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1 The Tianjin Eco-City model in the academic literature on urban 2 sustainability

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9 Abstract

10 Recent intensive eco-city development in China has been accompanied by rising
11 enthusiasm for environmental sustainability indicators. Whilst there are calls for the
12 indicators to be standardised, and criticism of the difficulties in applying them, little
13 effort has been made to understand their scientific rationale. This article employs a
14 comprehensive bibliometric analysis to investigate the use of environmental
15 indicators from the Tianjin Eco-City Key Performance Indicators by the international
16 scientific community working on urban sustainability. The findings draw a clear
17 picture of the place of Tianjin Eco-City's indicators in the international scientific
18 literature. China's ecological problems are found to attract interest not only from
19 domestic researchers but also researchers outside the country. The indicators are used
20 not only for urban planning and management but also for a wide range of urban-
21 related and non-urban-related purposes. The scientific rationale of the eleven
22 indicators is specifically addressed, revealing a number of underlying questions about
23 the Tianjin Eco-City indicators.

24 Key words

25 Urban sustainability, environmental indicators, Tianjin Eco-City KPI, scientific
26 rationale, bibliometric analysis, geographical analysis

27 1 Introduction

28 Following the recent promotion of eco-cities, there is increasing interest among
29 researchers and policy makers in sustainability assessment. A sustainable city can be
30 defined by analogy with the Brundtland Commission's definition of sustainable
31 development (WCED, 1987) as a city that *ensures that development meets the needs*
32 *of the present without compromising the ability of future generations to meet their*
33 *own needs*. Conventionally incorporated into the triple bottom line of environmental,
34 social and economic criteria, the substantive purpose of sustainability assessment is to
35 provide policymakers and city planners with tools for evaluating their cities and to

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36 help them to decide what actions to take and not to take (Devuyst et al., 2001). In this
37 context, the main functions of sustainability assessment include decision-making and
38 decision management, target setting, advocacy, participation and consensus building
39 (Joss et al., 2012; Parris and Kates, 2003; Pastille Consortium, 2002). The indicators
40 can be broken down into single-unit indices (such as ecological footprint, wellbeing
41 index, energy) and indicator-based indices. By contrast with single-unit indices,
42 which score the combined performances of a city, indicator-based indices provide
43 disaggregated information and are used to track sector-level factors (Fiala, 2008).

44 China has been characterised in recent decades by growing enthusiasm for the
45 development of large-scale eco-cities. At the time of writing, there is no consensus on
46 a rigorous definition of what an eco-city is, and in practice the term is used
47 interchangeably alongside other words for sustainable city models such as
48 “sustainable cities”, “low carbon cities”, “resilient cities”, and so forth, despite the
49 underlying conceptual differences that may exist (de Jong *et al.*, 2015). So the term
50 eco-city may encompass a broad range of factors: carbon-neutral and renewable
51 energy supply; a dense urban fabric supported by a public transport system; resource
52 conservation; water and waste reduction and reuse; green buildings; urban renewal;
53 local urban agriculture; decent and affordable housing for all socio-economic and
54 ethnic groups; improved job opportunities; and voluntary change in lifestyle choices.

55 The Sino-Singaporean Tianjin Eco-City project has been widely discussed since its
56 inception in 2007. Built close to the centre of Tianjin Binhai New Area and the
57 second government-to-government urban project between China and Singapore,
58 Tianjin Eco-City has been designed to leverage Singaporean expertise in “practical”,
59 “replicable” and “scalable” city planning and management (de Jong et al. 2013; M.-C.
60 Hu et al. 2015; Lee et al. 2014; Weiss 2014). In parallel with the making of master
61 plan, a set of indicators – entitled Key Performance Indicators (KPIs) – an umbrella of
62 twenty-two “control” indicators and four “guidance” indicators, was jointly developed
63 by Chinese and Singaporean specialists. The indicators cover major urban sectors
64 such as air, water, transport and energy (Li et al., 2018). Presented as one of the
65 standout features of Tianjin Eco-City and “the first indicators system bespoke to
66 Chinese eco-cities”, the KPI system has been extensively discussed in scientific
67 publications and media communication. However, in-depth studies, among which we
68 can cite the report by Caprotti et al. (2015), have focused on the lack of social balance
69 in this primarily upper-middle-class new town project. There has been little attention
70 on the expected environmental performance of Tianjin Eco-City, which seems have
71 been taken for granted. Other papers are content to praise the high-profile bilateral
72 cooperation in the new town development and the KPIs, with little in-depth scientific
73 investigation.

74 Echoing the enthusiasm for eco-city development in China, there has been intense
75 discussion of sustainable city indicators by both government institutions and urban
76 specialists around the world. Reflecting today’s mainstream concern with the
77 promotion of social equity and economic viability, criticisms of the indicator systems
78 have unsurprisingly concentrated on the imbalance between the environmental and
79 socio-economic aspects (Greed, 2012; Medved, 2016). While recognising the

80 importance of reinforcing social equity and environmental viability in the
81 construction of sustainable eco-cities, we argue that this overwhelming focus on the
82 socio-economic dimension may obscure the importance of the environmental
83 indicators themselves. First, environmental challenges remain in the forefront of
84 political discourse (Cook et al., 2017; Hao, 2012; Nelson, 2012; Shih-Shen, 2013).
85 Second, environmental performance is a precondition for any achievement in the
86 social and economic arenas, as is apparent in the conventional expression “social and
87 economic development that should be environmentally sustainable”.

88 Given the inherent importance of this environmental dimension of sustainability,
89 governments and non-governmental organisations are keen to devise indicators for the
90 assessment of environmental performance. For instance, the European Union
91 approved the “20-20-20 target” for its environmental agenda towards 2020: a 20
92 percent reduction in greenhouse gases emissions, a 20 percent share of renewable
93 energy resources and a 20 percent rise in energy efficiency (Moldan et al., 2012). A
94 number of scholars have been calling for environmental indicators to be standardised.
95 In the recent report *Tomorrow’s City Today*, Simon Joss and his collaborators argue
96 for the standardisation of indicators in order to drive innovation and render locally
97 generated knowledge and practice transferable (Joss et al., 2015), following an earlier
98 analysis of the absence of global standardisation of eco-city indicators produced by
99 the same authors (Joss et al. 2012). In the same vein, Shen et al. (2011) point out that
100 the lack of consensus on urban sustainability indicators in local practices has caused
101 confusion in the setting of targets and implementation of policies. A number of
102 governments and non-governmental organisations, such as the World Bank (Suzuki et
103 al., 2010), the United Nations (United Nations, 2007) and Ecocity Builders (2015)
104 have been endeavouring to build overarching systems of sustainability indicators.

105 Meanwhile, there are impediments to the on-the-ground application of an
106 environmental indicator and substantial questions remain un-answered and in need of
107 elucidation. By way of example, one indicator in the Tianjin Eco-City KPIs refers to
108 the *proportion of green trips*. Apparently simple and easy to use, this indicator is in
109 fact hard to monitor for multiple reasons. First, there is no consensus at this time on
110 what types of travel (commuting, leisure...) should be included in this category.
111 Second, the geographical range of “green trips” has been defined as the inner part of
112 Tianjin Eco-City, which prompts questions about how the concept of “green trips” is
113 defined in the international literature. For instance, should intercity travel and transit
114 traffic be included in the calculation? Third, the meaning of “green” can sometimes
115 be unclear. How should a vehicle be judged as being green or not? On the basis of
116 vehicle type or power source? Is public transport inherently green? Fourth, what
117 should be the unit of measurement for green trips? Proportion of trips? Cumulative
118 distance? Travel time? This partial list gives an idea of the many questions raised by
119 an apparently simple indicator, which need to be answered before any standardisation
120 can be achieved. While there is no shortage of debate on these conceptual questions,
121 we note that the debates are mostly sectorial, i.e. limited to one indicator or a series of
122 indicators for a given sector, e.g. urban transport.

123 As previously mentioned, plenty is known about both (Chinese) eco-city development
124 and environmental sustainability indicators, thanks to the work of scientific
125 researchers in recent years. As far as we know, however, there has been no in-depth

126 study comparing the two, i.e. examining the environmental indicators within the
127 context of a real-world eco-city. Our paper seeks to fill this gap. It takes as its object
128 of study a set of major environmental indicators produced by Tianjin Eco-City, and
129 employs a bibliometric analysis to investigate the scientific rationale behind these
130 indicators. The number of occurrences of each indicator in the international scientific
131 literature was counted, by reference to the following questions: What is the exact
132 definition of a given indicator? What is it supposed to measure? Is the indicator
133 problem-oriented and relevant to the most urgent local concerns? Is it specific to the
134 urban environment? What are the unsolved scientific questions underlying the
135 indicator? Intertwined with these global scientific questions is the question of whether
136 the indicator is specific to the Chinese context or, conversely, context free. Put
137 another way, is the indicator recognised and widely used by researchers inside and
138 outside China? This question will be addressed by geographical analyses of the
139 publications. This will cast light both on whether Tianjin Eco-City's indicators are
140 aligned with mainstream challenges in the field of urban sustainability and on the
141 status of Chinese urban environmental problems in the international research agenda.

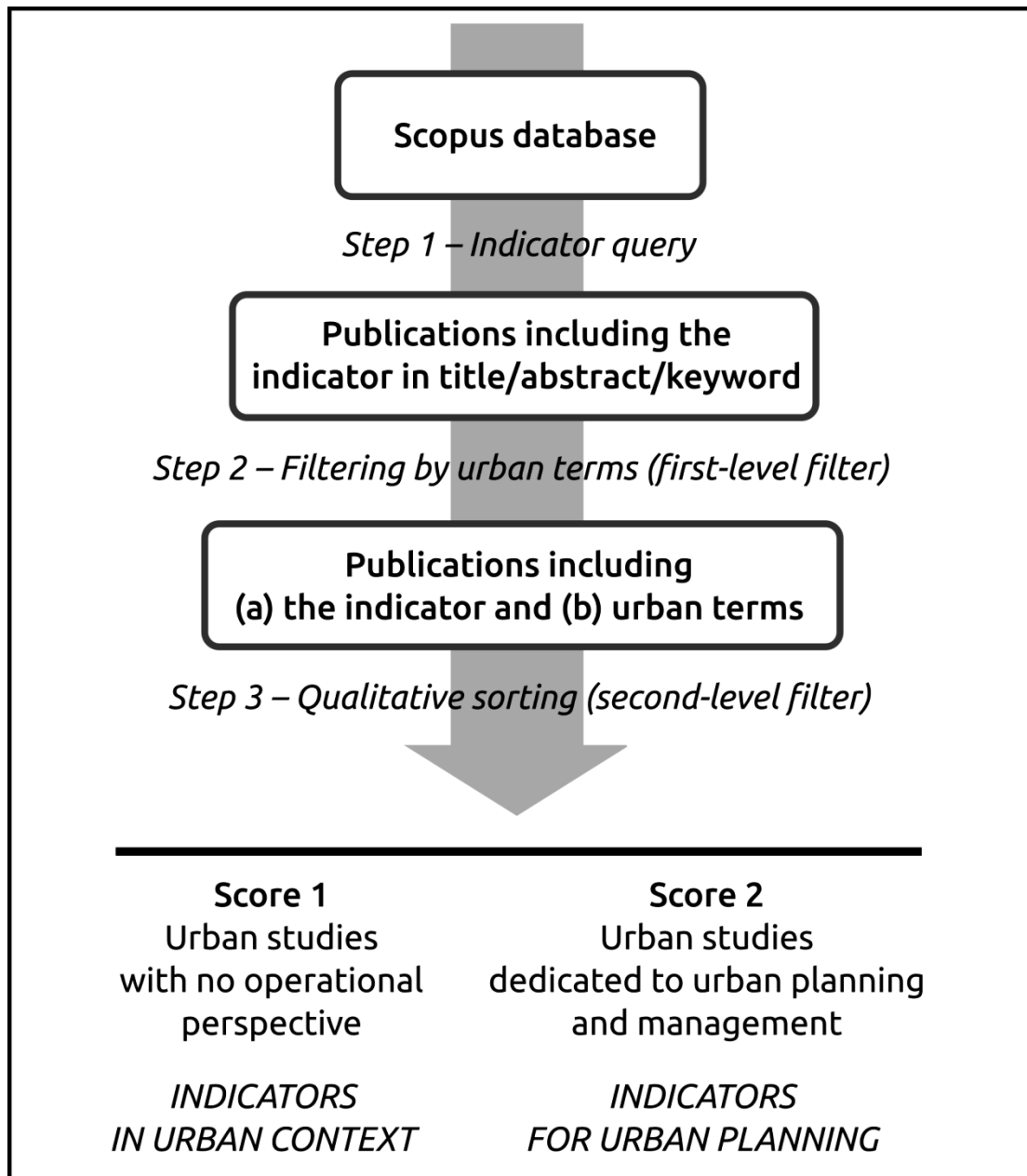
142 The remainder of the article is organised as follows. Section 2 outlines the
143 methodology informing this research, especially the empirical methods used to pick
144 out publications relating to the Tianjin Eco-City KPIs. Section 3 presents the main
145 results of this bibliometric exercise, followed by an overall discussion of the findings
146 and study conclusion in Section 4.

