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

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Abstract

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

Key words

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

1 Introduction

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

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

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

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

Echoing the enthusiasm for eco-city development in China, there has been intense discussion of sustainable city indicators by both government institutions and urban specialists around the world. Reflecting today’s mainstream concern with the promotion of social equity and economic viability, criticisms of the indicator systems have unsurprisingly concentrated on the imbalance between the environmental and socio-economic aspects (Greed, 2012; Medved, 2016). While recognising the importance of reinforcing social equity and environmental viability in the construction of sustainable eco-cities, we argue that this overwhelming focus on the socio-economic dimension may obscure the importance of the environmental indicators themselves. First, environmental challenges remain in the forefront of political discourse (Cook et al., 2017; Hao, 2012; Nelson, 2012; Shiuh-Shen, 2013). Second, environmental performance is a precondition for any achievement in the social and economic arenas, as is apparent in the conventional expression “social and economic development that should be environmentally sustainable”.

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

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

As previously mentioned, plenty is known about both (Chinese) eco-city development and environmental sustainability indicators, thanks to the work of scientific researchers in recent years. As far as we know, however, there has been no in-depth study comparing the two, i.e. examining the environmental indicators within the context of a real-world eco-city. Our paper seeks to fill this gap. It takes as its object of study a set of major environmental indicators produced by Tianjin Eco-City, and employs a bibliometric analysis to investigate the scientific rationale behind these indicators. The number of occurrences of each indicator in the international scientific literature was counted, by reference to the following questions: What is the exact definition of a given indicator? What is it supposed to measure? Is the indicator problem-oriented and relevant to the most urgent local concerns? Is it specific to the urban environment? What are the unsolved scientific questions underlying the indicator? Intertwined with these global scientific questions is the question of whether the indicator is specific to the Chinese context or, conversely, context free. Put another way, is the indicator recognised and widely used by researchers inside and outside China? This question will be addressed by geographical analyses of the publications. This will cast light both on whether Tianjin Eco-City's indicators are aligned with mainstream challenges in the field of urban sustainability and on the status of Chinese urban environmental problems in the international research agenda.

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

2 Methodology

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

Figure 1 depicts the methodology underpinning this study. Among the twenty-two indicators in the Tianjin Eco-city KPIs, we selected eleven environmental indicators relating to water, air, energy, transport and waste, as listed in Table 1. The indicator numbers are the same as those published in official documents and research papers, which explains their discontinuity. The Scopus database was chosen for our bibliometric inventory, because it includes publication records for journals since 1996, irrespective of changing ISI status (de Jong et al., 2015). The time span of our collection is from 2000 to 2016, given that the early 2000s are recognised to be the starting point of urban sustainability policies in China, with the proliferation of eco-city initiatives at both regional and continental scales (Joss et al., 2013), and 2016 was the most recent ended publication year at the time of writing.

