrences and evolution of 35 city labels in the scientific literature over three decades (1990-2019); (2) the conceptual dimensions of these city labels as part of a dynamic network; and (3) the likely future trajectories in the decades ahead. Overall, the research reveals a steep rise in academic output featuring city labels, especially within the last ten years: we found no less than 11337 articles.

The findings significantly take forward recent bibliometric research on city labels by: first, extending the range of labels to 35; second, advancing conceptualisation through the analysis of a sophisticated two-mode network consisting of city label co-occurrences and keyword co-occurrences; third, generating a time series to chart the evolution of city labels across three decades; and fourth, producing a novel future forecast. The research is underpinned by an integrated set of bibliometric techniques which are presented in detail to aid replicability (see Box 1). The full dataset produced (selection of 35 labels from longlist of 148; corpus of 11337 articles; corpus of 22820 author keywords) is also made available to the wider scholarly community for further data mining.

Apart from the contribution to the conceptualisation and analysis of city labels within the scientific literature, the findings should benefit the ongoing discussion about how to address the Sustainable Development Goals. First, the findings point to the need for conceptual differentiation regarding the urban SDG11 itself: its joint descriptors 'inclusive', 'safe', 'resilient' and 'sustainable' cannot be assumed to be automatically part of the same; they have differing normative undergirding and address distinct theoretical, empirical and programmatic aspects of urban development and planning. Here, the network perspective helps to identify the distinctive characteristics as well as commonalities of these key descriptors. Moreover, second, the study offers insight into how SDG11 can be related to its sister SDGs: the city label network provides useful orientation on thematic constellations and interconnections, so that different city labels point to synergies with different dimensions of sustainable development.

Beyond the SDGs, the study findings offer useful guidance for urban planning and practice: in drawing attention to differentiation among diverse city labels, this could encourage policy-makers and practitioners to make considered choices when mobilizing city labels (e.g. when drawing up master plans or promoting city initiatives). Finally, the scholarly community itself should find the results a rich basis upon which to explore and interrogate further the range of city labels and their interdependences. The 'future city' most explicitly intones the future-oriented purpose and use of city labels, but there are many more that equally stake a claim for how sustainable urban development, and more broadly the SDG agenda, should be realized.

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