147 **2 Methodology**

148 As stated above, our aim is to investigate the scientific rationale behind the
149 environmental indicators used in the Tianjin Eco-City KPIs by analysing the
150 international scientific literature on urban sustainability relating to the indicators in
151 question. To do this, we above all have to construct the corpus of scientific
152 publications that will be the subject of our analysis. However, we encountered
153 methodological hurdles to automatic corpus generation by keyword query, which
154 included the semantic problems caused by the polysemic nature of indicators and the
155 increased blurring of the distinctions between urban and non-urban areas. To
156 overcome these difficulties, we designed a three-step roadmap, which will be
157 described below.

158 Figure 1 depicts the methodology underpinning this study. Among the twenty-two
159 indicators in the Tianjin Eco-city KPIs, we selected eleven environmental indicators
160 relating to water, air, energy, transport and waste, as listed in Table 1. The indicator
161 numbers are the same as those published in official documents and research papers,
162 which explains their discontinuity. The Scopus database was chosen for our
163 bibliometric inventory, because it includes publication records for journals since
164 1996, irrespective of changing ISI status (de Jong et al., 2015). The time span of our
165 collection is from 2000 to 2016, given that the early 2000s are recognised to be the
166 starting point of urban sustainability policies in China, with the proliferation of eco-

167 city initiatives at both regional and continental scales (Joss et al., 2013), and 2016 was
 168 the most recent ended publication year at the time of writing.



169 **Figure 1** Research design.

170 **2.1 Step 1: Indicator query**

171 As indicated above, the study was carried out in three steps. The first was to pick out
 172 scientific publications containing references to the indicators through keyword query.
 173 The keywords used to query each indicator were constructed through careful
 174 interpretation and translation of the official formulation of the indicator. As with
 175 many indicators, synonyms and similar expressions can exist and be used in
 176 publications at the authors' discretion, so we incorporated all possible variants of the
 177 indicators' official formulation into our query. By way of illustration, for the indicator

178 *Carbon emission per unit GDP*, the terms “CO₂”, “greenhouse gases” and “GHG” are
 179 all possible variants of “carbon” and were therefore incorporated into the query.
 180 Similarly with “per unit of GDP”, for which “per unit of gross domestic product” and
 181 “CO₂ intensity” were included in the search as possible variants. The detailed
 182 syntaxes of the search query are provided in the Appendix.

183 For certain indicators, we judge that the official formulation is not lucid enough and
 184 provide further explanations of the definition, as shown in Table 1. These
 185 explanations are based on a thorough examination of the guide to the Tianjin Eco-City
 186 KPIs published by the eco-city’s Administrative Committee, entitled “Navigating the
 187 Eco-City” (Tianjin Eco-city, 2010). To give two examples, for the indicator
 188 *Proportion of green buildings*, we explain that the eco-city designed its own standard
 189 of green building; for the indicator *Overall recycling rate*, we give supplementary
 190 information on waste categorisation in the eco-city.

191 The result of the query is a corpus of publications for each indicator in which the
 192 indicator is referred to in a publication’s title, abstract, or keywords.

193 **Table 1 Indicators and targets of the Tianjin Eco-City KPIs selected in the present study.**
 194 **Supplementary explanation of the indicators is provided when necessary to clarify the definition**
 195 **of the indicator.**

| N° | Indicator | Supplementary explanation | Target |
|----|--|---|---------------------|
| 1 | Ambient air quality | Days per year on which ambient air quality meets Grade II of Chinese National Ambient Air Quality Standard (GB 3095-1996) | 310 days |
| | | Days per year in which SO ₂ and NO _x content in the ambient air meets the requirement of Grade I of Chinese National Ambient Air Quality Standard (GB 3095-1996) | 55 days |
| 2 | Quality of surface water in the Eco-city | Surface water quality meets Grade IV of Chinese National Surface Water Quality Standard (GB 3838-2002) | - |
| 5 | Carbon emission per unit GDP | - | t/million US dollar |
| 7 | Proportion of green buildings | Tianjin Eco-City’s own green building standard | 100% |
| 10 | Per capita domestic water consumption | - | 120 l/per/day |
| 11 | Per capita domestic waste generation | - | 0.8 kg/per/day |
| 12 | Proportion of green trips | - | 90% |
| 13 | Overall recycling rate | <ul style="list-style-type: none"> Waste is categorised into domestic waste, industrial solid waste, construction waste and other waste. ‘Recycling’ includes reuse, recycling and energy recovery. | 60% |

| | | | |
|----|---|--|------|
| | | <ul style="list-style-type: none"> There are no separate categories for hazardous waste from hospitals, industry and construction | |
| 15 | Treatment to render solid waste non hazardous | - | 100% |
| 19 | Renewable energy usage | - | 15% |
| 20 | Water supply from non-traditional sources | Refers to alternative water resources | 50% |

196 2.2 Step 2: Filtering by “urban” terms

197 The second step in the process was to crop the corpus generated by the first step, in
 198 order to select urban-related publications by filtering out all studies that are not
 199 relevant to urban areas. This was difficult in that urban research is not set as a specific
 200 category in Scopus, given that cities are multifaceted and the boundary between
 201 urbanised and non-urbanised areas is increasingly blurred (European Commission,
 202 2016). There was therefore no automatic way of filtering out non-urban studies, so
 203 one was developed for the present study based on an *ad hoc* filter on urban terms. To
 204 construct the list of urban terms, we used the EuroVoc thesaurus, a multilingual and
 205 multi-disciplinary thesaurus which provides a controlled vocabulary set in multiple
 206 fields (<http://eurovoc.europa.eu/drupal>). In the EuroVoc’s English language interface,
 207 a “construction and town planning” micro thesaurus list is available in the “social
 208 questions” domain. The 176 terms included in this list were retrieved and used as our
 209 urban filter. It should be noted that the plurals of the terms were also incorporated.

210 Once the urban filter had been constructed, the abstract, title and keywords of each
 211 publication for each indicator were run individually through it. Using the text-mining
 212 function in the RapidMiner software (<https://rapidminer.com/>), the time of occurrence
 213 of any word in the urban term list was calculated and numbered. Publications that did
 214 not include any urban terms in their title, in their abstract or in their keywords, were
 215 considered to be non-urban studies and rejected from the corpus. The outcome of this
 216 step was therefore to produce a refined corpus of urban-related studies.

217 2.3 Step 3: Unavoidable qualitative sorting

218 As described above, the publications rejected by the urban filter can safely be
 219 assumed not to be urban-related. Nevertheless, those retained after this step may still
 220 not be limited to urban studies, because many words from EuroVoc’s “construction
 221 and town planning” list, such as “building”, “electricity”, “community”, can also be
 222 used in rural settings.

223 This semantic complication in distinguishing between urban-related and non-urban-
 224 related studies was bound up with a concern about the paper’s subject. For example,
 225 should we leave in the corpus relating to *water supply from non-traditional sources* a
 226 publication on techniques for monitoring organic pollutants in sewage treatment
 227 plants, given that its abstract does include “water reuse”, a term that was included in
 228 the search query for the indicator (Robles-Molina et al., 2013)? On the one hand, such

229 a study can arguably be considered to be urban, given the overlap between the topic
230 and urban sewage and water reuse. On the other hand, it seems somewhat remote
231 from the paper's focus on sustainability indicators for urban planning and
232 management. One possible approach for dealing with such a paper would be to retain
233 it in the corpus but to separate it from those that fully match the focus.

234 At this stage, therefore, we were facing a twofold challenge. First, the non-urban
235 studies that had not been filtered out by the first two automatic steps had to be found
236 and rejected. Second, the urban-related studies had to be classified in terms of their
237 match with our focus. These two tasks entailed a third step, content-based qualitative
238 manual sorting of the publications. In this step, the abstracts of the articles were
239 studied one by one and scored on a 0-1-2 scale, where 0 means totally outside our
240 scope, and 2 highly relevant to our focus on urban planning and management.
241 Particular care was taken when the name of a city was used to provide this study
242 location, as a city name might refer both to the central city area and to the sublevel
243 administrative zones. This is particularly common in China, where a study that refers
244 to Beijing is not necessarily restricted to its inner-city areas but may also include the
245 extensive and still largely rural hinterland.

246 **2.4 Abstract analysis and geographical analysis**

247 The total number of 896 publications retained after the three-step query process
248 formed our final corpus, on which an abstract analysis and a geographical analysis
249 were conducted. In the abstract analysis, the abstract of each paper was thoroughly
250 studied, with attention to the following key questions: which indicator is used or
251 mentioned in the study? In which country? Is it the same as the indicator from Tianjin
252 Eco-City? If not, what are its advantages and drawbacks in terms of scientific
253 rationale? This "abstract" analysis was reinforced by a review of the article text in
254 cases where the abstract was too vague to provide any relevant information on the
255 indicator in question.

256 The purpose of the geographical analysis was to understand how international
257 researchers use the Tianjin Eco-City KPIs. For each article, three pieces of
258 geographical information were retrieved: 1) the country of origin of the authors, i.e.
259 here *authors' country*; 2) the *country studied*; and 3) the link between the two. The
260 authors' country, as an aggregate location, quantifies the relative importance of the
261 countries as a source of research. The country studied, also an aggregate location,
262 quantifies the relative interest in a given country as an object of research. The link
263 between the two locations is a piece of relational information that indicates the level
264 of scientific interest in a country A for a country B. A set of text mining methods was
265 employed in order to extract the locations from the corpus. The algorithm was
266 developed under the R software (R Development Core Team, 2011). A set of specific
267 packages were used, mainly stringr (Wickham, 2017) for string manipulation, igraph
268 (Csardi and Nepusz, 2006) and bipartite (Dormann et al., 2009) for network analysis,
269 and ggplot2 (Wickham, 2016) for plotting.