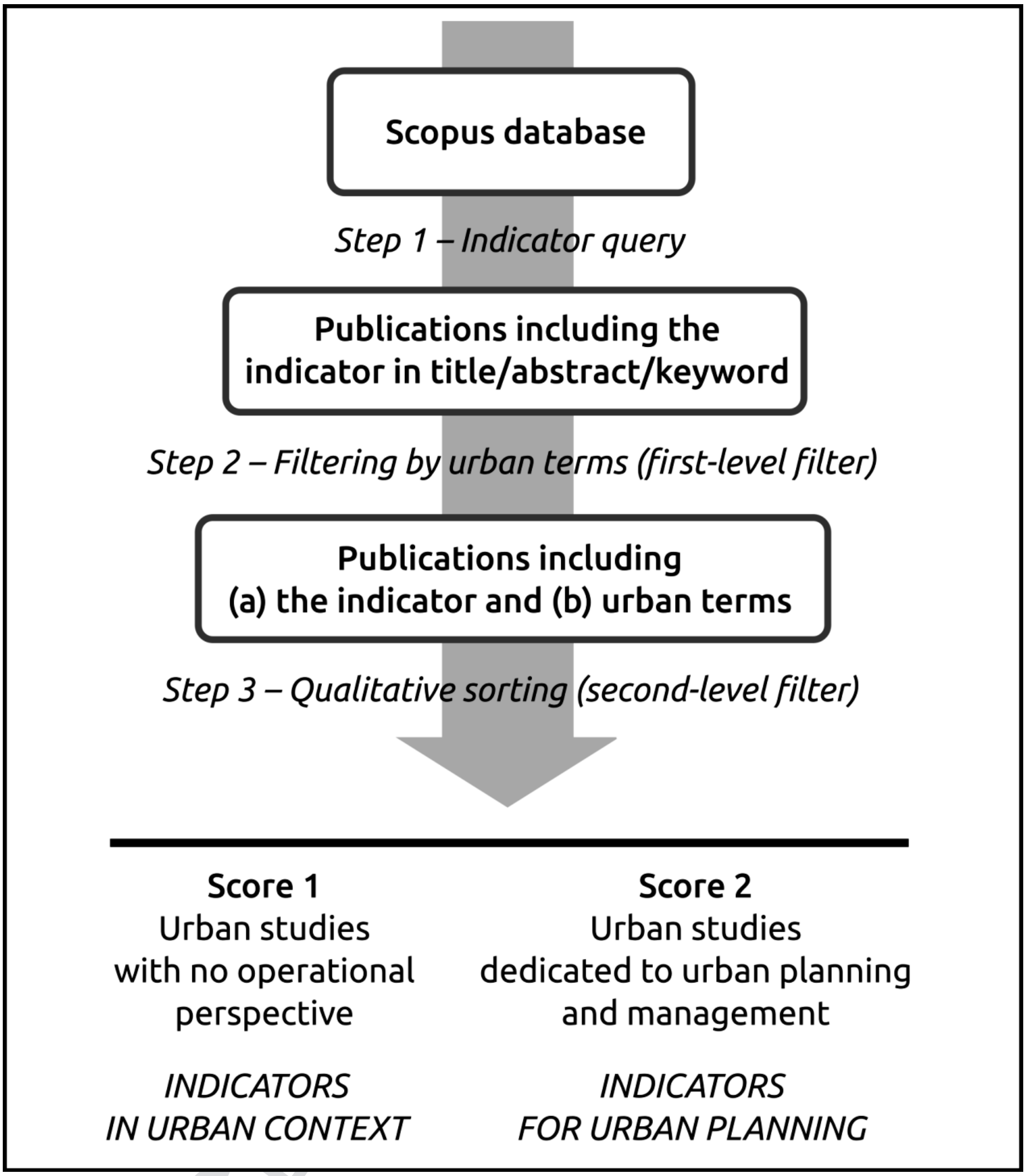


Figure 1 Research design.

2.1 Step 1: Indicator query

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

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

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

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

Table 1 Indicators and targets of the Tianjin Eco-City KPIs selected in the present study. Supplementary explanation of the indicators is provided when necessary to clarify the definition 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 SO2 and NOx 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	• Waste is categorised into domestic waste, industrial solid waste, construction waste and other waste. • 'Recycling' includes reuse, recycling and energy recovery.	60%

		- 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%

2.2 Step 2: Filtering by "urban" terms

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

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

2.3 Step 3: Unavoidable qualitative sorting

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

This semantic complication in distinguishing between urban-related and non-urban-related studies was bound up with a concern about the paper's subject. For example, should we leave in the corpus relating to *water supply from non-traditional sources* a publication on techniques for monitoring organic pollutants in sewage treatment plants, given that its abstract does include "water reuse", a term that was included in the search query for the indicator (Robles-Molina et al., 2013)? On the one hand, such a study can arguably be considered to be urban, given the overlap between the topic and urban sewage and water reuse. On the other hand, it seems somewhat remote from the paper's focus on sustainability indicators for urban planning and management. One possible approach for dealing with such a paper would be to retain it in the corpus but to separate it from those that fully match the focus.

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

2.4 Abstract analysis and geographical analysis

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

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

Four fields were examined for each study: address of the corresponding author, title, keywords and abstract. The first step was to clean the data (lower case conversion, punctuation and removal of editor's location (such as "Copyright Springer Berlin, Germany")). Then, country detection was performed using a dictionary of locations available in the GeoNames database (http://www.geonames.org). We implemented a simple method, applying regular expressions from a list of level-1 administrative units (countries) and some level-2 administrative units. A comparison between the locations retrieved and the results yielded by the Aylien API (http://aylien.com) showed that the simple detection of high-level administrative units would be sufficient to return the location at country level. In most cases the location name is followed by an indication of the country, such as "Muritz National park (Germany)". This indication is missing in a few US and Chinese cases for which only the lower-level administrative unit is given, for example "Everglades National Park (Florida)" or "Foshan (Guangdong)".