270 Four fields were examined for each study: address of the corresponding author, title,
271 keywords and abstract. The first step was to clean the data (lower case conversion,

272 punctuation and removal of editor's location (such as "Copyright Springer Berlin,
 273 Germany"). Then, country detection was performed using a dictionary of locations
 274 available in the GeoNames database (<http://www.geonames.org>). We implemented a
 275 simple method, applying regular expressions from a list of level-1 administrative units
 276 (countries) and some level-2 administrative units. A comparison between the
 277 locations retrieved and the results yielded by the Aylien API (<http://aylien.com>)
 278 showed that the simple detection of high-level administrative units would be
 279 sufficient to return the location at country level. In most cases the location name is
 280 followed by an indication of the country, such as "Muritz National park (Germany)".
 281 This indication is missing in a few US and Chinese cases for which only the lower-
 282 level administrative unit is given, for example "Everglades National Park (Florida)"
 283 or "Foshan (Guangdong)".

284 The time incidence of the country name as the location studied was then calculated
 285 both for the entire corpus, expressed as "absolute frequency", and for the corpus of
 286 each indicator, expressed as "relative frequency". The difference between the absolute
 287 and relative frequency for a country gives the relative weight of the indicator among
 288 the eleven indicators regarding that country.

289 3 Results

290 3.1 A multi-level final corpus

291 Table 2 shows the gradual, step-by-step evolution of the corpus. Figure 2 shows the
 292 interplay between the datasets. In total, 8129 publications were generated by the
 293 keyword search in step 1. The urban keyword filter in step 2 and the qualitative
 294 sorting in step 3 reduced the number of publications to 896, the final number
 295 analysed. This corpus is further divided into two categories. The first contains 562
 296 publications, 63% of the total, which are considered to be specifically linked to the
 297 topic of urban planning and management. The remaining 37% relate to cities and to
 298 indicators, but are considered not directly applicable to a city planning and
 299 management perspective.

300 There are two main comments to be made on the changes in the number of
 301 publications included in the corpuses. First, the indicators examined are common in
 302 non-urban studies, which suggests that the indicators are not specific to problems
 303 found in urban environments. Second, even when the indicators are associated with
 304 urban settings, the objective of the research may in many cases go beyond the
 305 dimension of urban planning and management.

306 **Table 2 Quantity of publications generated by each step. It should be noted that the "Urban"**
 307 **column also includes publications that scored 0 in the "Qualitative sorting" column, i.e. which**
 308 **are not urban studies but were not filtered in step 2.**

| N° | Indicator | Query (step 1) | Urban (step 2) | Qualitative sorting (step 3) | Papers examined (score 1 and 2) |
|----|-----------|----------------|----------------|------------------------------------|------------------------------------|
| | | | | | |

| | | | | Score | number | |
|----|---|------|------|-------|--------|-----|
| 1 | Ambient air quality | 350 | 206 | 2 | 89 | 142 |
| | | | | 1 | 53 | |
| | | | | 0 | 64 | |
| 2 | Quality of water bodies within the Eco-city | 330 | 144 | 2 | 88 | 119 |
| | | | | 1 | 31 | |
| | | | | 0 | 25 | |
| 5 | Carbon emission per unit GDP | 505 | 92 | 2 | 18 | 70 |
| | | | | 1 | 52 | |
| | | | | 0 | 22 | |
| 7 | Proportion of green buildings | 107 | 33 | 2 | 19 | 30 |
| | | | | 1 | 11 | |
| | | | | 0 | 3 | |
| 10 | Per capita domestic water consumption | 58 | 48 | 2 | 28 | 36 |
| | | | | 1 | 8 | |
| | | | | 0 | 12 | |
| 11 | Per capita domestic waste generation | 46 | 33 | 2 | 27 | 27 |
| | | | | 1 | 0 | |
| | | | | 0 | 6 | |
| 12 | Proportion of green trips | 2312 | 1259 | 2 | 89 | 121 |
| | | | | 1 | 32 | |
| | | | | 0 | 1138 | |
| 13 | Overall recycling rate | 1584 | 169 | 2 | 86 | 123 |
| | | | | 1 | 37 | |
| | | | | 0 | 46 | |
| 15 | Treatment to render solid waste non hazardous | 2155 | 132 | 2 | 21 | 51 |
| | | | | 1 | 30 | |
| | | | | 0 | 81 | |
| 19 | Renewable energy ratio | 620 | 162 | 2 | 67 | 127 |
| | | | | 1 | 60 | |
| | | | | 0 | 35 | |
| 20 | Water supply from non-traditional | 62 | 62 | 2 | 30 | 50 |

| | | | | | | |
|-------|---------|------|------|---|------|-----|
| | sources | | | 1 | 20 | |
| | | | | 0 | 12 | |
| Total | | 8129 | 2340 | - | 2340 | 896 |

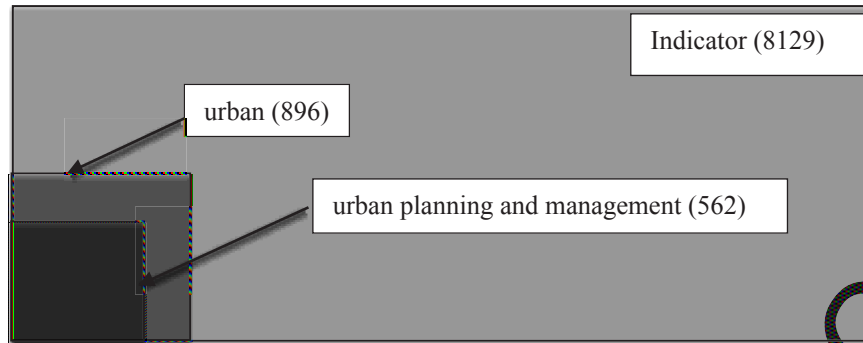


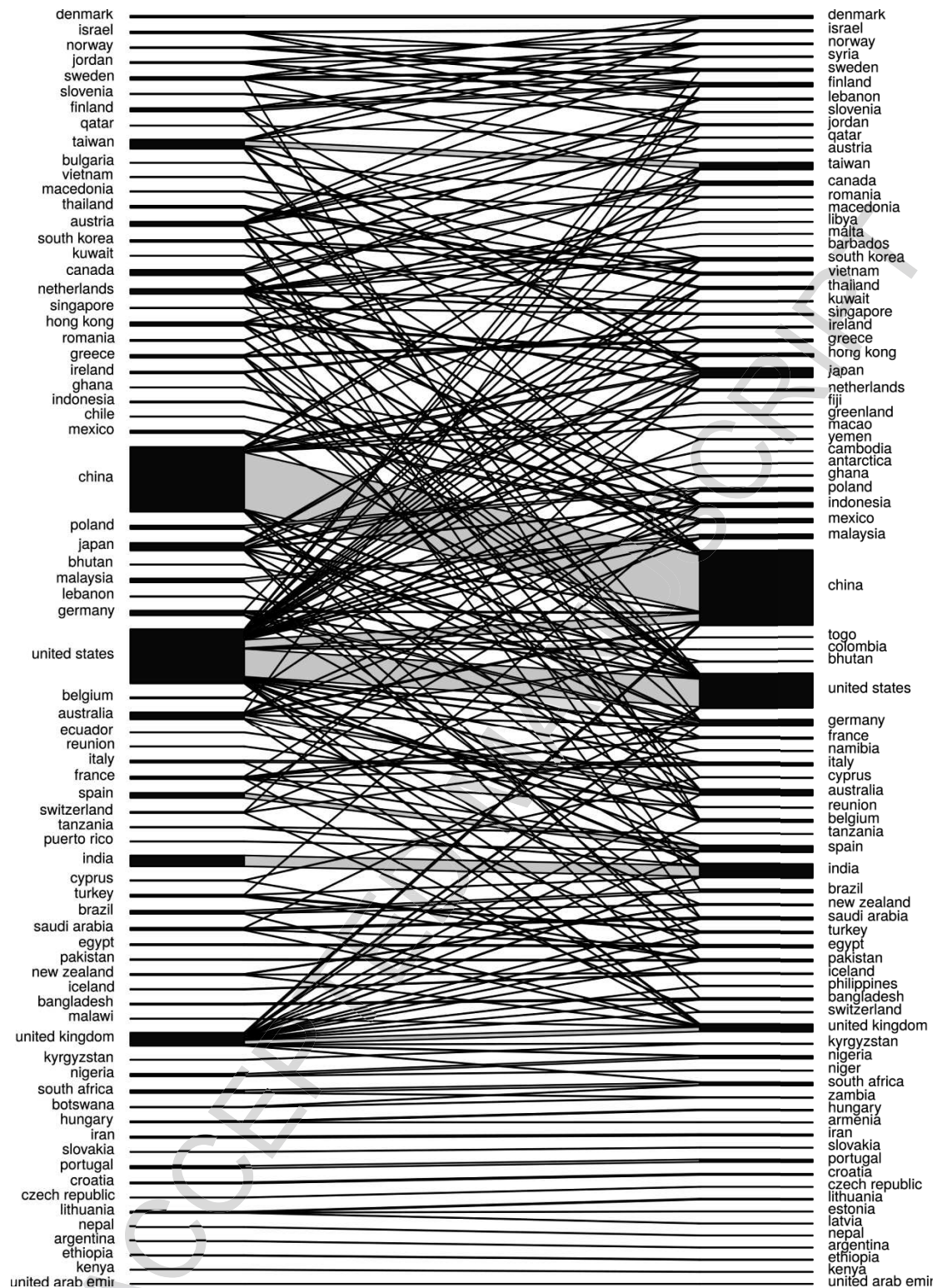
Figure 2 Interplay of the corpuses generated in each step.

309 3.2 Authors' countries and studied countries

310 Figure 3 provides an overview of the links between the authors' countries on the left
 311 and the countries studied on the right. The thickness of the line connecting a country
 312 A on the left and a country B on the right is proportional to the volume of publications
 313 about B produced by authors from A.

314 As can be seen in Figure 3, China and the United States share the first and second
 315 positions on the lists of countries studied and authors' countries, respectively. The
 316 two countries combined account for 40% of the cases studied and 42% of the authors'
 317 origins, far ahead of India and the UK, which are respectively in third place on the list
 318 of countries studied and on the list of authors' countries. Besides the top four, Japan,
 319 Australia, Germany and Spain are well positioned in both lists. Studies relating to the
 320 top 10 countries account for 60% of the total number of publications in the corpus.

321 A dominant share of the studies relating to China are conducted by Chinese authors,
 322 the rest being from the US, Australia, Japan, Singapore, UK, Canada, European
 323 countries, as well as Hong Kong and Taiwan, which have close links with mainland
 324 China. Moreover, the primary research focus of Chinese authors is China, as shown
 325 by the multiple links to China on both the left and right sides of Figure 3. American
 326 authors, by contrast, have far-flung interests across the world. This is further
 327 illustrated by indicator 5 (Figure 7), for which authors from the US publish on 21
 328 countries other than their own, including China.



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Figure 3 Connections between authors' countries and countries studied for the entire indicator set.

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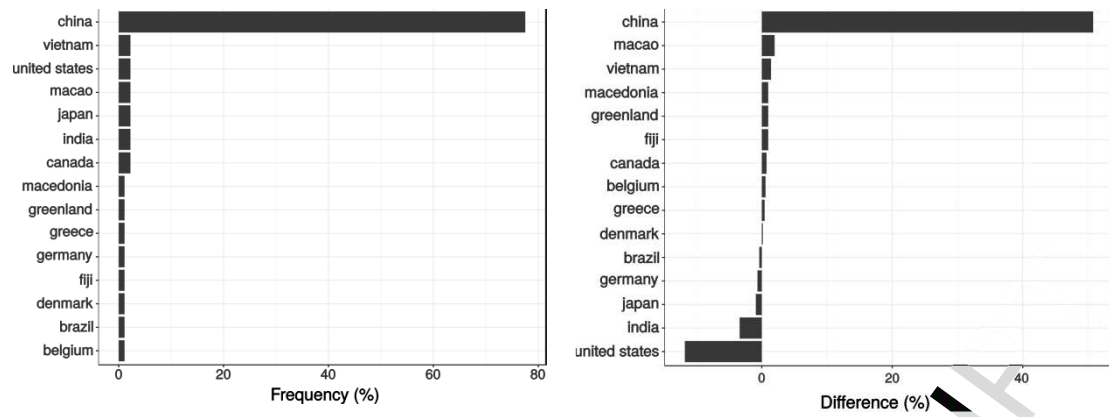
In order to better understand this overall pattern of connections between authors' countries and countries studied, each indicator's situation was further examined. China and the US are no longer in the first two positions when the focus is shifted to individual indicators. The United States is the country most studied for five out of the

336 eleven indicators, including *Ambient air quality*, *Proportion of green buildings*,
337 *Overall recycling rate*, *Treatment to render solid waste non hazardous* and *Water*
338 *supply from non-traditional sources*. China is the country most studied for the other
339 five indicators, including *Quality of water bodies*, *Carbon emission per unit GDP*,
340 *Per capita domestic water consumption*, *Proportion of green trips*, and *Renewable*
341 *energy ratio*.

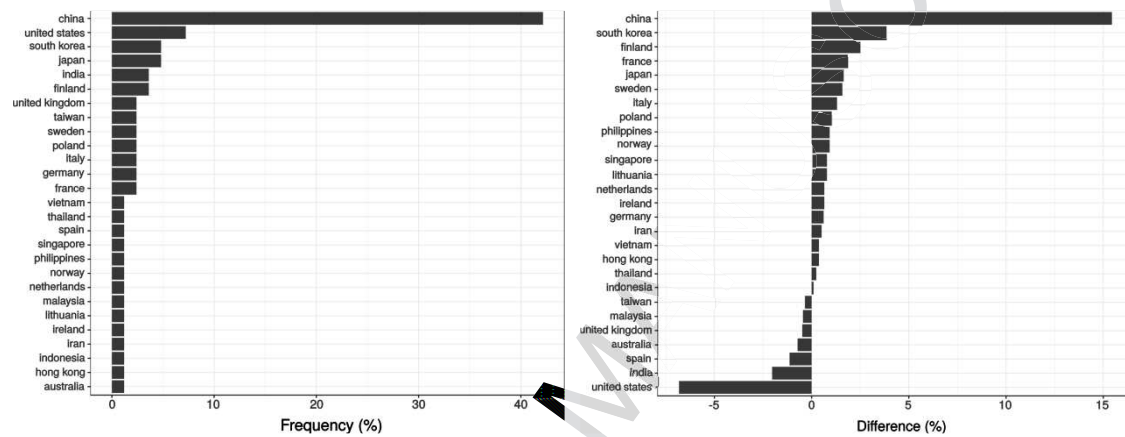
342 Details for each indicator are given in Appendix B. Here only the two most relevant
343 indicators – *Quality of water bodies* and *Carbon emission per unit GDP* – are
344 discussed. Figure 4 and Figure 5 show the absolute and relative frequencies of the
345 countries studied for indicators 2 and 5 respectively. The absolute frequency of a
346 studied country for an indicator was calculated by dividing the number of occurrences
347 of the country by the total number of publications on this indicator. The relative
348 frequency of a studied country for an indicator was calculated as the difference
349 between the number of occurrences of this indicator for the country and the
350 occurrence of all the indicators combined. The relative frequency of a country reflects
351 the weight of the indicator in the set of indicators concerning the country, and
352 therefore provides at least a partial measure of the relative attractiveness to
353 international scholars of the problems in the sector targeted by the indicator compared
354 with other sectors in the country in question. 78% of the publications for *Quality of*
355 *surface water* (Figure 4) and 42% for *Carbon emission per unit GDP* (Figure 5) relate
356 to China. Most of these studies have been conducted by Chinese authors, followed at
357 a considerable distance by American authors (Figure 6 and Figure 7). There are two
358 hypotheses concerning the dominance of Chinese authors for these two indicators.
359 The first is that the perception of surface water quality as an urban concern is a
360 specifically Chinese perspective, rather than one that is widespread elsewhere in the
361 world. Indeed, it is rarely the case that rivers (and to a lesser extent lakes) endure
362 pollution from urban activities alone. The second hypothesis is that the deterioration
363 in surface water quality in China is so serious today that it has become a focus of
364 international research. As to the indicator *Carbon emission per unit GDP*, the
365 dominance of China as an object of study is more likely attributable to the method of
366 normalisation used. The explanation of this is given in 3.3.2-(2).

367 The wide-ranging interest of US researchers is clearly shown by Figure 7 for the
368 indicator *Carbon emission per unit GDP*, where US researchers are observed to have
369 published on 21 countries across the globe besides the United States.

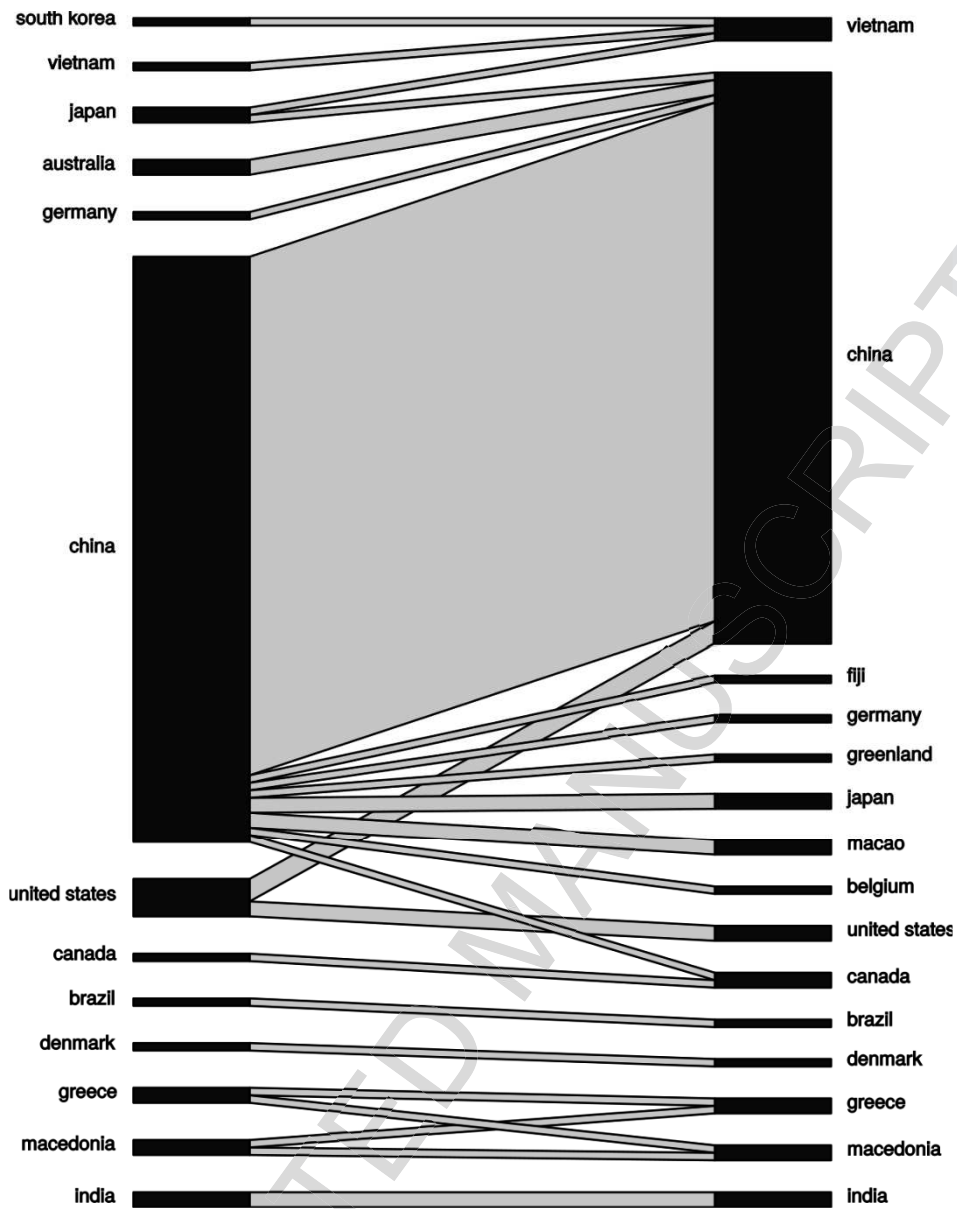
370 It is interesting to note that China does not appear in the corpus for indicator 15,
371 *treatment to render solid waste non-hazardous* (the graphic not shown here), a fact
372 that relates to the definition of the indicator. Detailed explanation is given in section
373 3.3.4.



374 Figure 4 Absolute frequency (left) and relative frequency (right) of countries studied for
 375 indicator 2 -- *Quality of surface water in the Eco-city*.

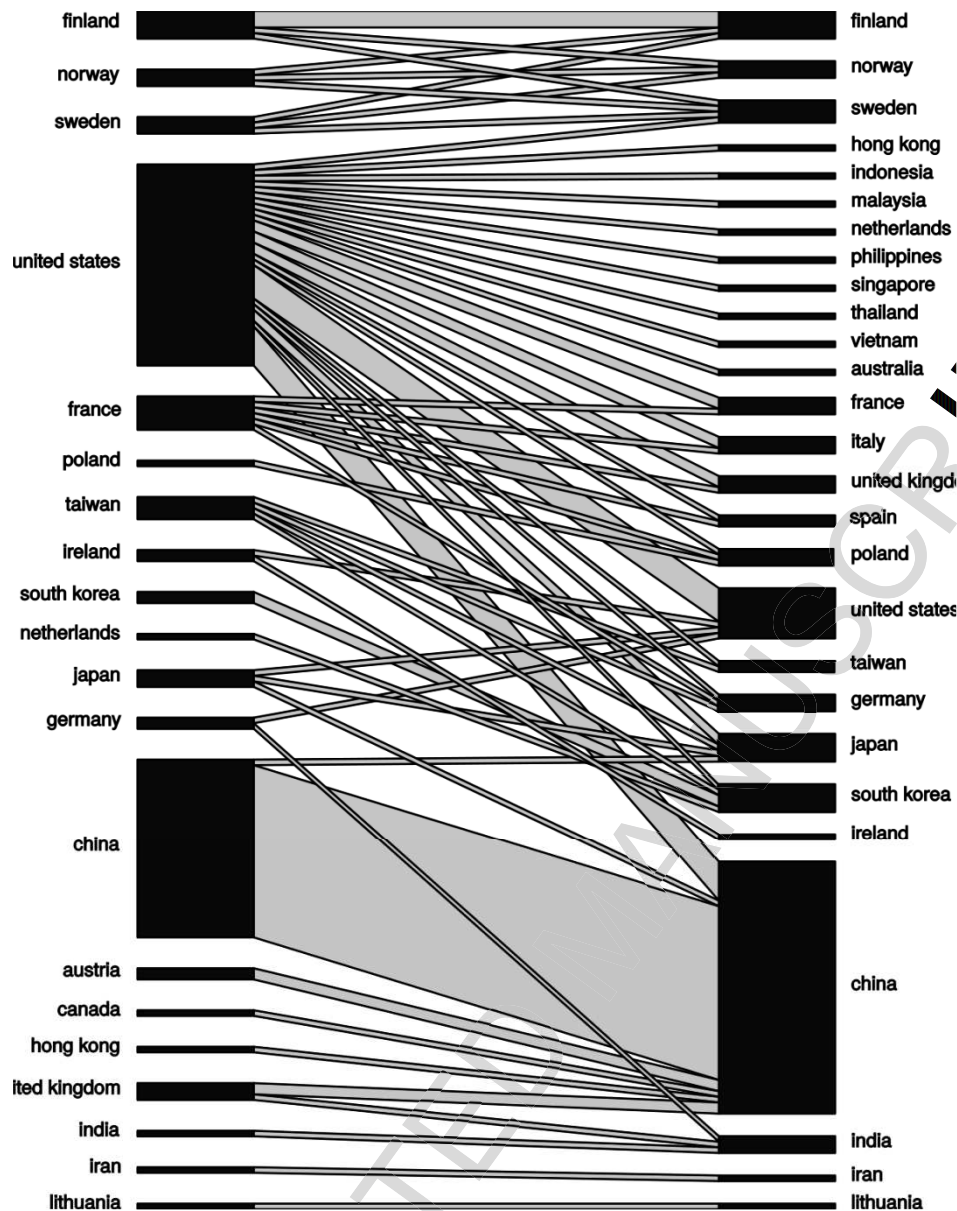


376 Figure 5 Absolute frequency (left) and relative frequency (right) of countries studied for
 377 indicator 5 -- *Carbon emission per unit GDP*.