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

3 Results

3.1 A multi-level final corpus

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

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

Table 2 Quantity of publications generated by each step. It should be noted that the "Urban" column also includes publications that scored 0 in the "Qualitative sorting" column, i.e. which 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

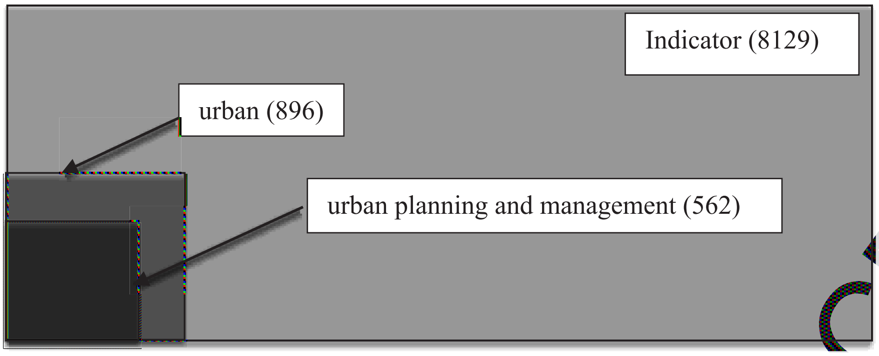


Figure 2 Interplay of the corpuses generated in each step.