378

379 Figure 6 Connections between authors' countries and countries studied for indicator 2.



380

381 Figure 7 Connections between authors' countries and countries studied for indicator 5.

382 **3.3 Scientific rationale of the indicators**

383 The eleven environmental indicators are classified into four groups according to their
 384 levels of scientific rationale, as discussed below. A detailed note for the scientific
 385 rationale of each indicator is provided in Appendix-B.

386 **3.3.1 Group 1 Aggregated indicators**

387 There are two aggregated indicators among Tianjin Eco-City's environmental
 388 indicators, which are *Ambient air quality* and *Quality of surface water*. Both
 389 indicators are, in fact, a composition of sub-level indices for individual pollutants
 390 affecting ambient air quality in the first case and surface water quality in the second
 391 case. As can be expected, this type of indicators are made for larger spatial scales and
 392 administrative jurisdictions than those of a city – national level in most cases and
 393 regional level in the case of the European Union. In the case of a city, such as Tianjin

394 Eco-City, it is understandable that city managers apply the sectorial standards that
395 have been developed at national level. On this understanding, a comparison was made
396 between the Chinese national standards and the standards from several developed
397 countries in the present study. The current national air quality standard in China,
398 GB3095-2012, is found generally less strict than that of developed countries such as
399 the United States (NAAQS, <https://www.epa.gov/criteria-air-pollutants>) and the
400 European Union (EU, 2008), which are in their turn less strict than the WHO air
401 quality guidelines (WHO, 2005). For all the criteria pollutants encompassed by these
402 standards, except NO₂, GB3095-2012 is more tolerant than the American and
403 European standards. Especially for PM₁₀ coarse particles, the threshold for 24-hour
404 mean concentration defined in the Chinese standard is 150 µg/m³ for residential
405 zones, which is 3 times that of the European and WHO standards, at 50 µg/m³. It can
406 be argued then, achieving the ambient air quality target as defined by this indicator,
407 should it happen sometime in the future, will still fall far short of guaranteeing air
408 quality in the city with respect to public health.

409 The current Chinese national quality standard for surface water, GB3838-2002, was
410 promulgated in 2002. It is a revised version of the 1983 standard GB3838-83. During
411 the revision, the criterion values were updated, essentially by referencing to the
412 standards of developed countries, including the US, the EU and Japan, given that
413 “*there were no lake nutrient criteria related studies during the revision period for*
414 *GB3838-2002*” (Zhou et al., 2014). As a result, the strictness of the criteria values for
415 pollutants in the GB3838-2002 is quite close to that of the developed countries.
416 Certain thresholds in the Chinese standard are even stricter, as noted by Su et al.
417 (2017). The same authors point out however the lack of contextualisation in the
418 implementation of the standard, stating that GB3838-2002 is “*generally applied (in*
419 *all the lakes) in China without considering the differences in different*
420 *regions...various climates, elevation, geography and other factors*”.

421 It has to be recognized that China needs to consider its economic and social realities
422 (industry-dominant economy, demographic challenge, need of urbanisation...) while
423 making progress in environmental protection. This to some extent explains the lower
424 air pollutant threshold set in the national standard GB3095-2012. Bearing this in
425 mind, the immediate challenge for Chinese environmental protection may not be how
426 to match the standards of developed nations at all costs, but how to develop tailor-
427 made indicators that take local specificities into account.

428 3.3.2 Group 2 Scientifically-sound indicators

429 This category covers the majority of Tianjin Eco-City’s environmental indicators,
430 which are:

- 431 (1) the two proportion indicators, one pointing to the built sector, *proportion of*
432 *green buildings*, the other the transport sector, *proportion of green trips*;
- 433 (2) one of the two energy indicators, *renewable energy*;
- 434 (3) the two indicators of the waste sector, *per capita domestic waste generation*
435 *and overall recycling rate*;

436 (4) and the two indicators on water consumption, *per capita water consumption*
437 and *water supply from non-traditional sources*.

438 These indicators are clearly defined, measurable, widely known and used across the
439 world for the purposes of sustainability assessment and inter-city comparison. Their
440 main advantage is their concreteness and problem specificity – it is easy to interpret
441 the meaning of the indicator and which problem it targets. Because of this
442 concreteness however, these indicators have relatively limited reach and are little use
443 on their own for assessing holistic performance. For instance, while ratios of
444 renewable energy or green trips can be used to measure the level of deployment of
445 renewable energy and low-emission transport facilities in a city, they cannot measure
446 the city's overall sustainability performance in the energy and transport sectors. Not
447 to mention the technical difficulties of accurately calculating the “ratios”, as discussed
448 at the beginning of the paper. Even more bothering, an exclusive focus on these
449 indicators could impede holistic consideration of sustainability -- even at sectorial
450 level -- by overlooking other aspects, such as urban regeneration in the case of *green*
451 *building*, water saving in the case of *water supply from non-traditional sources*,
452 economic viability in the case of *renewable energy use*, the inclusion of informal
453 collectors in the case of *overall recycling rate*, and walkability in the case of *green*
454 *trips*.

455 The conciliation between global and local is another critical question raised by the
456 analysis. On the one hand, there are growing calls for the standardisation of
457 sustainability assessment methods and indicators and intensive research efforts made
458 in that direction (Ecocity Builders, 2015; Eurostat, 2016; Suzuki et al., 2010) . On the
459 other hand, the importance of accounting for regional disparities and local
460 characteristics is increasingly recognised, as noted by Joss et al. (2012): “*indicators*
461 *specify in concrete terms what urban sustainability means to a given community by*
462 *defining the elements and benchmark targets*”. Taking the built sector for example,
463 whilst the leading certification schemes, namely LEED, BREEAM, CASBEE, and
464 France's HQE, have been widely recognised around the world, their use at local scale
465 is far from systematic. This is undoubtedly attributable to the overwhelming
466 enthusiasm of politicians for economic growth, but also to the fact that these
467 certification schemes are not applicable to local contexts (Zhou et al., 2011). In the
468 case of Tianjin Eco-City, all these well-known foreign green building standards, as
469 well as the Chinese national standards (ESGB and EIASGG), were rejected, giving
470 way to a green building standard developed by the eco-city its own, in order that
471 “*local climatic and cultural specificities are taken into consideration during the*
472 *buildings' performance assessment*” (Li et al. 2018).

473 3.3.3 Group 3 Indicator under scientific scrutiny

474 This group concerns one indicator, *carbon emission per unit GDP*. The indicator is
475 conventionally used to assess a city's energy performance, together with another form
476 of normalisation for carbon emissions, namely *per capita*. Despite their widespread
477 use, there is intense debate among scientists over their scientific rationale.

478 The problem is twofold. The first concerns the measurement of carbon emissions.
479 How to accurately measure total greenhouse gas (GHG) emissions for a given city, in
480 a global context of increasing interaction between economic activities? Should
481 indirect emissions from local production and consumption be counted in the total
482 GHG? How should emissions relating to import and export activities be counted for?
483 Despite the efforts of scholars to answers these questions (Ala-Mantila et al., 2014;
484 Ramaswami and Chavez, 2013), we seem to be a long way from any universal
485 agreement. The second problem concerns the two possible ways of standardising total
486 emissions, namely *per capita* or *by GDP*. Normalising the total emissions of a city by
487 capita or by GDP can lead to contrasting results. For example, Price et al. (2013)
488 reported the carbon emission of two large cities in China, Beijing and Chongqing.
489 Both cities were found to be 20 times more carbon-intensive than international cities
490 when assessed using the GDP-based indicator, but show a similar scale of carbon
491 emissions with the per capita indicator. The authors conclude that indicators of CO₂
492 emissions per unit of GDP or per capita were too aggregated, and cannot fully explain
493 end-use energy consumption and emissions within a city.

494 3.3.4 Group 4 Indicator lacking scientific foundation

495 *Treatment to render solid waste non-hazardous* is the indicator that seems to be the
496 most problematic of the eleven. First, the literal definition of the indicator is
497 confusing. To all appearances this indicator relates to hazardous waste such as
498 electronic or medical waste. In fact however, as explained in “Navigating the Eco-
499 City”, the indicator is a portmanteau of multiple waste-treatment goals that basically
500 refer to two fundamental issues in the waste treatment sector. The first is hazardous
501 waste, a term that refers to byproducts of the medical, industrial or construction
502 sectors, and listed in relevant legislative documents promulgated by the Chinese
503 authorities. The second issue concerns the so-called “solid domestic waste”, which
504 refers to all the waste generated by urban human activities, with the exception of the
505 three types of hazardous waste mentioned above. Rendering this kind of waste “non-
506 hazardous” means “*setting up an appropriate hierarchical disposal system through*
507 *landfill, biological treatment, recycling, incineration and energy-recover facilities*”
508 and “*assuring that the emissions from each of these procedures meet the relative*
509 *national standards*”. As a whole, the indicator “treatment to render solid waste non-
510 hazardous” means “*to proceed to non-harmful disposal of the hazardous waste and*
511 *solid domestic waste in order that the harmful substances contained in these wastes*
512 *meet the current national or sectorial pollutant discharge standard*” (Tianjin Eco-
513 city, 2010). The value of the indicator will be a calculation of the ratio between the
514 quantity of hazardous/solid waste that has been rendered “non-hazardous” and the
515 total quantity of such waste generated in the eco-city before disposal.

516 Having clarified the definition of the indicator, we can now fairly safely argue that the
517 indicator should be replaced by one or more indicators that will be simpler, more
518 concrete and more problem-focused, in a nutshell, more scientifically sound. It would
519 be interesting to know why the indicator has been formulated in this way, but that is
520 beyond the scope of this paper. Here we will be content to note that the United

521 Nations sets separate guidelines for the indicators on “waste treatment and disposal”
522 and “generation of hazardous waste” (United Nations, 2007).

523 **4 Discussion and conclusion**

524 In this paper, we have conducted a comprehensive bibliometric investigation into the
525 scientific rationale for the environmental indicators used in the Tianjin Eco-City KPI
526 system. To our knowledge, this is the first time that the well-known Tianjin Eco-City
527 KPIs have been scientifically studied, and also the first time that a set of real-case
528 environmental sustainability indicators has been addressed as a whole.

529 The results reveal above all that the Tianjin Eco-City KPIs are far from being a
530 system specifically dedicated to the urban scale, but are applicable to a city, to a
531 region, or to a country. This is in fact not so surprising if two realities are recognised:
532 1) that the boundaries between urban and rural are increasingly blurred, both
533 conceptually and in practice; and consequently 2) that no one can tell today how
534 *urban sustainability* might differ from *sustainability* in general. There are actions and
535 programmes dedicated to both themes, but the difference between urban and non-
536 urban sustainability is never specifically discussed and the formulation is more likely
537 to be case-specific (*urban sustainability* when the case studied is a city and
538 *sustainability* otherwise) than to be based on a scientific rationale. Suffice it to say
539 that applying nationwide sustainability indicators to a city without contextual
540 adaptation could lead to inappropriate measures and unwanted consequences. In the
541 case of Tianjin Eco-City, the course of the river within the jurisdiction of the
542 Administrative Committee has been artificially cut off from the polluted river
543 upstream, so that surface water quality inside the city meets the requirements of the
544 indicator (Li et al., 2018), a pragmatic measure that can safely be described as
545 unsustainable.

546 That having been said, most of the environmental indicators from Tianjin Eco-City
547 are found to be scientifically relevant, which means that they are clearly defined,
548 problem-oriented, measurable and widely used by the international community
549 involved in urban sustainability. This is the case, for example, of *per capita domestic*
550 *water consumption* and *renewable energy ratio*. Nonetheless, there is still the
551 challenge of how to standardise measurement/calculation of the indicator and how to
552 gear considerations towards holistic urban sustainability by avoiding excessive
553 attention to one facet at the expense of the others.

554 As for the two indicators taken from the national standards on ambient air quality and
555 surface water quality, the question concerns the rationality of applying the national
556 scale indicators to city-level management. Clearly, the eco-city's managers can do
557 little about upstream water pollution outside the city (except through drastic measures
558 such as cutting the water course), or about air pollution originating from other parts of
559 Tianjin and north China. In other words, meeting air and water quality targets depends
560 less on measures taken inside the eco-city than regional and national policies. In
561 consequence, the relevance of setting such indicators at eco-city scale, though
562 politically acceptable and necessary, is questionable.

563 The differences in the scientific rationale for Tianjin Eco-City's environmental
564 indicators are further reflected in their dispersal across the international scientific
565 literature, as revealed by our geographical analyses. The connections between the
566 authors' country and the country studied for the whole set of indicators clearly
567 confirm that China remains the hotspot of world research on environmental
568 sustainability, and that the Western world (US, Europe, Japan, etc.), to which China
569 has turned for finding new planning strategies and technical environmental solutions
570 during the recent decades, maintain their interests in China's urban and ecological
571 transition. Furthermore, the eco-city's environmental indicators, at least the main ones
572 that have been selected in this study, are consistent with the major challenges in
573 making sustainable cities that have been recognised by international scientists: urban
574 air pollution, clean energy use, traffic congestion, CO₂ emissions, water saving and
575 reuse, waste reduction, etc. These challenges are a matter of debate in a wide range of
576 countries across the world, as shown by our geographical analysis. Two of the eleven
577 indicators are found to be very "Chinese", namely *Quality of water bodies* and
578 *Carbon emission per unit GDP*, for which papers about China account for 78% and
579 42% of the corpus, respectively. Since the possible reasons of this have already been
580 developed, here we will focus on two important issues revealed by these indicators:

- 581 • Should trans-boundary pollution, such as that of a river, be defined as the
582 responsibility of a city and incorporated into the assessment of the city's
583 sustainability performance? While the answer is *a priori* negative, in a country
584 like China where administration is highly segmented, strictly top-down, and
585 framework for watershed management has yet to be built, it seems difficult to
586 see other ways to tackle the watercourse pollution problem that has already
587 become critical.
- 588 • Bundling environmental performance with economic outcome, as embodied
589 by the indicator *Carbon emission per unit GDP*, to some extent reflects the
590 tricky choice between economic growth and environmental protection in
591 Chinese cities, at a time when a balance between economic and environmental
592 objectives remains to be found, whether in China or elsewhere. Still,
593 measuring pollution in relation to GDP is fraught with risk as it presupposes
594 that "you can continue to pollute if it creates enough growth".

595 Based on the bibliometric analyses presented in this article, we made the following
596 recommendations on sustainable city indicators:

- 597 • The nature of existing indicators should be defined if these indicators are to
598 be recycled in a new system. Local conditions and the characteristics of the
599 (eco-city) project are main factors that impact the suitability of the indicators
600 in the specific setting. In case where an indicator is an aggregated one or/and
601 has been made for national- or regional-scale management, such as those used
602 for air quality and water quality in Tianjin Eco-city, the applicability of the
603 indicator in the new setting should be considered with caution.
- 604 • The exact definition of an indicator should be clearly understood, and its
605 scientific rationale sufficiently evaluated. An indicator is a highly synthetical

606 thus simplified expression of sustainability goals, and this simplicity could
607 easily lead to inexact even incorrect interpretation of the goals. Exact
608 understanding of the meaning of the indicator is a pre-condition for
609 evaluating its scientific rational, which in its turn impact the utility and
610 exportability of the indicator.

611 • Last but not least, an indicator system embodies its makers' understanding of
612 and preference to sustainability, thus its nature and scientific rational can be
613 conditioned by the makers' speciality. It is thus of importance to investigate
614 the construction process of an indicator system – who made the indicators,
615 how were the indicators selected – before taking the system as a reference.

616 The scientific contribution of this paper is three-fold. First, it is the first time that the
617 Key Performance Indicators of Tianjin Eco-City is analysed, with a focus on their
618 scientific rationale. To our knowledge, it is also the first time that a set of urban
619 environmental indicators is analysed about scientific rationale. Second, instead of
620 higher-level social-economic reflections, we deal with the most basic one among the
621 three pillars of sustainability, environment, in which field problems are far from being
622 solved, especially in rapidly urbanised countries like China. We suggest environment
623 performance of our cities remain an issue to be tackled and should not be overlooked.
624 Third, we show a picture of the consilience and contrast between Chinese perception
625 of urban environment performance and international ones. The information revealed
626 is expected inspirational both for Chinese and international specialists in
627 sustainability.

628 Finally, our work has limitations. The most significant is perhaps the source used for
629 the bibliometric survey. We used bibliometric tools to sample the most relevant
630 academic publications in Scopus that contain environmental indicators that overlap
631 with the Tianjin Eco-City KPIs. However, urban development and sustainability are
632 core concerns not only for academics, but also for policymakers, practitioners,
633 consultants, think tanks, environmental industries, non-governmental organisations,
634 economists, the media.... Writings produced by these actors, such as reports, policy
635 documents and technical manuals, may not be published in scientific journals.

636 **5 Acknowledgements**

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640 of Technology for his helpful comments on an earlier version of the manuscript.

641 **Appendix**642 **A. Keyword query per indicator**643 **Table 3 Search terms employed and the number of publications found in each step.**

| N° | Indicator | Query in Scopus |
|----|---|--|
| 1 | Ambient air quality | TITLE-ABS-KEY ("Ambient Air Quality" AND "days") AND PUBYEAR > 1999 |
| 2 | Quality of water bodies within the Eco-city | (TITLE-ABS ("surface water" W/2 "quality Standard")) OR (TITLE-ABS-KEY ("Quality Standards for Surface Water" OR "surface water environmental quality standards" OR "standard of Environmental Quality Standards for Surface Water" OR "surface water environment quality standard" OR "surface water quality standards" OR "water quality standards for surface water")) AND PUBYEAR > 1999 |
| 3 | Carbon emission per unit GDP | (TITLE-ABS-KEY (((carbon OR "CO2" OR "greenhouse gas" OR "GHG") W/2 emission) AND ("per unit of GDP" OR "per unit GDP" OR "per GDP indicator" OR "per unit of gross domestic product")) OR "CO2 intensity" OR ("tons of carbon equivalent" AND (gdp OR "gross domestic product"))) AND PUBYEAR > 1999 |
| 4 | Proportion of green buildings | TITLE-ABS-KEY (("Sustainable buildings" OR "Green Buildings" OR "High-performance buildings" OR "eco construction" OR "ecoconstruction" OR "sustainable construction" OR "green construction" OR "eco architecture" OR "eco architecture " OR "sustainable architecture " OR "green architecture") W/1 (proportion OR rate OR ratio OR percentage)) AND PUBYEAR > 1999 |
| 5 | Per capita domestic water consumption | TITLE-ABS-KEY (("domestic water consumption" OR "Household water consumption" OR "Residential Water consumption" OR "water consumption of Household") AND ("per capita" OR "per person" OR "per habitant" OR "per citizen" OR "per resident" OR "per inhabitant")) AND PUBYEAR > 1999 |
| 6 | Per capita domestic waste generation | TITLE-ABS-KEY (((("waste generation" OR "waste production" OR "generation of waste") W/3 domestic) OR "domestic waste") AND ("per capita" OR "per person") AND ("kg" OR kilogram OR ton)) AND PUBYEAR > 1999 |
| 7 | Proportion of green trips | TITLE-ABS-KEY ("low carbon transportation" OR "low carbon transport" OR "green trip" OR "green transport" OR "green transportation" OR "sustainable transportation" OR "sustainable transport" OR "eco mobility" OR "ecomobility") AND PUBYEAR > 1999 |
| 8 | Overall recycling rate | TITLE-ABS-KEY (("recycling rate" OR "recycling ratio" OR "recycling performance")) AND PUBYEAR > 1999 |
| 9 | Treatment to render solid waste | (TITLE-ABS-KEY ((nonhazardous OR (toxic W/1 non) OR (hazardous W/1 non)) AND (waste AND NOT wastewater)) AND PUBYEAR > 1999) |

| | | |
|----|--|---|
| | nonhazardous | |
| 10 | Renewable energy usage | (TITLE-ABS-KEY ("Renewable energy usage" OR "Renewable energy utilization" OR "Renewable energy use")) AND PUBYEAR > 1999 |
| 11 | Water supply from nontraditional sources | TITLE-ABS-KEY ((urban OR city OR town) AND ("water reuse" OR "rain water harvesting" OR (water AND "non-traditional sources") OR "non-traditional water sources" OR (water AND "alternate sources") OR (water AND "alternative sources") OR "alternate water sources") AND ("per capita" OR "per person" OR "per inhabitant" OR "m3/d" OR "gal" OR "litre" OR "liter" OR "m/day" OR proportion OR percentage)) AND PUBYEAR > 1999 |

644 B. Notes per indicator on the scientific rationale

645 B.1 Indic 1 Ambient air quality

646 Clean air is recognised as a basic requirement of human health and well-being. The
647 primary factors of ambient air quality include land use, traffic emissions, industrial
648 emissions, biomass burning and trans-border air movement (Ling et al., 2010). Many
649 countries have set their own air quality standards. The most frequently cited standard
650 is the US Environmental Protection Agency's National Ambient Air Quality
651 Standards (NAAQS). Of the 144 studies scored 1 or 2, 50 use the NAAQS, of which 9
652 are about areas outside the United States. The second mostly used standard is the
653 Chinese Ambient Air Quality Standards (GB3095-2012), with 20 occurrences,
654 followed by the Indian National Ambient Air Quality Standards, 14 occurrences. The
655 European Union Air Quality Standard (EU, 2008) is commonly applied in European
656 Member States. The World Health Organisation guidelines (WHO, 2005), which set
657 lower guideline values for air pollutants than those of national standards, is only
658 referred to in 4 of the 144 studies.