3.2 Authors' countries and studied countries

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

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

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

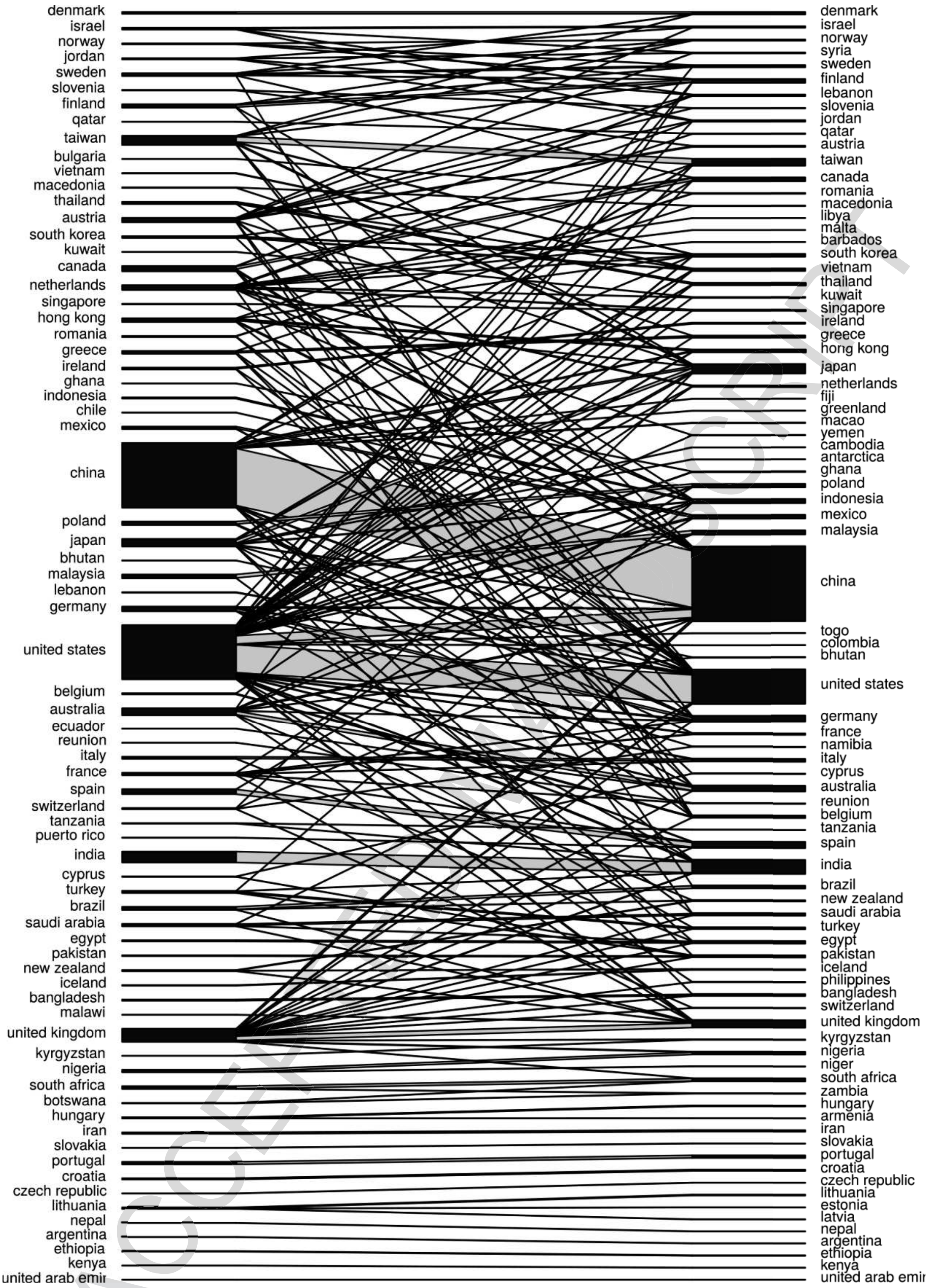


Figure 3 Connections between authors' countries and countries studied for the entire indicator set.

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

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

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

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

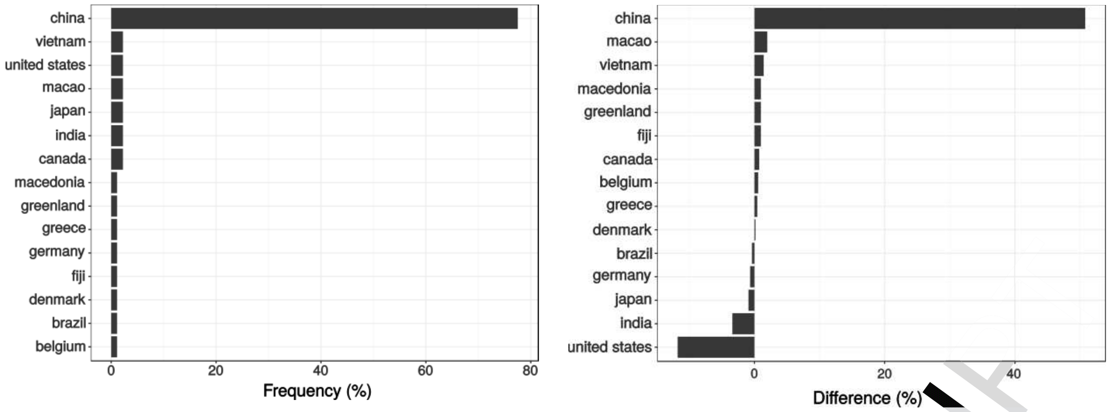


Figure 4 Absolute frequency (left) and relative frequency (right) of countries studied for indicator 2 -- ***Quality of surface water in the Eco-city.***