659 Few studies address the relevance of the standards themselves. Among them, Tao et
660 al. (2015) monitored air quality and hazy weather conditions on an urban site in
661 Guangzhou, and found that the incidence of hazy weather was not reduced as much as
662 expected, because of humidity. The authors therefore suggested more stringent PM_{2.5}
663 guideline values in the national standard, with a distinction between dry and wet
664 conditions. J. Hu et al. (2015) found that the current Chinese air quality index based
665 on the maximum value of individual pollutants underestimated the severity of the
666 health risk associated with air pollution caused by multiple pollutants.

667 As to the metrics of air quality, maximum daytime hourly value is probably the most
668 representative indicator, because the daytime concentration profile of the pollutants is
669 influenced by meteorological drivers and anthropogenic activities. In Chinese cities,
670 except for ozone (Shan et al., 2008), there is *a priori* not distinction between
671 weekdays and weekend (Hu et al., 2014), probably because of the relatively
672 homogeneous patterns of urban activity within Chinese cities across the week.
673 Andrews (2008) was the sole author who questioned the current air quality metrics
674 used in China. By analysing the discrepancy between reported 'Blue sky' days in
675 Beijing and published monitoring station data for the period 2002-2007, the author

676 observed that the reported improvements in air quality were more attributable to
677 deficiencies in the metrics than to tangible air quality improvement.

678 B.2 Indic 2 Quality of surface water in the eco-city

679 The first finding for this indicator is that Chinese studies, *i.e.* both the authors and
680 case study are Chinese, represent a majority of the corpus. Nevertheless, of the 119
681 papers retained, no one investigates urban water quality from a planning perspective.
682 The studies focus mostly on surface water sampling and chemical analysis of the
683 water quality. This finding has two implications. The first is the cross-boundary
684 nature of the water quality deterioration, of which contributors go beyond urban
685 activities. For example, intensive use of pesticides in rural areas is a main contributor
686 to water body deterioration. Second, the quality of watercourses should be managed
687 by basin and not by administrative jurisdictions. Integrated river basin water
688 management (IRBM) is governance approach of surface water in Europe (EU, 2008).
689 China is also on its way to setting up its own IRBM systems (NPC, 2002). Clearly
690 then, surface water quality goes beyond the scope of city planners and managers.

691 The current National Environmental Quality Standard for Surface Water in China,
692 GB3838-2002, promulgated in 2002, is the third revision of the 1983 standard
693 GB3838-83. In GB3838-2002, the guideline values were mostly set in reference to the
694 standards of certain developed countries (US, EU and Japan), in a context where
695 “*(there was) not lake nutrient criteria related studies during the revision period for*
696 *GB3838-2002*” (Zhou et al., 2014). Therefore, the stringency of the guideline values
697 set in the Chinese standard is similar to, and sometimes even more stringent than that
698 from other countries. However, there seems a lack of consideration of local conditions
699 when the guideline values were chosen. Chinese authors Su et al. (2017)
700 acknowledged the findings of Ding et al. (2015) and noted that GB3838-2002 is
701 “*generally applied (in all the lakes) in China without considering the differences in*
702 *different regions...various climates, elevation, geography and other factors*”. Besides,
703 Ma et al. (2015) indicate that the current water quality identification indices in the
704 GB3838-2002 do not consider the degree of importance of each parameter.

705 B.3 Indic 5 Carbon emission per unit GDP

706 Only 69 out of 505 search-generated articles (step 1 and 2) are urban studies, which
707 indicates that greenhouse gas (GHG) emissions is a concern that crosses the boundary
708 between urban and rural. The examination of the articles’ abstracts reveals that the
709 development of scientifically sound approaches of emission assessment remains a
710 topic of debate. Scholars disagree on a multiple of issues, as described below.

711 1) GHG emissions calculation

712 Numerous questions about how to accurately calculate total GHG emissions for a
713 given country or city remain unsolved. These include: Should indirect emissions from
714 local production and consumption be left out of total GHG emissions? Should GHG
715 from infrastructures and local community consumption be included? How do you
716 account for emissions associated with import and export? Despite of the efforts made

717 by many researchers on questions (Ala-Mantila et al., 2014; Ramaswami and Chavez,
718 2013), there seems to be a long way to go before any universal agreement be found.

719 2) Normalisation

720 Indicators of GHG intensity build generally on a normalisation by GDP - this is the
721 case for Tianjin Eco-City - or per capita. Depending on specific conditions, these two
722 normalisations methods may lead to contradictory results. In a comparative study
723 conducted by Price et al. (2013), for instance, the two Chinese cities studied, Beijing
724 and Chongqing, were found to be 20 times more carbon intensive than international
725 cities as calculated by the GDP-based indicator, while they manifested similar scales
726 of carbon emissions according to the capita-based indicator. The authors argued
727 furthermore that indicators of CO₂ emissions per unit of GDP or per capita were too
728 aggregated and could not fully explain end-use energy consumption and emissions in
729 a given city. They developed therefore a composite end-use low-carbon indicator that
730 took into account, for a given city or country, both the normalised per-sector energy
731 consumption and the percentage contributions of the end-use sectors to total local
732 energy use.

733 3) Energy consumption and GHG emissions

734 Last but not least, energy consumption and GHG emissions should be distinguished
735 even though they are closely connected. Between them lies a hidden variable – carbon
736 intensity in energy supply – which expresses the amount of carbon emitted per unit of
737 energy and depends on the energy fuel mix (Ramaswami and Chavez, 2013). In
738 concrete terms, a decline in a city's GHG emissions does not necessarily imply better
739 energy-saving policies, since it can be a consequence of, say, a global shift from coal
740 to renewable energy in national energy production.

741 B.4 Indic 7 Proportion of green buildings

742 The quantity and diversity of green building rating systems around the world is
743 increasing. The current frontrunners include LEED (USA), BREEAM (UK),
744 CASBEE (Japan) and, to a lesser degree, France's HQE. In China, two standards co-
745 exist, which are, ESGB promulgated by the Ministry of Construction, and EIASGG
746 by the Ministry of Environment. Their on-ground implementation is, however, not for
747 granted. A convincing example is Tianjin Eco-City, which has established its own
748 green building standard. in order that "*local climatic and cultural specificities are*
749 *taken into consideration during the buildings' performance assessment*" (Li et al.
750 2018). Vij (2010) advocated for developing countries to produce their own
751 assessment and rating tools which cater to their '*specific concerns and factors in the*
752 *local building industry and construction standards*'.

753 In broad terms, the proportion of green buildings is an indicator frequently used to
754 appraise sustainability. Paradoxically, however, it is not easy to find rankings of cities
755 or countries based on the proportion of green buildings. According to a report by
756 Mohan and Loeffert (2011), approximately 5% of buildings in the United States were
757 LEED certified green buildings as of 2011.

758 Buildings have been recognised as major consumers of energy and emitters of
759 greenhouse gas, so it is understandable that the quantity of green buildings in a city
760 represents to a certain level its performance as regard to sustainability. As
761 certification schemes for green buildings have become increasingly popular, it seems
762 crucial today to clarify how these international and local schemes differ from one
763 another. All of them undoubtedly cover factors such as energy efficiency, reduced
764 carbon emissions, rainwater recycling and reuse, etc. What is interesting to know is
765 how the indicators for the same factor are differently defined in different certification
766 systems. More importantly, constructing green buildings should not be a goal in itself,
767 but a way of achieving tangible sustainability outcomes. The undue enthusiasm for
768 green building labelling and for the construction of new buildings to be labelled can
769 blind us to the importance of renovating existing buildings. As Onat et al. (2014)
770 remarked, *'focusing on the construction rate of net zero or high performance green
771 buildings alone did not help with stabilising or reducing GHG emissions unless the
772 retrofitting of existing residential building stock was seriously considered as a strict
773 policy along with green building policies'*. Should a city district that consists
774 exclusively of new green buildings with old buildings entirely demolished be
775 considered more sustainable than a district where old buildings have been preserved
776 and retrofitted but without being able to be labelled as green buildings?

777 B.5 Indic 10 Per capita domestic water consumption

778 Residential water consumption is an essential field of urban planning (Troy and
779 Holloway, 2004). Our review shows that per capita consumption is the indicator
780 commonly used to measure domestic water demand and to plan water supply.

781 Water demand is expected to increase in coming years as a result of climate change,
782 especially in arid and semi-arid regions (Yan, 2013). Rain water harvesting and water
783 reuse offer two major water supply alternatives. While it is obvious that reuse policies
784 can save large quantities of water from potable sources (Gonzalez et al. 2011), public
785 perception has proved to be a big challenge to the implementation of such policies. It
786 has been found that the public tends to be more supportive of low-contact reuse, less
787 so for higher-contact reuse (Friedler and Lahav, 2006; Matos et al., 2013). It is thus
788 recommended to use holistic tools, which assess not only technological and
789 environmental benefits but also socio-cultural, institutional and economic factors
790 when water reuse is planned (Garcia et al., 2015; Rahman et al., 2010; Urkiaga et al.,
791 2008). Furthermore, the question of alternating water sources should be considered
792 within a broader category of urban water management (Capodaglio et al., 2016).

793 With regard to technological possibilities contributing to better management of urban
794 water demand, automated water meters are proved to be efficient appliances because
795 of their monitoring capacity. The installation of such equipment can lead to an
796 immediate reduction in water use (Harutyunyan 2012; Joo et al. 2015).

797 While there are growing international calls for water conservation, current pricing
798 policies for this fundamental and inelastic need are seemingly inconsistent with the
799 international consensus (Salman et al., 2008). A survey in the city of Qingdao, China,
800 shows that the average proportion of household expenditure on water is no more than

801 0.40% (Jin et al., 2015). Harutyunyan (2012) found that water consumption would
802 rebound after a short, though sharp decline following the installation of water meters,
803 if water prices were not adjusted at the same time. Similar finding have been reported
804 by Fielding et al. (2013).

805 There seems to be a need for technological improvement in household appliances in
806 order to avoid waste. In the UK, 10% of daily per capita household water
807 consumption is caused by waiting for tap water to become hot (Nawaz and Waya,
808 2014). Separate indicators for cold and hot water consumption might provide a better
809 guide to action than aggregated per capita water consumption.

810 B.6Indic 11 Per capita domestic waste generation

811 *Per capita per day* is a conventionally used norm for measuring the rate of urban
812 waste generation, alongside its two alternatives, *per week* or *per year*. The lack of
813 international standards and methodologies for characterising urban solid waste is
814 recognised to be problematic: the content of reported waste may vary from one city to
815 another, making intra-city comparisons difficult (Edjabou et al., 2015). An example of
816 this concerns Chinese cities. While one study reported a waste generation rate of
817 1.08 kg/person/day in Chongqing (Hui et al., 2006), another study showed a very low
818 rate of 0.23 kg/person/day in Beijing (Qu et al., 2009). The stark contrast between the
819 two Chinese megacities is less likely a reality than an artefact of possible differences
820 in the method of measurement.

821 Of equal importance are the manner and the extent to which socio-economic
822 conditions influence waste generation. Findings on this issue diverge. Gomez et al.
823 (2008), Sujauddin et al. (2008) and Ogwueleka (2013) found positive correlation
824 between household income and per capita waste generation, whereas Phuntsho et al.
825 (2010) reported an absence of ‘conclusive result’ between the two. Qu et al. (2009)
826 even found negative correlation between household size/income and waste
827 generation. In general terms however, economic and policy incentives such as ‘pay-
828 as-you-throw’, and spending on education, are found to be effective measures for
829 reducing waste generation (Grazhdani, 2016).