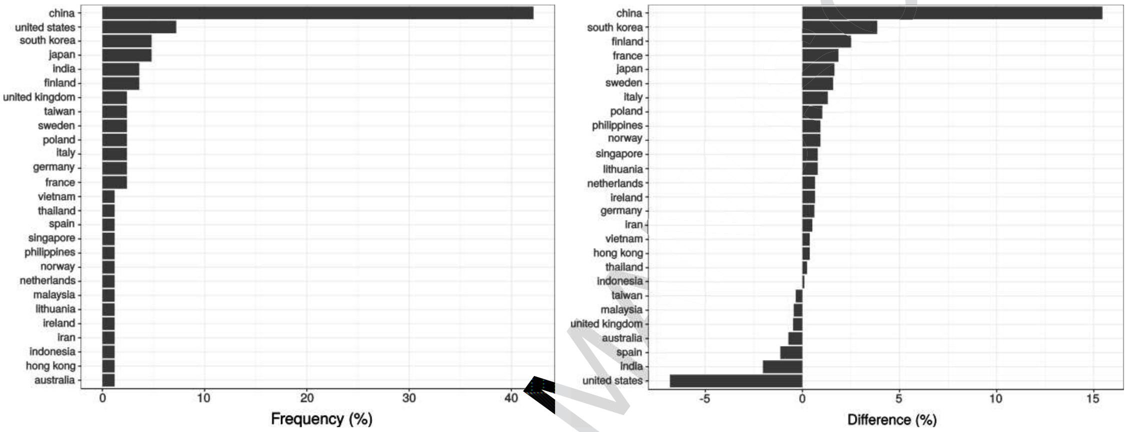
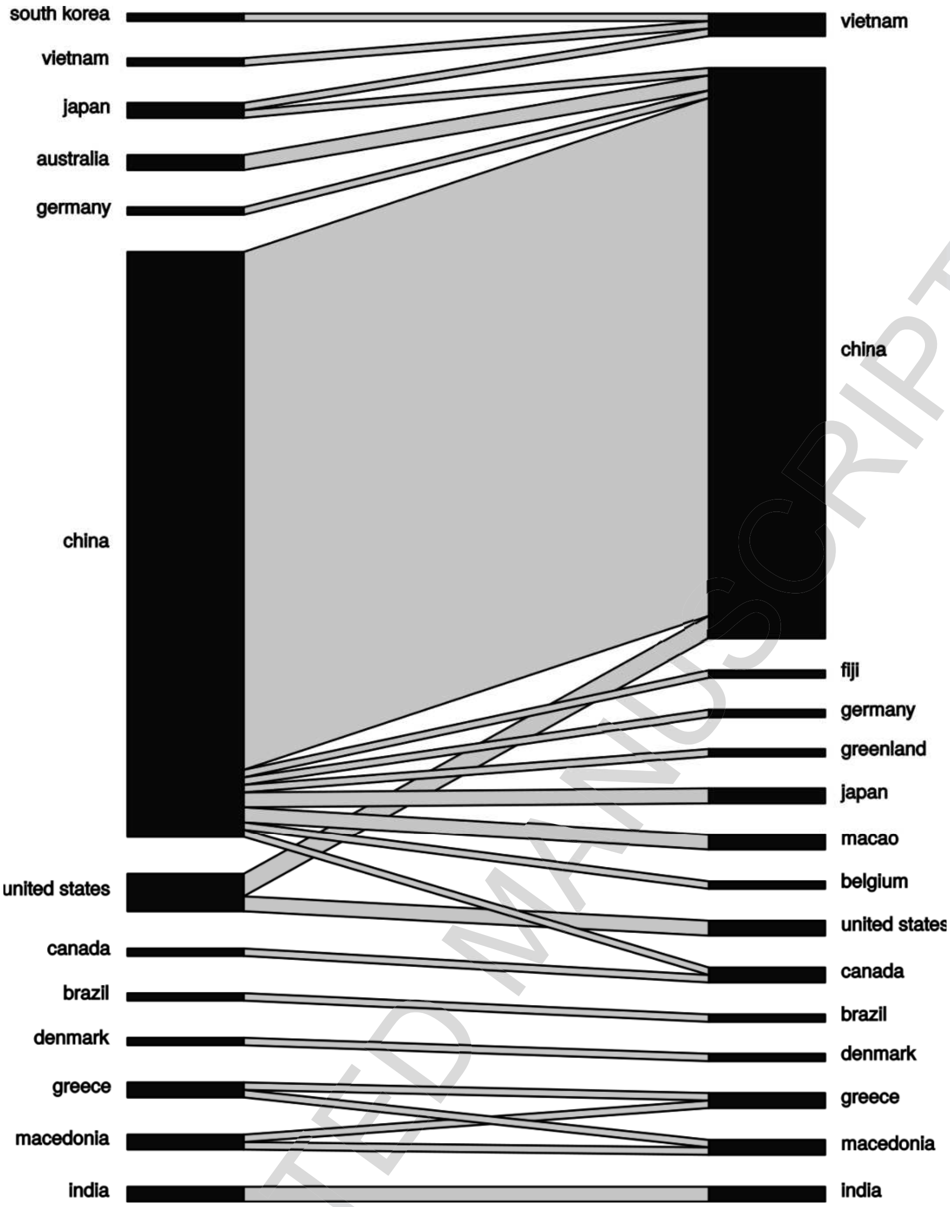


Figure 5 Absolute frequency (left) and relative frequency (right) of countries studied for indicator 5 -- ***Carbon emission per unit GDP.***



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

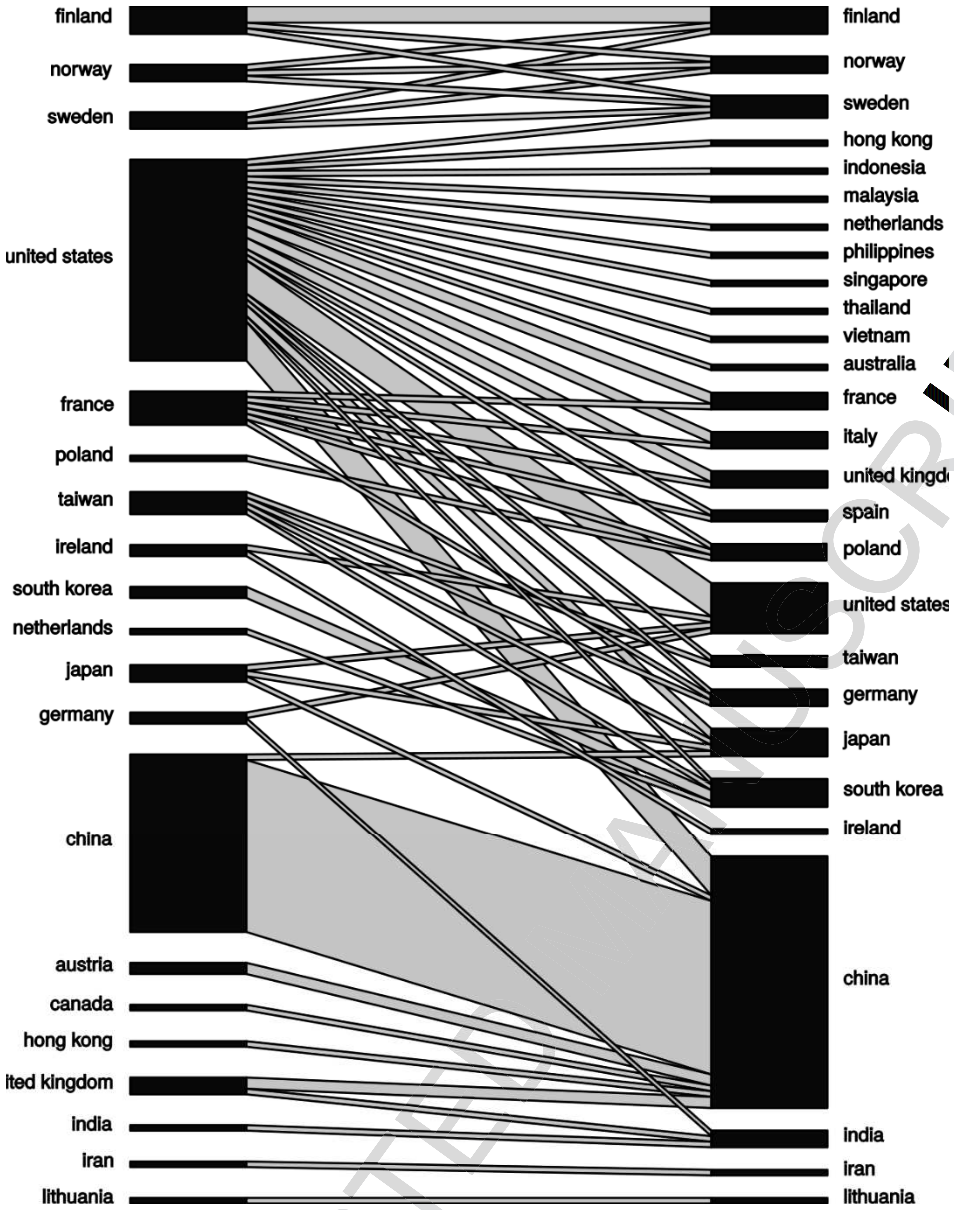

Figure 7 Connections between authors' countries and countries studied for indicator 5.