830 B.7Indic 12 Proportion of green trips

831 Sustainable transport is a pre-requisite for a sustainable city (Wadhwa, 2000). To
832 date, however, there is no generally accepted definition of sustainable transport, or its
833 variant, “green trips” used in Tianjin Eco-City. Indeed, indicator occupies a core
834 position among urban transport studies (Buzási and Csete, 2015). Baggen and Aben
835 (2006) suggest using time, price and comfort as criterion to compare the performance
836 of urban transport solutions. Jiang et al. (2013) developed a system of 26 indicators to
837 measure transport sustainability in Chinese cities. Among the indicators, “public
838 transport and non-motor share (%)” is similar with Tianjin Eco-City’s green trips
839 indicator.

840 Developing a transit network that offers a variety of transport options and favouring
841 walkability is the primary policy for city sustainability (Haghshenas et al., 2015; Wey
842 and Hsu, 2014). Assessing the performance of a city’s transport system is an

843 extremely complex task, bound up with issues such as renewable energy use, GHG
844 emissions, and socio-economic reliability. As Kasperska (2015) says, “*How to*
845 *minimise the costs generated by the development of innovative transport*
846 *infrastructures and offset them by environmental and social gains is still a challenge*”.
847 In light of this, a high green trip proportion alone suffices hardly to make transport
848 sustainable, not to mention the difficulties in appropriately computing the so-called
849 “green trip proportion” (Cottrill and Derrible, 2015; Schipper, 2002). Similar with
850 renewable energy development, sustainable transport is intertwined with a large board
851 of questions of the urban system and requires holistic approaches to tackle with.
852 Integrated analytical and decision-making support tools are thus needed for the make
853 of sound urban transport policies (Praticò and Vaiana, 2012).

854 B.8 Indic 13 Overall recycling rate

855 Recycling rate is a widely used indicator for assessing waste management in cities,
856 aside indicators of waste generation and collection. Another indicator often used is
857 “equivalent CO₂ emissions” (Wilson et al., 2012). Kaila (2013) addressed the issue of
858 potential hazardous substances in recycled and re-used materials and suggested using
859 material flux to different types of sinks as an indicator of waste management
860 performance. Harder et al. (2008) proposed a Maximum Practicable Recycling Rate
861 Provision indicator for measuring the percentage of local waste that could be recycled
862 by the existing municipal services. The European waste management programme
863 ACR+ (De Clercq and Hannequart, 2010) makes recommendations on setting
864 common indicators for European countries. Wilson et al. (2015) developed a set of
865 indicators on the basis of two overlapping “triangles” defined by UN-Habitat: one
866 triangle containing the three physical components, i.e. collection, recycling, disposal,
867 and one triangle containing the components of governance, i.e. inclusivity, financial
868 sustainability and proactive institutional policies.

869 In Western countries, the transition from landfill to integrated urban waste
870 management has almost been accomplished, though challenges remain in terms of
871 disparities between areas (Clarke and Maantay, 2006; Rudden, 2007). In these
872 countries, the focus of research has shifted from technical issues relating to public
873 services to the socio-economic factors of neighbourhood scale recycling rate. For
874 instance, Clarke and Maantay (2006) developed a Recycling Education, Awareness,
875 and Participation index for measuring the socio-economic variables of recycling rates
876 in urban districts. In developing countries where municipal waste collection and
877 recycling are largely carried out by the informal recycling sector (individual waste-
878 pickers), it is crucial to incorporate this sector into the waste management network in
879 order to create synergies around sustainable waste management targets. This
880 integration is believed by many scholars to offer an opportunity for win-win solutions
881 (Linzner and Salhofer, 2014; Sim et al., 2013; Tirado-Soto and Zamberlan, 2013).

882 B.9 Indic 15 Treatment to render solid waste non-hazardous

883 According to “Navigating the Eco-city” (Tianjin Eco-city, 2010), this indicator refers
884 to the proportion of the total waste produced in the eco-city that are rendered non-
885 hazardous. This includes: 1) treatment of dangerous and toxic waste generated by

886 medical, industrial and construction activities; and 2) treatment of domestic through
887 recycling, re-use, biological methods, incineration and landfill. In the book, the
888 authors provide a further explanation relating to point 2):

889 *“the first form (recycling and re-use) is considered by default as non-*
890 *hazardous treatment, the second (biological) and third (incineration)*
891 *forms need to meet requirement by relevant standards; (as to) the fourth*
892 *form (landfill), it is obligatory to assure non-hazardous landfilling.”*

893 In a nutshell, this indicator is not restricted to *hazardous* solid waste as sensibly seems
894 to be, but to all solid waste. It can therefore be reformulated more generically, for
895 example as *safe treatment and recycling of solid waste*.

896 After this definition clarification, it will come as little surprise that the corpus shrunk
897 very substantially after the two filters for urban (step 2 and 3), from a considerable
898 volume following the keyword search on non-hazardous (Table 2). Among the papers
899 retained, we can cite Farzadkia et al. (2009) who points out the absence of appropriate
900 separation of hazardous waste from non-hazardous waste in some cities, and the paper
901 on the European Council Directive that suggests an impermeable mineral layer for
902 sealing non-hazardous landfills (Simon and Müller, 2004). A certain number of
903 papers talk about healthcare waste, one paper deals with the impacts of (hazardous)
904 waste on real estate, certain papers explore the use of incineration bottom ash as a
905 *non-hazardous* material in road construction. But there is not any paper dealing with
906 the treatment of hazardous waste from an urban planning and management
907 perspective.

908 A further examination of the larger corpus before filtering on the urban criterion
909 reveals that many studies on hazardous and non-hazardous waste originating from
910 construction and industrial were rejected because they did not include any terms from
911 the list of urban terms. This finding implies certain discordance between hazardous
912 industrial and construction waste and urban waste management. Whereas the
913 management of non-hazardous waste is the responsibility of local governments
914 (Bacinschi et al., 2010), that of hazardous waste from the healthcare, construction and
915 industrial sectors may remain the responsibility of the producers, which could be a
916 matter of concern with regard to more comprehensive urban waste management.

917 B.10 Indic 19 Renewable energy ratio

918 Renewable energy (RE) ratio is widely used for the assessment of energy
919 performance, especially in the green building and electric vehicle sectors (Begum et
920 al., 2013; Beheiry, 2011; Chen et al., 2014; Gerylo, 2010; Januševičius and
921 Streckienė, 2013; Monteiro and Nunes, 2015; Prata et al., 2013). Other indicators for
922 measuring the development and outcome of RE include “investment in renewable
923 energy” (Spalding-Fecher, 2003), and “household savings” with smart energy control
924 systems (Mourad et al., 2014).

925 Xia et al. (2008) show the importance of taking into account the extra conventional
926 energy consumed in the use of renewables in order to obtain more realistic RE

927 outcomes. Otherwise the contribution of RE systems may be exaggerated, leading to
928 “wide use of renewable energy without improving energy efficiency”.

929 A majority of studies in our corpus assess the potential contribution of renewable
930 energy to total energy or total electricity demand by considering the availability of RE
931 facilities or the remaining space for the installation of further facilities. Few studies
932 address RE from a planning perspective. Some explanatory clues can be found in the
933 analysis by Wall et al. (2012), in which the authors identified three architectural
934 barriers to the greater integration of solar technologies into buildings, namely: 1)
935 limited diversity/range of designs for integration into buildings, stemming from
936 insufficient architectural knowledge among manufacturers, 2) lack of knowledge of
937 technology and innovative products among architects, 3) lack of tools to quantify,
938 illustrate and communicate the outcome of including solar energy at the early design
939 phase. We can assume by analogy that the lack of sufficient shared knowledge
940 between planners and RE professions impedes the development of appropriate
941 support tools for holistic RE planning and assessment. Comprehensive planning that
942 includes a variety of city scale RE solutions seems yet to come. As Pitt and Bassett
943 (2013) observed: “*While many cities are aggressively pursuing clean energy
944 opportunities in their municipal operations, far fewer are taking action to promote
945 clean energy community wide.*”

946 The RE ratio is certainly a criterion that makes sense in promoting RE development,
947 since it enables comparisons between cities and countries. Nevertheless, introducing
948 RE facilities should be seen less as an ultimate goal than a way of tackling energy
949 demand and GHG emission challenges. It is essential to develop holistic approaches
950 that consider other criteria alongside RE ratio. In particular, the economic reliability
951 of any RE planning should not be neglected. Unfortunately, there seems a paucity of
952 literature addressing the economic viability of RE solutions, though we can cite the
953 study of Bassiouny et al. (2011), who evaluated the cost and value of connecting wind
954 farms to electricity grid.

955 B.11 Indic 20 Water supply from non-traditional sources

956 As might be expected, increasing the proportion of water supply from non-traditional
957 sources, *i.e.* from outside the municipal supply network, is one of the major objectives
958 of urban water management. All of the 50 papers ranked 1-2 deal with this issue. The
959 reuse of grey/black water and rain harvesting are two major sources for non-potable
960 water supply that receive the most attention. Research topics from our corpus include
961 the potential of the aforementioned two sources, their drivers, and the barriers to their
962 large-scale implementation. Wung et al. (2006) estimated that 35% of the water
963 supply to Taipei’s schools could be provided by rainwater harvesting. Garcia et al.
964 (2015) examined the sociological drivers of rainwater harvesting for garden irrigation in
965 a Spanish region, and found that household income, estimated water requirement and
966 education level were direct drivers, and interest in gardening and attitudes to water
967 conservation were indirect drivers. In the context of the USA, Steffen et al. (2013)
968 found that the performance of household rain harvesting systems depended on cistern
969 size and climate patterns.

970 In Dhaka city, average household grey water was 85 l/cap/d, i.e. 60% of the total waste
 971 water generated (Biswas et al. 2012). A survey taken by Yamagata et al. (2003) showed
 972 that 61% of non-potable water demand in 23 wards of the metropolitan region of Tokyo
 973 was met by reclaimed water, thanks to biological treatment and ultra-filtration processes.

974 The advantages of scale have been found in the construction cost of on-site water
 975 recycling systems. In the case of Tokyo, a capacity of 100m³/d was found to be the
 976 threshold for greater economic viability. In the case of Houston in humid sub-tropical
 977 Texas, increasing the size of rainwater cisterns was found to increase payback (Sweeney
 978 and Pate, 2015).

979 The performance of parcel rainwater harvesting systems greatly depends on climatic
 980 conditions, as demonstrated by research carried in a number of regions and cities
 981 (Steffen et al., 2013; Sweeney and Pate, 2015).

982 The risks to human health of using reclaimed water are found to be relatively low,
 983 provided that rigorous and appropriate treatment processes are implemented for the
 984 target usage (Barker-Reid et al., 2010; Sinclair et al., 2010; Wang et al., 2011;
 985 Yamagata et al., 2003). Apart from routine issues, which are the object of continuous
 986 research, including patterns of indoor water use (Matos et al., 2013), the quality and
 987 aesthetics of reclaimed water (Biswas et al. 2012), further progress in regulations and
 988 incentive strategies also seems to be a key contributor to the use of alternative water
 989 sources. A change in public attitudes from acceptance of low-contact reuse only
 990 (Friedler and Lahav, 2006) to acceptance of higher-contact reuse, can only be
 991 achieved through greater awareness.

992 Last but not least, the request for alternative water sources should not be a substitute
 993 of water-conservation measures and encouragement of behavioral change. It is easy to
 994 understand that reuse could lead to excessive consumption because of the lower price
 995 of reused water compared with tap water, which in turn would have an adverse impact
 996 on sewage (more wastewater to be drained). From this perspective, continuing
 997 encouragement is needed both for the use of *different* water and of *less* water, in order
 998 to alleviate the pressures on surface and underground water resources.

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