3.3 Scientific rationale of the indicators

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

3.3.1 Group 1 Aggregated indicators

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

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

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

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

3.3.2 Group 2 Scientifically-sound indicators

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

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

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

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

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

3.3.3 Group 3 Indicator under scientific scrutiny

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

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

3.3.4 Group 4 Indicator lacking scientific foundation

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

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

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

4 Discussion and conclusion

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

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

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

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

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

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

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

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

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

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

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

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

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Appendix

A. Keyword query per indicator

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

B. Notes per indicator on the scientific rationale

B.1 Indic 1 Ambient air quality

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

Few studies address the relevance of the standards themselves. Among them, Tao et al. (2015) monitored air quality and hazy weather conditions on an urban site in Guangzhou, and found that the incidence of hazy weather was not reduced as much as expected, because of humidity. The authors therefore suggested more stringent PM2.5 guideline values in the national standard, with a distinction between dry and wet conditions. J. Hu et al. (2015) found that the current Chinese air quality index based on the maximum value of individual pollutants underestimated the severity of the health risk associated with air pollution caused by multiple pollutants.

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

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

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

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

B.3 Indic 5 Carbon emission per unit GDP

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

1) GHG emissions calculation

Numerous questions about how to accurately calculate total GHG emissions for a given country or city remain unsolved. These include: Should indirect emissions from local production and consumption be left out of total GHG emissions? Should GHG from infrastructures and local community consumption be included? How do you account for emissions associated with import and export? Despite of the efforts made by many researchers on questions (Ala-Mantila et al., 2014; Ramaswami and Chavez, 2013), there seems to be a long way to go before any universal agreement be found.

2) Normalisation

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

3) Energy consumption and GHG emissions

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

B.4 Indic 7 Proportion of green buildings

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

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

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

B.5 Indic 10 Per capita domestic water consumption

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

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

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

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

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

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

B.6 Indic 11 Per capita domestic waste generation

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

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

B.7 Indic 12 Proportion of green trips

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

Developing a transit network that offers a variety of transport options and favouring walkability is the primary policy for city sustainability (Haghshenas et al., 2015; Wey and Hsu, 2014). Assessing the performance of a city's transport system is an extremely complex task, bound up with issues such as renewable energy use, GHG emissions, and socio-economic reliability. As Kasperska (2015) says, "*How to minimise the costs generated by the development of innovative transport infrastructures and offset them by environmental and social gains is still a challenge*". In light of this, a high green trip proportion alone suffices hardly to make transport sustainable, not to mention the difficulties in appropriately computing the so-called "green trip proportion" (Cottrill and Derrible, 2015; Schipper, 2002). Similar with renewable energy development, sustainable transport is intertwined with a large board of questions of the urban system and requires holistic approaches to tackle with. Integrated analytical and decision-making support tools are thus needed for the make of sound urban transport policies (Praticò and Vaiana, 2012).

B.8 Indic 13 Overall recycling rate

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

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

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

According to "Navigating the Eco-city" (Tianjin Eco-city, 2010), this indicator refers to the proportion of the total waste produced in the eco-city that are rendered non-hazardous. This includes: 1) treatment of dangerous and toxic waste generated by medical, industrial and construction activities; and 2) treatment of domestic through recycling, re-use, biological methods, incineration and landfill. In the book, the authors provide a further explanation relating to point 2):

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

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

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

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

B.10 Indic 19 Renewable energy ratio

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

Xia et al. (2008) show the importance of taking into account the extra conventional energy consumed in the use of renewables in order to obtain more realistic RE outcomes. Otherwise the contribution of RE systems may be exaggerated, leading to "wide use of renewable energy without improving energy efficiency".

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

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

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

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

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

The advantages of scale have been found in the construction cost of on-site water recycling systems. In the case of Tokyo, a capacity of 100m^3/d was found to be the threshold for greater economic viability. In the case of Houston in humid sub-tropical Texas, increasing the size of rainwater cisterns was found to increase payback (Sweeney and Pate, 2015).

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

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

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

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